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THE USE OF OUTRANKING METHODS
IN THE COMPARISON OF CONTROL OPTIONS
AGAINST A CHEMICAL POLLUTANT :
THE CASE OF VINYL CHLORIDE MONOMER

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UTILISATION DE METHODES DE SURCLASSEMENT
DANS LA COMPARAISON D'ACTIONS DE LUTTE
CONTRE UN POLLUANT CHIMIQUE :
LE CAS DU MONOCHLORURE DE VINYLE

RESUME

Ce cahier montre l'utilisation d'une méthodologie d'aide à la décision multicritère (méthode de surclassement) dans la résolution de problèmes de choix de dispositifs industriels de lutte contre la pollution causée par les rejets de monochlorure de vinyle dans l'atmosphère. Cette substance, cancérigène, est un produit de base de la fabrication des matières plastiques. Dans un premier temps, le cahier présente une analyse historique des choix effectués par les industriels depuis 1974 et des différentes études permettant de rationaliser ces choix. Il propose ensuite une modélisation du problème décisionnel cohérente avec sa complexité actuelle. Enfin, il développe une méthode opérationnelle permettant de mesurer l'impact de la mise en place d'actions de lutte contre la pollution et de proposer des solutions, dans divers types d'usines, compte-tenu des préférences des industriels et des pouvoirs publics.

Mots-clés : Monochlorure de Vinyle (MCV) ; Aide à la Décision Multicritère ; Méthode de Surclassement.

THE USE OF OUTRANKING METHODS IN THE
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ABSTRACT

This paper shows the use of a multicriteria decision aid methodology (outranking methodology) in resolving the problem of choice among industrial options against the pollution caused by vinyl chloride releases into the atmosphere. This carcinogenic substance is a basic product in the manufacture of plastics. The paper presents at first a historical analysis of the choices made by industry since 1974 and the various studies that helped to rationalize these choices. It then proposes a modelling of the decisional problem coherent with its actual complexity. Finally, it develops an operational method allowing to measure the impact of the implementation of pollution control options and to propose solutions for different types of installation given the preferences of industry and those of public authorities.

Acronyms : VCM = Vinyl Chloride Monomer, PVC = Polyvinyl Chloride, MDA : Multicriteria Decision Aid, OM = Outranking Method.

1 - INTRODUCTION

1.1 - A historical outlook of the problem

The importance and the social and economic complexity of the problems related to the environment protection in industrialized countries have been growing in the last ten years. In order to work out a more realistic modelling of the problems, a much higher number of dimensions both quantitative and qualitative, must be taken into account. This, has led analysts to attach more and more importance to multicriteria decision aid methods. This paper bears on the use of multicriteria analysis methods in the choice of industrial control options against the pollution caused by vinyl chloride monomer (VCM) releases into the atmosphere.

Polyvinyl chloride (PVC) obtained by polymerization of VCM, is eminent among basic chemical products (resins), for its economic importance (see table 1). It can be seen that the produced quantities of PVC are high in absolute value (710 500 tons in 1981) with world production in the order of 15 million tons. PVC is first among resins in tonnage produced (25 %).

Table 1 : Annual quantities (10^3 tons) of PVC and of resins produced in France.

	1974	1978	1981
PVC	623	664.5	710.5
All plastics (resins)	2 616	2 865.5	2 897
% PVC	23.8 %	23.2 %	24.5 %

There are about ten plants in France today manufacturing VCM and/or PVC. At present VCM releases into the atmosphere in France are given in Table 2. These releases correspond to a maximum capacity operation of the production plants for 1982, but under present circumstances one should really count on a rate of use of 60 to 70 % of full capacity with large variations from plant to plant, some being very efficient while others are on the way to obsolescence. The release figures account for all new equipment installed in 1981.

Table 2 : VCM atmospheric releases in France in 1981.

Plant Type	Number of plants per type	Production capacity (tons/yr)	VCM releases (tons/yr)
VCM Production	3	750 000	530
PVC Production	5	650 000	910
Mixed plants	2	320 000 (VCM)	2 030
<u>TOTAL</u>	10	400 000 (PVC)	3 470

Historically the implementation of prevention actions has developed the following way since 1974 : following the evidence linking the risk of liver angiosarcome with the workers of the PVC sector, important efforts were made to reduce occupational exposure to VCM in VCM and PVC plants. The implementation of these measures succeeded in reducing the occupational exposure levels up to about 1 ppm(*) (a figure fixed by decree in March 1980), but also, correlatively, reduced considerably VCM external emissions. The prevention of the occupational risk was in fact based, to a large extent, on measures aiming at reducing so-called "fugitive" VCM emissions as well as on procedures intended to prevent the release of non-negligible VCM quantities into the plant's atmosphere and eventually to its neighbourhood. From 1980 on, a special campaign oriented towards the reduction of VCM extra muros emissions has begun. An account of these actions is given in /4/.

Total VCM emissions for 1974 have been estimated to be about 10 000 tons/yr. The prevention of occupational risks cost about 190 million 1981 francs out of a total of 240 million 1981 francs spent between 1974 and 1981. A reduction of up to approximately 5 600 tons resulted in 1980. The special campaign against "extra muros" emissions has cost more than 150 million 1981 francs between 1980 and 1982. It has led to the present emission level of about 3 500 tons/yr (see Table 2).

In the future, VCM emissions could drop to below 1 800 tons/yr, depending on the choices made in plants for which decisions are yet to be made. As a comparison, it may be mentioned that a survey carried out in VCM/PVC plants in

(*) 1ppm = 1 part per million in volume. The VCM content of air is then inferior to 10^{-6} .

the United States by EPA (see /13/) showed considerable VCM emission levels in 1974, since an "average plant", producing 68 000 tons of PVC per year, released more than 2 000 tons/yr of VCM.

1.2 - Object of the study

In order to judge the actual situation regarding VCM releases, it is possible to refer to release limit values set by the French "Service de l'Environnement Industriel" with a view to guiding regulating action on the local level. These values differ and depend on the plant i.e VCM or PVC :

- 0.05 kg of VCM per ton of produced VCM,
- 2.00 kg of VCM per ton of produced PVC.

If we refer to these limits it turns out that in a number of plants, actual prevention choices are inadequate (cf /4/). The problem of choice of better actions is then still unresolved in these plants.

Such a situation offers a favorable context to the development of a decision aid study that could guide the decision makers in the different plants in choosing their options. The "risk assessment" study carried out in the United States (/2/ /3/) deviates considerably from this point of view as it refers to "generic" approach based on an average plant concept and not on real situations, calling upon specific local criteria. The Centre d'Etude sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN) has carried out recently a cost-effectiveness analysis of certain VCM treatment options actually used in France (/4/). This method consists of determining a posteriori the implicit value of human life by an analysis of earlier protection decisions : expenditures allowed to save one human life statistically. The results of this study (/4/) show significant differences in the implicit cost of human life among the plants studied (a 1 to 600 ratio : from 3 to 40 MF for a VCM plant vs 2000 to 25 000 MF for a PVC plant).

Such disparities show the limitations of the cost-effectiveness analysis that only considers two indicators : the cost and the collective risk while in reality several other dimensions come into play to explain the choices made by the decision makers. Integrating these multiple dimensions into the framework of decision aid implies accordingly resorting to a multicriteria approach. The outranking method used in this study has been already successfully applied in the case of the

radiological risk management in nuclear plants (see /9/) as well as in comparing alternative energy technologies.

In the next section we present the complexity of the problem on several levels before formulating it within a multicriteria decision context. Section 3 briefly presents the outranking method that allows us to compare globally control options against VCM emissions as well as the method's implementation in the decisional framework concerned. Finally, the various results obtained are analyzed and discussed in Section 4.

2 - THE COMPLEXITY OF THE PROBLEM AND ITS FORMULATION IN TERMS OF MULTICRITERIA CHOICES

2.1 - The density of VCM emissions

VCM emissions originating in VCM and PVC manufacturing plants have diverse characteristics. They are also classified, in general, into three categories : canalized, fugitive (or diffuse), accidental.

Canalized emissions, contain, besides VCM, variable quantities of "inerts" (incondensable gases) and, in the case of VCM manufacture, other co-pollutants such as carbon monoxide, ethylene, hydrochloric acid, and various chlorinated hydrocarbons.

Canalized emissions are released into atmosphere at certain spots of the plant, from chimneys or, more modestly, from releases pipes situated at various heights (sometimes at less than 10 meters). These emissions entail exposure for the population at the plants vicinity and, to a certain extent, for the plant's personnel when the release heights are low.

Fugitive emissions have numerous sources :

- equipment with insufficient performance specifications as to guarantee durable airtightness : pump joints, compressors, safety valves, pipe fillets etc...
- conception defaults on the level of certain operating procedures :
 - loading and unloading VCM,
 - draining of material,
 - sampling for quality control, etc...

The diversity of the sources and the multiplicity of the emission points explain the "diffuse" character of this type of VCM release, which takes place in the atmosphere of the shops and concerns primarily the plant personnel. The VCM thus released leaks afterwards to the plant's neighbourhood. The fugitive emissions affect then the intra and extra muros environment simultaneously. They constituted a considerable VCM emissions source before the implementation of occupational risk prevention.

Accidental emissions belong to vast set of rare events of low probability and of potentially important consequences. There exists in fact a category of accidents whose origin is an uncontrolled polymerisation reaction and which it is not possible to ignore here. They are also a quite interesting example insofar as such events, frequent and even very frequent in the past because of poor control of the polymerisation reaction, resulted each to the release of several tens or hundreds of kilograms of VCM.

The considerable increase of the size of polymerisation reactors has diminished the frequency of uncontrolled polymerisation reactions but would result today to a release in the order of several tons of VCM. Such a potential risk has given rise to the implementation of rigorous prevention measures that have significantly reduced the occurrence probability of an uncontrolled reactions and placed this type of accident among rare events.

2.2 - Description of the different control options against VCM pollution

Among the ten or so production sites in France, only those representative of a type of activity (VCM or PVC) were selected ; on the other hand for each production type a recent and an old unit were chosen because prevention problems are different for each situation ; furthermore, the cost of the options and above all their effectiveness are appreciably different ; for these reasons no average plant was studied (as was the case in the EPA /2,13/ study) but four "contrasting" sites :

VO : old VCM manufacturing plant,

VR : recent VCM manufacturing plant (constructed after 1974),

PO : old PVC manufacturing plant,

PR : recent PVC manufacturing plant (constructed after 1974).

For each of the four plants studied, one or more options are used or considered. As it has already been underlined, this study concerns problems of both 1974 and 1981 ; it is therefore necessary to consider systems implemented between 1974 and 1981, those under study during this period and those projected for 1981.

Actually there are 5 main prevention systems :

- The Quench (noted as Q) : a supplementary purification column in which VC contaminated or flows are treated. The VCM thus recovered is then recycled.
- The Incinerator (noted as I) : the VCM contaminated fluxes are collected and burned inside the incinerator.
- The Carbon adsorbtion (noted as CA) : Air flows pass over an active carbon bed that traps VCM that can then be recycled.
- Improved gas removal PVC resins are treated in columns in order to extract most of the remaining VCM.
- Fugitive control (noted as FC) : the placing of airtight equipment (joints....) of systems collecting vents originating with certain operating procedures, and of beak detecting measuring and alarm apparatus. These systems act mainly on shop security and content and therefore, a fortiori on releases into the environment.
- VCM Storage Improvements (noted as S) products are stocked outside the plant in double casing enclosed spaces, which considerably improves operation security.

For each of the above mentionned plants, we have envisaged as high a number of actions as possible, considering all feasible treatment option combinations for the plant in question. Furthermore, the "do nothing" action (noted as DN) has been added in each plant in order to check the need for intervention in the plant and to position the actions proposed for it.

2.3 - The different aspects of decision-aid

The appreciable decrease in occupational exposure, which was given priority between 1974 and 1980, allowed us to turn our attention to releases into the environment ; the problems are different though from those of 1974 and 1981 so that the study can not be made the same way for these two periods.

Besides, although industry is a main decision maker, it is nonetheless subject to regulations imposed by the public authorities who are thus another actor in the decision making.

Four different situations are then possible :

- the industrialist's point of view (for his own plant in 1974),
- the industrialists point of view in 1981,
- the Public Authorities point of view in 1974,
- the public authorities point of view in 1981.

2.4 - The elaboration of a multicriteria evaluation system

The determination of the evaluation criteria for the various treatment actions (see 2.2) brings together three consequences levels :

- normal or disrupted plant operation,
- type of impact : health or economic,
- stakes : the consequences concern or not the production system (economic aspect) and concern the public or the workers.

The scheme presented in Figure 1 allows us to both visualize the different dimensions resulting from preceding consequence levels, and to make certain that these dimensions are independant, a necessary aspect in a multicriteria approach. As far as costs are concerned, a single criterion was used to combine both investment and operation cost : the per year cost. This combining was necessary because, on the one hand, a manufacturer is mainly concerned over the total annual cost of the system, and on the other, as systems are not amortized over the same periods, in order to compare them, uniform values had to be obtained by converting the investment cost with an annual amortization constant.

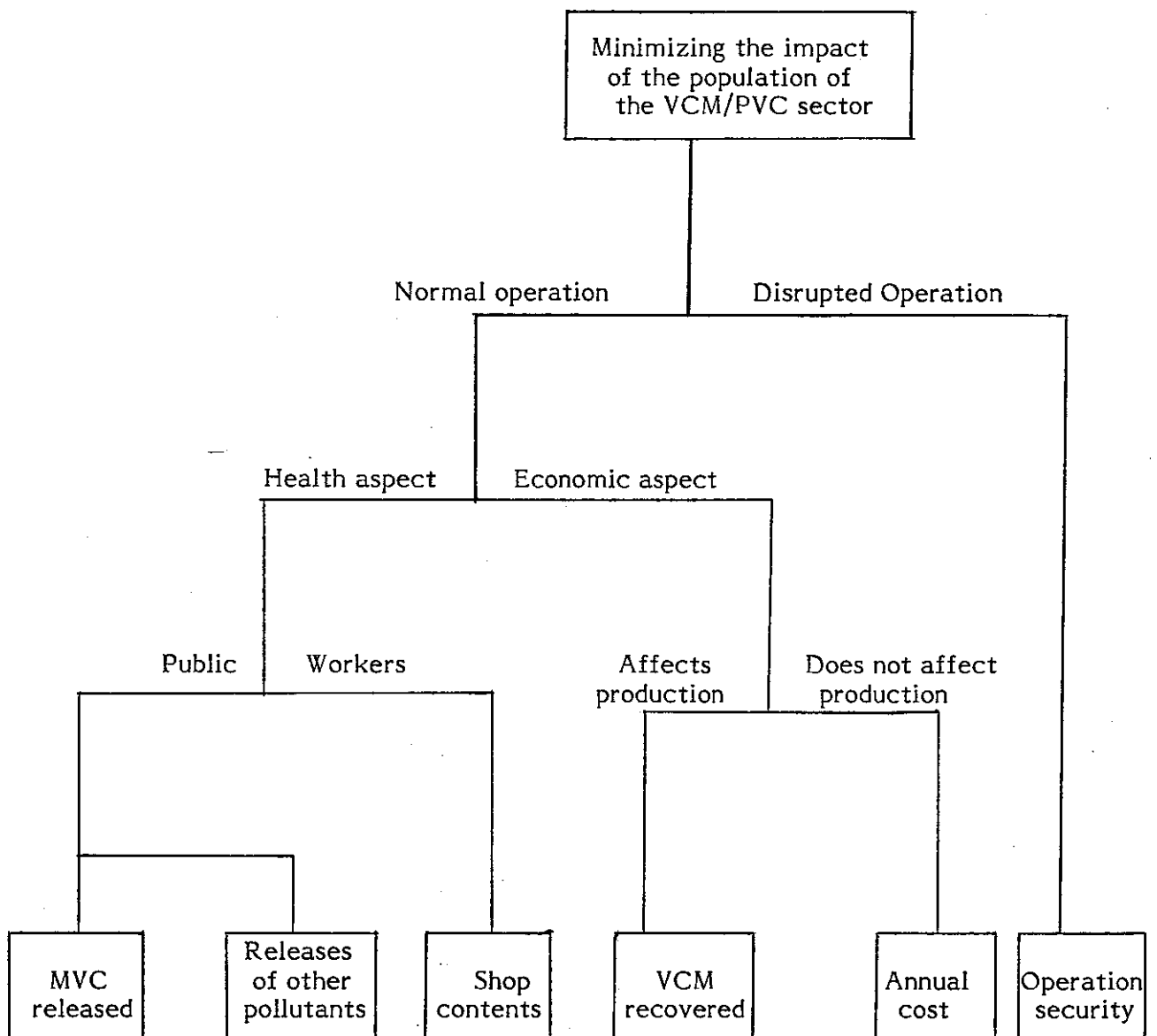


Figure 1 : A typology of the VCM/PVC sector pollution impact.

There are then six action evaluation criteria left :

1) The annualized cost : it is expressed in 1981 francs per year ; this includes annual amortization calculated with a 9 % amortization rate and the additional annual cost due solely to the operation of the new system.

2) The VCM released : this corresponds to VC releases taken for a normal at 100 % capacity plant operation ; the unit is 100 tons/year.

3) The VCM recovered : the quantity of VCM recovered in the fluxes and then recycled ; it is expressed in 100 tons/year.

4) Co-pollutant releases avoided : these are co-pollutants (fluid and gases) treated by the system and releases of which into the atmosphere are avoided. The chosen unit is 1 000 tons/yr (A 100 % capacity operation is again assumed).

5) The variation of the shop content : expressed in ppm (parts per million) ; this criterion indicates if the studied system reduces the worker's exposure in the shops.

Remark : for these last two criteria we supply the variations because real values are difficult to measure and little known ; this does not affect the results as our multicriteria method (see 3.1) uses variations for the evaluations to compare actions globally.

6) The impact on operating security : evaluated on an ordinal scale between -10 and + 10 this criterion indicates if the implemented system results to a gain (+) or a loss (-) of operation security. For example an incinerator that collects VCM fluxes from various zones of a plant would result to a security loss. The values of this criterion for the various actions (per plant), have been obtained by questioning experts.

The evaluations of the actions were made under the following assumptions :

System functioning :

- 8000 hrs/year
- Full capacity production
- Normal operation

System cost :

- Interest rate : 9 %
- Investment : Lifetime of 8 or 12 years
- Annual cost : K (investment cost) + operation cost
- Amortization coefficient = 0.1807 for 8 years
= 0.1397 for 12 years

System effectiveness :

- Hoped for effectiveness

We obtain then :

- four 1981 data tables : VO, VR, PO, PR
- two 1974 data tables : VO, PO (VR, PR did not exist in 1974).

These six tables are given in /8/. Only the 1974 PO case is given here as an example (See table 3). The analytical calculations of the performances of the elementary options are given in /4/.

Table 3 : Multicriteria evaluation of actions in a PO type plant in 1974 ; the first two criteria are negative.

N°	ACTIONS	Annual cost (in 10 ⁶ FF)	VCM released (in 10 ² tons)	VCM recovered (in 10 ² tons)	Co-pollutant(*) avoided (in 10 ³ tons)	Fall in shop content (in ppm)	Impact on security (note between - 10 and + 10)
1	Do nothing (DN)	0	17.0	0	0	0	0
2	Improved gas removal, fugitive, control (FC)	14.53	12.1	1.55	0	130	0
3	Incinerator (I)	2.48	6.0	0	0	0	-1
4	Carbon Adsorbtion (CA)	4.26	6.2	10.90	0	0	0
5	Combination (CA + I)	5.28	5.8	10.90	0	0	-1
6	Combination (FC + I)	17.07	0.9	1.55	0	130	-1
7	Combination (CA + FC)	18.80	1.1	11.00	0	130	0
8	Combination (FC + CA + I)	19.81	0.7	11.00	0	130	-1

(*) This criterion applies to both VCM and mixed plants.

3 - THE MULTICRITERIA OUTRANKING METHOD

In the multicriteria decision systems that we study, we come across phenomena of uncertainty and of imprecision concerning the information used, imputation doubts, and subjective qualitative estimations. It has therefore been necessary to work within a framework that would admit imprecision : the chosen method is based on the fuzzy outranking concepts /5,6,11/, as a preference representation model. A synthesis of multicriteria methods can be found in /1/ or in /4/.

3.1 - The principles of the method

A discrete problem of multicriteria choice is modeled with the help of a set of alternatives, noted by $A = (a, b, c, \dots)$, and of a family of n criteria $(g_1, g_2, \dots, g_n)$ with g_i a real function defined over the set A in such a way that $g_i(a)$ represents the performance or the evaluation of action $a \in A$ for criterion g_i , thus, the more action a satisfies the criterion in question. Consequently the multicriteria evaluation of an action $a \in A$ will be represented by vector $g(a) = (g_1(a), g_2(a), \dots, g_n(a))$ consisting of the n values of the action for the criteria.

All the steps of the proposed methodology are given in figure 2. With the exception of the domination analysis, listed among the ranking techniques, the entire process constitutes the ELECTRE method /6,12/.

3.1.1 - Monocriteria outranking relations

In order to modelize uncertainty on a single criterion level, ROY /6/ uses the pseudocriterion concept according to which, with each criterion g_i are associated two threshold functions :

- the indifference threshold : q_{g_i}
- the preference threshold p_{g_i}

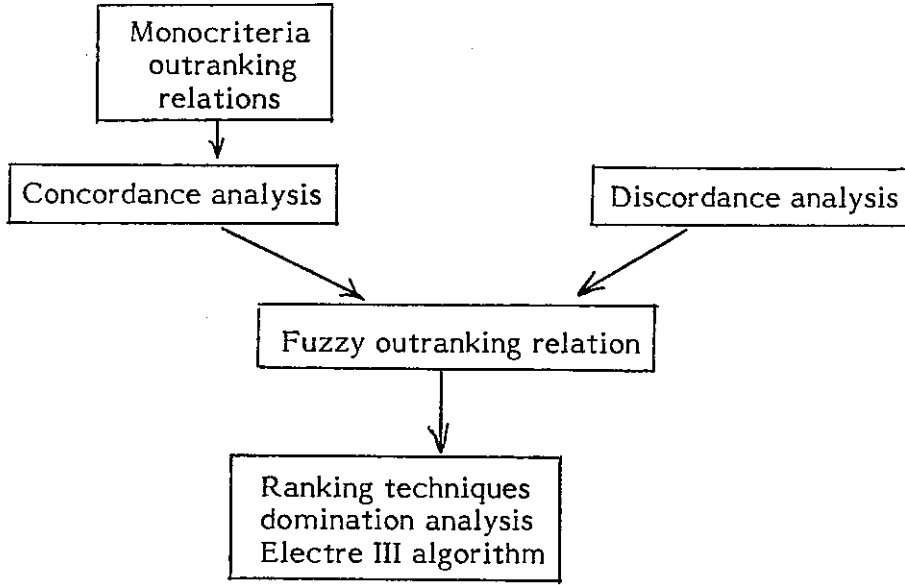


Figure 2 : Plan of the proposed methodology.

The modelization of monocriteria preferences is clarified by the construction of a fuzzy outranking relation : $d_i : A \times A \rightarrow [0,1]$ which is given below :

$$d_i(a,b) = \begin{cases} 1 & \text{if } g_i(b) - g_i(a) \leq q_{g_i} \\ 0 & \text{if } g_i(b) - g_i(a) \geq p_{g_i} \\ \frac{g_i(a) - g_i(b) + p_{g_i}}{p_{g_i} - q_{g_i}} & \text{otherwise} \end{cases}$$

$d_i(a,b)$ represents the outranking intensity or credibility degree of criterion to compared to criterion a. Let it be noted however that the proposition "an alternative outranks another" means simply that the first alternative is "at least as good as" the second.

The values taken by the functions q_{g_i} and p_{g_i} are not necessarily absolute in general they depend on the alternative considered. For example :

$$p_{g_i}(a) = \alpha + \beta g_i(a) \quad \text{with } \alpha \text{ and } \beta \text{ real.}$$

3.1.2 - Concordance analysis

If to each criterion g_i is assigned an importance index (weight) p_i in such a way as to satisfy the known relation :

$$\sum_{i=1}^n p_i = 1$$

then it is possible to calculate over A a concordance relation $C : A \times A \rightarrow [0,1]$ given below :

$$C(a,b) = \sum_{i=1}^n p_i d_i(a,b)$$

with $C(a,b)$ the degree of concordance of the n criteria to the proposition "a outranks b" globally.

3.1.3 - Discordance analysis

An important advantage of the ELECTRE III type of method is that the comparison of alternatives in A can be partial, given that the criteria retain their intrinsic properties and may "refuse" certain comparisons (discordance effects). This phenomenon may occur in both senses for a given pair of alternatives (a,b) ; this means that "a and b are not comparable", namely that there is no outranking in any of the two senses.

Let us suppose, in fact, that for a pair (a,b) we have $C(a,b) = 1$; this means that for any criterion g_i we have $g_i(b) - g_i(a) \leq q_{g_i}$ (a better than b, near the indifference threshold, for all criteria). If now $C(a,b) < 1$ for a given pair (a,b) , there exists at least one criterion index i^* such that $g_{i^*}(b) - g_{i^*}(a) > q_{g_{i^*}}$ if this favorable to b difference exceeds a veto threshold $v_{g_{i^*}}$, that is a very large quantity $(g_{i^*}(b) - g_{i^*}(a)) \geq v_{g_{i^*}}$, then the proposition "a outranks b" is definitely excluded and criterion g_{i^*} is surely in discordance with this proposition. We will see later on that this phenomenon corresponds globally to a zero outranking ($d(a,b) = 0$). Consequently, the situation $d(a,b) = d(b,a) = 0$ corresponds to an incompatibility between a and b.

Let us take an example from table 3. Action 1 "do nothing", of zero cost, results to a VC release of 1 700 tons/yr ; the VC release corresponding to action 8 is reduced to 70 tons/yr, but to a cost in the order of 20 millions francs. If we fix for instance $v_{g_1} = 20 \times 10^6 \text{ FF}$ and $v_{g_2} = 1\,000 \text{ tons/yr}$ we find $d(1,8) = 0$ because of the veto on VCM release and $d(8,1) = 0$ because of the veto on cost. Actions 1 and 8 than are not comparable.

The modelization of the criteria discordance is done by means of n fuzzy discordance relations $D_i : A \times A \rightarrow [0,1]$, defined as follows :

$$D_i(a,b) = \begin{cases} 1 & \text{if } g_i(b) - g_i(a) \geq v_{g_i} \\ 0 & \text{if } g_i(b) - g_i(a) \leq p_{g_i} \\ \frac{g_i(b) - g_i(a) - p_{g_i}}{v_{g_i} - p_{g_i}} & \text{otherwise} \end{cases}$$

where $D_i(a,b)$ is the degree of discordance between criterion g_i and the proposition "a outranks b". The veto threshold function varies linearly with the action evaluations :

$$v_{g_i}(a) = \alpha + \beta g_i(a) \quad \text{with } \alpha \text{ and } \beta \text{ real.}$$

3.1.4 - Fuzzy outranking relation

This concept is meant to unite the preceding analyses, concordance and discordance. It is a relation $d : A \times A \rightarrow [0,1]$ that represents the degree of global outranking of an alternative by another.

In the preceding paragraph we presented two cases of contrasting picture : the case of certain outranking ($d(a,b) = 1$) when there is perfect criteria concordance ($C(a,b) = 1$), and the case where, for sure, there is no outranking ($d(a,b) = 0$), a case that occurs when there exists at least one criterion g_{i^*} that is in complete discordance with this outranking ($D_{i^*}(a,b) = 1$). The in between cases are modeled by the following analytical formula of $d(a,b)$:

$$d(a,b) = \begin{cases} C(a,b) & \text{if } C(a,b) \geq D_i(a,b) \forall_i \\ \frac{C(a,b)}{1-C(a,b)} \prod_{i^*} (1-D_{i^*}(a,b)) & \text{with } i^* \in \{i / D_i(a,b) > C(a,b)\} \end{cases}$$

where $d_i(a,b)$, $C(a,b)$ and $D_i(a,b)$ are the functions defined already.

3.1.5 - Ranking techniques

A classic method of interpretation and of analysis of an outranking relation consists of obtaining a ranking of the alternatives that would be as compatible with $d(a,b)$ as possible.

Here we use two techniques of this kind that seem to be complementary. The first is the ELECTRE III algorithm /6,12/ ; it assembles a descending order ranking beginning with the best alternative(s), and then an ascending order one in the opposite sense and gives as result the weak order intersection of the two rankings. The second is a technique based on the transitivity of fuzzy relations in general (see 3). It consists of calculating first a fuzzy domination relation $d^D : A \times A \rightarrow [0,1]$ defined by the formula :

$$d^D(a,b) = \begin{cases} d(a,b) - d(b,a) & \text{if } d(a,b) \geq d(b,a) \\ 0 & \text{otherwise} \end{cases}$$

and then, for each alternatives, the indicator :

$$\mu^{ND}(a) = 1 - \max_{b \in A} d^D(b,a)$$

where $\mu^{ND}(a)$ represents the non domination degree of alternative a by all the others at the same time. One then only has to maximize $\mu^{ND}(a)$ over A in order to determine the least dominated (or rather the least bad) alternative of A . This method is useful only when it determines any actions with high non domination degree (between 0.9 and 1) and with the remaining actions much more dominated ; otherwise, this means that there is no little dominated action in A , and that, therefore, the studied options are very close or non comparable thus making the ranking difficult.

3.2 - Estimation of the method parameters

3.2.1 - Preference and indifference thresholds

These are parameters related to the action evaluations. Their estimation involves certain difficulties inherent in their definition, but it is relatively easy to fix an interval for each evaluation into which the estimated value would almost certainly fall. We have therefore obtained, by questioning experts, dispersion thresholds :

$$\begin{aligned} n_1^+(a) &= \alpha + \beta g(a) \\ n_1^-(a) &= \alpha' + \beta' g(a) \end{aligned}$$

From these dispersion thresholds it is possible to estimate the preference and indifference thresholds p_g and q_g with ROY's formulae /12/ :

$$q_g(g(a)) = \min(\alpha + \beta \cdot g(a); \frac{\alpha' + \beta' g(a)}{1 - \beta'})$$

$$p_g(g(a)) = \frac{\alpha + \alpha' + (\beta + \beta') g(a)}{1 - \beta'}$$

Since experts have only given a single dispersion threshold per criterion ($n_i^+ = n_i^-$), $\beta = \beta'$ and $\alpha = \alpha'$ and, furthermore, $\beta \ll 1$, we obtain :

$$q_g(g(a)) = \alpha + \beta g(a)$$

$$p_g(g(a)) = 2 q_g(g(a))$$

for every criterion g . The values of these thresholds for the three policies (Industry 1974, Industry 1981, Public authorities 1981) are given in /8/. In addition those concerning industry 1974 are presented in Table 4.

Table 4 : Thresholds for the industrial 1974 policy.

Type of threshold Criterion	Dispersion $n^+ = n^-$	Indifference q_g	Preference p_g	Veto v_g
Cost	0,1 + 5 %	0,1 + 5 %	0,2 + 10 %	20
VCM released	0,5 + 20 %	0,5 + 20 %	1 + 40 %	50 + 50 %
VCM recovered	5 %	5 %	10 %	50 + 50 %
Co-pollutant avoided	10 %	10 %	20 %	50 + 50 %
Variation in content	1	1	2	20
Variation in security	0,5	0,5	1	30

3.2.2 - Veto thresholds

As far as industry is concerned they have to do with costs :

- On the investment cost level, it does not accept a system that represents more than 10 % of the cost of the plant (500 MF) ; or a figure in the order of 7 MF after annualization,

- Concerning operation and maintenance, we have two cases :

In 1974 industry accepted up to 10 % of the cost of the product, that is a figure of 12 MF and 600 F the ton of PVC for a production of about 0.2×10^6 tons.

In 1981 it accepts only 5 % of the cost of the product because of stronger competitiveness and higher PVC prices ; we thus obtain a figure of 25 MF at 2 500 F the ton.

The veto then, in 1974 for the total annual cost is 19 MF and 32 MF in 1981. But because of the high imprecision inherent in these calculations we have chosen as veto values the figures of 20 MF and 30 MF respectively for 1974 and 1981 (see Table 4).

As far as shop content is concerned a veto figure of 20 ppm was chosen. In fact, in the PO plant certain options result to a content reduction of 130 ppm as opposed to others that result to no reduction. Given that existing regulations require a rate inferior to 5 ppm, the existence of a veto is necessary for this plant. The value is such that it only applies to the PO plant.

Let us note that the Public Authorities' veto for VCM emissions is 500 tons/yr, which corresponds to 62 kg/hr which is not easily detectable.

As far as co-pollutant releases are concerned, little is done by the Authorities, as the released quantities are well known.

The other criteria thresholds were chosen high enough as not to apply.

3.2.3 - The relative importance of the criteria (weight)

The weights were worked out in two different ways :

- 1) Experts provided a weight range for each situation (see /8/),
- 2) These same experts answered a questionnaire form based upon which the criteria weights were ranked and a range was fixed (this method which is characteristic of the ELECTRE methods is described in detail in /7/).

These two surveys resulted to several weight ranges for each situation (Table 5) :

- 1 weight range for industry in 1981,
- 3 weight ranges for industry in 1974,
- 1 weight range for public authorities in 1981.

The second is a step by step method :

a) A reference option, $\underline{s} = (s_1, s_2, \dots, s_n)$ which is often the average action, is determined ; (in general, this option is not realizable).

b) A two by two criteria comparison.

Let i and j be two distinct criteria and $\underline{s}'$ and $\underline{s}''$ two actions equal to $\underline{s}$ for all criteria other than i and j .

	i	j	Complement
$\underline{s}'$	$s_i + p_i(s_i)$	s_j	$\bar{s}$
$\underline{s}''$	s_i	$s_j + p_j(s_j)$	$\bar{s}$

where $p_i(s)$ and $p_j(s)$ represent the preference thresholds for criteria g_i and g_j for $\bar{s}$ the complementary vector of (s_i, s_j) in $\underline{s}$. The decision maker chooses between $\underline{s}'$ and $\underline{s}''$; by varying i and j we obtain an order for the criteria ; if for instance the decision maker prefer $\underline{s}'$ over $\underline{s}''$, we deduce that $p_i > p_j$. This step is repeated ($n-1$ times) until an order or a weak order is obtained for coefficient p_i , $i = 1, 2, \dots, n$.

c) Criteria - coalition comparison :

A coalition (s') of two criteria (i, j) is such that $\underline{s}'$ is equal to $\underline{s}$ for all criteria other than i and j with :

	I	J	Complement	k
$\underline{s}'$	$s_i + p_i(s_i)$	$s_j + p_j(s_j)$	$\bar{s}$	s_k
$\underline{s}''$	s_i	s_j	$\bar{s}$	$s_k + p_k(s_k)$

$\bar{s}$ represents this time the complementary vector of (s_i, s_j, s_k) in $\underline{s}$. If the decision maker again prefers $\underline{s}'$ over $\underline{s}''$ then $p_i + p_j > p_k$ otherwise $p_i + p_j \leq p_k$. This step is taken in such a way as not to question the order obtained in step b, that is by taking the more important criteria vs. The less important criteria coalitions.

d) Coalition - coalition comparison

The principle is the same as in c. This procedure should result to a system of compatible linear constraints from which we obtain two compatible weight ranges (see /7/). In case of several weight being acceptable, a stability analysis should be carried out.

The procedure should be repeated starting with step a and with new reference points $\underline{s}$ in order to make certain that the importance indices are independant of the reference consequence level.

As an example, we present below the weighting that results from running the algorithm with data provided from one of the three experts questioned (Table 5, 1974 : Q3).

Table 5 : Weights derived from the questionnaire for industry in 1974 and 1981, and for public authorities in 1981.

Decision Criterion	INDUSTRY : Questionnaire				PUBLIC AUTHORITIES
	1974 : Q1	1974 : Q2	1974 : Q3	1981	Questionnaire 1981
Cost	30	32	26	29	15
VCM released	6	4	5	15	39
VCM recovered	11	8	10	12	4
Co-pollutant avoided	0	0	0	0(3)*	4
Content variation	36	43	41	30(28)	27
Security variation	17	13	15	14(13)	11
<u>TOTAL</u>	100	100	97	100	100

System of inequalities obtained (1974-Q3) :

$$\begin{array}{ll}
 p_4 < p_2 & p_3 + p_6 < p_1 \\
 p_4 + p_2 < p_3 & p_6 + p_1 = p_5 \\
 p_2 + p_3 = p_6 &
 \end{array}$$

which leads to relatively stable normalized weight range $p = (26, 5, 10, 3, 4, 15)$.

(*) The figure in parentheses are those used when the "co-pollutant avoided" criterion is taken into account.

4 - THE ANALYSIS OF THE RESULTS

In these section we present a global analysis of the results obtained by the method, following the formulation of the problem as developed in section 2 (a plant by plant approach and three decision makers : Industry 1974, Industry 1981, Public Authorities 1981). For the Industry 1974, PO plant case, which is used to illustrate the method here, we develop some of the obtained results.

4.1 - Industry 1974

a) PO plant

The results that we present for this case are derived from the data of tables 3, 4 and 5. They can be classified and interpreted in three categories :

- outranking table : (analysis of relations between actions)
- fuzzy non domination indicators
- ELECTRE classification.

Thus, two last results, for cases Q1, Q2, Q3 (see Table 5), are represented in Table 6 and figure 3 respectively.

Table 6 : Non domination degrees of the actions of a PO type plant (Industry 1974).

N°	Actions (Code)	Case Q1	Case Q2	Case Q3
1	Do nothing (DN)	0.31	0.37	0.27
2	Improved gas removal Fugitive control (FC)	1.00	1.00	1.00
3	Incinerator (I)	0.30	0.36	0.27
4	Carbon adsorption (CA)	0.30	0.35	0.27
5	Combination (CA + I)	0.30	0.32	0.27
6	Combination (FC + I)	0.59	0.59	0.63
7	Combination (FC + CA)	0.87	0.80	0.88
8	Combination (FC + CA + I)	0.70	0.67	0.73

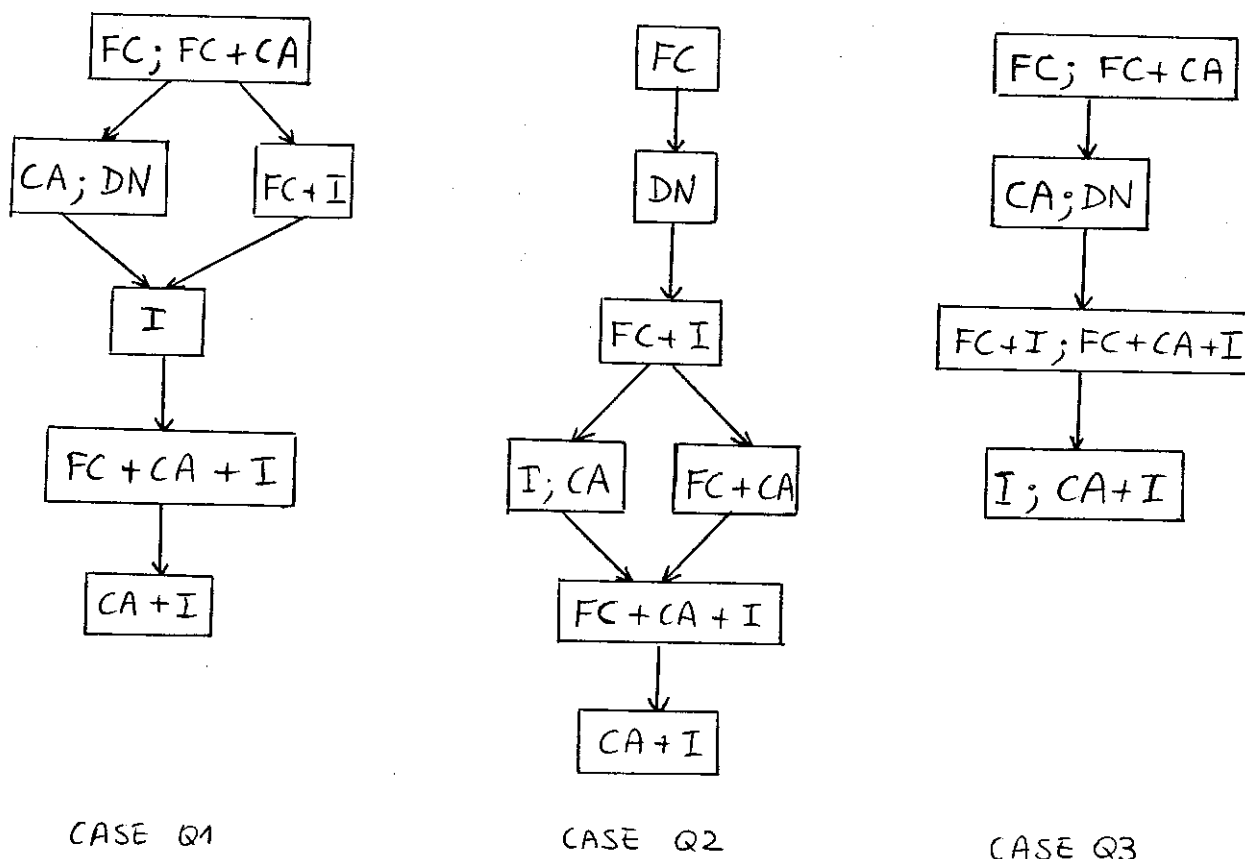


Figure 3 : Ranking of the actions of a PO plant by ELECTRE (Industry 1974).

It turns out in fact, the option 2 (improved gas removal, fugitive control) is on top of the ranking in every case and with a non degree equal to 1 ; this position is explained by the fact that this system acts on the shop content (130 ppm) and especially as the veto (of 20 ppm) on this criterion penalizes 4 options. It would be more fair to distinguish two types of actions :

- type 1 : those that act on shop content ; it is then option 2 that comes on top ; because of its cost (14.5 MF), followed by action 7 that allows recovering a large quantity of VCM and appreciably reducing the releases but at a high price (18.8 MF).

- type 2 : those that do not act on shop content ; here option DN easily prevails with a non domination degree of 1. The other actions that act only on releases (5 % weight) and on recovering VCM (8 % weight) are judged to be too expensive by the decision maker (cost has an importance in the order of 25 %).

These remarks are independent of any changes in the weight ranges ; which do not after all modify the results. It must be noted that option 2 does not have very high outranking degrees (in the order of 0.6) in relation to type 2 options ; this shows that this system is not very effective except on shop tenor variation criteria.

b) VO plant

Action 2 (Fugitive control) presents high outranking degrees and non domination degrees equal to 1 ; it finishes easily on top of the list with option 5 (fugitive control + quench) which has always a non-domination degree higher than 0.9).

The dominating position of these 2 actions is due to the fact that they are complementary and coherent with the decision maker's preferences :

- the fugitive control permits recovering VCM thus avoiding its release, this acts also on the shop content which is the more important criterion for industry (a weight of 40 %).

- the quench which recovers a lot of VCM at a very low cost (0.5 MF), thus avoiding its release.

These results are confirmed as well by the average non domination indicators :

DN : 0.65

FC : 1.00

FC + Q : 0.93

FC + I : 0.57

The incinerator involving options appear too expensive (a cost higher than 10 MF) to the decision maker whose "cost" criterion veto is at about 20 MF ; furthermore, the incinerator does not act on shop content and has little effect on security.

Let it be noted also, that weight variations have no appreciable influence on the results.

4.2 - Industry 1981

a) VO plant

The results are very stable and independent of the analysis and the weights used (questionnaire, expert, analysis).

It seems that options FC and FC + Quench have high and stable credibility degrees in relation to weighting variations ; their domination is due to the fact that they act effectively on all criteria and at a low cost ; option "DN" is always easily dominated : average degrees : DN (0.54), FC (0.94), FC + Q (0.96).

The system FC + Q seems to be the best to implement. Let it be noted that fugitive control was implemented between 1974 and 1980 while the Quench was added in 1982.

b) PO plant

The fugitive control and improved gas removal + carbon adsorption option is always the least dominated (average degree of 1) ; it also appears as the best action from the credibility degree point of view.

The other options have quite low and variable credibility degrees ; this explain the variable results and disrupts the ranking. However the improved gas removal and fugitive control option comes out in general on second place (average degree of 0.8) tied with the improved gas removal + incinerator option or with the improved gas removal + carbon adsorption + incinerator option.

On the other hand, the stability analysis confirms that the FC + CA action has high and stable outranking degrees and non domination degrees superior to 0.93. This result is not altered when we apply the "shop content" veto of 20 ppm to 250 ppm.

The other actions have always very variable outranking degrees ; the average non domination degrees are : DN (0.43), FC (0.92), FC + CA (0.98). We must note the poor position of the DN option, which proves the necessity of implementing the FC + CA action.

c) VR plant

The recent plant was little polluting, which explains the good position of the "do nothing" option (average non domination degree in the order of 0.9) ; it must however be noted that the results vary as far as determining the best action is concerned (rather high but fluctuating outranking degrees). In fact, although the DN option leads slightly, it would be better to consider all four actions : DN, Storage, I, Storage + I.

This closeness can be explained by the special nature of each option none of which acts favorably on all criteria :

- DN has a zero cost for a low pollution,
- the incinerator eliminates all pollution at a rather high cost,
- the storage improves appreciably the security (+ 5) at a low cost.

The stability analysis confirms the closeness of the actions with average non domination degrees : DN (0.96), storage (0.86), Storage + I (0.70). The first two actions stay, in general, on top of the ELECTRE rankings, even if there exist slight variations. However, as all non domination degrees are high (between 0.6 and 1) none of the actions can be really excluded.

And yet it is surprising to see that it is the storage + incinerator option that was implemented in 1980, although it is always last in the rankings. This is certainly due to the fact that for this plant, the decision maker's preferences were such that he gave more than the usual importance (3 %) to the co-pollutants. The insistence of the Public Authorities on seeing large quantities of co-pollutant being treated influenced the decision.

b) PR plant

The options presented for this plant have an effect on all criteria which gives a real "multicriteria" dimension to the study. In reading the results, the outranking degrees seem to be not very high, which leads to similarly low and closely spaced non domination degrees for the leading options in the ranking : degrees between 0.75 and 0.85, it must be noted, however, that this group of actions is almost always the same : FC, FC + I + CA, I + CA.

The stability analysis shows that the FC and FC + I + CA options are both candidates for first place in the ranking with quite high variations in non-domination and outranking degrees (FC : between 0.68 and 1), I + CA : between 0.44 and 0.49, FC + I + CA between 0.7 and 0.96). It seems therefore that the last one is the best.

Having two actions, FC and I + CA, on top at the same time is due to the fact that each one partially satisfies the decision maker's preferences ; their combination though (action FC + I + CA, between 0.7 and 0.96), does not seem to be very dominating because of the higher cost.

Surprisingly, however, it is the FC and improved gas removal + I + CA that was implemented in 1981 ; the reasons for this choice were : slight reduction of VC releases ; moderate increase of VC recovery ; low extra cost (2 MF). It seems that the choice was made as if the "decision maker was not at his last 2 MF" and that his preferences in cost terms (weight of this criterion) varied inversely with the action evaluations. There was a particular problem having to do with the local acceptability of the lay out at the plants site, as the municipality opposed the creation of this production unit using the product's carcinogenic risk as argument. The manufacturer who already had other installations complementary to the unit, on the site allowed expenses that he considered excessive. The authorities used this local dispute to make this plant a "show case" that present a very distinct exemplary character.

For the two recent plants we see that industry had not a full initiative in the choice and that the public authorities influence was significant.

4.3 - Public authorities 1981

Goal of this study was to determine the most effective options (inter plant approach) in terms of pollution control, that is to compare the actions already implemented in each plant. This approach, however, can not give precise indications since :

- the plants are not easy to compare ; a large scale action in a plant which still is polluting, will be better "judged" than a limited action in another plant which already was very little polluting.

- in PVC plants there are sources of VCM pollution that are irreducible. This phenomena does not appear in VCM plants,

- the preferences of the public authorities can vary from one plant to another and depend, among other things, on the plant's environment (number of inhabitants, local climate,...) a criteria that does not apply here.

On the top of the rankings though, come options that act strongly on shop content and which furthermore reduce VC releases to almost zero : for instance "FC + improved gas removal + I + CA" in the PO, "Storage + I" in VR and "improved gas removal + I + CA" in PO. These actions whose effect and cost are high, reflect both the wishes and demands of the public authorities in the field of pollution control in the VCM sector.

5 - CONCLUSION

The global approach proposed here, satisfied two objectives :

- establish a modelization of the decisional problem in the control of a characteristic form of chemical pollution, a problem whose complexity was shown in this paper.

- propose an operational methodology permitting to measure the impact of the eventual implementation of systems against VCM pollution, to evaluate other alternatives of control of this pollution and to propose solutions compatible with the preferences of industry and authorities.

Finally, it is interesting to compare the results obtained in 1974 and in 1981 with the choices actually implemented we can thus remark :

- that in 1974 there is perfect agreement between what was implemented (FC for the VP plant and FC + improved gas removal for the for the PO plant) and the results of the "1974 industrial" policy ;

- that in 1981 there is perfect agreement between what as implemented in the old plants (FC + Quench for VO and FC + improved gas removal + CA for PO) and the results of the "1981 industrial" policy, but for the recent plants there is perfect agreement between what was implemented (storage + CA + I for PR) and the results of the "Public Authorities" analysis.

These last results can be explained by the strong pressure of the authorities on recent plants in 1981 given the existing procedures of operation authorization in France.

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