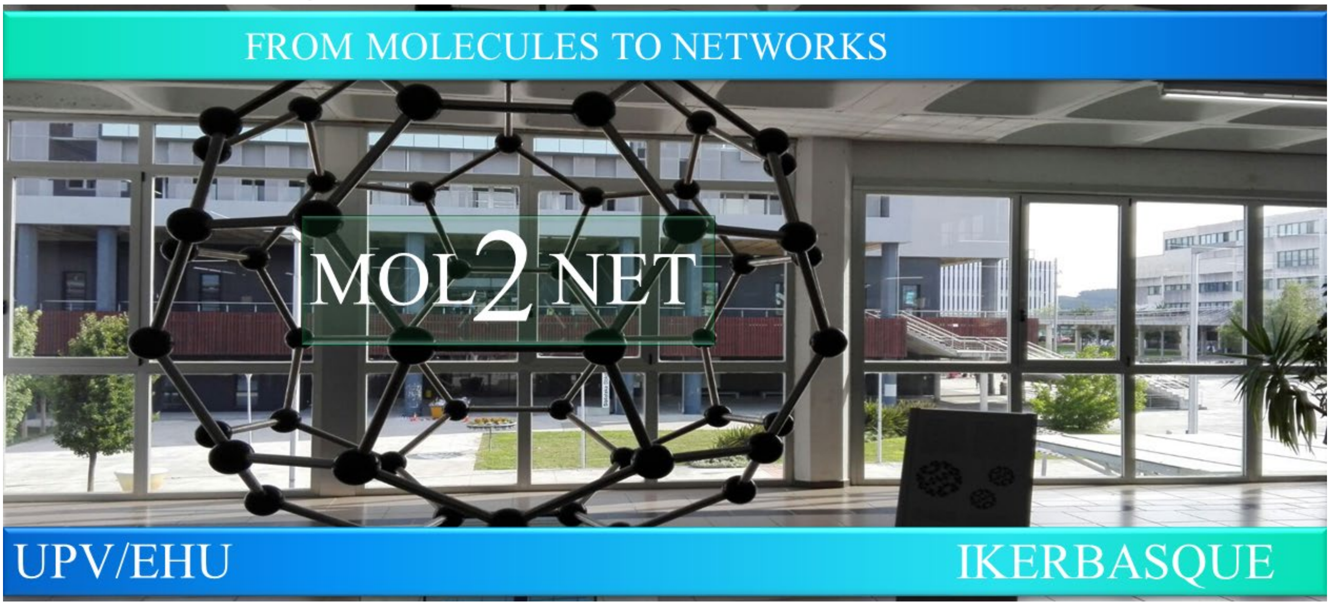
MOL2NET'21, Conference on Molecular, Biomedical & Computational Sciences and Engineering, 7th ed.



Application of Multicriteria Analysis to Increase the Quality of Cuban Tobacco

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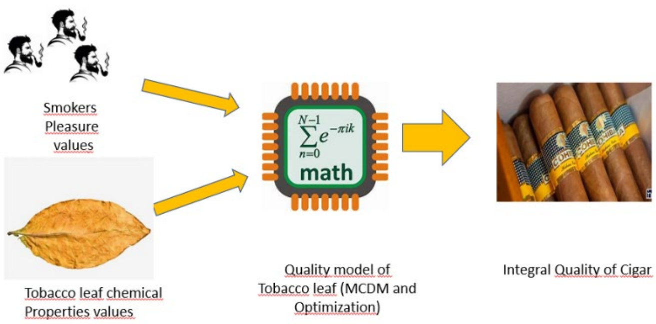
Graphical Abstract



Abstract.

The application of multicriteria analysis methods to the creation of models that allow evaluating the pleasure of the smoker, and optimizing the integral quality of the tobacco leaf, ensuring the degree of sensory satisfaction and the harmfulness of the habit, is presented. The quality model was verified in practice, comparing it with the opinion of a representative group of expert tasters. A proposal for a decision support system (DSS), capable of simulating and increasing quality with high computational efficiency, is briefly described.

1. INTRODUCTION

Simulation makes it possible to increase the economic efficiency of modern production by replacing costly experimentation with a model that reflects the essential features of the object. In its application to market studies, it is about simulating the consumer's criteria through a mathematical model to propose a more attractive product (for example [4, 13]). In the case of the tobacco industry, this is particularly important because it is necessary to reduce the harmfulness of smoking without appreciably diminishing the pleasure of the smoker.

The modeling and integration techniques of multi-criteria analysis preferences can be used to represent the consumer's response, but they must be adapted to the characteristics of market studies; In the case of tobacco, this specificity is even more significant due to the strong dependence between the determining attributes of the smoker's pleasure, and its sensory-specific nature.

The paper presents the application of multicriteria analysis to model the integral quality of Cuban tobacco, and its use in a decision support system (DSS) to increase it. The next section is devoted to the formulation of the problem; in point 3 several premises that constitute the theoretical basis of the solution are presented, and on it (section 4) it is proposed how to model the sensory satisfaction of the smoker, and the experimental verification of the model; in the fifth section, a vector optimization approach that increases the quality of the product is discussed, and finally in section 6 the conclusions are presented.

2.Formulation of the problem

Let **X be** a vector of $\mathbb{R}^n$whose components represent the concentrations of the chemical elements present in the tobacco leaf. Without loss of generality, the first K components of **X will be considered** as controllable decision variables in certain intervals by chemical or genetic procedures; let **Z** of $\mathbb{R}^k$ be a vector containing only decision variables.

The problem is: to find the best compromise $\mathbf{Z_{op}}$ that maximizes the overall quality of the leaf, considering the sensory satisfaction associated with the smoker, and reducing, as much as possible, its harmfulness.

The solution process is carried out in three phases:

a. Define the set of attributes that determine sensory pleasure and find its functional dependence on the decision variables.

b. Obtain a multi-attribute model that reflects the sensory satisfaction of the smoker.

c. Solve a multi-objective problem to arrive at a good compromise solution for comprehensive quality (pleasure versus harm).

The problem has not been previously resolved. It is not possible to apply the classic preference integration models of multicriteria analysis, based on the solution of indifference equations, due to the decisive importance of sensory, and non-rational, factors that determine satisfaction. An original approach is needed that combines classical and heuristic techniques to capture, in a model, the integrated preferences of a population.

3.Premises

a. The main attributes that determine the pleasure of the smoker are the following:

a1. strength (F)
a2. scent (A)
a3. Flavor (S)
a4. combustibility (C)

b. These attributes make up a complete set, which is of minimum size, and non-redundant ([9]). Each attribute is "understandable" and "measurable" on a qualitative scale. Moreover the attribute set has mutual preferential independence ([7]).

c. There are functions F(**X**), A(**X**), S(**X**), C(**X**) that depend on the chemical composition of the leaf, and whose image is the level of achievement of each attribute on the qualitative scale.

d. A commission of 25 experts, selected from among the main Cuban tobacco factories, is considered representative of the population of smokers.

e. Each expert can establish a transitive and complete preference relation $\succcurlyeq$ (weak order) on any set of tobaccos.

f. For each expert, there is a value function

$$U(F,A,S,C) = U_1(F) + U_2(A) + U_3(S) + U_4(C) \qquad (1)$$

which agrees with $\succcurlyeq$ on the set under evaluation.
U_1, U_2, U_3, U_4 are cardinal functions.

Observations:

1. Premises a and c were introduced earlier in [5]. Using regression models, the functions F, A, S and C of **X were obtained** in good agreement with an important set of data.

2. An expert is unable to compare two products T_1 and T_2 in abstract, by only knowing the level of the attributes. The affirmation $T_1 \succ T_2$ or $T_2 \succ T_1$ can only be made because of smoking; judgment comes from sensuousness.

3. The hypothesis of preferential independence was verified in interviews with the experts.

4. The existence of a value function is theoretically guaranteed from the premise e, (see for example [7]). The existence of an additive value function, like the one given in expression (1), is more questionable; preferential independence is a necessary condition for representation (1), but it is also the most important premise for its validity ([14]). The premise f will then be accepted as plausible, and the concordance between the theoretical model and the experimental data will be tested afterwards.

4. **A model for sensory satisfaction**

Let V_i be any cardinal function on the i-th attribute. According to the uniqueness theorem for functions of this type, there exist real numbers $C_i > 0$ and B_i such that the one-dimensional function U_i of (1) is according to [7] :

$$U_i = C_i V_i + B_i \qquad (2)$$

Without loss of generality, using the arbitrariness of "zero", it can be considered that Vi = Ui = 0 at the worst level of the attribute. So, substituting (2) in (1) we have:

$$U = C_1V_1 + C_2V_2 + C_3V_3 + C_4V_4 \qquad (3\ )$$

If the same scale is assumed for the V_i functions, the real numbers C_i in (3) appear as weighting factors that express the relative importance of the attributes and their impact on the global criterion U.

4.1 Assignment of the one-dimensional preference function.

The cardinal information present in V_i requires cardinal values to be assigned to the different levels of each attribute. For the aroma, flavor, and combustibility criteria, five states of a natural qualitative scale were considered, "excellent, good, fair, bad and very bad". The attribute F requires the consideration of other states, because from this point of view a judgment like "good" can have opposite meaning for different people; for this reason, we worked with the states "very weak, weak, slightly weak, medium, slightly strong, strong and very strong".

Vi was assigned in individual interviews, identifying the worst level of the attribute with "zero" on the scale, and assigning a value no greater than 100 to the best; the arbitrariness of the "zero" and of the scale find their theoretical basis in the invariance of the cardinal information under positive affine transformations ([7,9]). The values associated with the remaining levels were obtained by direct assignment, with a consistency check, repeating the process whenever necessary.

Once the values of V(y) for the natural levels of the attribute Y have been found, an approximate value V(y*) can be obtained by interpolation, for any state y* of Y.

4.2 Determination of weighting factors

In the literature on MultiCriteria Decision Making appear different methods to obtain weighting factors (see for example [2, 12]). The ordinal "ranking" achieved with consensus methods ([3]) does not work in the expression model (3), which requires cardinal information. Procedures based on the solution of indifference equations more reliably capture the cardinality of the information, but they are not applicable here due to the sensory nature of the expression of preferences, and because indifference can only be established because of act of smoking the assignment of "weights" as a result of a parameter adjustment of a theoretical model to experimental data that includes sensory evaluation seems more realistic.

On this basis, the following experiment was carried out: a relatively large set of different tobaccos were chosen, covering a wide range of each attribute; Each expert was required to provide a comprehensive sensory evaluation, and their specific judgment on each attribute according to the natural scale presented in section 4.1. The first evaluation is an estimate of the global criterion U given by the expression (3); the second judgment allows to obtain an approximate value of each V_i, and to use (3) as a theoretical model dependent on the C_i parameters, from whose adjustment to the sensory data the most appropriate weighting is obtained.

The classical method of least squares is not the most convenient here, because the "weights" must be positive magnitudes, and because the quality of the fit is better determined by the error at each point than by a measure of global deviation. A vectorial optimization approach could offer better solutions, so the methodology proposed in [6], based on multiobjective nonlinear programming, was used.

4.3 A model for group opinion

Once C_i and V_i have been obtained, the expression (3) can be evaluated and an estimate of the sensory evaluation of each expert can be obtained. As a last step, it is necessary to integrate them into a model that expresses the opinion of the group.

Following an idea of Keeney and Raiffa ([9]), let us consider that there is a "supra decision maker " (SDM) that tries to integrate the preferences of the group into a value function. Given N experts, the SDM considers each opinion as a different attribute of the problem, and looks for a group model $U_g = U_g(U_1, U_2, U_3, \ldots U_N)$, where U_i are the individual preference functions given by (3).

Since the premise of preferential independence is easily verified, the value function of the SDM must have the form:

$$U_g = \sum_{i=1}^{N} g_i(U_i) \qquad (4)$$

where g_i is a cardinal function that the SDM associates to the i-th expert.

Since U_i carries cardinal information, it is reasonable to admit that its relationship with g_i is through a positive affine transformation, so:

$$U_g = \sum_{i=1}^{N} w_i \cdot U_i \qquad (5)$$

where w_i reflects the importance that the SDM attaches to the opinion of the i-th expert. It would make sense to assign greater importance to the opinion of those whose preferences represent broader sectors of the market. If this information is not available, according to hypothesis d of section 3, it must be recognized that the sample is representative of the population; in such a case, it seems plausible to propose:

$$U_g = \frac{1}{N} \sum_{i=1}^{N} U_i \qquad (6)$$

4.4 Experimental verification

The model given by expression (6) was experimentally tested in the following way:

Eleven different kinds of tobacco were evaluated by the group of experts, and information on their judgments was collected. Each expert evaluated the set of attributes separately, and issued an integral qualitative evaluation, which is associated to a real number by the preference function discussed in 4.1. Taking the average value of these individual evaluations, there is a quantitative measure of the group's preferences that is shown in Table 1, along with the theoretical value obtained using expressions (3) and (6). Table 1 also shows the qualitative opinion of the group; the Excellent, Good and Fair judgments result from an almost unanimous vote; in other cases of clear majority, but not consensus, the terms Good (less) and Regular (more) are used; the Acceptable classification is used when the opinions between Good and Fair are divided, without a clear trend.

From the analysis of Table 1, the following conclusions emerge:

a. The qualitative and quantitative evaluations given by the tasting commission show a good coincidence.

b. The prediction of the model from (3) and (6) agrees very well with the sensory evaluation, mainly in the classes of good or excellent quality; in other cases the coincidence is less convincing, although perfectly acceptable; This effect is explained by the fact that the expert introduces unconscious veto conditions to the affirmation of the good quality of a class when it evaluates two (or sometimes only one) of its attributes as "regular"; however, according to expression (3), an intermediate integral evaluation between "regular" and "good" would be more reasonable; the error is caused by the non-rational attitude of the taster, in contrast to the normative model given by (3). The theoretical model then behaves like a Roy pseudo -criterion ([11]), trying to reflect preferences that leave a margin for irrationality.

These conclusions were confirmed in different applications carried out in 1993, in which only slight deviations were observed when comparing the proposed model with the evaluations of a much larger team of experts.

5.A proposal of a system to increase the overall quality of tobacco

The model can be used to achieve two different goals:

a. Simulation; just evaluating the model a " decision maker " (DM) can rate a new class, without additional expenses (for example, like those derived from sowing and harvesting severe parcels of land for implementing the statistical experiment.

b. Optimization: with a multi-objective approach the DM can solve the problem formulated in section 2.

The proposed system covers those goals. The expert judgments needed to evaluate (3) and (6) (including the functions F, A, S, C that depend on **X**) are stored, making simulation possible. To solve the optimization problem, the search for a new compromise solution is proposed, considering the sensory pleasure, the harmfulness, and the accuracy of the model, through the following vector optimization problem:

Optimize (Nic , Ug , F)
Z

subject to: (7)

$$Nic \leq A_{c1}$$

$$P \geq A_{c2}$$

$$S \geq A_{c3}$$

$$C \geq A_{c4}$$

$$U_g \geq G$$

F belongs to $F_{min} \leq F \leq F_{max}$

where:

Nic: is the concentration of nicotine in the sheet.

A, S, F, and C: denote the values of the attributes in their natural scale.

Ug : is the value obtained from (6).

A_{c1}, A_{c2}, A_{c3}, A_{c4} and G: are symbols that denote acceptable levels. The value of G is approximately 80.

F_{min} , F_{max} : These are states that describe an interval of acceptability for the attribute F.

Z : is the vector of the decision variables.

The restrictions on Ug, A, S, C and F are imposed to reduce the imprecision of the model, in accordance with conclusion **b** of section 4.4. Nicotine concentration is a "proxy" variable that is associated with the "harmfulness" attribute and should be minimized; the restriction to it is related to the requirements that are already imposed in numerous European countries. The presence of the attribute F as an objective to be optimized is associated with the characteristics of the market to be penetrated with the product, because the preferences on F are not distributed geographically homogeneously.

To solve (7), ISISS uses an original method called MONOLIT ([1]), whose name comes from MultiObjective NOn Linear Interactive technique ; it is a combination of interactive goal programming ([10]) with the method of satisfactory goals ([8]), which in other applications has proven to be very efficient in solving vector optimization problems.

The solution of (7), different according to the characteristics of the market, is obtained in a very short execution time.

6. Conclusions

Known techniques of assigning a multi-attribute value function were used to create a model that expresses very well the degree of sensory satisfaction of a group of tobacco tasting experts from the main Cuban factories.

Based on this model, a decision-making support system was created that, based on the chemical composition of the leaf, can evaluate a quality index, and using multi-objective non-linear programming, allows seeking a compromise between sensory pleasure and the harmfulness of habit.

The optimization process offers excellent solutions with very little computational effort; With its use, the acceptance of the product in different markets can be increased.

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ANNEX A

Class	Qualitative evaluation	Cuantitative evaluation	Teoretical value
1	Excellent	96.25	95.34
2	Good	83.68	87.48
3	Good	81.15	80.19
4	Good	82.83	85.12
5	Good (less)	80.35	82.04
6	Aceptable	73.01	77.57
7	Aceptable	68.75	75.54
8	Aceptable	68.78	75.44
9	Regular	64.43	71.50
10	Regular	59.35	65.89
11	Regular (more)	67.30	71.91

Table 1 Group model

The second and third columns correspond to commission evaluations. The fourth column contains the value of the group model.