Multicriteria decision making for the choice of dyeing process in the frame of sustainable development

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Abstract: Sustainable development becomes more and more a basic preoccupation of textile enterprises because consumers are now concerned by sustainable purchase. Many approaches have been developed since 10 years, from the study of Best Available Technologies, to the development of eco-conception thanks to the use of LCA software.
Dyeing is a step of the global textile process. It can be considered in an environmental point of view, as having a very high contribution to the environmental assessment, yet the environmental effect of logistics in the whole supply chain cannot be minimised. Use of adequate decision systems for the choice of a good dyeing technology is an important point of greener production.

1. Introduction

Mathematician and economists have developed systems called Multicriteria Decision making systems aimed to help the decider to take “not so bad “decisions when criteria are numerous and conflicting: a good decision is one that is produced by a quality decision making process.
The characteristics of a quality decision making process include that it involves the appropriate people, identifies good alternatives, collects the right amount of information, is logically sound, uses resources efficiently, and produce choices that are consistent with the preferences of the decision maker(MERK 99)
Life-Cycle impacts (LCA) Assessments are complex because they almost always involve uncertain consequences relative to multiple criteria. This is precisely the sort of problem addressed by methods of decision analysis (JOLL 07, CAIL 03, SEPP 02).
Similarities exist between the different stages of an LCA and the phases of a structured decision analytic approach to decision making, which allows LCA to benefit from the approaches and tools developed within the decision analysis field.
These tools, especially those based on outranking relationship (like Electre family or Prométhée) could help in the choice of a dyeing technology. They are currently used in environmental decision making, because they allow to model decisions that do not correspond to situations were all choices are comparable: instead of computation of a synthesis criterion, these algorithms act by comparison of couples of solutions.

After a presentation of these decision algorithms and tools, that are designed to take in account the strategy and preferences of the decision maker, we present a decision support system whose entrances are classical results of assessments systems: Values can be obtained from data bases of LCA software of from BREF (BREF 07, IPPC 2003).

2. An overview of Multicriteria Decision Support Systems

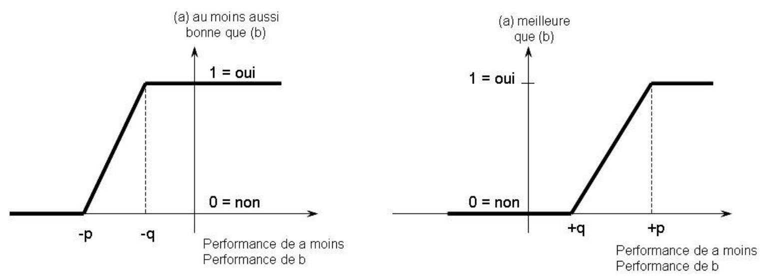
MCDA methods are based on the assumption that decision makers try to make rational choices, that is to say that they approach a decision in a structured and logical manner. There are various methods for different decision making situations because rules for rational decision making can be structured and modelled in different ways.
The problem of decision is first decomposed into components, each of which is subjected to evaluation by the decision maker. The individual components are then recomposed to give overall insights and recommendations on the original problem.
After the definition of the possible alternatives called “actions” and their evaluation thanks to “criteria”, all the methods need the construction of a preference model this involves the evaluation and comparison of the performances of the alternatives. It is necessary to determine a decision rule to apply in order to identify and select the alternative that best meets the objectives in some overall sense.
Then, it can be interesting in case of imprecise or uncertain data to realise sensitivity analysis to precise the decision.
The starting point is the definition of alternatives A_j (j=1,…n) , the attributes are characterised by X_i (i=1,…m)
Attributes have to be measurable; in general we have to judge the attractiveness of alternatives on the basis of the scores of the attributes X_i (A_j).
Multicriteria decision methods differ with respect to input data and aggregation procedures. The aggregation procedure specifies the set of rules that is used to process the information and generate a ranking of alternatives.
We will give emphasis in this paper to the methods that process cardinal information as, for example, results of LCA.
Attributes being expressed in a great variety of measurement units, there are transformed in a common dimensionless scale that can reflect the decision maker‘s relative preference for different levels of that attribute (criteria scores c_i (A_j)).
Weights w_i are used to reflect the trade-offs that decision makers are willing to accept between performances in different objectives.
The aims of multicriteria decision making methods can be different: complete ranking, research of the best alternative, research of a set of acceptable alternatives, incomplete ranking of alternatives. Those aims correspond to different mathematical concepts: complete preorders (some alternatives can be regarded as equal), complete orders and partial orders.
The preferences of the decision maker can be modelled in various ways, but often, basis binary relations are used (strict preference, indifference, weak preference)
According to Guitouni (GUIT 98), methods can be divided into “performance aggregation” and “preference aggregation” approaches.
Performance aggregation means the aggregation of the various criteria scores in a single score. In “Preference aggregation” approach, it is information on the relative preference for good performance in different criteria that are aggregated.

Another important point is that methods can be compensatory, not compensatory or partially compensatory.
As compensatory methods allow good performance relative to one attribute to compensate for low performance relative to another attribute, we imagine immediately that those methods cannot be convenient for environmental decision methods where effects must not be hidden.
Based on those considerations, we will briefly describe multiattribute utility theory methods and explain why they cannot be considered for our problem.
This theory assumes that exist only strict preference of indifference relations, it produces a total preorder of alternatives. Then, this theory elaborates through a utility function a unique synthesis criterion whose result will lead to the ranking and the decision. So, these methods are based on compensation of consequences and they suppose that all the alternatives are comparable. Those two facts make them not very convenient for sustainable development decision.

3. Outranking methods: Promethée Method

On the contrary, outranking methods consider that the decision maker can express strict preference, indifference or weak preference when comparing one alternative to another for each criterion.
The outranking relation holds when there is a strong reason to believe that, considering all n criteria, an alternative a is at least as good as b. Pair wise comparisons between each pair of alternatives under consideration for each of the criteria leads to support or refute the hypothesis that one alternative is better than the other.
These methods allow a non compensatory approach to decision making, furthermore, uncertainties can be incorporated explicitly into the evaluation of the differences between the alternatives. All the situations where human being is faced to incomparability, or situations where preference and indifference are not transitive relations can be treated by these methodologies, but it is impossible to define a unique synthesis criterion to solve the problem.
These methods have been first been imagined in France in the 68 by B Roy, through ELECTRE (ELimination Et Choix TRaduisant la REalité), other variants have been defined by the Belgium school such as Prométhée (BRAN 85). These methods are sometimes called partial aggregation.
The construction of the outranking relations takes in account the preferences of the decision maker, thresholds for discrimination on preference and indifference are also introduced.
In all the outranking methods, alternatives are compared by pair to verify if one action outranks the other and from these comparisons a synthesis is realised. The methods differ by the way these two steps are realised. In general an action a outclasses an action b, if a is at least as good as b for a majority of criteria (concordance condition) without being more bad concerning the other criteria (condition of non-discordance).

In Electre methods there are concordance and discordance indexes while in Prométhée there is no discordance index, but this method uses the idea of broad preference P:



A graph of outranking S is realised with credibility indexes. From this graph it is possible to compute for each action its power and its weakness.
Prométhée 1 elaborates a ranking allowing incomparability, Prométhée 2 simplifies the problem and gives a ranking without incomparability but both use the same concepts. It is sometimes interesting to use first Prométhée 1 so as to have an idea about the potential decisions and then obtain a ranking.

From the preferences P_j translated into credibility indexes π, flows entering and going out the nodes of the graph are computed (P represents the sum of the weights on the criteria).

$$\pi(a,b) = \frac{1}{P}\sum_{j=1}^{k} w_j \; P_j(a,b)$$ k is the number of criteria

Power $$\phi^{+}(a) = \frac{1}{n-1}\sum_{b\in A} \pi(a,b)$$ $$A = \{A_1, A_2, ..., A_i\}$$

Weakness $$\phi^{-}(a) = \frac{1}{n-1}\sum_{b\in A} \pi(b,a)$$

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a)$$

$$aSb \quad si\ \phi_a^{+} > \phi_b^{+}\ et\ \phi_a^{-} < \phi_b^{-}\quad ou$$
$$si\ \phi_a^{+} = \phi_b^{+}\ et\ \phi_a^{-} < \phi_b^{-}\quad ou$$
$$si\ \phi_a^{+} > \phi_b^{+}\ et\ \phi_a^{-} = \phi_b^{-}$$

$$aIb \quad si\ \phi_a^{+} = \phi_b^{+}\ et\ \phi_a^{-} = \phi_b^{-}$$

Elsewhere a and b are not comparable

For Promethée 2, the qualification of actions (power minus weakness) is computed then a ranking without incomparability is done, according to the ranking of qualifications.

$$aSb \quad si\ \phi_a > \phi_b$$
$$aIb \quad si\ \phi_a = \phi_b$$

The software Promcalc gives a graphic representation in a plane called GAIA (for *Graphical Analysis for Interactive Assistance*).

It is possible to obtain sensibility analysis according to the variation of the weights; it is very interesting for investigations linked to impact assessment.

4. Choice of a good technology for dyeing from an environmental point of view

Many works have been made in Europe in the field of best technology for textile dyeing: COST 628 (NIEM 06) has allowed getting a good view of possible improvements.
As a non specialist in dyeing, the multicriteria decision methods will be applied through the values given by Kazakeviciute (KASA 04) about wet processing of cotton/polyester fabrics. The real difficulty is to get data that could be compared; it is possible using the values given in its paper.

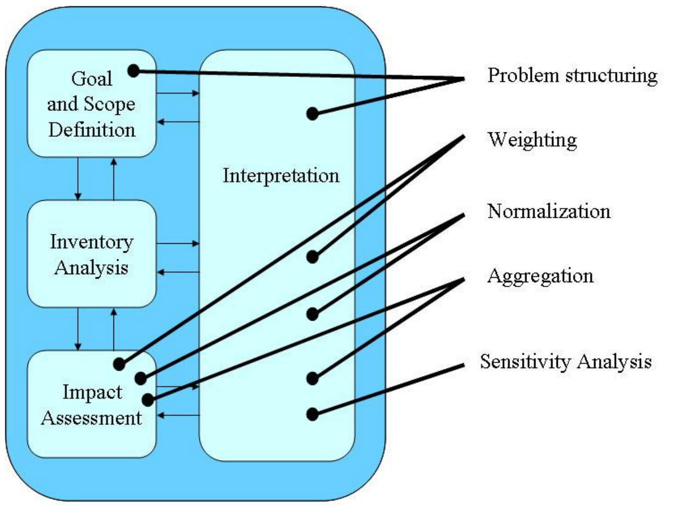
The choice for measures of the impacts too could be definite in an other way , for example Ecoprofil of ADEME (ADEM 06) uses as criteria : energy consumption, water consumption, climatic change, destruction of thickness of ozone, eutrophization of water, toxicity for human being, ecotoxicity for water ,production of waste. One can realise that these criteria could be obtained from the first ones. Having no values on enough technologies for that assessment, I did not use them, but they could as well be relevant for the use of Promethee.

Our decision study will concern textile wet processing, because it is one of the most polluting industrial process, and also because it is a complex process, moreover the same result can be achieved by applying some different technologies and with the use of some different kinds of chemical materials and machines. The complexity of finishing process also depends on the composition of textile material. The more complex finishing processes are for fabrics of blended fibres.
Processing of blended fabrics involves many factors such as dye selection, fastness properties, machinery selection, processing condition, colour matching difficulties, finishing routine. Fabric pre-treatment can be performed by continuous, semi continuous or batch method. Polyester/cellulose fabrics can be dyed by continuous or exhaust dyeing methods using various dye class combinations. New technologies in wet finishing of cotton/polyester fabrics are mainly based on the use of new more effective chemical materials and introducing modern machinery. An exhaustive comparison of all the combinations of these steps of the process would need a powerful decision system but the real problem results only in the difficulty to have data obtained in a comparable way.

The environmental performance indicators considered are water and energy consumption as well as consumption and emission of chemical materials. These indicators are common for environmental comparison of textile finishing processes as well as textile products and are widely applied for evaluation of cleaner technologies, selection of best available techniques and comparison of different textile products (KAL 00, NIEM 03).

The data for evaluation of environmental impact of cotton/polyester processing were collected from the Lithuanian textile companies producing or processing cotton/polyester fabrics. Calculations were made for one kg of textile material (50% polyester, 50% cotton, batch size 1000m).

It is interesting to remember that the intellectual demarche of multicriteria analysis is very similar to that of LCA, so the preliminary step which is problem structuring is perhaps the more fundamental one.
In this fist step we will define the goals of the decision, the actions and criteria



Phases of an LCA
According to ISO 14040

Phases of MCA
(Multi Criteria Analysis)

The actions considered are the different technologies.
The criteria used for evaluation were obtained in the following way:
-water consumption was calculated from the information on technological recipes or by direct measurement (including water for chemical preparation and cleaning)
-process information (temperature, duration), information about machinery and approximation from direct measurements on certain amount of production was the basis for the calculation of energy consumption.
-emissions to water were calculated from the data on chemical consumption, percent of dyestuffs fixation obtained from information on chemicals and amount of processed material.
Next part will present how this problem has been treated through Prométhée method.

5. Promethee and Decision lab for the choices concerning dyeing

So as to use the method it is necessary to define the previous problem in a more structured way.

The available alternatives are:

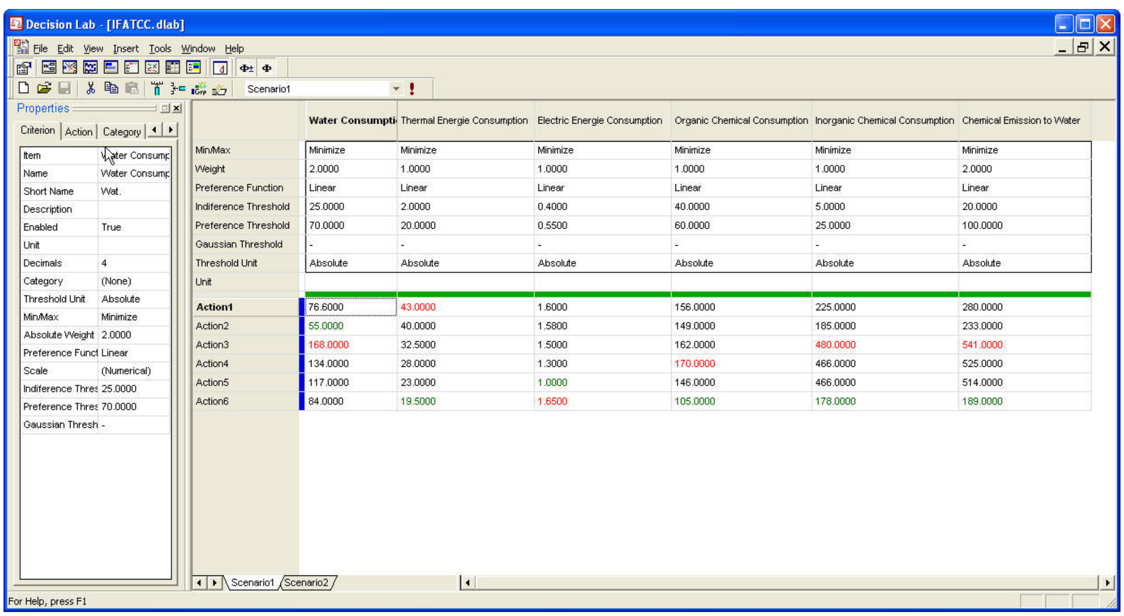
A1: Continuous treatment with bleaching
A2: Continuous treatment without bleaching
A3: Batch jet, bath ratio1/10
A4: Jet dyeing after optimizing rinsing processes by applying new chemical materials and enzymes
A5: One stage two baths dyeing of polyester/cotton fabrics with selected disperse and reactive dyes.

A6: Jet dyeing (solution ¼) then airflow

The criteria under consideration are:

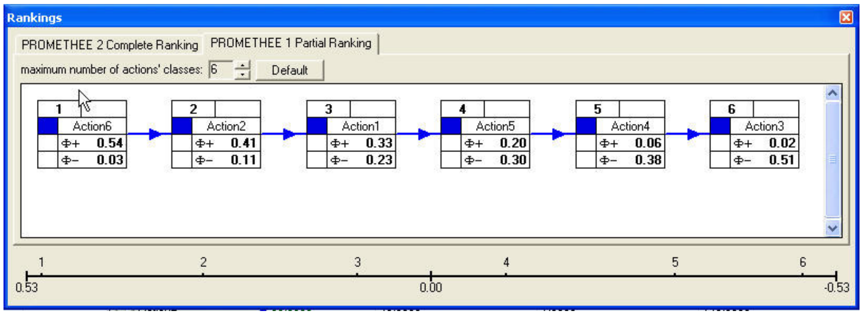
C1: Water consumption (l/kg)
C2 Thermal Energy consumption (MJ/kg)
C3: Electric Energy Consumption: (kWh/kg)
C4: Organic Chemical Consumption (g/kg)
C5: Inorganic chemical consumption (g/kg)
C6: Emission to water (g/kg)

The idea is to realise different scenario with weights of criteria different and observe then the evolution of decision.
In this paper we only present two scenarios changing the weights. The first one is importance given to water
The second one is importance given to energy consumption.
Thank to the software, it is possible to observe the evolution a decision in a continuous way as the function of the evolution of the weights.
We have taken linear preference relations to take in account the imprecision on the data. Thresholds have been fitted to the data.
The following array gives the decision problem for scenario1;

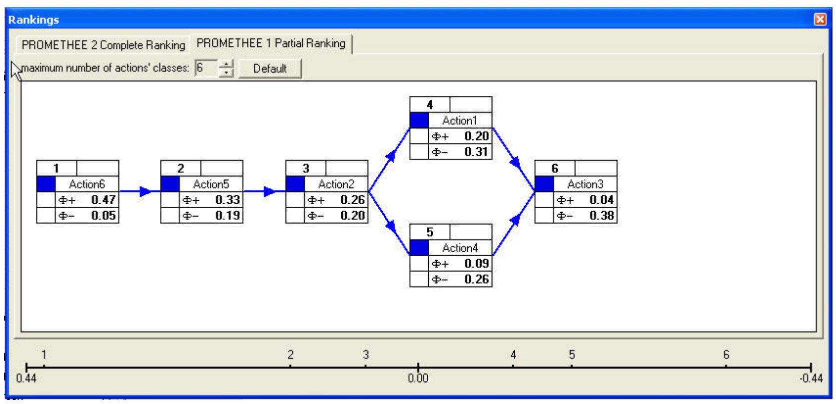


	Water Consumpti	Thermal Energie Consumption	Electric Energie Consumption	Organic Chemical Consumption	Inorganic Chemical Consumption	Chemical Emission to Water
Min/Max	Minimize	Minimize	Minimize	Minimize	Minimize	Minimize
Weight	2.0000	1.0000	1.0000	1.0000	1.0000	2.0000
Preference Function	Linear	Linear	Linear	Linear	Linear	Linear
Indiference Threshold	25.0000	2.0000	0.4000	40.0000	5.0000	20.0000
Preference Threshold	70.0000	20.0000	0.5500	60.0000	25.0000	100.0000
Gaussian Threshold	-	-	-	-	-	-
Threshold Unit	Absolute	Absolute	Absolute	Absolute	Absolute	Absolute
Unit						
Action1	76.6000	43.0000	1.6000	156.0000	225.0000	280.0000
Action2	55.0000	40.0000	1.5800	149.0000	185.0000	233.0000
Action3	168.0000	32.5000	1.5000	162.0000	480.0000	541.0000
Action4	134.0000	28.0000	1.3000	170.0000	466.0000	525.0000
Action5	117.0000	23.0000	1.0000	146.0000	466.0000	514.0000
Action6	84.0000	19.5000	1.6500	105.0000	178.0000	189.0000

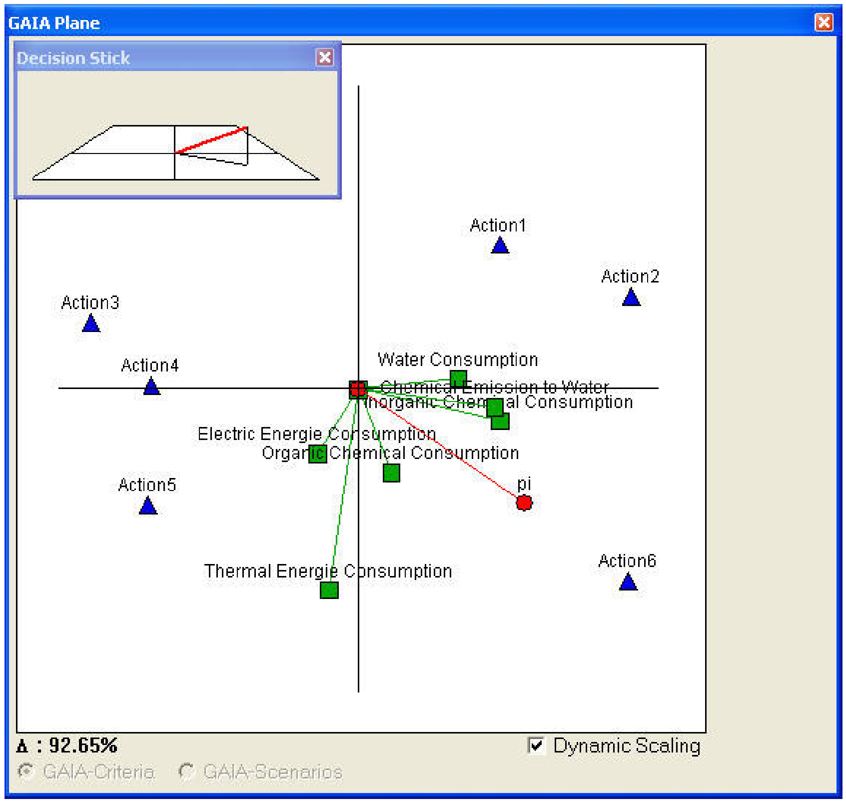
For scenario 1 , the ranking obtained by Promethee 1 is a complete ranking:
Action 6, then 2, then 1……
In this case Promethée 1 and 2 give the same ranking.



For scenario 2, actions 1 and 4 can be considered as well because they give advantages on different fields.



This is a view of the Gaia plane for this decision problem.
When making a sensitivity analysis the direction of “good decision”: Opi evolves directly as a function of weights.



6. Conclusion

The aim of this communication is only to show how decision tools could help textile chemists in their choice of process.

As a non specialist on those fields I thank Professor Anne Perwuelz Responsible of Dyeing and Finishing in ENSAIT, for providing me pertinent information about this process.

Unfortunately, I realised that it was difficult to obtain data on environmental impact of dyeing in a universal way. But I think that it would be interesting to apply this t the new technologies described in the BREF.

Moreover these systems can include criteria linked to social or economic considerations, in that way they are completely in the spirit of sustainable development.

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The researches she makes in laboratory GEMTEX deal about multicriteria decision making and data fusion when data are imperfect. These researches are particularly applied in the field of textile sustainable development management.