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Distribution of subjective assessments in a controlled aircraft environment

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ABSTRACT

Within the project ICE ("Ideal Cabin Environment", funded by the European Commission under contract no. AST4-CT-2005-516131), the impact of different environmental conditions on comfort was investigated by 1500 participants in total. The ICE consortium was made up of 15 members from eight countries. Simulated flights of 8 hours each with 1100 passengers on 29 days were conducted in a large-scale aircraft cabin environment facility near Munich, Germany in winter 2006/2007. During these tests, typical in-flight conditions for noise, vibration, temperature, humidity, and pressure were presented with different level combinations on different days in order to analyze possible effects of these parameters on participants' comfort and well-being. The environmental conditions and passengers' physiological response were monitored by sensors, while psychological response was recorded using PDA-based questionnaires. For our share of evaluation, extensive statistical methods were used, applied on a flight-by-flight analysis.

As one outcome, the possibility to describe a large class of responses by a function based on the Poisson distribution is shown. An approximation of observed data was performed using the d_{max} test criteria of the Kolmogorov–Smirnov goodness-of-fit test. In addition, R as the variance-to-mean ratio (VMR) was determined and compared to the quality of the predictions with a significant equality to the observed data. For subjective ratings on a unipolar scale and a calculated VMR of $R \geqslant 0.72$ in raw distribution data, a success rate of nearly 95% in representing the observed data distribution with one single parameter was identified. This approach allows for a representation of an average participant's impression (answer distributions of questionnaire data) of a defined environmental condition and enables for a prediction of not measured, interim situations.

1. Introduction

An increasing amount of passengers spend more and more time in aircraft cabins [1] and are exposed to environmental conditions created artificially by aircraft's onboard system. Aircraft manufacturers therefore put emphasis on the development of an aircraft cabin interior that offers as much comfort as possible, keeping expenditure in mind. Information on passengers' perception and acceptance of certain environmental conditions as a competitive edge in airlines' choice are of great value. Different methods to measure customer satisfaction are available like market share or turnover of a company as objective and analysis of passengers' complaints or questionnaire surveys as subjective tools [12]. One early investigation of in-flight comfort at short haul travel, using questionnaires with 758 respondents, was performed and published between 1972 and 1978 by Richards and Jacobson [13,14, 20,21]. As customer requirements may change with time, several surveys (some of them performed by airline companies and thus unpublished, others performed by research projects, e.g. [9]) followed.

Objective of the ICE project[1] (scheduled to run for three years from October 2005 to September 2008 and prolonged until March 2009) was to identify an ideal combination of different ambient factors towards agreeableness and comfort for today's flying public. To evaluate combined effects of temperature, relative humidity, cabin pressure, and noise and to provide a European pre-Standard for an optimized aircraft cabin environment [19], a large number of 'passengers' were exposed to different conditions during simulated flights, including not only typical in-flight conditions but also values expected to offer different levels of comfort. Evaluated psychological and physiological tools were used by the consortium to record passengers' perception, effects on health and on well-being as well as passengers' preferences.

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[1] Official project website: http://www.ice-project.eu.

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Table 1
Overview of the 5 analyzed sections [with abbreviations]. For each section (column 1), quantity of items dealing with this topic and scale, used in the questionnaire, are listed in column 2 and 3. In column 4, an example question is given together with unipolar-scaled response options.

Section [abbr.]	Consists of	Used scale	Example quest./response option
Usage of blankets [*B*]	1 item	4-cat.	"Have you used a blanket?" 1 = not at all ... 4 = all the time
Environmental perception [*E*]	5 items/indices	4-cat.	"Currently, the air movement is" 1 = strong ... 4 = imperceptible
Comfort [*C*]	8 items/indices	4-cat. (6x) 7-cat. (2x)	"For me, the air is currently" 1 = too stale ... 4 = comfortable
Personal mental state [*st*]	4 items/indices	7-cat.	"Currently, I feel sleepy" 1 = not at all ... 7 = very much
Perceived symptoms [*sym*]	11 items/indices	4-cat.	"Currently, I have pain in the back" 1 = not at all ... 4 = very severely

The major achievement of the ICE-investigation was to develop a "Predictive Design Model" (PDM), allowing to predict a passenger's perception of certain environmental conditions in an aircraft cabin and the passenger's satisfaction with those conditions. As the first step, gathered data were analyzed by the authors in order to describe the observed answers (distributions) by an appropriate mathematical approximation. The innovative approach presented in this study should yield a simplified mathematical description of data and thus enable a significant data reduction. Furthermore, the parametrization allows for methods of interpolation of comfort ratings being used in the final ICE-model.

2. Data collection

The ICE consortium performed a total of 36 simulated flight tests at the *Aircraft Cabin Environment* (ACE) rig (7 flights) located at the Building Research Establishment Ltd. (BRE) in Watford, UK [2] and at the *Flight Test Facility* (FTF) at Fraunhofer Institute for Building Physics (IBP) in Germany [18] (29 flights). Even though in the ICE project all flights were used in data analysis, the present study aims exclusively at data gathered during FTF simulator-flights. The FTF consists of a fuselage of an Airbus A310 front section with the same interior as used during its previous service. From November 2006 to January 2007, 29 tests took place, each consisting of a 30-minutes pre-base phase, 7 hours of simulated flight and a 30-minutes post-base phase, so the overall time onboard was 8 hours. During "flight", environmental parameters as cabin pressure, relative humidity, temperature, and noise were varied on a day-by-day basis according to predefined test plan. Pre- and post-base phases were held constant for all flights at ambient conditions. For development of the PDM, physiological and psychological data were gathered of approx. 1150 persons (40 persons per flight), aged from 18 to 93, showing an equal distribution across the age groups 18 to 34, 35 to 50, and 50+ years. Further details on the test design, the parameter variation, and the experimental conditions can be found in [11] and [10].

During each simulation run in the FTF (divided into 5 segments), a PDA-based questionnaire with 117 CMSB[2] and 93 PC questions[3] (1x) was handed out to the participants, 3 times during "flight" (segments 2, 3, 4), once during the pre- (segment 1) and once during the post-baseline phase (segment 5). Answers were given on four-, five- or seven-category scales, either unipolar or bipolar. The topics addressed were subjects' state of comfort, mood, symptoms, and behavior (asked at all 5 inquiries) as well as subjects' personal characteristics, state of health, general well-being, and sensitivity to certain environmental situations (asked only once, as these conditions are not likely to change during one "flight"). Questionnaires were developed, supervised, and preprocessed for later analyses by the Unit for Psychology of Ergonomics, Environment, Health and Performance at the Institute for Environmental Hygiene, Medical University of Vienna (MUV), Austria [22].

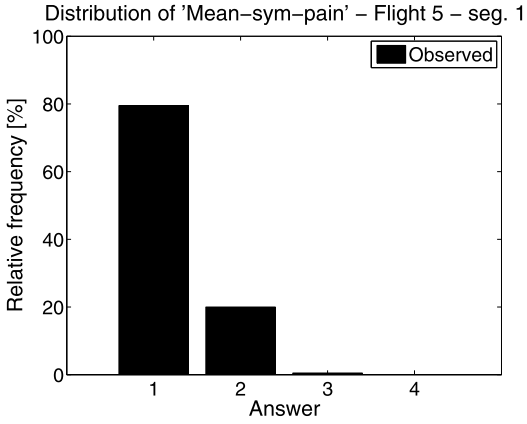

Fig. 1. Example of an observed answer distribution (relative frequency for flight 5, 1st segment) for combined pain-index **Mean-sym-pain**, asking for *pain in the back/... neck/... bottom/... legs* with response options ranging from "1" (not at all) to "4" (very severely).

3. Data analysis

During tests at FTF, one flight was aborted due to external circumstances, so 28 flights were available for analysis. After a thorough principal component analysis (PCA) carried out together with MUV, 72 questionnaire items were identified to be part of the future PDM. Numerous items were combined to representative indices.

As a subgroup, a set of 29 questionnaire items and indices was used in this study for approximation approach. 29 items were assigned to five sections, as listed in Table 1. A list of all items can be found in Table 3.

For this listed set, answers were given on a unipolar scale with a proposed prominent cumulation at one end of the scale: For each question, the scale offers a descending sequence of responses from 'no effect', 'no disturbance', or 'optimal condition' to 'severe effect', 'a great deal of disturbance', or 'adverse condition'.

At first, distributions of answers from the 40 participants (per flight) for these questionnaire items and indices were calculated. An example is given in Fig. 1, showing observed distribution of index *Mean-sym-pain*[4] for flight 5, 1st segment.

Comparing the (right-skewed) shape of observed distributions with well known discrete probability distributions, especially

[2] Passenger cabin environment survey.
[3] Passenger personal characteristics.

[4] *Mean-sym-pain* is a combined index representing the perception of muscle pain in different parts of the body (back, neck, bottom, and legs, based on the results of PCA).