SOME OPEN PROBLEMS OF HAND EVALUATION

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In proposed contribution the reproducibility of the subjective hand evaluation and prediction of subjective hand are discussed. For reliable subjective evaluation of hand the reproducibility and good representation of results has to be performed. For representation of results the approach based on categorized variables is used. For the case of subjective hand the ordinal median and its 95% confidence interval were applied. The set of properties indirectly connected with hand are specified. The methodology of prediction of subjective hand based on these properties is described. The whole procedure is demonstrated on PET/wool men's winter suit fabrics

1. INTRODUCTION

The basic properties of clothing textiles (strength, shrinkage, drape ability, etc.) can be measured objectively and then applied for estimation of garment behavior. These properties have usually physical sense. The other ones (appearance, comfort, hand) are not directly measurable in laboratory. Evaluation is carried out by consumer on the basis of his feeling evoked by in contact of his preceptors (eye for appearance, eye and fingers for handle). These so-called tactile properties play important role as the first characteristics entering to contact with consumer. Evaluation is carried out by consumer on the basis of his feeling evoked by textile with contact of his preceptors (e.g., eye for appearance, fingers and palms for hand). The second possibility is to use the so-called indirect measurements in combination with calibration equations. With development of new types of technologies and textile products objective characterization hand becomes more important. The use of computer oriented methods for textile design needs of objective hand prediction evaluation as well.

2. SUBJECTIVE HAND AND ITS EVALUATION

Principles of textile production are known more then 6000 years. In this period the optimal condition of their manufacturing was found. However, mechanisms affecting the psychophysical appearances of textiles leading to pleasant sense during wearing are not fully explained up to this time. One of the basic contact properties of textiles is hand. The term "hand" is difficult to define precisely. It belongs to textile quality evaluation as one of the most important utility properties. It is possible to include hand among subjective feelings evoked by measurable textile characteristics. The subjectively evaluated hand is connected especially with surface, mechanical and thermal properties. The first attempts of hand evaluation of textiles were published in 1926 [1].Two basic procedures of subjective hand evaluation were proposed [5]:

a) **direct method** – is based on principle of sorting of individual textiles to defined subjective grade ordinal scale (e.g., 0 – very poor, 1 – sufficient,...., 5 – very good, 6 – excellent)

b) **comparative method** – is based on sorting of textiles according to subjective criterion of evaluation (e.g., ordering from textiles with the most pleasant hand to textiles with the worst hand).

The wide range of word expressions is connected with term hand, e.g., smooth, full, bulky, stiff, warm, cool, sharp, etc. The expressions are used for denotation of primary hand [2, 3, 4, 5, 6]. For prediction of hand using any subjective method it is necessary to solve following problems:

- choice of respondents
- choice of grade scale
- definition of semantic.

2.1. Choice of respondents

The method of choice of respondents has very strong influence on obtained data and therefore also on results of hand evaluation. It is obvious, that subjective evaluation is based on quality of sensorial receptors of the individual respondents. Results of evaluation are also dependent on the psychical state of respondents and the state of environment. Different results are often obtained by experts and by consumers. It is given by different points of view on textile and used terminology.

Above indicated problems show that it is very difficult to maintain reproducibility and choice of respondents has to be strongly defined. The significant differences exist between men and women, too. The men evaluate usually close to scale center in comparison with women. The special problem is size of respondent group. The minimum size for expressing of consumer meaning is 25–30 people and for looking for relationships with objective characteristics more then 200 people.

2.2. Choice of grade scale

If the paired comparison [7] is not applied it is possible to choose grade scale according to the actual criterion and needs. The size of grade scales varies from 5 to 99. The 99 grade scale is more suitable for experts handling with fabrics. For consumers grade scale from 5 to 11 is preferred as they have not so high sensitivity for judgement of very weak differences. Generally is valid, that the area of grade scale centre is frequently used in comparison with the areas near the scale ends.

2.3. Definition of Semantic

Evaluation of total hand is not sufficient when more precise results are required. It is suitable to introduce primary hand values. Primary hand values are connected with surface, thermal and geometric properties. Following polar pairs are very often used for expressing of primary hand values:

rough – smooth
stiff – flexible
open – compact
cold – warm.

Paired comparison of several samples is often carried out and then the ranks are got together. This method is easy for statistical data processing but it is suitable for small sets of textiles only.

3. OBJECTIVE HAND EVALUATION

A lot of methods are used for indirect objective hand evaluation. These techniques can be divided to three groups according to used instruments:

a) **special instruments** – the hand is result of the measurement. Drawing of textile through the nozzle of defined shape and evaluation of dependence "strength-displacement" course is usual principle [9].

b) set of special instruments for measuring of properties corresponding to hand. Kawabata's evaluation system (KES) belongs here. It consists of four instruments for measuring of tensile, shear, bending, surface and compressive properties under special conditions of measuring. By these instruments 16 mechanical characteristics are measured [10].

c) **standard instruments** for evaluation of properties corresponding of hand [11].

Techniques of objective hand evaluation can be divided to two groups according to data processing.

a) result is **one number** characterizing hand – this number is very often obtained from conversion equation (e.g., regression model), where subjective hand is endogenous variable and measured properties are exogenous ones [10, 11].

b) result is the **vector of numbers** characterizing hand. Comparison of hand is then carried out on the basis of multivariate statistical methods (e.g., factor analysis [12], discrimination analysis [10] and cluster analysis [13]).

Applicability of various methods for objective hand evaluation is connected with the choice of measured textiles properties.

4. SUBJECTIVE HAND AND APPEARANCE

During the subjective hand evaluation the visual inspection of samples can have influence on final decision. In this section the comparison of results obtained with and without "visual inspection" are presented. The handle evaluations were compared and influence of appearance on handle evaluation was investigated.

The 28 fabrics for men's suit were chosen for subjective appearance evaluation and subjective handle evaluation with and without visual inspection. For achievement of reproducibility of handle evaluation two groups of respondents were applied. Size of the first was 92 and the second was 160. Ratio of ages of respondents and ratio of men and women was similar. As respondents the consumers were used. Each of them was precisely informed what and how has judge. The second group beside handle evaluation with visual inspection carried out evaluation of handle without visual inspection and appearance evaluation. The second group judged one year after the first. The first group had to disposal five grade scale and the second group eleven-grade scale. For comparison of judgment Spearman's rank correlation coefficient was applied.

The relationship between results of both groups is high (Spearman's rank correlation coefficient is 0.89). It can be said, if respondents are well informed, it is possible to achieve reproducibility. On other hand, five-grade scale is less sensitive to differences in judgment and this less sensitivity leads to higher loss of information.

Relationship between two types of subjective handle evaluations (with and without visual inspection) is high, as well (Spearman's rank correlation coefficient is 0.98). It indicates that well-informed respondent is able to restrain visual perception even if majority of respondents remarked their influence by pattern (color of textile). The relation between handle and appearance is weaker (Spearman's rank correlation coefficient is 0.52 for the case with visual inspection and 0.47 for the case without visual inspection). It is interesting that most of fabrics at whom the handle was evaluated at the borders of scale (it means with very good handle or very poor handle) had the similar appearance evaluation.

The results indicate when the respondents are well prepared it is possible to ensure the reproducibility of data concerning the handle evaluation. The handle can be judged with visual inspection but the condition of well-informed respondents is necessary, as well.

5. PREDICTION OF THE SUBJECTIVE HAND

Subjective hand of the set of 28 men's suit fabrics was carried out by means of group of 92 well-informed respondents. They had 5-order grade scale to disposal (1 – very bad, 2 – poor, 3 – average, 4 – good, 5 – excellent). The estimations of hand grades from subjective evaluation results were treated by means of technique described bellow. The basic characteristics are presented in Table 1.

Table 1 Range of Basic Parameters of Tested Fabrics

weight	[g/m^2]	140–380
sett – warp weft	[yarns/10 cm]	160–500 140–300
blending		100% wool 45/55 wool/PES 70/30 PES/viscose wool/PES/PAD
basic types of weaves	plain, two-and-two twill, satin, prunell	

Statistical analysis of subjective hand results is obviously based on the classical arithmetic mean. The more correct approach based on the categorized variables [15, 16] is proposed in this contribution. Generally, for categorized variable case the population of all events is divided to the categories $C_1, \ldots\ldots, C_P$. Here, $P = 5$ categories were used. Special case of categorized variable is ordinal variable [10, 14]. For ordinal variable the categories $C_1, \ldots\ldots, C_P$ are sorted according to external criterion (here hand). It is assumed that the first category is worst and last category is best. The category C_{i+1} is better that C_i for all $i = 1, \ldots.., P - 1$. Statistical treatment of ordinal variable is based on absolute frequencies n_i, $i = 1, \ldots.., P$ corresponding to categories $C_1, \ldots\ldots, C_P$.

Total number of events is

$$n = \sum_{i=1}^{P} n_i \qquad (1)$$

Relative frequencies are then

$$f_i = \frac{n_i}{n} \qquad (2)$$

and cumulative relative frequencies are

$$F_j = \sum_{i=1}^{j} f_i, \quad j = 1, \ldots\ldots, P \qquad (3)$$

For characterization of location of ordinal variable the sample rating median can be computed. The median category Me is defined by inequalities

$$F_{Me-1} < 0.5, \;\; F_{Me} \geq 0.5 \qquad (4)$$

The sample-rating median of ordinal variable has the form

$$X_{Me} = Me + 0.5 - \frac{F_{Me} - 0.5}{f_{Me}} \qquad (5)$$

Subjective judgment of fabrics handle is widely used within the textile, clothing and by the ultimate consumers.

For estimation of mean handle grade the sample rating median X_{Me} defined by eqn. (5) is suitable. Characteristic X_{Me} is estimator of population rating median *Med*. Median of ordinal variable X_{Me} was used as y_i for prediction of subjective hand.

The prediction of the subjective hand was made from eight objectively measurable characteristics selected from four basic groups of properties corresponding to the hand sensorial centers.

1. For characterization of the fabric **surface roughness**
   - Coefficient of static friction $f_s \equiv x_6$ [-] has been selected.
2. The **deformability** have been characterized by the
   - Shear resistivity $G \equiv x_1$ [N],
   - Initial tensile modulus $Y \equiv x_8$ [MPa],
   - Stiffness $T \equiv x_7 \, 10^{-7}$ [N m^{-2}].
3. **Bulk behavior** has been expressed by the
   - Area weight $M \equiv x_2$ [g m^{-2}]
   - Compressibility $S \equiv x_5$ [-]
   - Thickness $t \equiv x_4$ [mm].
4. **Thermal part** of hand has been characterized by the
   - Warm/cool feeling coefficient $B \equiv x_3$ [W m^{-1}K^{-1}].

The data y_i, x_{1i}, x_{1i}, x_{2i}, x_{3i}, x_{4i}, x_{5i}, x_{6i}, x_{7i}, x_{8i}, $i = 1,2,\ldots.47$ were collected for 47 woolen men suit fabrics. Individual x data are mean values computed from 10 repeated measurements.

Predictive, regression type models were constructed in the following steps:

I. Standardization of data x_{ji}, $j = 1,2,\ldots.8$ $i = 1,2,\ldots.47$ by using of relation

$$u_{ji} = \frac{x_{ji} - x_j^*}{s_j} \qquad (6)$$

where x_j^* is sample mean and s_j is corresponding standard deviation for j-th variable, see Table 2.

II. Non-linear transformation to the special psycho-physical scale by using of Harrington type function

$$w_{ji} = \exp(-\exp(-u_{ji})) \qquad (7)$$

Table 2 Sample mean values and variances.

Property	Mark	x_j^*	s_j
subjective hand	y	3.126	0.775
shear resistivity	x_1	0.118	0.051
areal weight	x_2	209.74	42.03
warm/cool feeling coeff.	x_3	42.23	5.156
thickness	x_4	0.521	0.072
compressibility	x_5	1.375	0.105
coeff. of static friction	x_6	0.291	0.0274
stiffness	x_7	3.501	2.76
initial tensile modulus	x_8	119.88	55.076

III. Selection of statistically suitable regression sub-model from following three basic ones

LIN: $$y_i = b_0 + \sum_{j=1}^{8} b_j . w_{ji} + \varepsilon_i \quad (8)$$

GEOM: $$\ln y_i = \ln b_0 + \sum_{j=1}^{8} \ln w_{ji} + \varepsilon_i \quad (9)$$

TAYL: $$y_i = b_0 + \sum_{j=1}^{8} b_j . w_{ji} + \sum_{j=1}^{8}\sum_{k=2}^{8} b_{jk} w_{ki} w_{ji} + \varepsilon_i \quad (10)$$

Predicted correlation coefficient R_P, mean quadratic error of prediction *MEP*and mean relative error of approximation E [%] can be used for determination of regression model quality. For calculation of *MEP*, the following equation is valid

$$MEP = \frac{1}{n}\sum_{(i)} \frac{e_i^2}{(1-H_{ii})^2} \quad (11)$$

where $e_i = y_i - y_{ipred}$ and H_{ii} are diagonal elements of projection matrix $X(X^TX)^{-1}X^T$.

Predicted correlation coefficient R_P is defined as

$$R_P = \sqrt{\frac{1-n.MEP}{\sum_{(i)} y_i^2 - n.y^{*2}}} \quad (12)$$

where y^* is median of ordinal variable of hand. Both these characteristics use the special prediction from estimates when single points are left out when the prediction is calculated (prediction in i-th point is calculated without information about this point).

Table 3 Characteristics of regression model quality for various models.

Model	R_P	*MEP*	*E*
LIN	0.621	0.308	12.0
GEOM	0.476	–	12.7
TAYL	0 *)	1.9	5
RLIN	0.693	0.261	12.1

*) Close to zero

Table 4 Regression results for LIN model

parameter	estimation	standard deviation of estimation	Test $H_0: b_j = 0$ t-criterion	a
b_0	2.914	0.302	9.638	0.000
b_1	−1.238	0.376	−3.295	0.002
b_2	0.770	0.493	1.561	0.127
b_3	−0.342	0.342	−0.999	0.324
b_4	0.0634	0.415	0.153	0.879
b_5	0.929	0.414	2.243	0.031
b_6	−0.0449	0.299	−0.150	0.882
b_7	−0.399	0.689	−0.579	0.566
b_8	0.528	0.295	1.79	0.081

For above-mentioned models the characteristics R_P, *MEP* and *E* are shown in Table 3.

It is evident, that from the point of view of prediction ability the LIN model is the most suitable. The estimations of b_0,......b_8 parameters together with standard deviations and significance tests ($H_0: b_j = 0$) are presented in Table 4.

It is clear that, the independent variable x_4 (thickness) and x_6 (coefficient of static friction) are the least significant.

The model without these ones is marked as RLIN. The characteristics of regression quality (Table 3) show that RLIN has better prediction ability then origin LIN model. For this model the estimations of b_0,......b_6 parameters and results of basic tests are shown in the Table 5.

In respect to the fact, that chosen textiles created representative sample of woolen textiles it is possible use parameter estimations of RLIN model for subjective hand prediction of other woolen textiles of the same type.

Methodology of prediction of subjective hand consists from following steps:

a) **determination** of sample means for shear resistance $G = x_1$, area weight $M = x_2$, warm/cool feeling coefficient $b = x_3$, compressibility $S = x_5$, stiffness $T = x_7$, and initial modulus $Y = x_8$ by the above mentioned techniques,

b) **transformation** to standardized variables x_j (eqn. 6) with use the x_j and s_j values (Table 2),

Table 5 Regression results for RLIN model

parameter	estimation	standard deviation of estimation	Test $H_0: b_j = 0$ t-criterion	a
b_0	2.903	0.262	11.071	0.000
b_1	−1.260	0.336	−3.753	0.001
b_2	0.809	0.426	1.901	0.065
b_3	−0.337	0.315	−1.071	0.291
b_5	0.950	0.392	2.421	0.020
b_7	−0.371	0.614	−0.603	0.550
b_8	0.516	0.283	1.824	0.076

c) **non-linear transformation** using Harrington type function (eqn. 7), i. e., computation w_j,

d) **substitution** to the final predictive relation

$$y = 2.9 - 1.27w_1 + 0.81w_2 - 0.34w_3 + \\ +0.95w_5 - 0.37w_7 + 0.52w_8 \quad (13)$$

This model has been successfully tested for subjective hand prediction.

6. DISCUSSION

Prediction model defined by the eqn. (13) is simple and suitable for estimation of the median of woolen fabrics subjective hand based on the measurable characteristics.

Described method can be used for other types of fabrics as well. Precision of the prediction is comparable with precision of subjective estimation.

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7. REFERENCES

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