Comfort evaluation of aircraft cabin system employing a hybrid model

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Title page

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Abstract: Comfort is becoming one of the most important principles in the process of design and evaluation of civil aircraft cabin. However, the comprehensive quantitative evaluation of comfort in an aircraft cabin is a complicated issue, because of the subjectivity of comfort perception and a large amount of factors involved in the whole complex cabin system. A hybrid model combined with Decision Making Trial and Evaluation Laboratory (DEMATEL) method and fuzzy comprehensive evaluation is proposed, which considers both the interrelation between the criteria and the fuzziness of subjective comfort perception concurrently. The result of empirical study from questionnaire survey in flight was consistent with that of the hybrid model. The proposed model is effective. It could provide a more reasonable priority to improve comfort in the aircraft cabin. According to the measured results of cabin environment, cabin facilities and layout, seat and service, the specific differences between the criteria can be displayed clearly, which is helpful to improve the cabin comfort level.

Keywords: Comfort in aircraft cabin, a hybrid model, DEMATEL, fuzzy comprehensive evaluation

Introduction

Comfort in aircraft cabin system is becoming an important issue with which airlines differentiate themselves in a competitive market. Passengers are paying more attention to it with the increase of traveling by airplane. Some studies show that comfort has a close relation with passenger's choice about airlines and flight. Data indicate that about 35% of passengers base their choices on comfort, past flight experience, and delays (Brauer, 2004). Richards and Jacobson (1975) suggested that comfort levels would influence how willing a person is to fly again on future occasions. Therefore, there is no doubt that the research about comfort in aircraft cabin system plays an increasingly important role in the aviation industry.

The aircraft cabin is an artificial closed space at high altitude with high speed when the aircraft is in flight, in which the physical environment is of great difference with ordinary cabin environment. Passengers are required to stay in the seat with safety belt and are not allowed to walk around. At the same time, passengers need to stay together for a period of time with other passengers and crews from diverse countries and cultures. The comfort perceived by passengers is influenced on both objective environment, facilities, services, etc., and subjective and emotional factors, such as expectations, emotions and preferences, characterized by ambiguity and uncertainty.

The existing comfort researches mainly focus on the automobile seat, office seat, hand tools, trains, etc. In the field of comfort in the aircraft cabin, the studies are relatively not many. Some scholars conducted some empirical studies to identify the influencing factors and generating mechanism (Richards & Jacobson, 1977; Vink & Brauer, 2011). Some researchers studied the relationship between passenger comfort and influencing factors (Liu, Yu, Chu, & Gou, 2017). These studies discuss the influences of one aspect in the aircraft cabin. Little attention has been devoted to establishing a comprehensive comfort evaluation of the whole cabin system. As a subjective and personal perception state (De Looze, Kuijt-Evers, & van Dieen, 2003), the comprehensive evaluation of comfort in aircraft cabin system from the holistic perspective is a complicated issue. The main reasons are the subjectivity of comfort perception and the complexity of a large number of factors involved in the whole cabin system. Furthermore, these studies mainly adopt the interview and data statistics to evaluate the passenger comfort in the aircraft cabin. They could not evaluate the comfort in aircraft cabin system from a holistic perspective and could not offer a quantitative and visualized display result.

Referring to the comfort evaluation, many scholars are devoted to studying the objective and quantitative measurement and evaluation methods of comfort (Antonsen et al., 2018). Fuzzy set theory can be applied to measure ambiguous concepts associated with human's subjective perceptions and judgments, which is suitable to describe passenger comfort perception. Voisin and Levrat (2001) presented the evaluation of a sensory measurement fuzzy system intended for the design of car seat comfort, and by comparing with seat evaluators to test validation and the result was shown correspondingly. Grabisch, Duchêne, Lino, and Perny (2002) established a model of subjective sensation of discomfort and different macro-zones of the body using fuzzy measures and Choquet integrals, which is more flexible and has a good accuracy. The above methods are mainly applied to assess the ground vehicle seats comfort or environment comfort, just a part of overall comfort. And they have not been used in the field of comfort evaluation in an aircraft cabin system. However, they could provide good references and lay a foundation for comfort evaluation in an aircraft cabin system.

As a consequence, the purpose of this paper is to establish a new evaluation model for comfort in aircraft cabin system with consideration of interrelationship between criteria from the perspective of the whole cabin system. Based on summarizing the factors influencing on comfort in aircraft cabin system, a comprehensive evaluation criteria system is established. A new hybrid model combined with Decision Making Trial and Evaluation Laboratory (DEMATEL) method and fuzzy comprehensive evaluation method is proposed, which takes full advantage of these two approaches. The DEMATEL method is applied to illustrate the interrelations between criteria and calculate the corresponding weights. Fuzzy comprehensive evaluation is used to evaluate the subjective comfort perception and provide a quantitative result, which could be applied to the process of improving comfort in aircraft cabin system with a more reasonable priority.

Methods

Procedures

A hybrid model for evaluating comfort in aircraft cabin system is proposed and introduced, which integrates the DEMATEL method with multi-level fuzzy comprehensive evaluation. The DEMATEL method is used to construct the interrelationship between criteria and calculate their weights according to their importance important degree. Multi-level fuzzy comprehensive evaluation is applied to deal with the subjectivity of evaluation and quantify the comfort level.

The procedures of the hybrid model are shown briefly in Fig.1.

Fig.1 The hybrid model procedures

Decision Making Trial and Evaluation Laboratory (DEMATEL) was first proposed and developed by The Battelle Memorial Institute through its Geneva Research Centre in 1973 (Fontela & Gabus, 1976), which is one of the structural modeling techniques based on graph theory and matrix. Unlike the traditional methods such as Analytic Hierarchy Process (AHP) with the assumption that elements are independent, it could not only analyze and visualize the causal relationships between criteria through causal diagram but also provide weights ranking according to the importance degree of criteria. This method could classify the criteria into two groups, one is cause group (criteria impose an effect on others), and the other one is effect group (criteria receive effect from others). This can help researchers understand the structural relationship between criteria better. The DEMATEL method has been currently applied in many fields except for the field of comfort evaluation. This paper will adopt this effective structural modeling method to discuss the interrelationship between criteria.

Subjectivity and fuzziness exist in the process of comfort perception and evaluation. Passengers give their assessment or describe their perception using qualitative criteria and lingual expressions instead of crisp values, which makes further analysis difficult to compute. Therefore, the fuzzy evaluation may be more suitable to measure ambiguous concepts associated with human being's subjective perceptions and judgments. Fuzzy comprehensive evaluation based on the fuzzy set theory is proposed as a new decision-making method that is particularly useful in multivariable circumstances (Guo, Gao, Yang, & Kang, 2009). The numerous criteria will be classified into different layers according to the multi-level fuzzy comprehensive evaluation method, which could realize the evaluation from the lower levels to higher ones.

Comfort Evaluation Criteria System

The numerous criteria will be classified into different layers according to the multi-level fuzzy comprehensive evaluation method, which could realize the evaluation from the lower levels to higher ones. On the basis of a literature review, a comprehensive evaluation criteria system of comfort in aircraft cabin system was established (Fig.2), which can be divided into target layer, factor layer, and criteria layer. Comfort evaluation (U) is the main objective of this system, thus it is located in target layer, which includes four factors: cabin environment comfort (U_1), cabin facilities and layout comfort (U_2), seat comfort (U_3) and service comfort (U_4), i.e., $U=f(U_1, U_2, U_3, U_4)$. These four factors constitute the factor layer, which are the four major categories of evaluation criteria. They have different weights, which means they are different in importance. Every factor includes the specific related criteria. For example, U_1 is consisted of the criteria temperature (u_{11}), humidity (u_{12}), pressure (u_{13}), air quality (u_{14}), light (u_{15}), vibration (u_{16}), noise (u_{17}), color (u_{18}) and cleanness (u_{19}). U_2 refers to the criteria seat layout (u_{21}), pitch (u_{22}), luggage room (u_{23}), washroom (u_{24}), kitchen (u_{25}), porthole (u_{26}), aisle (u_{27}), ceiling (u_{28}), safety instructions (u_{29}). U_3 focuses on the criteria seat height (u_{31}), width (u_{32}), depth (u_{33}), material (u_{34}), backrest height (u_{35}), backrest width (u_{36}), backrest shape (u_{37}), adjustability (u_{38}), legroom (u_{39}), lumbar support (u_{310}), headrest (u_{311}), armrest (u_{312}) and tray table (u_{313}). U_4 includes books and magazines (u_{41}), music (u_{42}), videos (u_{43}), button layout (u_{44}), meals (u_{45}), drinks (u_{46}), crew's attitude (u_{47}), crew's appearance (u_{48}), response time (u_{49}) and information broadcast (u_{410}). These criteria in this layer would be the main basis for evaluating and improving passengers' comfort.

Fig.2 Passenger comfort evaluation criteria system

Results

According to the procedures of the hybrid model, the results were obtained and displayed in this section.

Results of the hybrid model

After establishing the evaluation criteria system, the DEMATEL method is applied to analyze the interrelations among criteria and calculate the weights of them based on importance degree.

Firstly, according to the linguistic scale, a pair-wise comparison of criteria was conducted by selected totally six experts, who were two cabin designers, two industrial designers, and two passengers. Then the direct-relation matrix *Z* was obtained. The average of the direct relation matrix was calculated from the six experts. The normalized direct-relation matrix *D* and the total relation matrix *T* are obtained according to the steps of DEMATEL.

Influencing degree *R* and influenced degree *C* can be obtained by calculating the sum of rows and columns from the total relation matrix *T*. Besides central degree (*R*+*C*) and relation degree (*R*-*C*) were calculated by $\left(r_i + c_i\right)$ and $\left(r_i - c_i\right)$. The weights of criteria and factors were calculated, which were shown in Table 1.

Table 1. The weights of factors and criteria

Target layer	Factor layer	Weights of factors	Criteria layer	Weights of criteria
Comfort evaluation criteria system	Environment U_1	0.2304	Temperature u_{11}	0.0265
			Humidity u_{12}	0.0272
			Pressure u_{13}	0.0075
			Air quality u_{14}	0.0215
			Light u_{15}	0.0298
			Vibration u_{16}	0.0237
			Noise u_{17}	0.0240
			Color u_{18}	0.0233
			Cleanness u_{19}	0.0487
	Cabin facilities and Layout U_2	0.2192	Seat layout u_{21}	0.0359
			Pitch u_{22}	0.0429
			Luggage room u_{23}	0.0198

		Washroom u_{24}	0.0211
		Kitchen u_{25}	0.0402
		Porthole u_{26}	0.0123
		Aisle u_{27}	0.0275
		Celling u_{28}	0.0111
		Safety instructions u_{29}	0.0114
Seat U_3	0.3498	Height u_{31}	0.0179
		Width u_{32}	0.0212
		Depth u_{33}	0.0278
		Material u_{34}	0.0083
		Backrest height u_{35}	0.0399
		Backrest width u_{36}	0.0245
		Backrest shape u_{37}	0.0330
		Adjustability u_{38}	0.0502
		Legroom u_{39}	0.0385
		Lumbar support u_{310}	0.0198
		Headrest u_{311}	0.0108
		Armrest u_{312}	0.0203
		Tray tables u_{313}	0.0476
Service U_4	0.2008	Books and magazines u_{41}	0.048
		Music u_{42}	0.0116
		Videos u_{43}	0.0265
		Button layout u_{44}	0.0167
		Meals u_{45}	0.0469
		Drinks u_{46}	0.0264
		Crew´s attitude u_{47}	0.0154
		Crew´s appearance u_{48}	0.0135
		Response time u_{49}	0.0220
		Information broadcast u_{410}	0.0178

A causal diagram was drawn by mapping the data set of (R+C, R-C), employing the prominence (R+C) as a horizontal axle and the relation (R-C) as a vertical axle, which was shown as Fig.3.

Fig.3 The causal diagram

On the basis of having obtained the weights of factors and criteria, the multi-level fuzzy comprehensive evaluation of comfort in aircraft cabin system was conducted. Firstly, a survey was carried out during the flight from

Xi'an to Qingdao, which belongs to the Shandong Airlines SC CDG. The airplane type is a Boeing 737-300. The Seat pitch is 31 inches. Seat width is 17 inches. The Configuration of seat is 3-3. The In-Flight Entertainment (IFE) employs the TV overhead.

The duration of this flight was 2.5 hours. The questionnaires were distributed to the passengers at half an hour before landing, which is shown in the appendix. 200 questionnaires were distributed in one week and the valid ones were 178, including 127 males and 51 females. Their average age was 37 years (22-63 years), average stature 1.72m (1.50-1.88 m) and average weight 67 kg (45-88 kg). They gave their evaluation on this aircraft cabin system adopting five comment grades, which is denoted as $V = \{v_1, v_2, v_3, v_4, v_5\}$, respectively represent "worse", "bad", "general", "good", "better". The number of these five comment grades aiming at every evaluating criterion was counted. And the normalization was carried, therefore, the fuzzy evaluation matrix of different factors was obtained. Take the criteria "temperature" in cabin environment factor, for example, 53 passengers chose "better", 71 chose "good", 36 chose "general", 18 chose "bad", no one chose "worse". Therefore, the comment set of "temperature" was calculated as $C = (53/178, 71/178, 36/178, 18/178, 0/178) = (0.3, 0.4, 0.2, 0.1, 0)$. The rest comment sets were obtained in the same way, and an evaluating matrix was composed of the comment sets of whole criteria in a factor layer. For example, the result of the cabin environment factor layer was shown in Table 2.

Table 2. Evaluating sets of criteria in cabin environment layer

U_1	Comment grades				
	better	Good	General	Bad	Worse
u_{11}	0.3	0.4	0.2	0.1	0
u_{12}	0.1	0.1	0.5	0.2	0.1
u_{13}	0	0.1	0.4	0.4	0.1
u_{14}	0	0.1	0.5	0.2	0.2
u_{15}	0.1	0.1	0.4	0.3	0.1
u_{16}	0	0.1	0.4	0.4	0.1
u_{17}	0.5	0.3	0.2	0	0
u_{18}	0.2	0.2	0.6	0	0
u_{19}	0.1	0.4	0.3	0.1	0.1

The corresponding evaluation matrixes were obtained.

The fuzzy calculation was conducted with weighted average fuzzy arithmetic operators, the results were shown as follows.

$$\begin{aligned} S_1 &= W_1 \circ R_1 \\ &= (0.1604\ \ 0.2300\ \ 0.3773\ \ 0.1582\ \ 0.0741) \end{aligned}$$

$$\begin{aligned} S_2 &= W_2 \circ R_2 \\ &= (0.0582\ \ 0.2120\ \ 0.3312\ \ 0.3237\ \ 0.0748) \end{aligned}$$

$$\begin{aligned} S_3 &= W_3 \circ R_3 \\ &= (0.0850\ \ 0.2537\ \ 0.3436\ \ 0.1974\ \ 0.1203) \end{aligned}$$

$$\begin{aligned} S_4 &= W_4 \circ R_4 \\ &= (0.2327\ \ 0.3488\ \ 0.2661\ \ 0.1238\ \ 0.0284) \end{aligned}$$

The fuzzy evaluation matrix R of the target layer could be formed by these results.

$$\begin{aligned} R &= \left(S_1, S_2, S_3, S_4\right)^T \\ &= \begin{bmatrix} 0.1604 & 0.2300 & 0.3773 & 0.1582 & 0.0741 \\ 0.0582 & 0.2120 & 0.3312 & 0.3237 & 0.0748 \\ 0.0850 & 0.2537 & 0.3436 & 0.1974 & 0.1203 \\ 0.2327 & 0.3488 & 0.2661 & 0.1238 & 0.0284 \end{bmatrix} \end{aligned}$$

The fuzzy calculation was conducted again with weighted average fuzzy arithmetic operators to obtain the final results.

$$S = W \circ R = (0.1248\ \ 0.2570\ \ 0.3339\ \ 0.2024\ \ 0.0819)$$

The comfort evaluation result could be displayed in Fig.4.

Fig.4 Measured results of comfort in aircraft cabin system

Results of empirical study

In order to obtain the basic data of passenger comfort in aircraft cabin, a questionnaire was designed according to the literature review, which comprised 6 themes and totally 58 comfort related questions. The questionnaires were distributed by way of field survey during one week. 200 questionnaires were distributed in Xi'an Xianyang International Airport, and the valid ones were 178. On a 5-point scale (1-worse, 2-bad, 3-general, 4-good, 5-better), the passengers were asked the comfort experience about this flight. The data was analyzed employing

SPSS 22.0. The average score of overall comfort experience in this flight was 3.7, which indicated that passengers' comfort feeling was more than "general", but not at a "good" level in this flight. This result was consistent with the computation result of model.

Discussions

Interrelationship analysis between criteria

There are some information and indications to be extracted from the results of the causal diagram. These suggestions are of great importance to direct cabin design for improving comfort in aircraft cabin system. The criteria could be analyzed according to their values of central degree and effect degree. Because there are so many criteria in the evaluation system, we take some typical criteria for example to show the interrelationship between them.

The criteria are classified into two groups according to the value of (R-C): cause group, and effect group. The criteria in cause group (R-$C>0$) dispatch more influence on the ones in effect group (R-$C<0$). Therefore, it is necessary to pay more attention to the criteria in cause group. Backrest shape (u_{37}) has the highest value of (R-C), which means that u_{37} is the most influential criterion because it influences other criteria most and is influenced by others least. Table 1 shows that the central degree of u_{37} is 0.1830, located in the middle of X axle, which represents that u_{37} is an important criterion impacting on the passenger comfort. The improvement of u_{37} can lead to the amelioration of the whole passenger comfort level. Therefore, in order to improve the passenger comfort feeling, the backrest shape (u_{37}) should be attached more importance.

Legroom (u_{39}) has the lowest value of (R-C), while its central degree is located in the relatively front place in the X axle, which indicates that u_{39} has a low influence on the whole comfort evaluation system, but is susceptible to other criteria. The adjustment of other criteria would lead to the improvement of u_{39}. For example, the legroom is impacted by seat pitch, seat width, backrest shape, etc. If we want to improve the u_{39} to enhance the passenger comfort perception, we can take measures from the corresponding cause criteria. The improvement of these criteria would trigger the change of u_{39}.

From analysis of central degree, adjustability (u_{38}) belongs to the effect group, while it has the highest central degree, which means that it is the most important criterion in comfort evaluation system. Although the impact it imposes on others is relatively low, it is still needed to consider first, including the adjustable angle of the backrest, armrest, and headrest, etc.

The weights of all criteria are assigned according to their importance degree. In factor layer, seat comfort (U_3) has the highest weight value of 0.3540, which is the most influential factor and should be considered first. The reason is that passengers spend the most time on the seat, therefore, seat comfort has a direct relation to comfort evaluation. The rest is cabin environment, cabin facilities, layout and service. In criteria layer, seat adjustability (u_{38}) has the highest weight. Cleanness (u_{19}), button layout (u_{45}), tray table (u_{313}) are the more important criteria.

Evaluation analysis

Fig.4 shows that the result of cabin comfort affiliated with “better”, “good”, “general”, “bad” and “worse” respectively are 0.1248, 0.2570, 0.3339, 0.2024 and 0.019. According to the maximum membership principle, the comfort level of this aircraft cabin system is regarded as “general”, which needs to be improved in future. This result is consistent with the result of questionnaire survey in flight.

Referring to what measures are necessary to be taken to improve the cabin comfort level, the measured results of factor layers could offer some suggestions, which show the specific differences between the criteria.

From the perspective of cabin environment, the measured results affiliated with “general” and “good” respectively are 0.3773 and 0.2300, accounting for 60.73% of total measured results, which means that the comfort level of cabin environment basically satisfies the demands of passengers currently. If we want to take measures to improve environment comfort, the criteria such as cleanness (u_{19}), light (u_{15}), temperature (u_{11}), noise (u_{17}), etc. are needed to pay more attention according to their importance. With the development of technology, passengers attach great importance to higher requirements, the cabin cleanness is becoming the most important criterion. If cabin environment is tidy and clean, the passenger would perceive more intensive comfortable feelings, which also testify the research result of Ahmadpour, Lindgaard, Robert, and Pownall (2014). Moreover, the lighting system in the cabin will be the next candidate in the improvement measures. Fig.3 and Table 1 show that the light has higher value of (R-C) and belongs to cause group, which could impact other criteria such as meals, cleanness, temperature, activities, etc. The current light system is always simple with illumination function. If the light system could provide more functions, for example, Finnair’s A350 cabin adopts northern lights as their lighting mood, which could offer the different experience about Finnish characteristics for passengers, consequently to improve the passenger comfort perception. Referring to temperature, it will be better with more stability. Many passengers complained that when the airplane was taking off and landing, the cabin was always cold. Noise does not only result from the vibration but also the passengers' communication and children' s crying. The improvement of noise could start with these aspects.

Referring to a factor of cabin facilities and layout, the measured results affiliated with "general" and "bad" respectively are 0.3312 and 0.3237, accounting for 65.49% of the total, which indicates that this factor does not meet the passengers' demands. The evaluation result is not good enough. The ranking of important criteria is the seat pitch (u_{22}), layout (u_{21}), kitchen (u_{25}), etc., which is also the priority of taking measures to improve the cabin comfort. From Fig.3 and Table 1, seat pitch has a higher importance degree among criteria and is a cause criterion, which is a critical one impacting on passenger comfort. In the flight from Xi'an to Qingdao, which belongs to the Shandong Airlines SC CDG. The airplane type is a Boeing 737-300. The seat pitch is 31 inches. It is not the most comfortable distance comparing with the deluxe class. For a specific type aircraft and type of class, seat pitch is not easy to change considering the economical reason. The layout is as same as pitch. If in the process of a new cabin design, it would be considered in advance. The kitchen is relative with a supply of meals and drinks, passengers pay more attention to it. If the kitchen is tidy, neat and sanitary, passengers would feel more comfortable.

The measured results of seat comfort affiliated with "general" and "good" respectively are 0.3436 and 0.2537, accounting for 59.73% of total measured results, which indicates that the current seat comfort of this type airplane is basically satisfied the passengers' demands. According to the weights assignment, what has greater importance on cabin comfort respectively are adjustability (u_{38}), legroom (u_{39}), tray table (u_{313}) and backrest shape (u_{37}). In the future process of cabin design, more attention should be paid to seat adjustability, especially the backrest adjustable angle, which is of great importance to the improvement of cabin comfort. Passengers spend the most time on the seat. The duration of flight is generally more than 2 hours. If the backrest of the seat is always kept upright, passengers would feel fatigued easily. It would improve spine stress if backrest has an appropriate angle of inclination. However, in this economy class cabin, due to the legroom is not large enough, passengers are not allowed to adjust their backrest freely, which would greatly impact on the activities of rear row passengers. Therefore, the seat adjustability of this cabin could not provide a better sitting perception. The legroom also plays an important role in cabin comfort. Fig.3 shows that it is an effect criterion with the highest value of (R-C), which is susceptive to other criteria. It is influenced by seat depth, tray table, backrest shape, etc. If we can improve these relative criteria, legroom would be improved correspondingly.

The measured results of service factor are respectively 0.2327, 0.3488, 0.2661, 0.1238 and 0.0284. The sum of "better", "good" and "general" accounts for 84.76% of total measured results, which means that passengers satisfy with the services in this cabin. In view of saving resources, service is not the first priority to consider to improve the cabin comfort.

Conclusion

Comfort evaluation of aircraft cabin system plays an increasing role in process of cabin design. As a complex system, the comprehensive comfort evaluation in aircraft cabin system from the holistic perspective is a complicated problem. Quantitative evaluation methods are needed to consider to provide a direction for cabin design from the view of comfort. Therefore, a hybrid model is proposed to deal with this problem. On the basis of literature review, a comprehensive comfort evaluation criteria system is outlined, including cabin environment, cabin facilities and layout, seat comfort and service four factors, 41 criteria in total. The DEMATEL method is adopted to analyze the interrelations between criteria and calculate their corresponding weights according to their importance degree. A multi-level fuzzy comprehensive evaluation is conducted to obtain a quantitative result about an airline. Finally, the evaluating results could provide a direction to improve the cabin comfort. The empirical study testified that this hybrid model combined with DEMATEL method and fuzzy comprehensive evaluation was an effective method.

However, there are still some limitations in this study. First of all, the hybrid model proposed in this study just analyzed the evaluating results about the current cabin in a certain aircraft. It could not be used as a predicted model. In the future research, more attention should be paid to establish an effective predict model to direct cabin design, which is of great importance to improve the cabin comfort. Besides, this paper just gives the suggestions on how to improve cabin comfort. More specific measures and data should be researched in a future study.

Declarations

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication. We declare that we have no competing interests.

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Figures

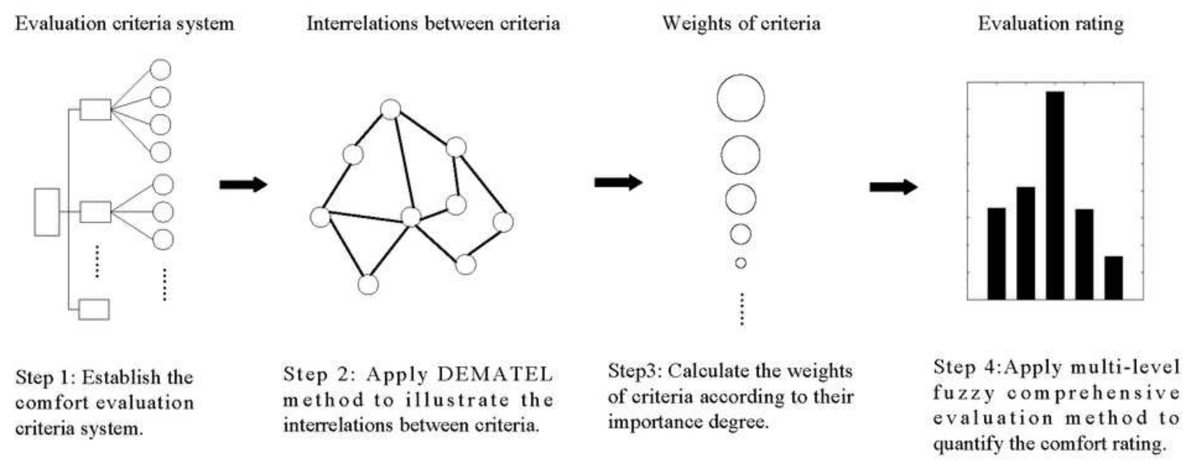

Figure 1

The hybrid model procedures

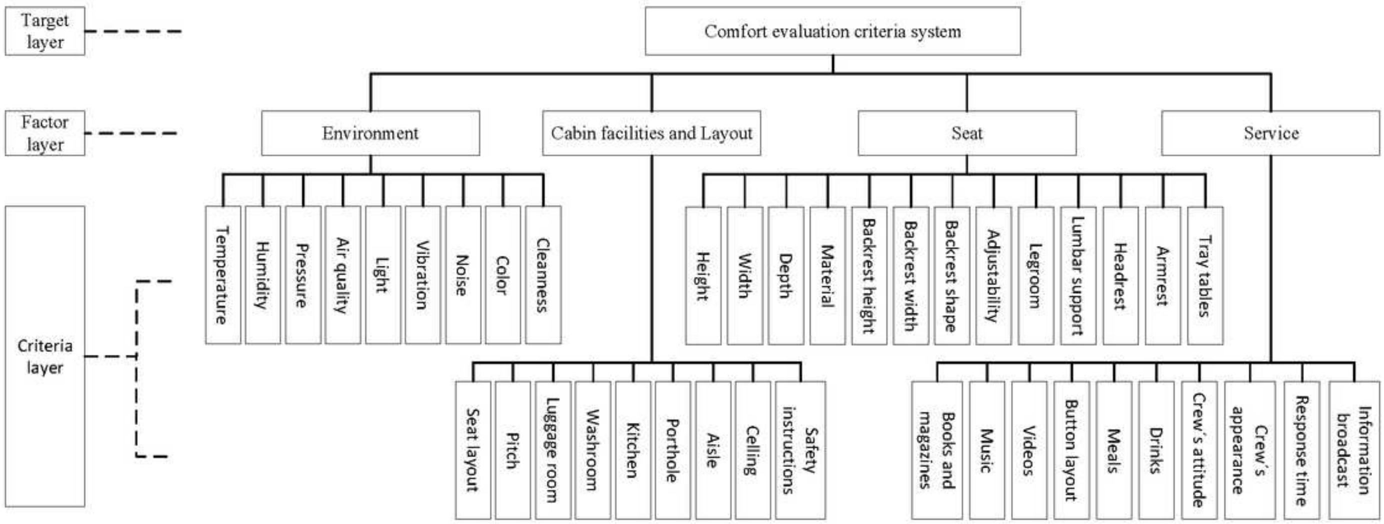

Figure 2

Passenger comfort evaluation criteria system

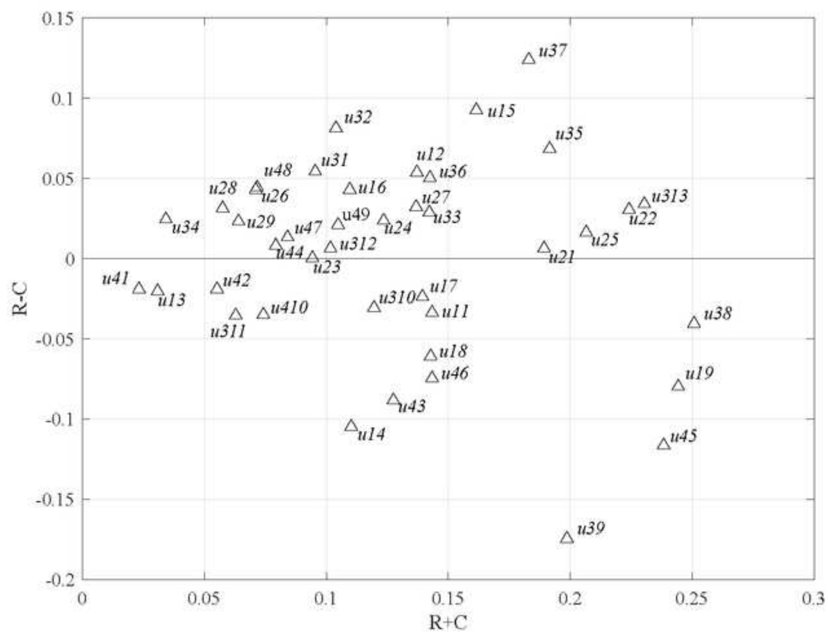

Figure 3

The causal diagram

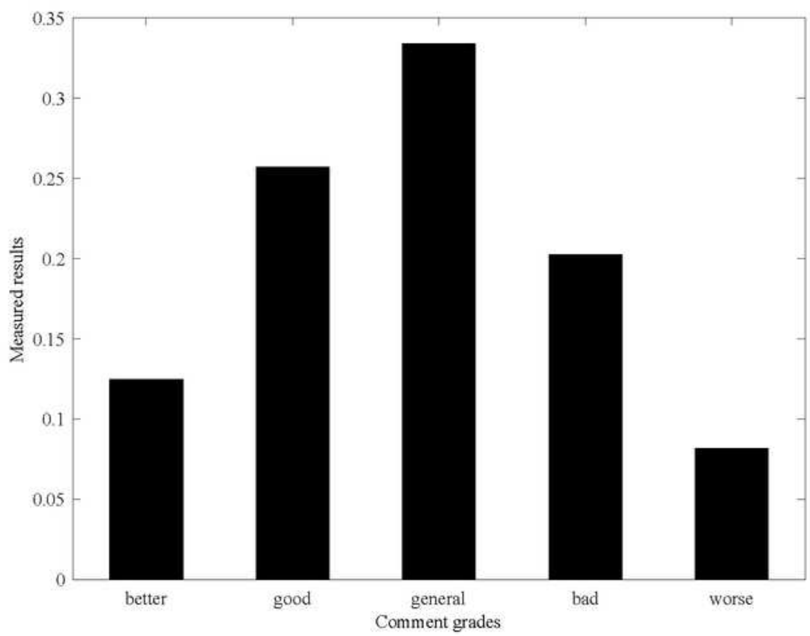

Figure 4

Measured results of comfort in aircraft cabin system