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New Concepts In Evaluating Fabric Hand

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ABSTRACT

Textile hand, h , is considered as the summation of the "weighted" contributions of stimuli evoked by a fabric on the major sensory centers presumably present in the human hand. Such centers can be uniquely sensitive to roughness, stiffness, bulk and thermal properties.

From subjectively obtained values of hand of a fabric and from objectively measured values of its properties, a profile of plus and minus responses with respect to the specific stimuli is derived. The plus and minus responses are taken as indications that the sensory centers respond as polar pairs, such that if roughness is plus, its opposite, smoothness, is minus; or vice versa.

Similarly for the other polar pairs, stiffness-flexibility, compactness-openness, and warmth-coldness, if one member is plus the other is minus. Thus the specific stimuli of the fabric are considered judged as plus or minus by their appropriateness for intended (or imagined) end use. The fabric is regarded as a communication channel into which the finisher "encodes" plus or minus information.

Using ideas borrowed from Information Theory and Decision Theory, a family of P_h vs. EU curves is derived which expresses the probability of acceptance P_h of the fabric as a function of its expected utility value EU. The expected utility that corresponds to 50% probability of acceptance is termed the Indifference Point (IDP).

This point corresponds to a fabric having textile hand that is neither acceptable nor unacceptable. This "zero" value fabric is taken as a standard of reference for the class of fabrics under consideration. Each class of fabric is defined by an index value α which is determined from the objectively measured properties of the Indifference Point fabric. The value of α determines which sigmoidally shaped P_h vs. EU curve is pertinent for characterizing the fabrics belonging to the class under consideration.

From the specific curve there follows directly the appropriate intervals of the scale, $-3, -2, -1, 0, +1, +2, +3$ for rating the fabrics of this class. The intervals of this scale may be

equal, or else skewed minus or plus from the zero point, depending on the level of quality of the fabric. When an "unknown" fabric belonging to the class is judged on its appropriate scale, the probable acceptance is estimated, at least in principle, by its projected position on the P_h vs. EU curve.

Information theory was developed specifically for the study of signs as signs ("syntactics"). The present discussion of signs brings into consideration additionally the relation of signs to the users of signs ("pragmatics"). The terms α and $(1-\alpha)$ are introduced as indices not only of the quality level of a product as reflection of its intrinsic structure, but also of the psychological factors relative to the user's judgment of the product's appropriateness for a specified end use.

The foregoing treatment may be useful in guiding fiber and fabric modifications by which broad changes are possible in the stimuli evoked to the hand by the treated fabric.

KEY WORD INDEX

Decision Theory
Fabric Hand
Factor Analysis of Hand
Hand Rating Scale
Information Theory
Statistical Treatment of Hand
Textile Hand
Textile Properties

TEXTILE hand implies human judgment. Human judgment of quality in general brings into the picture more than just the physical characteristics of products. It brings into consideration the individual's responses to stimuli. Although human judgments—for example of texture, color and luster—are notoriously difficult to quantify, progress is being made toward better understanding of consumer reactions to such stimuli.

Progress along these lines can be important to textile chemists and colorists because information on consumer likes and dislikes, when fed back to the laboratory, helps determine the direction of fabric finishing. Tradition-

ally the information on fabric appropriateness for specific uses is communicated largely by verbal statements carried by salesmen and market people.

The recent advances in automation and data processing allow for a more definitive specification of quality in relation to consumer desires. With the many new opportunities open for fiber and fabric modification, the processor needs more precise information than he had in the past on those fiber and fabric properties which determine greatest consumer appeal.

Psychologists define "quality" as that attribute of an elementary sensation which makes one sensation different from any other. Thus color, harshness and warmth represent qualities. The term "hand" is used to describe tactile and muscular (kinesthetic) sensations produced by a fabric.

It is just as difficult for textile people to agree on the meaning of the expression "hand" (or "handle") as an index of fabric texture as it is for a panel of theologians to agree on a definition of "sin." Some claim the term hand is as undefinable as the term "jazz." A seeker after truth once challenged Louis Armstrong to define jazz. Louis raised a fierce eyebrow and bellowed, "Why, man if you have to ask that, you ain't with it!"

What Louis means is that you have to *feel* jazz in your bones to appreciate it. But first, of course, you have to hear it. Indeed the textile man also uses his sense of hearing to detect features of fabric texture. The characteristic rustle of silk is an example. The appearance of a material also gives an impression of texture, but texture is more than that which meets the eye. We shall concentrate in this discussion on the features of the response of the sensory centers in the human hand to the material.

The human hand is a sensitive instrument. When trained it can discriminate small differences in fabric quality. The results of hand appraisal tests are

Evaluating Fabric Hand

described by textile people in a multiplicity of words such as soft, crisp, firm, hard, harsh, boardy, dead, lively, wiry, cold, warm, dry. There are perhaps hundreds of these terms. All of them help express human response to a fabric's feel.

In the first part of this discussion I shall suggest a mathematical model in which fabric hand is expressed as a linear function of four basic elements that have been derived by statistical analysis of the interconnections among the words commonly used to describe hand. Just as we decompose sound into its harmonics and white light into its monochromatic components, we resolve hand into its components.

This approach to understanding hand appears to offer an opportunity for learning more about preferences in product texture and finish. This approach may lead to better prediction of specific features of product qualities that will be in demand as well as to better control in fabric making and finishing.

The hand of a textile depends not only on the finish but also on details of the fabric's structure. Structure, of course, includes: fabric weave—the type and compactness; yarn structure—the type and degree and tightness of twist; and fiber structure—including supermolecular, macromolecular and molecular structures.

The contributions of all components of structure to texture depend on their distribution and amounts, as well as their sizes, shapes, compactness, cohesiveness and mobilities. For example, among the important determinants of the suppleness or stiffness of a fabric are the mobilities of the yarns and fibers as well as of the molecules that comprise the fibers. The mobilities in turn are determined by the friction

Fabric	Texture As Reflected By Hand
7W/3C/DK	
(a) W/C + Wurlan + DHMEU	$h_1 = 4$
(b) W/C + Wurlan	$h_2 = 3$
(c) W/C + KOH(alc)	$h_3 = 1$

Fig. 1—Comparison of the hand of a blend fabric modified by three treatments. The fabric is made of 70% wool and 30% cotton. The wool of sample (a) has received a shrink-resist treatment (Wurlan, giving a 6,10 nylon coating) and the cotton a durable press treatment (dihydroxymethylol ethyleneurea). Sample (b) has only the wool treatment and sample (c) has been treated with a butyl alcohol solution of potassium hydroxide purposely to roughen the fiber surfaces. The values of hand were determined subjectively by panelists using the scale 1 to 5 (with 5 rating excellent).

Fabric:	Roughness	Matrix A	Compactness
	(Surface Friction)	Stiffness	(Wt/Thickness)
7W/3C/DK	S_R	(Flex Rigidity)	S_C
(a) 7W/3C + Wurlan + DHMEU	0.305	0.154	0.310
(b) 7W/3C Control + Wurlan	0.305	0.195	0.238
(c) 7W/3C Control + KOH (alc)	0.553	0.353	0.216

Fig. 2—The objectively determined values of roughness, stiffness and compactness of the fabrics described in Fig. 1. Surface roughness is reported as coefficient of friction, μ , (dimensionless). Flexural rigidity is expressed as gram-centimeters and weight-per-unit thickness as grams per cubic centimeter.

between component structures and this includes the internal friction between molecules.

When yarns and fibers become progressively "spot-welded" through polymer treatments, or if the molecules within the fibers become increasingly stuck together through secondary bonding or primary bond crosslinking, a supple fabric becomes progressively boardy. Many modifications in the rheological (flow) behavior of natural and synthetic protein fibrous materials—for example, from hard to rubbery—are possible through chemically altering the balance of cohesiveness and internal friction. Moreover, the mobility of these substances with respect to each other can be modified progressively by treatments which affect their surface properties, for example by our treatments of mohair by electrical (corona) discharge, or by our polyfluorosiloxanes or by our interfacially polymerized polyurea.

Twenty-five years ago at the Western Regional Research Laboratory a group of us were busy converting various proteins into fibers and films. We found ways to convert egg albumin and other native corpuscular proteins into fibrous structures. We could vary the texture of these materials by the way we manipulated them so as to give different arrangements of the molecules. The simulated meats now being made from soluble proteins, for example, similarly require the proper manipulations to attain textures that meet consumer desires in "mouthfeel."

At our laboratory today we are working on wool and mohair. It is our aim in this research to transform these fibers, modified where necessary, into new and desired products. Although we have many opportunities for fiber and fabric modification, we need to know more about consumer preferences.

Because human preferences influence judgments of textile hand, there is need for a broader consideration of hand than the expression of intrinsic structure and properties of a material. Preferences take into account, consciously or unconsciously, the appropriateness of the product for an intended or possible end-use, as

well as its intrinsic structure and properties. (Thus—to use an extreme example—a fabric that would receive a high rating of appropriateness for men's Winter overcoating would receive a low rating for its use as underwear.) Associated with appropriateness is conscious or unconscious evaluation of a product's pleasantness or unpleasantness. To a greater or lesser degree the subjective evaluations of appropriateness and aesthetics "color" the objective evaluations of a product's quality.

By means of the statistical methods of component or factor analysis (now coming into wide use with the increasing availability of high speed computers), it is possible to condense (or "fractionate") the many subjective descriptions of textile hand into a few terms; that is, to their common denominators or factors. Considered as the elements of human response to texture, these factors account for most of the descriptions of fabric texture as related to hand.

In undertaking factor analysis, the test data, T_1, T_2, T_3, \dots , are first developed into a correlation matrix in which results are intercorrelated in every possible way. The matrix is simply a condensed means of showing all possible relationships among the set of data. Factor analysis begins with the correlation matrix. It involves special mathematical techniques (one of which extracts latent roots and vectors, also called eigenvalues and eigenfunctions) in order to arrive at the factors and their weightings which indicate the degree to which the factors are significant for each test.

By means of factor analysis techniques, Howorth in England (17) concluded that four factors account for most of the variance among descriptions of fabric hand^a. These are: (1) smoothness, (2) stiffness, (3) bulk properties and (4) thermal character.

In this discussion we shall assume that textile hand as a reflection of texture can be described as a function of

^a A recent paper by Yosikawa, *et al.* (32), describes the results of factor analysis applied to 80 words related to the texture of foods. This study also finds the common denominators of the descriptive terms for mouthfeel also include smoothness, stiffness and bulk properties.

these elements with each weighted according to its contribution to the hand of the material. Psychologists are employing the methods of factor analysis to study human response to stimulus situations. In his book "The Scientific Analysis of Personality," Cattell (4) gives the following relationship of response R of an individual to a profile of stimuli $S_1, S_2, S_3 \dots$ acting on the individual whose receptor profile of traits is $T_1, T_2, T_3 \dots$ (Equation 1).

Psychologists also are giving consideration to the response of sensory receptors to stimuli. In his 1965 paper, "Sensory Properties of Food and Their Function During Feeding," Sharon (30) pointed out four sensory receptors in the mouth that are involved in the perception of product texture described as mouthfeel. These are:

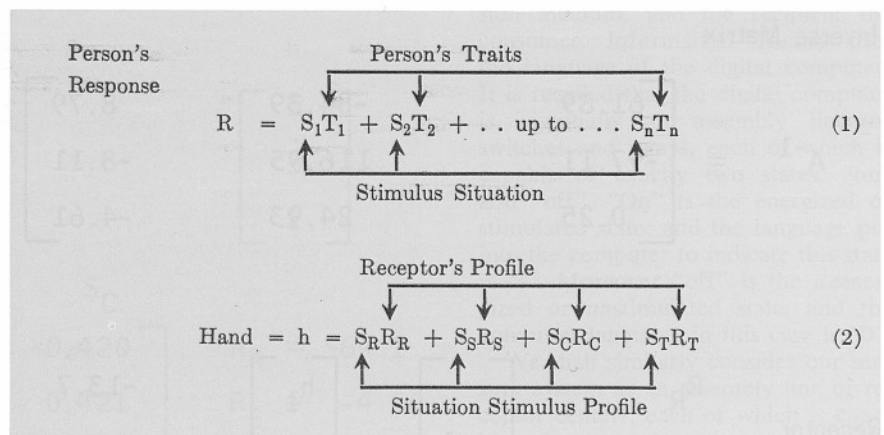
- (1) Sensors of surface smoothness to roughness, especially in the tongue,
- (2) Sensors of stiffness or flexibility, that is of alternating states of passive tension and contraction (referred to as proprioceptors),
- (3) Sensors for evaluation of bulk properties including size, weight and form, (called stereognosis centers), and
- (4) Sensors of heat and cold, the thermal centers.

Similar centers are found distributed over the whole of our bodies, but their sensitivities to stimuli vary with location.

The Human Hand As A Receptor

I shall consider that the four sensory centers found in the mouth are present in the hand and that each responds to its corresponding element of texture. And that, as a first approximation, the evaluation of hand of a textile will be considered as a linear function in which the four stimulus situations act on corresponding receptors. The following symbols will be used for the stimuli: S_R = roughness (we shall use the term roughness instead of its opposite smoothness); S_S = stiffness; S_C = compactness (we shall use this term rather than the expression bulk) and S_T = thermal character. The corresponding terms for the receptors will be R_R, R_S, R_C and R_T . The proposed linear relationship among these variables is shown in Equation 2.

Table I summarizes pertinent textile properties corresponding to the elements of hand. Mentioned in the table also are objectively measurable properties which reflect the fabric's roughness, stiffness, compactness and thermal character. Figs. 1 to 8 illustrate the application of the proposed linear relation to the estimation of receptor profiles from the results of sub-



jective appraisal of hand and from objective measurements of the pertinent fabric stimuli.

Three sets of fabrics were used in each illustration. Each set consisted of three fabrics having similar fiber composition and yarn and fabric constructions. They were selected to differ appropriately in roughness, stiffness and compactness. Since the fabrics used in each set are similar it is not necessary to include measurement of thermal character.

The first set of fabrics, labeled 7W/3C/DK, are of double knit. They were manufactured in our pilot plant from worsted-type yarns constructed from intimate blends of 70/30 wool and cotton. This double knit fabric is of the type appropriate for women's outerwear garments. Fabric *a* of this set has received two polymer treatments. The wool fibers in this fabric are coated with a submicroscopic skin of 6,10 nylon, made and chemically grafted as a sheath surrounding each wool fiber (our Wurlan treatment). The cotton fibers of this fabric have been given an *in situ* polymer treatment to confer durable press performance to the treated fabrics. The polymer is dihydroxydimethylol ethylene urea. Fabric *b* of this set has been treated with a solution of potassium hydroxide in butyl alcohol purposely to roughen the fiber surfaces.

The second set of fabrics, called

"wiry worsteds," are all of plain weave. Sample *a* is an equal blend of wool, rayon and polyester. Sample *b* is a 50/50 blend of mohair and rayon, and sample *c* is a 50/50 wool/cotton blend.

The third set, labeled WU-5297, are all-wool and of plain weave. They represent the same fabric at three stages of processing. Sample *a* is in the griegie state. It has a starched-like hand presumably desired for certain types of women's wear. Sample *b* is the same fabric after a mild scour. It has a "soft" hand with "open" structure. Sample *c* has had a vigorous scour. It is somewhat "fulled" and consequently has greater "body" (bulk) and "firmer" hand than sample *b*.

For the subjective appraisal, trained individuals rated the hand of these fabrics on a scale of 1 to 5, with the rating 1 = poor to unacceptable, 2 = slightly acceptable, 3 = moderate, 4 = good, and 5 = excellent. The reproducibility of the values for hand obtained by the panel evaluations is generally good, especially with individuals accustomed to making such evaluations. Such evaluations of hand must of course be made without significant influence of the appearance of the fabrics; for example, either by having the panel making the evaluations in a darkened room, or by having the fabrics being evaluated placed suitably behind a curtain. The

Table I—Pertinent Textile Properties Corresponding To The Elements Of Hand

Elements of Texture	Roughness	Stiffness	Compactness or Bulk	Thermal Character
Symbols of Stimulus Profile	S_R	S_S	S_C	S_T
Pertinent Textile Properties	Surface Contour Friction	Cohesiveness Mobility Flexibility Compressibility Extensibility Resilience Freedom of Motion	Size Amount Density Thickness Weight	Heat Conduction
Selected Objective Measurement	Surface Friction	Flexural Rigidity	[Weight/Thickness]	Heat Thermal Conductivity

Inverse Matrix

$$A^{-1} = \begin{bmatrix} 61.89 & -84.39 & 8.79 \\ -97.11 & 116.95 & -8.11 \\ 0.25 & 24.93 & -4.61 \end{bmatrix}$$

$$\begin{matrix} R_R \\ R_S \\ R_C \end{matrix} = \begin{bmatrix} A^{-1} \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} = \begin{matrix} -13.7 \\ +11.7 \\ +20.6 \end{matrix}$$

Fig. 3—Illustrating the determination of the receptor profile where R_R = roughness, R_S = stiffness, R_C = compactness. The inverse matrix A^{-1} of the fabric stimulus properties is multiplied by the column matrix of the values of hand in order to obtain the receptor values.

roughness, stiffness and compactness of each fabric were measured by standard methods for coefficient of surface friction, flexural rigidity and weight per unit thickness. (The coefficient of friction is dimensionless, flexural rigidity is expressed in gram-centimeters, and weight per unit thickness as grams per cubic centimeter.)

The receptor profile values— R_R , R_S and R_C —were obtained from the fol-

lowing algebraic procedure. From the set of stimulus profile values (S_R , S_S , S_C) considered as matrix A , the inverse matrix A^{-1} was determined (most conveniently by high speed computer). The values of R_R , R_S and R_C are obtained by matrix multiplication of A^{-1} with the column matrix of h values.

The receptor profiles— R_R , R_S , R_C —determined for the several sets of fabrics are shown in Figs. 4, 6 and 8.

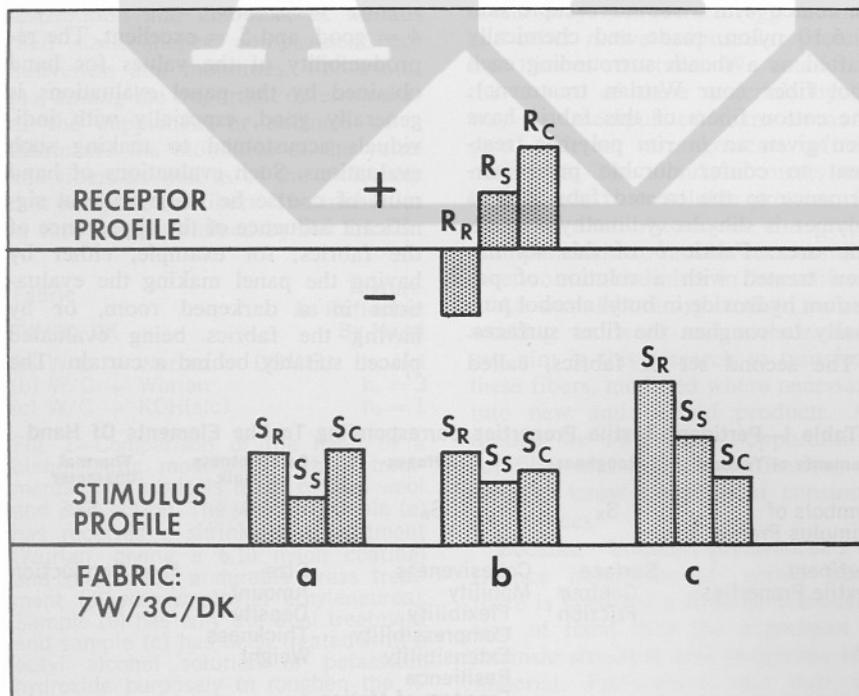


Fig. 4—Plot of receptor profile of the panelists for the fabrics described in Figs. 1, 2 and 3. The corresponding stimulus values for the set of fabrics used are also shown.

The estimated response values are seen to be plus or minus according to the way in which the stimuli evoked by the fabrics affect the observers. Corresponding to each set of receptor profile values are the stimulus profile values S_R , S_S and S_C determined by the objective measurements of surface friction, flexural rigidity and weight per unit thickness.

The plus-minus response profile for the double knit fabrics is seen to be similar to that for the "wiry worsteds." The chief difference is in the *positive* value of R_S (stiffness) for the double knits as compared with the *negative* value for this receptor for the wiry worsteds. This negative response may be taken as indication that in the worsteds the opposite of stiffness is desired, that is flexibility and resilience.

The third set of fabrics were rated by a male and by a female panel with consideration given by the men to their possible use in men's suiting and by the women for use in women's suiting. The values of hand and, accordingly, the receptor profiles for the men and for women differ somewhat as shown in Fig. 8. For men, the compactness of these fabrics is more desirable, whereas women seem to prefer openness of structure in the fabric.

The foregoing analysis suggests that the estimated plus-minus response profile may provide a useful index of the product's appropriateness for a specific (or imagined) end use. When minus response is obtained for a given stimulus type it may be considered that the complementary stimulus is plus. Thus when roughness is plus, its opposite smoothness is minus, or vice versa. A similar situation holds for the other polar pairs: stiffness-flexibility, compactness - openness, and warmth-coldness. The foregoing analysis moreover suggests that the response profile may provide a useful guide in tailoring the hand of fabrics to meet consumer desires.

Fabric As A Communication Channel

I should like to consider the finished fabric as a communication channel containing encoded information which is plus if it is desirable, or appropriate, to the individual, and minus if it is undesirable, or inappropriate. In using this approach I shall borrow ideas from concepts of present-day Information Theory and Decision Theory.

But first let me say a few words about rating scales. The rating scales used in describing product quality frequently have no reference point. For example, the rating scale, such as 1

"Wiry Worsteds"

- a. 1/3 / 1/3 / 1/3 W/R/P
- b. 50/50 M/R
- c. 50/50 W/C

h

$$\begin{bmatrix} 5 \\ 3 \\ 2 \end{bmatrix}$$

	S_R	S_S	S_C	
$\begin{bmatrix} 0.204 \\ 0.228 \\ 0.242 \end{bmatrix}$		$\begin{bmatrix} 0.088 \\ 0.200 \\ 0.125 \end{bmatrix}$	$\begin{bmatrix} 0.420 \\ 0.421 \\ 0.411 \end{bmatrix}$	$R_R = -64.1$ $R_S = -4.50$ $R_C = +44.0$

Fig. 5—Illustrating the determination of the receptor profile for fabrics called "Wiry Worsteds." These fabrics are blends of indicated proportions and where Wool = W, Rayon = R, Polyester = P, Mohair = M and Cotton = C.

to 5, is often used to rate high quality products as well as low quality materials without consideration as to whether the scale intervals are the same and without a standard point of reference.

On the other hand rating scale -3, -2, -1, 0, +1, +2, +3 has the feature of a zero point. The zero point in this case means the situation under consideration is neither acceptable nor non-acceptable (or equally acceptable and not acceptable). The "levels" on this scale may be described verbally as follows:

- +3 = extremely acceptable
- +2 = quite acceptable
- +1 = slightly acceptable
- 0 = acceptability neutral
- 1 = slightly unacceptable
- 2 = quite unacceptable
- 3 = extremely unacceptable

Modern decision theory considers human response to a situation as a function of its expected utility. Valuable insight into human response in relation to expected utility is being derived from studies of individuals asked to bid on poker hands having variable "odds." The bid one makes, the money one is willing to put up, or the risk one takes is found to vary systematically with odds.

For example, the S-shaped (sigmoidal) curve, as shown in Figs. 9 and 10, is obtained for bids on poker hands. The 50% acceptance (or bid) is designated as the indifference point (Fig. 11). Its position on the curve projected onto the expected utility value axis provides a reference point—that is, the point at which the expected utility value corresponds to the indifference point. The indifference point, which we shall refer to as IDP of the fabric, corresponds to its being neither acceptable nor unacceptable

(or equally acceptable or unacceptable). Accordingly the IDP provides the "zero" point of reference.

The term "utility" is often described as a situation which produces pleasure or satisfaction, or as the balance of pleasure (+) and pain (-). We shall consider the balance of + and - qualities in the fabric as determining its expected utility value. And in finishing fabrics we shall consider that we are adding utility values^b. Moreover, and borrowing from Information Theory, we shall consider the fabric as a communication system in which the information source is the processor, the fabric as the transmis-

sion medium, and the recipient the consumer. Information Theory uses the language of the digital computer. It is recalled that the digital computer is essentially an assembly line of switches and relays, each of which is capable of exactly two states, "on" and "off". "On" is the energized or stimulated state; and the language put into the computer to indicate this state is "1". Moreover "off" is the deenergized or unstimulated state, and the computer language in this case is "0".

We shall similarly consider our sensory system as an assembly line of receptor centers, each of which is capable of two states, the states of +

^b The expected utility of a fabric can be considered a function of its + information content times the probability that the + information is acceptable or appropriate to the recipient.

These considerations are similar to the bidding on a complex prospect where the total expected value, as defined by Decision Theory, is the dollar value of each component prospect times the probability of its occurrence.

People with different tastes will have different utility values. Decision theory considers the utility of a composite prospect P as the sum of component situations, $P_1 + P_2 + \dots$, each of which is "weighted" by the probabilities, P_1, P_2, \dots , with which the individual accepts the situation. In other words, each of these probabilities represents the appropriateness to the individual of the component situation. The composite utility function, accordingly, is expressed as follows:

$$U(P) = p_1U(P_1) + p_2U(P_2) + \dots$$

In a complementary - and + situation such as we consider in fabric evaluation, the utility function will be expressed simply as follows:

$$U(P) = pU(P_-) + (1-p)U(P_+)$$

where $U(P_-)$ and $U(P_+)$ are the "densities"; i.e., probability distributions of the states of + and - information. In the situation where smoothness is +, (for example where smoothness is regarded appropriate for a specific class of fabrics), this appropriateness will be represented by $(1-p)$. In this situation the complementary quality, roughness, will be - with probability p.

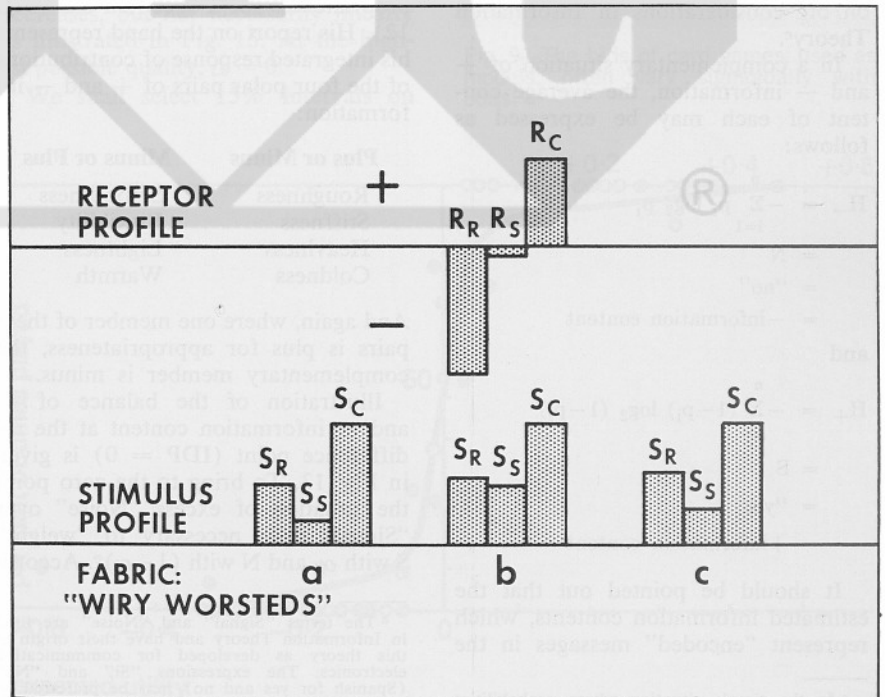


Fig. 6—Plot of receptor profile for fabrics described in Fig 5. The corresponding stimulus values for the set of fabrics used are also shown.

WU-5297
all-wool
plain weave

- A. in the "greige" state
- B. after mild scour
- C. after intense scour

	S_R	S_S	S_C		
A =	0.260	0.360	0.343	R_R	+0.47
	0.230	0.118	0.276	R_S	-12.7
	0.255	0.135	0.270	R_C	+15.9

	h_m	h_w
	1	1
	3	4.5
	2.7	5.0

	m	w
R_R	+0.47	+31.5
R_S	-12.7	-17.7
R_C	+15.9	-2.35

Fig. 7—Illustrating the determination of receptor profile for an all-wool plain weave fabric at the three indicated stages of processing. Two sets of values of hand are given. The set, h_m , was evaluated by men and the other, h_w , by women, both groups "trained." The corresponding estimated receptor profile values are shown at the lower right.

and - information content. Plus and minus responses to stimuli are in fact the elemental language of all living things. It is by refinement of language that we humans have become able to discover and define reality.

The average information content, H , of a system with n -encoded states whose probabilities (when non-equiprobable) are p_1, p_2, p_3 is defined by Information Theory as

$$H = -\sum_{i=1}^n p_i \log_2 p_i$$

where H is expressed as binary digits, or more commonly as "bits". The logarithm is to the base 2 because of on/off considerations in Information Theory^c.

In a complementary situation of + and - information, the average content of each may be expressed as follows:

$$H_- = -\sum_{i=1}^n p_i \log_2 p_i$$

= N
= "no"
= -information content

and

$$H_+ = -\sum_{i=1}^n (1-p_i) \log_2 (1-p_i)$$

= S
= "yes"
= +information content

It should be pointed out that the estimated information contents, which represent "encoded" messages in the

^c In the simple situation where probabilities are equal, such as in the toss of a coin where there are two equally possible messages, odd or even, the information content in this case is $H = \log_2 2 = 1$ bit.

fabric, reflect simply a potential for helping the recipient make a selection; that is, it gives him power to discriminate among, or select from, alternatives.

This treatment considers that the extremely acceptable fabric has the potential to evoke 100% "Signal" (S) whereas the extremely unacceptable fabric will evoke the opposite—100% "Noise" (N)^d.

Signals are considered here in relation to Noise as music is to the same set of notes scrambled. When the consumer compares an acceptable with an unacceptable fabric he "weighs" these in accord with his concept of their appropriateness for a specified use (Fig. 12). His report on the hand represents his integrated response of contributions of the four polar pairs of + and - information:

Plus or Minus	Minus or Plus
Roughness	Smoothness
Stiffness	Flexibility
Heaviness	Lightness
Coldness	Warmth

And again, where one member of these pairs is plus for appropriateness, the complementary member is minus.

Illustration of the balance of + and - information content at the indifference point (IDP = 0) is given in Fig. 13. To bring to the zero point the situation of excess "Noise" over "Signal" it is necessary to "weight" S with α , and N with $(1-\alpha)$ ^e. Accord-

^d The terms "Signal" and "Noise" are used in Information Theory and have their origin in this theory as developed for communication electronics. The expressions "Si" and "No" (Spanish for yes and no) may be preferred by those who object to the terms Signal and Noise in the present context.

^e Thus α and $(1-\alpha)$ correspond to the probabilities p and $(1-p)$ mentioned in footnote ^b.

ingly, the zero point is expressed as follows:

$$\text{minus } (1-\alpha)N = \text{plus } \alpha S,$$

or more completely by

$$\sum_{i=1}^n (1-\alpha) [p_i \log_2 p_i]$$

plus

$$= \sum_{i=1}^n \alpha [(1-p_i) \log_2 (1-p_i)]$$

The terms α and $(1-\alpha)$ represent the judgment factors, that is "weightings" of the appropriateness for a specific use of the class of the fabric in question. They "correct" the specific information in *this* fabric to give the human judgment of its appropriateness from its hand.

We shall consider the fraction of + information content in the fabric,

$$\frac{S}{N+S}$$

as a conditional index of the fabric's utility value; and when this fraction is "corrected" by the judgment factors, α and $1-\alpha$, the expression becomes

$$\frac{\alpha S}{(1-\alpha)N + \alpha S}$$

This corrected ratio is considered as the "weighted" utility value, also as the expected utility value, for which we use the abbreviation EU^f.

Thus

$$EU = \frac{\alpha S}{(1-\alpha)N + \alpha S}$$

$$= \frac{\alpha [(1-p) \log_2 (1-p)]}{(1-\alpha) [p \log_2 p] + \alpha [(1-p) \log_2 (1-p)]}$$

Values of EU were estimated (by computer) from values of p ranging from 0 to 1.0 and for α from 0.95 to 0.05. By plotting the values of p as a function of the corresponding expected utility values, the curves shown in Fig. 14 are obtained. The individual curves correspond to the selected values of α , the curve for $\alpha = 0.95$ is at the far right, and for $\alpha = 0.05$ at the left. In the plot p is designated as P_R . We shall consider P_R as probability of acceptance. P_R is a function of the weighted plus information in the fabric needed to overcome the "uncertainty" due to minus information present. The curves represent the fraction

^f These considerations are in accord with the concepts of Bayes' statistics which define a "likelihood ratio" for testing simple alternatives, such as the + and - situations in terms corresponding to those employed here.

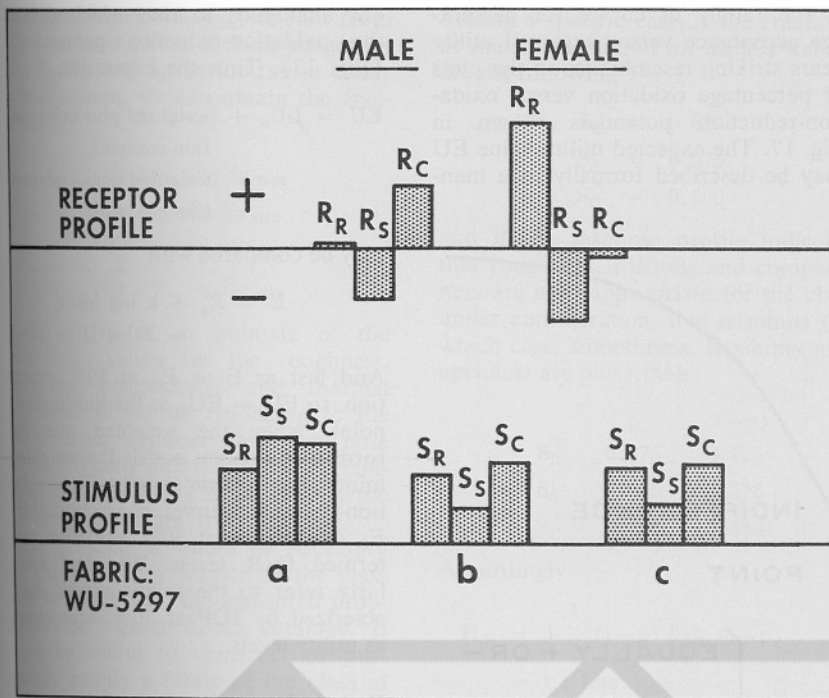


Fig. 8—The receptor profiles for fabrics described in Fig. 7 with the corresponding stimulus values for the set of fabrics used.

consumer acceptance P_R — here taken as numerically equivalent to the fraction p of maximum possible minus stimulus present in the fabric — as a function of the appropriately weighted plus information needed to overcome the uncertainty due to the minus stimulus present. Each P_R -EU curve represents the probability of acceptance of a situation P_R with respect to its expected utility value EU.

The curves are sigmoidal in shape, similar to the curves for bids versus odds mentioned earlier. Moreover, it is apparent that when low + information content is present in the material in question, the α values are high. As + information is added the α values decrease and, accordingly, the curves shift to the left. Furthermore for a material of low + information content the probabilities of acceptance, P_R , remain low over most of the EU axis, whereas for a material of high + information content the P_R values are high over most of the EU range. The index α can be looked upon as the amount of minus information present in the 50% acceptance (IDP) fabric which if replaced by plus information would be equivalent to bringing EU from 0 to the EU of the IDP fabric.

Information theory was developed specifically for the study of signs as signs ("syntactics"). The present discussion of signs brings into consideration additionally the relation of signs to the users of signs ("pragmatics"). The terms α and $(1-\alpha)$ are introduced

as indices not only of the quality level of a product as reflection of its intrinsic structure, but also of the psychological factors relative to the user's judgment of the product's appropriateness for a specified end use.

The term α may be considered as an index of material improvement as well as of appropriateness. For a "raw" product the α value can be considered as 1.0. With product improvement, α decreases, but not necessarily linearly as illustrated in Fig. 15. At the highest possible quality, $\alpha = 0$.

We shall select 15% intervals on

the percentage acceptance axis (i.e. at 5%, 20%, 35%, 50%, 65%, 80% and 95%) along the utility curve and project these positions onto the expected utility axis, to obtain a rating scale appropriate for the class of material under consideration. This rating scale, shown in Fig. 16, is assigned the values -3, -2, -1, 0, +1, +2, +3, with zero as the point of reference.

As in the case of bids versus odds, the 50% acceptance value projected onto the expected utility value axis gives the expected utility at the indifference point. Thus the indifference point can serve as a reference zero point for product quality for the class of material specified by the index α . Individual members of this class will rate + and - on the rating scale depending on the balance of their + and - information content.

Significantly the intervals between the numbers of the -3 to +3 rating scale will vary depending on the product quality. This is illustrated in Fig. 16. For a material of high appropriateness the scale will be + skewed, whereas for one of low appropriateness it will be - skewed. In the mid region of appropriateness the

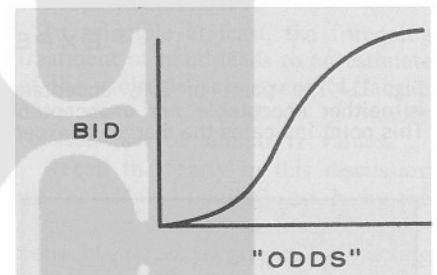


Fig. 9—The bids of card games, used as models, often vary sigmoidally with odds.

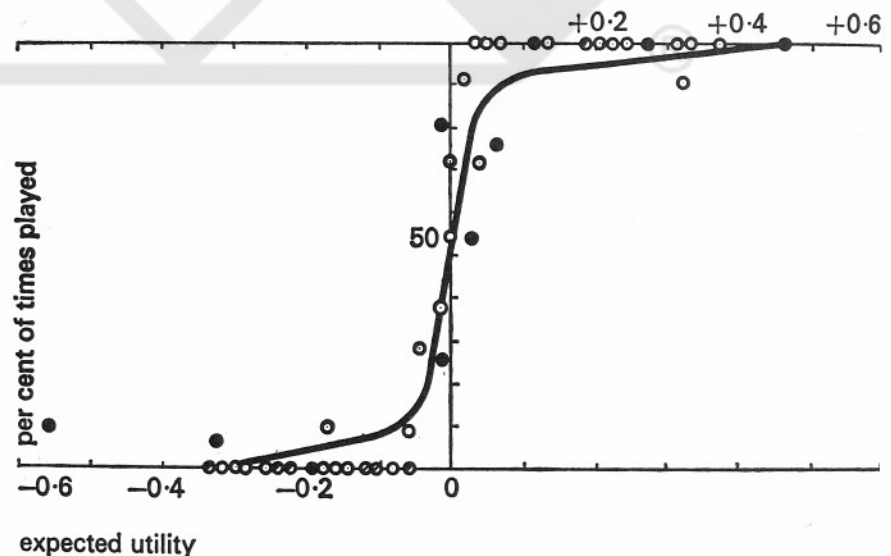


Fig. 10—Illustration of the variation in per cent of times poker hands are played with "odds," expressed as expected utility (value).

rating scale will have linearly spaced intervals.

According to the foregoing considerations, improvement in product quality is represented by a shift of the curves in Fig. 14 from right to left as indexed by decrease in α .

The family of curves for percentage acceptance versus expected utility bears striking resemblance to the plots of percentage oxidation versus oxidation-reduction potentials shown in Fig. 17. The expected utility value EU may be described formally in a man-

ner analogous to that which defines the oxidation-reduction potential E (Fig. 17). Thus the expression

$$EU = EU_0 + [\text{weighted plus information content}] - [\text{weighted minus information content}]$$

may be compared with

$$E = E_0 + k \log [\text{oxid}] - k \log [1 - \text{oxid}]$$

And just as $E = E_0$ at 50% oxidation, so $EU = EU_0$ at the indifference point, when the weighted plus information content equals the weighted minus information content. The oxidation-reduction curves, characterized by E_0 determined at 50% oxidation, are termed O/R levels. We shall similarly refer to the utility curves characterized by IDP at 50% acceptance as utility levels.

Prelude To Application

The foregoing considerations lead to the following suggestions for arriving at the representative utility level and rating scale for a class of fabrics:

(1) A trained panel is asked to select, from a set of fabrics belonging to the class under consideration, the indifference point fabric, i.e. the IDP standard for reference. The set from which the selection is made should cover an appropriate range in hand from acceptable to unacceptable.

(2) The panel is also asked to rank these fabrics on the "working" scale for hand of 1 to 5 in which 1 = unacceptable, 2 = slightly acceptable, 3 = moderate, 4 = good, and 5 = excellent.

(3) The +, - response profile is determined as illustrated in the first part of the paper on sets of the ranked fabrics from the tentative values obtained for the hand and from the stimulus values determined objectively. This response profile indicates which of each pair of stimuli is plus and which is minus for roughness-stiffness, stiffness-flexibility, compactness-openness, and warmth-coolness.

(4) Next determine the fractions of maximum possible + and - stimuli present in the indifference fabric (that is, the ratio of observed value of roughness S_R , stiffness S_S , compactness S_C , and thermal behavior S_T to the estimated maximum values of these stimuli for this class of fabric). In other words, for these determinations it is necessary to consider that the fabrics of the class to have upper limits of compactness, $S_{C \max}$, stiffness, $S_{S \max}$, and roughness, $S_{R \max}$, and

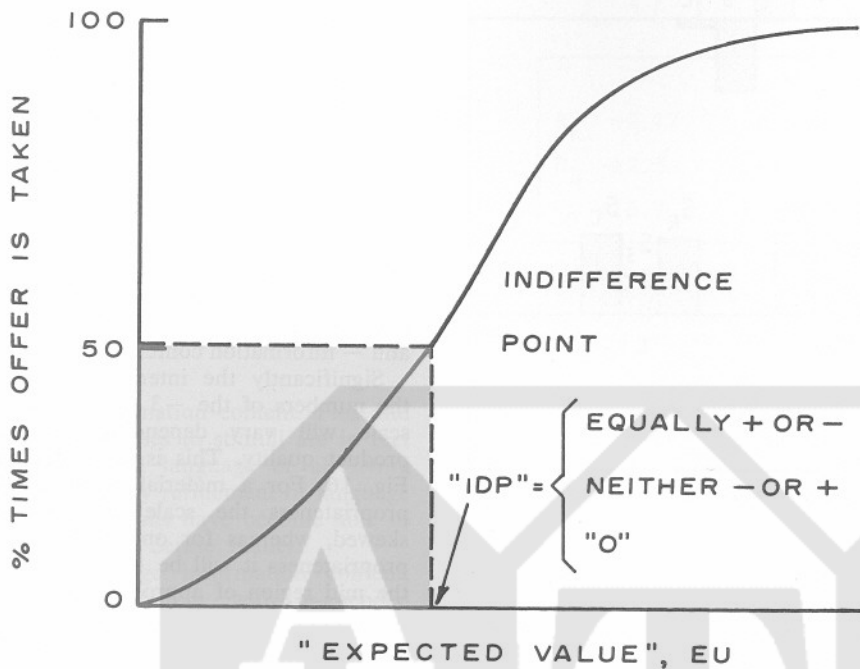


Fig. 11—The point of 50% acceptance of a risk—that is, when the situation is neither acceptable nor unacceptable—is termed the Indifference Point (IDP). This point indicates the margin of expected utility.

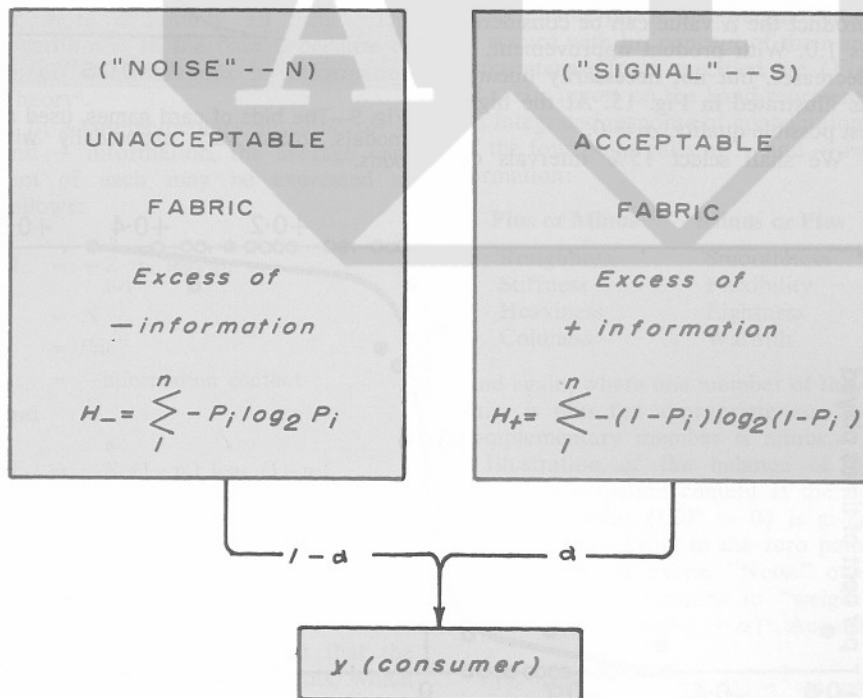


Fig. 12—Illustrating the "weighting" by the consumer (or panel) of fabrics having encoded + and - information content. The estimated information contents, representing encoded "messages" in a fabric, reflect a potential for helping the recipient make a selection; that is, it gives him power to discriminate among, or select from, alternatives.

thermal behavior $S_{T \max}$, so that from the measured values of these properties S_C, S_S, S_R and S_T , in the fabric under consideration, we can obtain the fractions

$$\begin{aligned} S'_R &= S_R/S_{R \max} \\ S'_S &= S_S/S_{S \max} \\ S'_C &= S_C/S_{C \max} \\ S'_T &= S_T/S_{T \max} \end{aligned}$$

To arrive at an estimate of the maximum values for the roughness, stiffness, compactness and thermal character of fabrics belonging to the class under consideration may pose some difficulty and there may be considerable uncertainty as to whether the values selected are truly limiting.

In principle it would be necessary to examine many fabrics of the class and to select from the measured properties the highest values obtained. It may be useful to construct or purposely modify a fabric of the class in order reasonably to arrive at the limiting values of the stimuli. Of course the fabric in this case must be representative of the class under consideration. The maximum value for compactness requires approximation of the highest possible weight per unit thickness (i.e. greatest density) of a fabric belonging to the class. The limiting thermal character, as reflected, for example, by minimum heat transfer, may be arrived at from measurements of many fabrics of the class with selection made of the lowest measured value. Moreover, the upper limit of stiffness may be taken as the highest flexural rigidity observed for fabrics of the class. Also the maximum roughness may be arrived at by finding the highest coefficient of friction among fabrics of the class under consideration.

(5) The + and - information contents H_+ and H_- are estimated for the IDP fabric as follows:

(a) The values of p and $(1-p)$ are determined from the plus-minus response profile and fraction maximum stimulus values. Thus if roughness

$$S'_R (= 1-p)$$

is plus, then its polar opposite,

$$\text{smoothness} = 1 - S'_R (= p),$$

is minus, etc.

(b) The values of H_+ and H_- are then estimated from the summations:

$$H_+ = -\sum_1^4 (1-p) \log_2 (1-p)$$

and

$$H_- = -\sum_1^4 p \log_2 p$$

Taking a specific case, if the fractions of maximum stimuli for an IDP fabric are the following^{*}:

$$\begin{aligned} S'_R &= 0.875 \\ S'_S &= 0.675 \\ S'_C &= 0.500 \end{aligned}$$

and if the response profile indicates that roughness, stiffness and compactness are all inappropriate for the class under consideration, that is minus (in which case, smoothness, flexibility and openness are plus) then

	p	$(1-p)$
S'_R	0.875	0.125
S'_S	0.625	0.375
S'_C	0.500	0.500

Accordingly

$$\begin{aligned} H_+ &= -\sum_1^3 (1-p) \log_2 (1-p) \\ &= 1.1 \text{ bits} \end{aligned}$$

and

$$\begin{aligned} H_- &= -\sum_1^3 p \log_2 p \\ &= 1.4 \text{ bits} \end{aligned}$$

(6) The index α is determined from the H_+ and H_- values as follows: Recall that at the indifference point

$$(1-\alpha)N = \alpha S,$$

so that

$$\left[\frac{\alpha}{1-\alpha} \right] = (N/S) = H_-/H_+$$

and

$$\alpha = \left[\frac{H_-/H_+}{1 + H_-/H_+} \right] = \left[\frac{H_-}{H_+ + H_-} \right]$$

Accordingly from the values of H_+ and H_- mentioned previously

$$\begin{aligned} \alpha &= \frac{1.4}{1.1 + 1.4} \\ &= 0.56 \\ &= EU_0 \text{ of the IDP fabric.} \end{aligned}$$

The value $\alpha = 0.56$ not only prescribes the expected utility E_0 at 50% acceptance but also defines the specific curve of probable acceptance as a function of expected utility, P_R vs. EU_0 .

(7) The appropriate - 3 to +3 rating scale for this class of fabrics is obtained directly, as outlined earlier in this discussion, by projections of 15 percentage intervals of acceptance, from 5 to 95%, onto the expected

* In this case, as previously, thermal stimulus S_T is neglected.

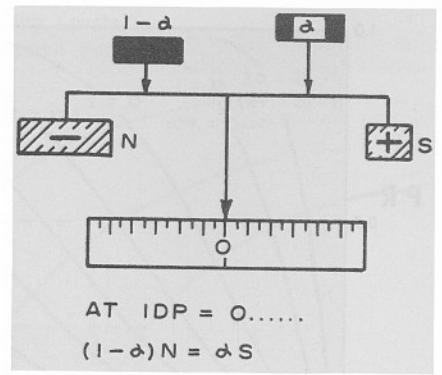


Fig. 13—Illustrating the corrected balance of - and + information (Noise and Signal) content at the 50% acceptance level.

utility axis as shown in Fig. 18.

(8) Having the representative utility level and rating scale, one may arrive at the probable acceptance of a fabric when judged within its appropriate class as characterized by the index α . Thus if an "unknown" fabric of the class characterized by $\alpha = 0.56$ receives a rating between 0 and -1, as illustrated in Fig. 18, (i.e. if it has an expected utility of about 0.5), it will have an estimated probable acceptance between 40 and 50%.

In principle at least, the foregoing treatment of hand leads to an estimate of the probable acceptance of fabrics of a class by individuals of similar "tastes," i.e. of similar α values.

Recall that early in this discussion we represented textile hand, h , by the summation of the weighted contributions of the elemental stimuli acting on the specific sensory centers for roughness-smoothness, stiffness-flexibility, compactness-openness, and heat-cold. With the further considerations we now assume that this summation is equivalent to the fraction of plus encoded information present,

$$\text{i. e. } \frac{\text{signal}}{\text{noise} + \text{signal}}$$

weighted by the probabilities of the products appropriateness, α and $1-\alpha$. Accordingly

$$\begin{aligned} \text{hand} &= h = \sum_1^4 S_i \cdot R_i \\ &= \frac{\sum [(1-p) \log_2 (1-p)]}{\sum [p \log_2 p + (1-p) \log_2 (1-p)]} \end{aligned}$$

corrected appropriately by α and $1-\alpha$.

Conclusion

It has been the purpose of this discussion to explore textile hand as a function of stimuli acting on major sensory centers presumably present in the human hand and to examine possi-

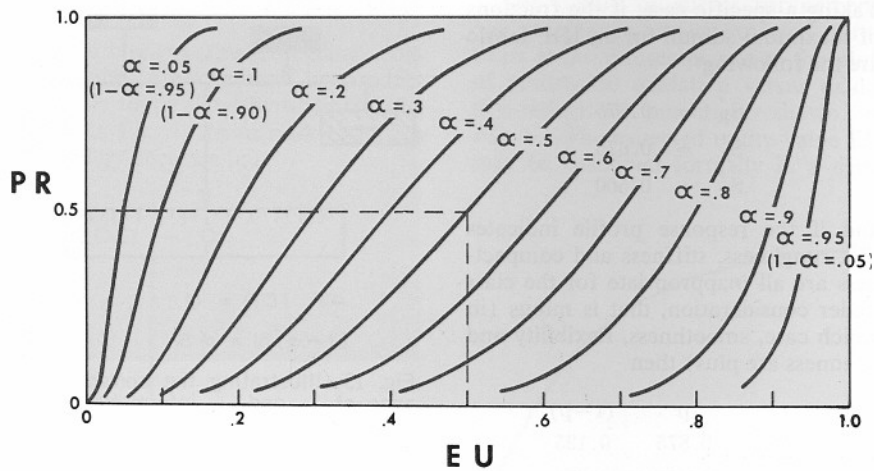


Fig. 14—The family of curves representing probability of acceptance as a function of expected utility is derived from concepts of Decision Theory and Information Theory. The curves shift from the right to the left as the level of class quality increases. Each curve represents the probability of acceptance P_R of a situation with respect to its expected utility value EU. Each curve is prescribed by the 50% acceptance (the indifference point [IDP]) of the situation under consideration. The placement of each curve on the "map" of curves is determined by the index α (or $1-\alpha$). The index α may be looked upon as the amount of - information present in the IDP fabric (which if replaced by + information will require an amount equal to EU_0).

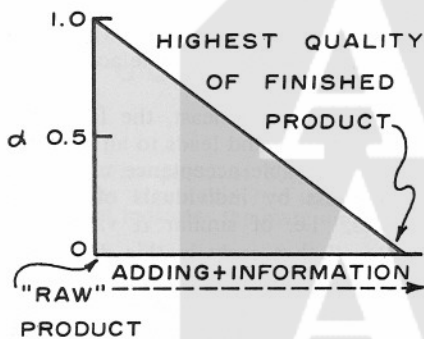


Fig. 15—The value of α decreases [and $(1-\alpha)$ increases], but not necessarily linearly, as the level of product quality improves. Each member of a product class is characterized by a specific α (or $1-\alpha$). [Other terms may be preferred over α and $(1-\alpha)$ as indices of quality levels; for example, Q. and Q.].

bilities of developing a more rational basis for quality rating scales. This study suggests a way to index quality improvement in terms of utility levels. Such mapping may be helpful in "tailoring" product qualities to meet consumer desires; in other words, in guiding the incorporation of the appropriate information content for hand consistent with the class of fabric under consideration. Such a guide can be helpful, for example, in fiber and fabric modifications by which broad changes are possible in the stimuli to hand evoked by the treated fabric.

It is the consumer who has the final say. But it is the finisher's task to impart the last word into the fabric. The finisher's job is fashioning into fabrics "the equivalent of the complex state of the consumer's desires."

Finishing is considered an art because art is concerned with the uniqueness of a thing as distinct from science which is concerned with the generalities. With refinement of ways to determine the uniqueness of a particular fabric, finishers will be able more systematically to impart into the fabric the "final word". And just as our appreciation of art increases as we learn to understand its language—its design, lines, color, texture, etc.—so does a consumer's appreciation of a superior fabric increase as he develops understanding of its language. If he does appreciate it, and this would

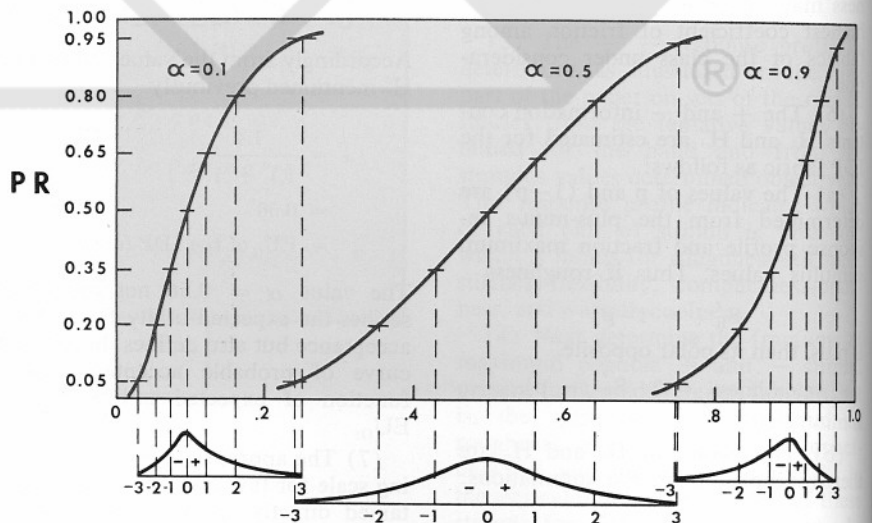


Fig. 16—The appropriate rating scale for a class of products is obtained by projecting the 15 percentage acceptance intervals onto the expected utility axis. The intervals between units of the rating scale will vary depending on the level of quality of the product class. At a low level of quality the scale will be - skewed, whereas at a high level of quality the scale will be + skewed. In the mid region of quality the rating scale is symmetrical.

be the same of Armstrong's jazz, his final say will most probably (frequently) be, "More, please!"

We have been dealing in this discussion with matters pertaining to human nature. Of course, human nature is highly complex. My approach has been necessarily simplified and empirical, and I have leaned heavily on a number of assumptions and theories. But while it is generally recognized that "no theory is sacrosanct or infallible," if assumptions and theories lead to describing more effectively some aspect of reality, they are considered useful. If the proposed models in this paper prove helpful in developing better means to predict consumer acceptability with respect to hand among sets of variously finished fabrics, or at least as a "stimulus" to further inquiry, the effort, I hope, is not wasted.

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About The Author

Harold P. Lundgren, chief of the U. S. Department of Agriculture's Wool and Mohair Laboratory, Albany, Calif., was the recipient of the Olney Medal for 1968, AATCC's highest scientific award. Dr. Lundgren, an international authority on wool, both in practical technology and in the fundamental chemistry of wool protein, has been cited many times for distinguished contributions to textile science.

Analogy of Utility Levels With Oxidation-Reduction Potentials

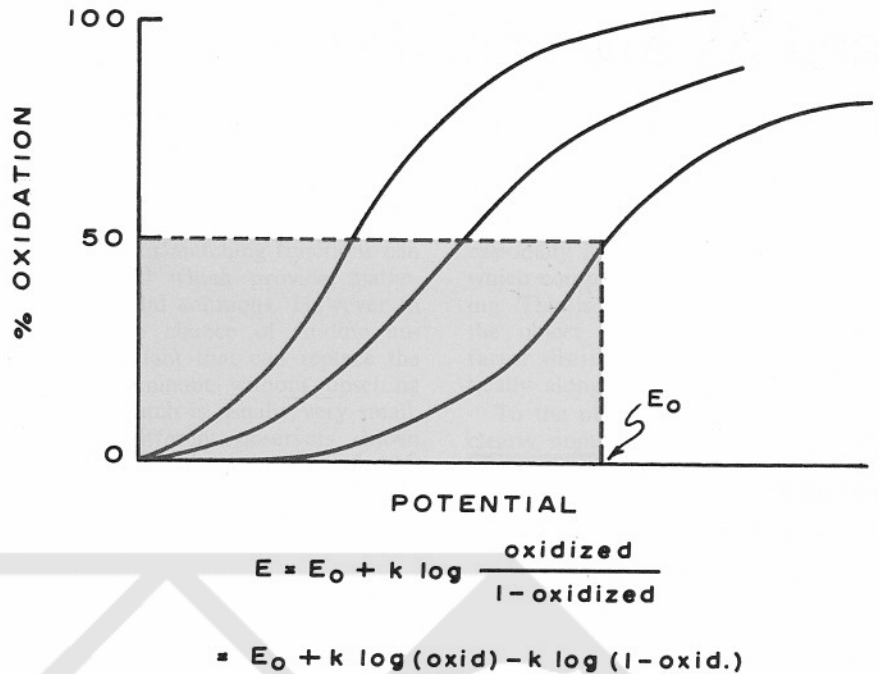


Fig. 17—The proposed utility levels bear resemblance with oxidation-reduction levels. The expected utility level EU may be described formally in a manner analogous to that which defines the oxidation-reduction potential E:

$$\text{Thus } EU = EU_0 + \frac{\text{(weighted + information)}}{\text{content}} - \frac{\text{(weighted - information)}}{\text{content}}$$

And just as $E = E_0$ at 50% oxidation so does $EU = EU_0$ at the indifference point when (weighted + information content) = (weighted - information content).

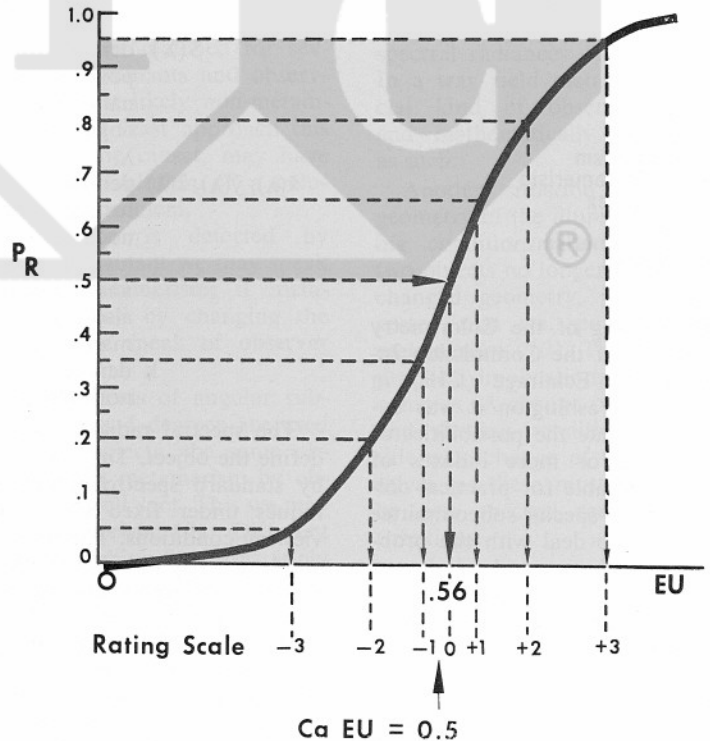


Fig. 18—Illustrating the characterization of an "unknown" fabric belonging to a product class having $\alpha = 0.56$. If this fabric receives a rating between 0 and -1 (i.e., has a EU of ca. 0.5) it will have a probable acceptance between 40 and 50%.