How evolutionary computation can be introduced to select and optimize scenarii along a product design process

*Claude BARON, **Daniel ESTEVE, *Samuel Rochet

*LESIA, INSA, 135 av. de Rangueil, 31077 Toulouse cedex 04, France
**LAAS, CNRS, 7 avenue du colonel Roche, 31077 Toulouse cedex 04, France

Abstract : This paper explores the interest and the possibility to join system design and project management methods and tools Our motivation is to prevent the obvious incompatibilities between technical objectives and socio-economical requirements in the enterprise. What we recommend is to work on a generic unique model based on the classical top down design steps, to which costs models and non-functional requirements are associated. Project management thus appears as an activity of diagnosis and optimisation, allowing to choose certain realisations between the different possible scenarios and to optimise the management by an allocation of tolerances, which is calculated for each supplier on the base of a global objective. This analysis concludes on the interest of two complementary tools : the evolutionary algorithms to arbitrate the scenarios, and the Monte-Carlo methods for the allocation of tolerances.

Key-Words: evolutionary computing, optimization techniques, modeling, system design, project management

1 Introduction

The accelerated development of technologies offers a wide range of materials, components, production modes … to the engineer. This is useful to design and sell products which life time is short : either products are destined to be consumables, either they become old-fashioned in front of more innovative products. Manufacturers, in this very concurrent international context, must be very reactive to their client needs and very efficient to shorten the time to market.

Once the product specifications are established, manufacturers have to simultaneously master both the product design methodology and project management. These dual of this shared problem are separately conducted and disposed of separated tools: CAD tools, economic planning tools, financial tools…. This practice presents risk of incoherence and lengthening delays for at least two reasons:

- the innovation process is not correlated enough to economical requirements, and enough introduced into the company life,
- project management is conducted on an insufficient knowledge of technical difficulties.

Obviously, these risks could be reduced if all technical, administrative and financial decisions relied on a shared model between partners.

In this perspective, our proposition relies on five items :

- this unique model must rely on a detailed representation of tasks and technological steps induced by the product design,
- the tasks and methodological steps must be detailed according to a refinement process till the practical designation of supplies and suppliers,
- the results of the previous steps must conduct to the development of possible scenarios : planning and scheduling,
- these scenarios must be improved by these pieces of information in order to facilitate their selection :
  - o time constraints : delays, tolerances, …
  - o supply constraints : at least two suppliers,
  - o direct costs : manpower, investments and common expenses,
  - o economical environment : origins and financing conditions of the project,
  - o other performance constraints : security, reliability, quality …
- choices and decisions must be based on chosen criteria, useful to manipulate the database previously defined for optimization procedures at the project beginning and whenever necessary [1].

The shared modeling we recommend does not reconsider project management nor product design methods themselves. Our goal is rather to favor their cooperation. It suggests the development of preliminary design step for which we use new tools like Hiles [2] and the optimization , to which are associated both functional and non-functional product requirements. This paper treats the selection and optimization tools that this shared approach suggests.

2 The shared modeling

At the beginning of the project, one can imagine an approach in which the project manager and the design engineer jointly define a global architecture for the project process as a whole: technological, financial … choices. This step consists in precisely estimating, scheduling, and anticipating the best general organization for the project. This basic general organization might subsequently become an initial generic project shared model, so far as the major steps usually followed during a project, according to project management or technical design tools, are not very different at a high level. Moreover, this architecture might be obtained in an assisted way , by the expression of precedence relations between steps, the choice of technological criteria related to the product to design, the financial constraints, the fixed delivery delays, …

If privileging the technical approach, we are convinced that the shared model could apply the top down refinement system design steps (specifications, preliminary design, virtual prototyping, production…) as useful steps to project management. This first description level can be considered as a generic model expressing technical tasks as well as management steps. It must be detailed and temporally improved regarding the following technical points on the one hand :

– specification : functional and procedural specifications, performance objectives, environment constraints, security directives,
– preliminary design : functional representation, verification, derivation of constraints and directives towards structural or temporal characteristics,
– virtual prototyping : replacement of functional components by real components, introduction of new constraints relative to these components, of production constraints,
– production : introduction of real technological constraints and performances, necessary adjustments on components supplies, validation criteria,

and, on the other hand, regarding non technical objectives, i.e. relative to the project management: costs, market, supply constraints, supplying delays, quality, certification, any types of risks…

The intersection between the tasks' content and the technical and non-technical objectives lead to establish several scenarios which are coherent with general specifications of products. These different scenarios can thus be optimized, hierarchically arranged and selected on the basis of complex compromise criteria associating technical and non-technical considerations.

Of course, with such specifications, no design nor project management operational tool already exists. The schema shown in figure 1 tries to illustrate contents and data structures. At each step, non-functional data modules are associated to functional data ones. For example, we distinguished non-functional technical requirements, costs and execution time requirements, … The functional approach can lead to several architectures which are compatible with the specifications.

Thus, a shared model can be reached by two different ways :

– from the point of view of traditional project management tools, such as planning and evaluation technico-economics tools,
– from the point of view of technical design tools, such as C.A.D. tools.

In the first case, data characterizing technical constraints will be associated to planning tasks. In the second case, costs and time constraints will be associated to design steps [3].

However, a shared model imposes that planned tasks and design steps should be completely equivalent. Of course, considering the numerous parameters taken into account in this decomposition, several competing scenarios are possible.

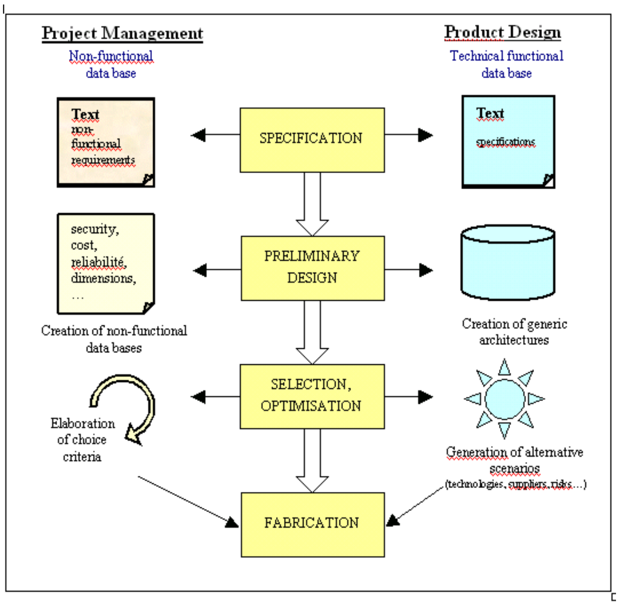

Fig.1 Shared approach : project management and product design

3 Generation of multiple scenarios

Scenarios are deduced from the options attached to each step- they correspond to global solutions respecting both technical specifications and strategic project requirements.

Of course, the number of scenarios increases as requirements and specifications are relaxed… This relaxing of requirements corresponds to a risk level that we judge acceptable on the basis of both strategic and technical plans.

Scenarios are thus deduced from initial options that only the project management team can determine under the form of a systematic questionnaire. The latter can be a technical one, for instance :

– Are there other product architectures, other types of supply, predictable evolution of technology, …?

– Which technical risks are associated to each option? Which solutions can be found to reduce these risks?

This questionnaire can also include administrative and financial points:

– Are allocated means sufficient?
– Are deadlines compatible with commercial and financial ambitions?

The criteria used to validate an option are simply the tests of whether this option verifies the technical specifications and the non-functional requirements. Acceptable scenarios will result from a compromise between compatible options, as illustrated on figure 2.

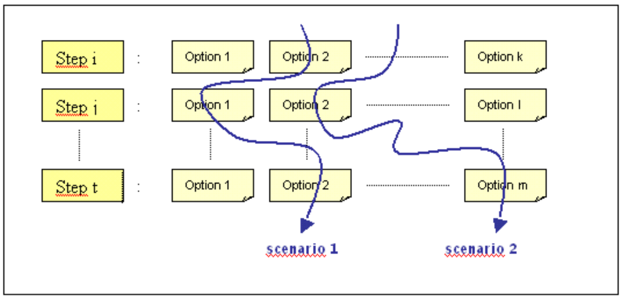

Fig.2 Generation of scenarios from compatible options

This is a first way to generate multiple scenarios; they can be classified according to criteria based on non-functional aspects, using several algorithms that will be exposed in section 4.

Other generation modes can be found into architectural variants that can be imagined by the designer to answer non-functional requirements such as tolerance allocation, reliability, functional risks, and other "project" risks… A special accent can be put on risk analysis during this preliminary phase [4].

Options are stored in a database. The initial database, obtained through the questionnaire and corresponding to the respective experiences of project managers and design engineers, will be progressively improved as projects are conducted.

Then, during the project, regular adjustments will be necessary to take into account events that have occurred which present new risks: longer delays, supplier bankruptcy, new security requirements on the product, insufficient performance… These adjustments will be easier to make if we make good use of the previously mentioned database; however, if it was not detailed enough to obtain one or several satisfactory solutions, new options could be added. This demonstrates the importance of the preliminary risk analysis and of the exhaustiveness of the questionnaire.

The selection of new options, and thus of alternative scenarios, will be done according to a new choice of functional (new technical performances) or non-functional (restricted budget) criteria. The question will thus be how to generate a set of possible solutions from the current state of the project that integrate new constraints; these solutions must also be close enough to the initial one in order to introduce a minimum of perturbations into the different aspects of the project (financial, human, technical …).

These solutions are acceptable from only one point of view of their conformance to the modified project architecture. They will be submitted to the decision-maker and he will select a set of solutions that best satisfy a multi-criteria compromise (for example, global low costs and delays, but man-power increase).

4 Different approaches for the selection and optimization of multiple scenarios

The process previously described offers the designer such elements as:

– A unique description: project tasks and steps, different options by tasks, multiple scenarios that conform to specifications and formulated requirements.
– These scenarios can be classified on the base of :
  - o technical optimization criteria of potential performances by the examination of precise technological questions,
  - o more complex optimization criteria dealing with technico-economical compromises (quality and cost for example),
  - o economical profitability criteria by the anticipation of production and industrial exploitation phases…

Optimization will lead to different hierarchies of scenarios that the decision-maker will arbitrate.

We will only discuss here the selection procedures of scenarios.

4.1 Monte-Carlo methods applied to the allocation of tolerance

This chapter focuses on the decisions made inside a scenario. When market and requirements analyses have defined the scenario and the objectives of a project, the goal of the project management is to strictly answer the deduced requirements for this project. Objectives can be varying: cost objective, time objective, performances objectives… What is considered here is that reaching the global objective results from actions on intermediate influent variables: product global cost depends of each component cost, global performance of each component performance.

Having a global adapted model is essential to appreciate the influence of each parameter on the global objective. This is conducted with a sensibility analysis to parameter variations. The analysis indicates to the project manager which are the sensitive parameters to examine but does not guide him with the decision strategy to adopt. For that, a model describing the consequences of gaps from the objective must be included. It is the proposition of Taguchi [5] to introduce a loss function when the objective is not exactly reached. Our hypothesis is that this idea is interesting whatever the objective is, either a technical performance or a socio-economical question. If you do not reach the goal, the client and the whole society will have to assume the consequences of these gaps. If you surpass the goal, the manufacturer will have to support the consequences.

This synthetic and attractive approach [6,7] motivates us to:

– represent in terms of costs all the consequences of the product requirements,
– introduce a generalized notion of tolerance which will express that each requirement of precision has a cost…

To decide thus consists, for the project manager, in calculating the allocations of tolerances for suppliers and partners. There are calculated with the global predictive model of the product, or the system to design, and a strategic vision which will appear with the loss function associated to gaps relative to nominal values initially fixed by the retained scenario.

The function to minimize corresponds to the sum of costs related to the tolerance requirement on each component parameters and on an estimation of costs related to gaps in the results relative to the fixed objective. The Taguchi proposition [8] is to estimate this complex dependence for each component. The statistical approach is best appropriated. But this approach is costly in terms of processing time because it requires the exploration of the whole research space with Monte-Carlo draws [9]. Hopefully, some optimization modes can be used in order to reduce this time.

In the context of the optimization of multiple parameters, Monte-Carlo methods are interesting when the number of parameters is reduced to tree or four thanks to their simplicity. If the number of parameters is higher, Monte-Carlo methods can be used in a restricted research space to evaluate the sensitivity of a technological device to technological uncertainties. However, other methods, such as neural networks, can be used: the simplified model is established by a direct identification of inputs-outputs. It is then exploited to allow a more rapid minimization, directly processed in terms of standard deviation [10].

4.2 Evolutionary algorithms for the scenarios selection

Evolutionary Algorithms (EA) can be used to select particular scenarios among multiple scenarios. Their principles are inspired from the "lntelligence" of Nature, that can be defined in such a way: "the capability of a system to adapt its behavior to meet its goals in a range of environments" [11]. If no general proof exists of the EA efficiency, it is easy to notice that the selection mechanism is quite efficient a posteriori.

4.2.1 General principles of evolutionary algorithms

Three types of EA have been separately developed in the sixties: genetic algorithms, evolution strategies, and evolutionary programming. Initially different, they now constitute convergent techniques [12] and are known under the term of Evolutionary Computation.

Among the EA previously mentioned, genetic algorithms (GA) seem to offer a good compromise between power, generality and ease of programming. They are inspired by the Neo-Darwinism movement- they are based on natural selection mechanisms. Indeed, they use the selection of best adapted individuals and the principles of genetic inheritance propagation. Intuitively, one can associate the problem to a given environment and the solutions to individuals evolving in this environment. At each generation, best adapted individual are selected. After a certain number of generations, the remaining individuals are particularly adapted to the given environment. In this way, one can obtain solutions that are very close to the optimal solution.

The applications of GA are numerous : optimization of difficult numerical functions, image processing, design optimization [13], industrial system control [14], neural network learning [15], etc. GA are used at every step in research, development and production for optimization or selection questions such as the problem that we are concerned with here.

4.2.2 Why genetic algorithms in our case ?

The choice of the various project's tasks is an optimization problem for which one no exact polynomial algorithm is known. The use of an exact method of optimization is then not very realistic for large-sized problems.

However some heuristics like simulated annealing, research with taboos, evolutionary algorithms or ants' colonies can allow to solve this problem. These heuristics have the following properties:

– The search for an optimal solution can be inappropriate in some kind of practical applications because of problem's dimension, of the dynamics which characterizes it, of the lack of precision in data collection, of the difficulty in formulating the constraints in explicit terms or in the presence of contradictory objectives.
– An exact method is often much slower than an heuristic method, which generates additional data-processing costs.
– A discovery method can easily be adapted or combined with others types of methods. This flexibility considerably increases the power of the discovery methods.

In front of this problem, we could note that a method using the evolutionary algorithms seemed adapted, mainly for two reasons. First, they are research algorithms well adapted to multiple parameters of which they consider many combinations at the same time. Thus, the risk of obtaining a local optimum is reduced. One thus lays out with each stage of calculation a unit of available solutions and not a single solution like the method of simulated annealing or with taboos do. It is an advantage in our case where a choice of solutions will have to be presented at the user.

Second, they use a very simple criterion of evaluation by allocating a note to each individual according to its performance. This avoids using more complex mathematic tools like the gradient or the derivative, which often is the case in a great number of other methods of optimization and which can be not easily usable or not very representative in a similar problem.

4.2.3 Application of genetic algorithms for the selection of scenarios

The generation of scenarios is processed from the different options of figure 2 ; the generated scenarios are already validated and optimized from a functional point of view. Here is how the genetic mechanisms proceeds.

A task, as defined on figure 1, is defined with three main parameters, cost, duration and prerequisites, and some additive informative categories.

A scenario is build as a combination of chosen options (an array) at each step. Options are also stocked into arrays at each step. A scenario contains the following pieces of information: total cost, total duration, fitness and some additive informative elements. The cost and duration parameters are calculated with simple addition operations. An initial population (an array) of scenarios is then randomly or quasi-randomly generated with all their non-functional characteristics. To it are associated three parameters : best individual fitness, best scenario and average fitness. At the beginning of the project, one must fix the objectives in terms of cost and delays generate the different options.

The genetic engine then makes this population evolve in order to obtain either the best valid and optimal scenario, or a set of optimized scenarios. The evolution of different scenarios is shown on figure 3; one can see that, in order to simultaneously make selection and optimization of scenarios, the classical scheme has been improved with a step of technical validation for candidates: before optimization, they are evaluated according to technical criteria, simulations of performances for instance. Scenarios are then evaluated according to criteria related to the project management domain.

A selection of individuals is then made among the population of candidates in order to favor "good" individuals according to the selected evaluation criteria; however, as a certain diversity has to be respected into the population, a few individuals, less adapted, must survive too. What has been chosen for the moment is to apply the roulette principle.

Selected individuals are then crossed and mutated in different percentages, often empirically determined, in order to constitute the next population. For the moment, only a single point crossover is implemented, the objective being to validate the principle of use of the genetic algorithm.

The algorithm proceeds in this way until the solution(s) is obtained, which means that one or more scenario(s) that is functionally satisfactory and corresponds to other technico-economical non-functional constraints have finally been obtained. This stop criterion could be improved further in the future version of the tool… When no optimal solution is reached, the algorithm can help the decision-maker to select the best approximated compromise...

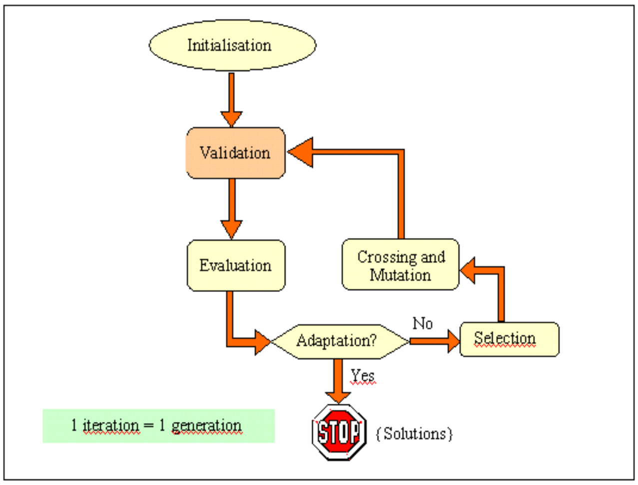

Fig.3 Genetic algorithm functioning

The use of the evolutionary algorithms is in this type of application is recent because until now they were used in problems of scheduling where the tasks are known but not the order in which they must be followed (problems of the type flow shop, job shop or open shop). Here, the problem is the opposite, the order of the tasks is determined and we try to find which chain of tasks would lead us as close as possible to our objectives. It is thus a new problem that is posed and that justifies why we chose to apply this method.

5 Conclusion

Nowadays, project management is basically funded onto tasks scheduling and resources (human and financial) management considerations. It supervises product design tasks in the way that the decisions made determine the allocation of resources. This situation is not totally satisfactory because it induces misunderstandings, as the project manager can be very far from technical requirements, and reciprocally the product designer can be unaware of financial constraints.

The main contribution of this paper is to submit a first exploration of an organization more closely associating project management and product design. This proposition consists of three recommendations :

– First: a shared model to describe technical design tasks and project management steps similarly at a high level. Our hypothesis is that this model is founded on top down systems design steps: specification, preliminary design, virtual prototyping, optimization, material prototyping,
– Second: proceed to a model exploration by associating options at the task level, and by generating multiple scenarios at the project level. The generation of options and scenarios must be systematically based on possible technological variants, on risks analyses and on financial and administrative variants.
– Third: process optimization treatments in order to select the most effective scenarios. These treatments must be activated at the beginning of the project, then regularly during the project. According to technical or financial cri-

teria, choices could highlight some incompatibilities that decision-makers will have to arbitrate.

In this paper, we focused on the development of the database and on the optimization tools that can be envisaged.

Considering the database development, supposing that the shared model is obtained on the base of the technical tasks decomposition, we suppose that each task be systematically documented with non-functional data related to project management : costs, manpower, deadlines, marketing requirements, strategic constraints … Data will consist of, with the product functional model, the shared model project management – product design, on which the optimization methods will rely.

Considering optimization methods, we illustrated their fundamentals on two points: the use of genetic algorithms for the selection of scenarios and the use of Monte-Carlo methods to tackle allocation of tolerance questions, those tolerances being either technical or non-technical. The Monte-Carlo draws are used to explore a system behavior around the nominal values of the model parameters. On the basis of data thus obtained, an optimization of the tolerance allocation is processed on the parameters considered as pertinent that best correspond to the allocation required for the global system. The paper showed that computational techniques can be employed to reduce computation delays which are often long as far as Monte-Carlo statistic evaluation are concerned…

6 References

[1] Maders H., Gauthier E., "Conduire un projet d'organisation (Guide méthodologique) ", *Les Editions d'Organisation*,1998.

[2] Hamon J.C., Esteve D, Pampagnin P., "HiLeS Designer: A tool for systems design". *International Symposium Convergence 03: Aeronautics, Automotive & Space,* Paris, décembre 2003.

[3] Provost H., "La Conduite de Projet de la conception à l'exploitation des réalisations industrielles*", éditions TECHNIP*, 1994.

[4] Guiochet J., Baron C., “UML based FMECA in risk analysis”, *European Simulation and Modelling Conference (ESMc’2003)*, Napoli, Italy, oct. 2003

[5] Pillet M., "Les plans d’expériences par la méthode TAGUCHI", *Les Editions d’Organisation*, Paris, 1997.

[6] Steele G., Byers S., Young D., Moore R., "An Analysis of Injection Molding by Taguchi Methods", *Proceedings of ANTEC '88 Conference,* 1988.

[7] Warner J.C., O'Connor J., "Molding Process is Improved by Using the Taguchi Method", *Modern Plastics* :65-68, 1989.

[8] Govaerts B., « La planification expérimentale vue par Taguchi », pp.1-16., http://www.stat.ucl.ac.be/cours/stat2520/transparents/taguchi.pdf, Institut de Statistique, Université Catholique de Louvain.

[9] Al-Mohammed M., "Conception des systèmes électronique : Les étapes d’optimisation et d’allocation des tolérances", thèse, INP, Toulouse, 2003.

[10] Goldberg D. E, *Genetic Algorithms in Search, Optimisation, and Machine Learning,* Addison-Wesley, Reading (MA), 1989.

[11] Fogel J. L, *Intelligence Through Simulated Evolution*, New York, N.Y. ISBN-0-471-33250-X, Wiley-Interscience, 1999.

[12] Bäck T., Hammel U., Schwefel H.P., "Evolutionary Computation: Comments on the History and Current State", *IEEE Transactions on Evolutionary Computation*, vol. 1, n°1, p. 3-17, april 1997.

[13] Baron C., Geffroy J.-C., Zamilpa C., "Identification of Evolutionary Sequential Systems. Genetic Simulation Experiments", Communications in Numerical Methods in Engineering, pp. 631-637, vol. 17, John Wiley Editor, july 2001

[14] Beasley D., Bull D.R., Martin R.R., "An Overview of Genetic Algorithms : Part 1, Fundamentals", *University Computing*, vol. 15, n°2, p. 58-59, 1993.

[15] Renders J., "Algorithmes génétiques et réseaux de neurones", *Hermès Science Publications*, 1995.