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Intelligent Dynamic Decision of Sustainable Supplier Selection

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Abstract—The purpose of this paper is developing dynamic strategies using proactive integration of decision criteria for Sustainable Supplier Selection. More specifically, we propose to solve a multi-objective problem with a Meta-heuristic, namely the Multi Ant Colony System. Our approach of Supplier Selection goes through several steps and several decision levels, namely strategic, tactic and operational levels. Our study adds particularly sustainability and risk criteria to the standard selection criteria. We model the problem with a multi-objective optimization approach using a new multi ant colony system. Our deployment model of supplier selection strategy is dynamic, adaptable to strategy changes that must always adapt to a dynamic socio-economic environment. Moreover, our smart and multi-objective model provides several scenarios available that can be used by decision makers. One of the implications of our work would be to make comparisons with other strategy deployment approaches, and extensions to decision making in an uncertain environment. To illustrate the approach and the algorithm we consider a didactic example of a company that has several potential suppliers. We have developed different strategies of multi-objective suppliers' selection by the proactive integration of the decision criteria as risk. The example set out in our study is particularly concerned with sustainability, risks, in addition to the criteria of cost, quality, and time. Pareto Front provides several valuable decision supports to stakeholders.

Index Terms—Sustainable Supplier Selection, Risk Management, Intelligent Systems, Ant Colony System, Multi-objective optimization.

1 Introduction

The dynamic socio-economic environment requires companies that proactively integrate the various criteria into their supply chain management strategy in general and the choice of suppliers in particular. At present, they must necessarily integrate sustainable development, risks, in addition to other criteria such as cost, quality, delay ... etc. These new sustainability and management criteria impact the management of physical flows and the management of relations with the various stakeholders (suppliers, service providers, customers…) and must be incorporated into the company's strategy. Integration of other criteria is imposed by the dynamics of the national and global socio-economic environment.

2 Literature Review

The selection of suppliers has received significant attention in recent years given its important role in supply chain management.

2.1 Supplier Selection, and Green Supplier Selection

Several articles have studied and summarized the development of scientific research in this field. SS. Jain, Wadhwa, and Deshmukh reviewed in 2009 the main approaches related to suppliers, including supplier selection, buyer-supplier relationship and flexibility [1]. Ho, Xu and Dey analyzed multicriteria decision approaches for supplier selection in an article published in 2010 [2]. Chai, J., Liu, J. N., & Ngai, E. W. have provided a study on the applications of decision-making techniques in supplier selection based on articles published between 2008 and 2012 [3]. Govindan, K., Rajendran, S., Sarkis, J., &Murugesan, P. analyzed articles that focus on the selection of green suppliers. The applied techniques are essentially based on fuzzy approaches with a single model and less on the hybrid models, published in 2015 [4].

2.2 Supplier Selection Criteria

According to Ho, W., Xu, X., &Dey, P. K. [2], 87.18% of the articles studied consider Quality as a selection criterion, 82.05% consider service or time, and 80.77% cost criterion. Businesses are increasingly under pressure from stakeholders to incorporate considerations of social, environmental and economic responsibility into operations, supply, and supply chain management strategies in general. The criterion most commonly considered for the selection of green suppliers was the "environmental management system". In their articles [4], Govindan, K., Rajendran, S., Sarkis, J., &Murugesan, P. examined the various criteria used to evaluate suppliers in scientific publications that appeared between 1997 and 2011.

2.3 Artificial intelligence

Several artificial intelligence techniques have been used to evaluate and select suppliers. For example, we mention the genetic algorithms (Genetic Algorithm) [5], neural networks [6],Rough Set Theory [7], The gray system theory [8] [9], Particle Swarm Optimization [10], Bayesian Networks [11], Ant Colony Sysem [12] [13]..

3 Dynamic Sustainable Supplier Selection ApproAch

In this section we describe our approach of Supplier Selection, which goes through several steps and several levels of decision.

3.1 Strategic Level of Decision

Step A.1 : Build Strategy

The strategy must be based on a technical-economic analysis of the company and its environment (segmentation and analysis of the global market, analysis and presentation of the technical environment, societal and environmental policy and knowledge of customer- Suppliers, the external customer-supplier relationship). This stage will give rise to all technical criteria (quality, cost, delay) as well as environmental ones, and those of sustainability, risk, management, safety, etc. It is on the basis of these criteria and their respective weight in the company policy that suppliers will be judged. The performance indicators of this relationship will be tools to continuously improve this strategy, these indicators will not be the subject of this article.
These strategic criteria of selection, called objectives, are noted $\mathbf{O}_f$, $f \in [\![1, s]\!]$, where $s$refers to the number of strategic criteria used.
$\lambda_{\mathbf{O}_f}$: The weight given to the overall criterion of Sustainable Supplier Selection (SSS) $o_f$with $\sum_{f=1}^{s} \lambda_{o_f} = 1$.

Step A.2 : Deployment of strategy

It is a question of communicating the strategy put in place, to internal actors, partner suppliers and other stakeholders, through dedicated reports. This involves ensuring internal communication and establishing an external communication plan.

Step A.3 : Strategic Review

It corresponds to analysing the results of the Supplier Selection strategy and taking into account the new criteria in the customer-supplier relationship, relative to the established indicators and the review of the objectives, with a view to continuous improvement. To this end, the management review examines the SSS management system and its results to ensure that it is always appropriate, sufficient and effective, and to set new objectives for improvement.

Step A.4 : Strategy Improvement

It is reflected in the implementation of corrective actions. It is therefore necessary to establish a specific procedure to eliminate the cause of a detected non-conformity or other undesirable situation, and update the criteria and their corresponding importance or weight.

3.2 Tactical Level of decision

Step B.1 : Preparing databases

This involves developing a database of suppliers and products or services offered. And to develop a survey encompassing all the criteria established in the strategy, the deployment of the strategic criteria to the tactical criteria can be made by the industrial tool "HoshinKanri" which allows the company to concentrate on the realization of the strategic targets [14]. There are certain criteria such as quality and environment that are already determined by a standard, the company can choose between applying what already exists or formulating its own requirements. One should place himself in the context where he can have several suppliers at the same time with different quantities, this is a necessity when the requested quantities are much greater than what can be delivered by each supplier.

Step B.2 : Development of goals and constraints

Each goal, denoted by g_h is a s-tuple of the desired values for the criteria given to a scenario encompassing several suppliers of a particular product or service.

$$(g_{h,1}, \dots, g_{h,p}, \dots, g_{h,s})$$

These goals can be defined using the experience feedback or expert opinion. In this step we also develop constraints on the strategic criteria O_f and the function to optimize.

Step B.3 : Request for analysis

Send a request for analysis of the suppliers of the operational decision level.

Step B.4 : Receiving response

Receive the answer, which will be a matrix given in Table II.

This table will be used to construct the graph, where a point X is characterized by a supplier S_i, a possible quantity Q_i^j and its score for the different criteria of strategic choices:

$$X_i^j = (O^{\,j}_{1,i}, \dots, O^{\,j}_{s,i})$$

Step B.5 : Decision support calculation

The program receives the strategic choice criteria, their weightings, and the table II matrix. And gives as output a set of possible solutions. One solution is:

a possible scenario consisting of a set of suppliers with the quantity to be ordered from each one of them in order to meet the demand of the company,

its score which is a constructed vector.

Let a scenario be $Sc = \left\{ X_{i_1}^{j_1}, \dots, X_{i_p}^{j_p}, \dots, X_{i_L}^{j_L} \right\}$ and let L its length.

Each tuplet $X_{i_p}^{j_p}$ designates a supplier S_{i_p} and a quantity $Q_{i_p}^{j_p}$ and the values of the evaluation of all strategic criteria: $\left\{O_{1,i_p}^{\ j_p}, \dots, O_{f,i_p}^{\ j_p}, \dots, O_{s,i_p}^{\ j_p}\right\}$ See Table I.

The Sc scenario score is the average of these scores:

$$\boldsymbol{Score(Sc)} = \frac{\mathbf{1}}{\boldsymbol{L}} \left(\sum_{p=1}^{L} \boldsymbol{O}_{\mathbf{1},\boldsymbol{i_p}}^{\ \boldsymbol{j_p}}, \dots, \sum_{p=1}^{L} \boldsymbol{O}_{\boldsymbol{f},\boldsymbol{i_p}}^{\ \boldsymbol{j_p}}, \dots, \sum_{p=1}^{L} \boldsymbol{O}_{\boldsymbol{s},\boldsymbol{i_p}}^{\ \boldsymbol{j_p}}\right)$$

The best solutions, all possible, will be gathered to help managers choose one. And others may be mitigation plans in case of a problem in the supply chain.

3.3 Operational Level of decision

Step C.1 : Receiving Supplier Analysis Requests

This request is received from the higher decision level.

Step C.2 : Collection of information

It is made with the suppliers by an established survey containing all the details of criteria elaborated in the SSS strategy. This collection must be complete and precise to allow a correct analysis.

Step C.3 : Analysis of suppliers

This analysis consists of verifying the compliance of the collected information with the requirements, and transforming the answers into numbers, and then summarizing the information for the higher level of decision.

For each product or service offered by the supplier, it is necessary to analyse technical data, risk management and security data, environment and sustainable development data, etc.

The differences can be, according to the company's strategy, communicated to suppliers for correction or improvement.

It is important to note that the values of the evaluation for given strategic criteria may vary for the same supplier, such as cost, time, and risk, they can vary depending on the quantity.

Step C.4 : Communication of results to the higher decision level

TABLE I
EVALUATION MATRIX OF SUPPLIER S_i

Quantity	Criteria					
	O_1	…	O_f	…	...	s
Q_i^1	$O_{1,i}^{\ 1}$					$O_{s,i}^{\ 1}$
…						
Q_i^j	$O_{1,i}^{\ j}$		$O_{f,i}^{\ j}$			$O_{s,i}^{\ j}$
…						
$Q_i^{M_i}$	$O_{1,i}^{\ M_i}$					$O_{s,i}^{\ M_i}$

$O_{f,i}^{\ j}$: The score of supplier F_i of criterion (the objective) o_f.

The quantities may be fixed or variable depending on the supplier.

TABLE II
EVALUATION MATRIX OF SUPPLIER

Supplier	Quantity	Criteria					
		O_1	…	O_f	..	…	O_s
S_1	Q_1^1	$O_{1,i}^{\ 1}$					$O_{s,i}^{\ 1}$
	…						
	Q_1^j	$O_{1,i}^{\ j}$		$O_{f,i}^{\ j}$			$O_{s,i}^{\ j}$
	…						
	$Q_i^{M_1}$	$O_{1,i}^{\ M_i}$					$O_{s,i}^{\ M_i}$
…							
S_i	Q_i^1	$O_{1,i}^{\ 1}$					$O_{s,i}^{\ 1}$
	…						
	Q_i^j	$O_{1,i}^{\ j}$		$O_{f,i}^{\ j}$			$O_{s,i}^{\ j}$
	…						
	$Q_i^{M_i}$	$O_{1,i}^{\ M_i}$					$O_{s,i}^{\ M_i}$
…							
S_N	Q_i^1	$O_{1,i}^{\ 1}$					$O_{s,i}^{\ 1}$
	…						
	Q_i^j	$O_{1,i}^{\ j}$		$O_{f,i}^{\ j}$			$O_{s,i}^{\ j}$
	…						
	$Q_i^{M_i}$	$O_{1,i}^{\ M_i}$					$O_{s,i}^{\ M_i}$

4 MATHEMATICAL MODEL

Our problem is a multi-objective problem. We propose to solve it with a Meta-heuristic, namely the algorithm of ant colonies.

The proposed algorithm is based on numerous ant colonies, each one for a specific goal. The purpose is to minimize the distance of this specific goal, which gives a set of solutions (scenarios). Each path or scenario corresponds to an evaluation value tuplet of each criterion. For example, if the strategic criteria are (Quantity, Risk, Delay, Cost) then each solution corresponds to a quadruplet of values.

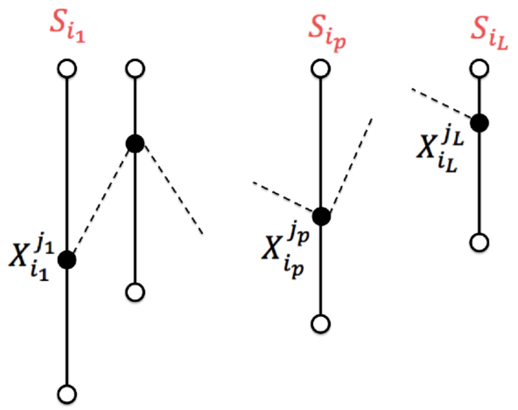

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Fig. 1Representation of a supplier path (scenario)

Each ant colonyAC_P is associated with a noted goalg_P and will seek to build a Pareto Front of optimal solutions for the objective g_P.
The graph G proposed is defined as$G = (\mathcal{N}, \mathcal{A})$ where $\mathcal{N}$is the set of nodes X_i^j of cardinal equal to$\sum_{i=1}^{N} M_i$.
Let A the set of arcs $(X_i^j, X_{i'}^{j'})$ which connect the nodes. Each arc contains $s$pheromone trails. Each trail corresponds to a specific objective (criterion of strategic choices). For an objective $O_f f \in [\![1, s]\!]$the pheromone trail on the arc $(X_i^j, X_{i'}^{j'})$ is noted$\tau^{O_f}_{(X_i^j, X_{i'}^{j'})}$.
The algorithm of an ant colony that wants to reach a goal $g_P$is described as follows:
All the ants of the colony are initialized on one of the nodes of the graph.
Each time that an ant k must choose from a node X_i^j, it chooses to reach the node$X_{i'}^{j'}$belonging to the neighborhood ofX_i^j, or the permitted list noted $\mathcal{D}^k_{X_i^j}$.
Indeed this list must verify some constraints: The constraint of not turning back to the same node and the constraint of quantities.
Let $Sc^k(X_i^j) = \{X_{i_0}^{j_0}, X_{i_1}^{j_1}, \ldots, X_i^j\}$ the partial scenario which realized the ant k that reached the node X_i^j.
The constraint of no return to a previously visited supplier prohibits all nodes $\{X_l^h \text{ such as } l \in i_0, i_1, \ldots, i\}$.
The quantity constraint prohibits nodes that will exceed the requested quantity Q with a toleranceε:
$\{X_l^h \text{ such as } Q_l^h + Q_{i_0}^{j_0} + Q_{i_1}^{j_1} + \cdots + Q_i^j > Q + \varepsilon\}$.
Then:

$$\mathcal{D}^k_{X_i^j} = \mathcal{N} \setminus (\{X_l^h \text{ such as } l \in i_0, i_1, \ldots, i\} \cup \{X_l^h \text{ such as } Q_l^h + Q_{i_0}^{j_0} + Q_{i_1}^{j_1} + \cdots + Q_i^j > Q + \varepsilon\})$$

The arc selection criterion is the one that maximizes the probability defined by:

$$p^k_{X_i^j, X_{i'}^{j'}} = \frac{\left(\prod_{f=1}^{s} (\tau^{O_f}_{X_i^j, X_{i'}^{j'}})^{\lambda_{O_f}}\right)^{\alpha} \left(\prod_{f=1}^{s} (\eta^{O_f}_{X_i^j, X_{i'}^{j'}})^{\lambda_{O_f}}\right)^{\beta}}{\sum_{X_l^h \in \mathcal{D}^k_{X_i^j}} \left(\prod_{f=1}^{s} (\tau^{O_f}_{X_i^j, X_l^h})^{\lambda_{O_f}}\right)^{\alpha} \left(\prod_{f=1}^{s} (\eta^{O_f}_{X_i^j, X_l^h})^{\lambda_{O_f}}\right)^{\beta}} \quad (1)$$

$$\eta^{O_f}_{X_i^j, X_{i'}^{j'}} = \frac{1}{gf - O^{j'}_{f,i'}}$$

$\tau^{O_f}_{X_i^j, X_{i'}^{j'}}$: The intensity of the arc $X_i^j, X_{i'}^{j'}$, update each iteration,

$\eta^{O_f}_{X_i^j, X_{i'}^{j'}}$: The visibility of $X_{i'}^{j'}$, with regard toX_i^j, according to the objective O_f, which is equal to$O^{j'}_{f,i'}$

λ_{O_f}: The weight given to the objective $O_f$with $\sum_{f=1}^{s} \lambda_{O_f} = 1$.

$\mathcal{D}^k_{X_i^j}$: The strategic neighborhood, or permissible list of the nodeX_i^j,

α, :Parameters that control the relative importance of arc intensity and visibility.

Therefore, this probability depends on:
- The local attractiveness of a node according to the objectives,
- The global pheromone corresponding to the objectives,
- The weight of the heuristics (visibility) in relation to the intensity of the pheromone,
- The strategy adopted: modeled by the weight of the objectives.

The score for a scenario Sc is the average of these evaluation scores:

$$Score(Sc) = \frac{1}{L} \times \left(\sum_{p=1}^{L} O^{j_p}_{1,i_p}, \ldots, \sum_{p=1}^{L} O^{j_p}_{f,i_p}, \ldots, \sum_{p=1}^{L} O^{j_p}_{s,i_p}\right)$$

And it must be as close as possible to the established goals.
In a multidimensional context, it is not a single solution but a whole of valid solutions called the Pareto front. When the ants of the AC colony have reached the last node of its scenario, a Pareto Front is built. Let $PF_{it}$the front of Pareto built at iteration it. Each ant that has made a solution ofPF_{it}deposits on the arcs of his path (scenario) a quantity of pheromones for each objective noted$q^{O_f}_{X_i^j, X_{i'}^{j'}}$. The intensity of the arcs is updated as follows:

$$\tau^{O_f}_{X_i^j, X_{i'}^{j'}}(it+1) = (1-\rho)\tau^{O_f}_{X_i^j, X_{i'}^{j'}}(it) + q^{O_f}_{X_i^j, X_{i'}^{j'}} \quad (2)$$

$$q^{O_f}_{X_i^j, X_{i'}^{j'}} = \frac{1}{\left|g_{h,f} - \frac{1}{L}\sum_{p=1}^{L} O^{j_p}_{f,i_p}\right|}$$

ρ : The rate of evaporation, a certain amount of pheromones disappears from the iteration it to the itera-

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tion $it\ +1$ for all the arcs.
The estimate of the quantity $q^{0_f}_{X_i^j, X_{i'}^{j'}}$ is all the more important as the point is close to the value of the goal for this test, but limited by a Q_{max} value not to exceed (if $g_{h,f} = \frac{1}{L}\sum_{p=1}^{L} O^{\ j_p}_{f,i_p}$ then $q^{0_f}_{X_i^j, X_{i'}^{j'}} = Q_{max}$.)

At the end of all iterations for a g_h, the algorithm converges to a Pareto Front PF_{g_h} which corresponds to the best non-dominated solutions obtained by the colony AC which wanted to reach the goal g_h during the iterations.
For our multi-objective optimization problem, there is no single solution that simultaneously optimizes each strategic criterion, as most multi-objective optimization problems do, because objective functions are contradictory. There are a number of optimal Pareto solutions where none of the objective functions can be improved in value without degrading some of the other objective values. Without any subjective preference information, all optimal Pareto solutions are considered to be all equally good. Our goal is to find a representative set of optimal Pareto solutions, and it is a good decision-making tool for the human decision-maker. The other solutions can be integrated into the company's mitigation plan with regard to supply chain risks.
There are several main approaches to informing the decision maker. First, a number of points of the Pareto front can be provided in the form of a list. An alternative idea is to visualize the front of Pareto.

5. Application to Study Case

5.1 Didactic example

We will consider to illustrate the approach and the algorithm a company that has several potential suppliers. The strategic decision-making level of the company decides that the current strategic criteria are quality, cost, deadline, sustainability and risk control, these criteria will be noted in order: $0_f, f \in [\![1,5]\!]$. As the criteria were not of equal importance, the strategic decision-makers assigned them different degrees of importance:
λ_{o_1}: 20%
λ_{o_2}: 10%
λ_{o_3}: 10%
λ_{o_4}: 20%
λ_{o_5}: 40%
$\sum_{f=1}^{5} \lambda_{o_f} = 1.$

This strategy is then deployed and communicated to customers and other decision-making levels of the company. It will be continually improved in response to changes in the economic, legal and other environment.
This decision level develops a questionnaire that meets the detailed requirements of the strategic objectives, the evaluation criteria for each question, and the calculation formula for each supplier's scores for each criterion and quantity.
Procurement experts develop goals because the strategic criteria are contradictory and it is better to set several goals for each product or service.
They have chosen to set up two goals, favoring the risk criterion or the criterion of sustainability:

$$(95\%, 95\%, 95\%, 70\%, 90\%)$$
$$(95\%, 95\%, 95\%, 90\%, 70\%)$$

The desired quantity is equal to 250 units.
They send the request for analysis to the operational level.
The operational decision level collects information from the three suppliers of the market, through the survey. It verifies the compliance of the information gathered against the requirements, then transforms the responses into numbers, and then summarizes the information for the higher decision level in the form of a table.

TABLE III
EVALUATION OF SUPPLIERS

Supplier	Quantity	Criteria				
		O_1	O_2	O_3	O_4	O_5
S_1	10	0.9	0.8	0.8	0.3	0.8
	20	0.9	0.8	0.8	0.3	0.8
	30	0.9	0.8	0.8	0.3	0.8
	40	0.9	0.8	0.8	0.3	0.8
	50	0.9	0.8	0.8	0.3	0.8
	60	0.9	0.9	0.7	0.3	0.8
	70	0.9	0.9	0.7	0.3	0.8
	80	0.9	0.9	0.7	0.3	0.8
	90	0.9	0.9	0.7	0.3	0.8
	100	0.9	0.9	0.7	0.3	0.8
S_2	20	0.85	0.8	0.85	0.8	0.3
	40	0.85	0.8	0.85	0.8	0.3
	60	0.85	0.8	0.85	0.8	0.3
	80	0.85	0.8	0.85	0.8	0.3
	100	0.85	0.8	0.85	0.8	0.3
	120	0.85	0.8	0.85	0.8	0.3
S_3	50	0.8	0.7	0.7	0.5	0.6
	100	0.8	0.7	0.7	0.5	0.6
	150	0.8	0.7	0.7	0.5	0.6

The program receives:

- The current strategy (objectives: quality, cost, delay, risk, sustainability and their weights) ie: $O_f, f \in [\![1,5]\!]$, λ_{o_1}: 20%, λ_{o_2}: 10%, λ_{o_3}: 10%, λ_{o_4}: 20%, λ_{o_5}: 40%
- The goals :(95%, 95%, 95%, 70%, 90%)
(95%, 95%, 95%, 90%, 70%)
- The table of suppliers, the quantities allowed and their evaluations for each strategic criterion.

And gives as exit:
- The Pareto fronts for each goal, i.e. the set of non-dominated solutions, with the possibility of knowing the exact scenario of each solution.

These results will serve as an aid to a final decision.

5.2Results

We launched our algorithm for the data in this example. The video https://goo.gl/qbjTJCshows the progress of the iterations with the updating of the Pareto front, which presents, at each iteration, all the optimal solutions in term of score for the different criteria of the strategies.

Fig.2 shows the "ACS Suppliers" program with the parameters of the model, the error margin of the quantity requested, the Pareto fronts, the amount of pheromones on the different tracks, and the solutions retained after the fixed number of iterations.

Fig.3 shows, this time, the different solutions chosen as a function of the quantities for each supplier. This output represents indeed the deliverable for the decision-makers who will then have to decide between multiple solutions all being valid, respecting the strategy required and close to the objectives set.

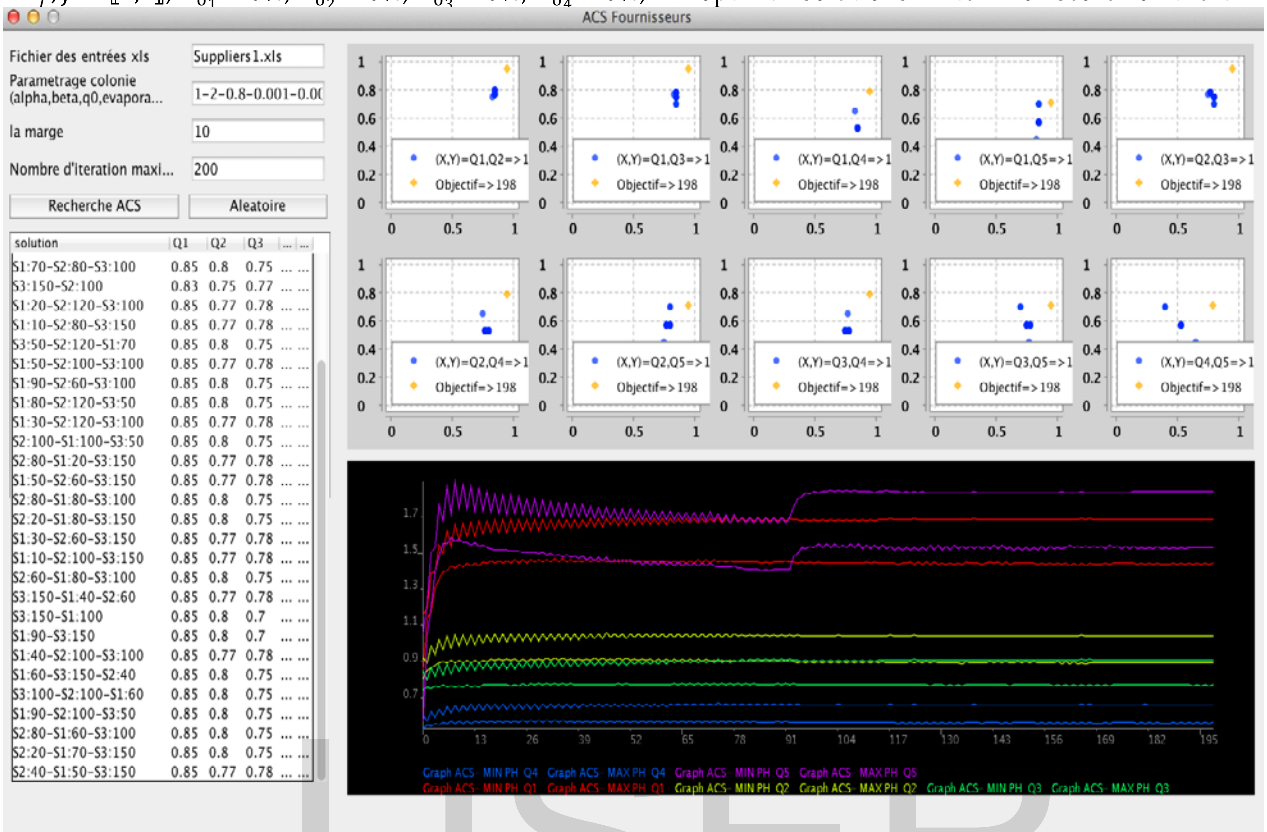

Fig. 2 "ACS Suppliers" Program with the Parameters of the Model

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Fig. 2The Different Chosen Solutions

6. Discussion & Conclusion

Our deployment model of supplier selection strategy is dynamic, adaptable to changes in strategy that must always adapt to a dynamic socio-economic environment. We have developed different strategies of multi-objective choice of the suppliers by the proactive integration of the decision criteria. The example set out in our study is particularly concerned with sustainability, risks, in addition to the criteria of cost, quality, and time. Our model has two main added values:

- A proactive supplier selection strategy that can adapt to changes in strategic criteria and their weightings. As well as its deployment on the different levels of decision of the company.
- Smart and multi-objective business modeling that provides valuable decision support to stakeholders.

In a work in progress, we propose to carry out a comparative study of the quantitative approach (the algorithms) as well as the qualitative approach (top-down strategy) of our SSS model.

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