Evolutionary Multidisciplinary Optimization in Globalised Services Management

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Abstract:

Optimization methods may be applied to the services operations management. A comprehensive objective function (a cost-function to be minimized) leads to a multi disciplinary optimization, considering all aspects of a services business unit. However, this introduces a very large number of variables (examples with tens of thousands of variables are presented), making classical optimization methods inadequate. The paper introduces the use of genetic algorithms for the Multidi sciplinary optimizations in Globalized Services Management

Key words : multidi sciplinary optimization; services operating management; genetic algorithms, total costs and risks.

1. Introduction

Globalization refers to the free movement of goods, services, people, capital and technology across the globe. Globalization has been given major thrust by agreements like GATS signed by several countries in the world. The major factors that drive globalization are changes in social factors, technology, political and legal conditions, the competition scenario and the urge to gain a competitive advantage. The parameters that can be used to measure the level of globalization achieved by an organization are presence in strategic markets, location of value-adding activities, achieving a desirable balance between globalization and customization, consistency in quality and pricing of services, and responding to the changes in the environment.

Price and quality have become order qualifiers i.e. they are essential to remain in competition but are not sufficient to beat competition. Responsiveness to customer demands is the ability to stay above competition by creating unique value to the customer. To retain and increase the list of customers, a company must make customer-centric decisions. Companies must create customer value either by charging less for the same benefits or providing more benefits for the same price as that of the competitors. An important element in managing customer relationships is time. Waiting time for a customer is attributed to non-value added activity, quality problems and forecast errors. Simplifying processes, shortening cycle times and eliminating queues are necessary for customer satisfaction.

Like many industrialized countries, Indian economy has seen tremendous transformation in her composition of national income. In particular, rapid expansion in the contribution of services sector towards national production has been an important phenomenon of her economic performance since Independence. Many traditional service sectors like trade, hotels and restaurants, real estate, public administration, transport, communications, banking andinsurance have been rapidly growing in the last two decades and have been joined by new growth sectors like data processing, computer programming, engineering and consulting services etc.

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Consequently, the half of the country's GDP is now originating from services sector and other half is being evenly distributed between industry and agriculture sector.

2. Challenges in the Globalised Economy

Globalization has many definitions, but at its root it is about the planet getting smaller and the free flow of people, goods, capital, and ideas across borders. Thanks to globalization, people around the globe are more connected to each other than ever before. Services produced in one part of the world are available in the remotest corner of the world. The world is moving closer to a frictionless, borderless economic system. More and more developing countries are embracing globalization for faster economic growth. The removal of trade barriers immediately expands the range of choices for consumers and places downward pressure on prices, thus raising the real value workers earnings. Foreign investment provides more jobs, new production technologies, infrastructure improvements and a source of capital for local entrepreneurs. Domestic businesses gain access to both cheaper inputs and vastly larger markets for their products. As a result of this cut throat competition, particularly in services sector, customers demand more high quality, low cost products and services. Organisations are exposed to never before time based competition, shorter product life, cost reduction techniques and the need for new products and services.

3. Multidisciplinary optimization as a Tool

The multidisciplinary optimization represents a nonlinear optimization model to minimize a comprehensive objective (cost) function, which comprises as many variables or criteria as possible, regarding the studied phenomenon, with respect to all relevant aspects from various disciplines, both technical and economical. In order to aggregate more simple cost functions into a multidisciplinary one, they must be measured in comparable units, like currency units. Constraints may be introduced as penalizing costs. Thus, the objective function will look like a hypersurface with steep surrounding "walls" due to the constraints, and our aim is at finding the lowest elevation point of this hypersurface (minimum minimorum).

In figure 1 we have illustrated a bidimensional case, when only two variables are involved. The multidisciplinary optimization typically extends this to a high number of variables, but the problem formulation is the same: for which value of the vector 0 x the hypersurface F(0 x) = min ?. In the past decades, the multidisciplinary optimization was not very practical, for two reasons: the difficulties with Theoretical and Applied Economics the classical gradient optimization methods when many variables are involved, and also the high demand of computing power, above the capacity of the current computers.

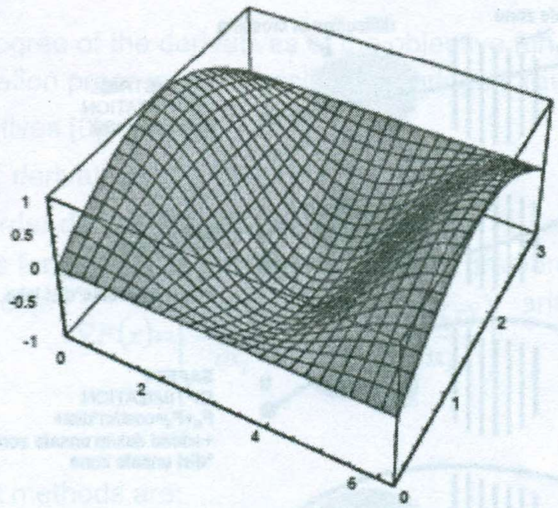

Figure 1. For which variables x0, y0 the surface F(x0, y0) = min?

4. The total costs and risks objective function

One of the first cases of multidisciplinary optimization problem in our research was the optimization of a trajectory of a transport aircraft. From the beginning we came to the conclusion that the less costly trajectories are very risky. This also applies to the economic problems, where the most profitable solutions are also the most risky . The inclusion of the risks in the objective function is the method we have successfully applied in more case studies. The direct constraints method is less natural and lacks stability in some cases (small variations in constraints lead to significant variations in solution).

Also, the constraints break the overall derivability of the objective function, which troubles all derivative-based methods.

The objective function which includes all known costs and risks was named TCR (Total Costs and Risks). Figure 2 illustrates the principle of a multidisciplinary optimization of a land transport route.

The multidisciplinary optimization of a subsystem k will pursue the minimization of the following function:

$$TCR_k = \sum_i C_{i,k} + \sum_j p_j \times R_{j,k} = \min$$

Where:

TCRk represents the value of the total costs and risks function for the subsystem k;

Ci,k are the costs generated by the subsystem k in the solution;

Rj,k are the damages estimated for the subsystem k;

pj are the probabilities of the damages to occur, as a function of the solution.

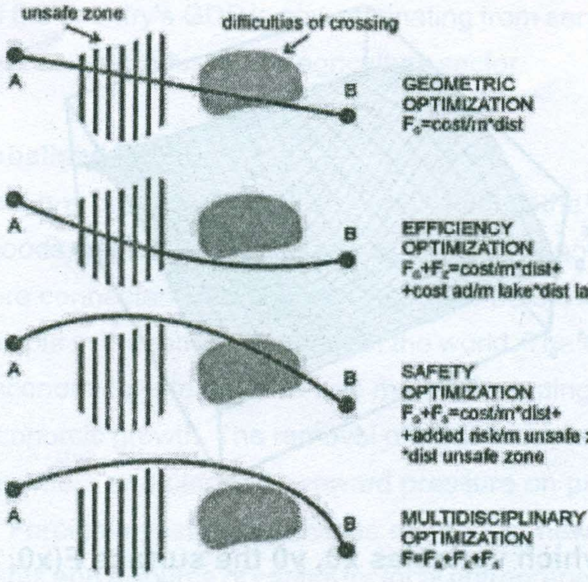

Figure 2. Multidisciplinary optimization of a transport route using TCR

The most interesting feature of the TCR function is its additivity, which facilitates its applications to complex systems. Thus, for a system made up by N subsystems, the Multidisciplinary optimization will be the result of the minimization of the following aggregate objective function:

$$TCR = \sum_{k=1}^{N} TCR_k = \sum_{k=1}^{N}\left(\sum_i C_{i,k} + \sum_j p_j \times R_{j,k}\right) = \min \quad (2)$$

5. Choosing genetic algorithms as an optimization method

The numerical optimization methods research is 60 years old. Today, many optimization methods are in use. We will present a classification framework and we will reveal the method of our choice for (non-linear) multidisciplinary optimization problems.

The first classification is based on the global minimum search strategy:

complete or exhaustive search methods [C];

- stochastic search methods [S].

The former are remarkable resource consuming. The computation effort increases with the factorial of the number of variables, making them inapplicable for multidisciplinary problems, which may reach to tens of thousands of variables. The later methods are economical, but they suffer from convergence problems and with finding an arbitrary stop criteria.

The stochastic methods do not guarantee finding an optimum, but a quasi-optimum, which is still very useful in practice.

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On the highest degree of the derivatives of the objective function which have to be calculated in the optimization process, the classification brings three types:

- methods without derivatives [0];
- methods with first order derivatives [1];
- methods with second order derivatives [2].

The best known methods for non-linear optimization are the gradient methods, which use partial derivatives of the obje ariable (Berbente at al. 2000):

$$\nabla F(x)=\left(\frac{\partial F(x)}{\partial x_1}\ \frac{\partial F(x)}{\partial x_2},\dots,\frac{\partial F(x)}{\partial x_N}\right)$$

The best known gradient methods are:

- Steepest Descent SD/Gradient Method = Gradient
- Search [C1];
- Conjugate Gradient Method (CG) [C1];
- Non-linear Conjugate Gradient Method [C1];
- Advanced Nonlinear Gradient Methods = Stochastic Gradient Descent [S1];
- Quasi-Newton Methods [C2]:
- Davidon-Fletcher-Powell (DFP) Method;
- Broyden-Fletcher-Goldfarb-Shanno (BFGS) Method
- Levenberg-Marquardt (LM) Method [C2].

There are also a few non-gradient methods, which do not require the partial derivatives of the objective function:

- Multi-Dimensional Search [C0];
- Random Search (Monte Carlo) [S0];
- Genetic Algorithms = Evolutionary Search/ Strategy [S0].

As we have already mentioned, the gradient and the exhaustive search methods are not applicable to multidisciplinary optimizations with many dimensions or variables. The [S0] type methods remain the only applicable in such circumstances, of which the genetic algorithms proved to offer the best results as revealed after a couple of years of research.

The genetic algorithms, known also under the acronym EMO (Evolutionary Multi-Criterion Optimizations), are inspired by the methods used by the species of animals and plants to adapt to the environment, discovered and published Charles Darwin (Darwin 1859 and 1871). These represent the optimization of each species as an adaptation process in order to survive. The human genome contains some 40,000 relevant genes, thus the human species optimization problem has the same number of independent variables or degrees of freedom. Exhaustive

In 1975, John Henry Holland of the University of Michigan extended the applications of genetic algorithms to artificial systems (Holland, 1975), opening the way to large dimensional multidisciplinary optimizations. The genetic algorithms are iterative procedures operating on a "population" of "individuals", each "individual" being represented by a finite string of symbols also known as a genome, coding a possible solution in the given space of a problem. This search space consists of all possible solutions to the given problem. This is recommended when the search space is too large to allow an exhaustive search (like the gradient methods). Selection itself does not open new routes in the search space, and we resort to genetics for specific operators : **crossover** and **mutation.** Unlike other search methods, which operate a single solution at a time, genetic algorithms operate with an entire population of solutions at any given moment.

To implement a genetic algorithm, we need to find a representation of the solution: this is known as a chromosome. Through crossovers and mutations, new individual solutions are created out of the existing ones. There are some methods to select candidates for breeding, all relying on an objective function measuring the fitness of each individual, or how close is the individual to the desired characteristics. A good choice of chromosome representation and objective function guarantee the success of the genetic algorithm no matter which version of selection method we choose, but certain variations in convergence speed could make the difference. The two chromosome operators "borrowed" from nature are illustrated in Figure 3.

The **crossover operator** generates two or more "children" chromosomes as combinations of two "parent" chromosomes. The main purpose of the crossover is to ensure that future generations include the good genetic heritage of the current one. The probability to inherit from one of the parents is known as the crossover rate. This mechanism is widely used in nature, moving the whole process to more promising areas of the search space with every new generation.

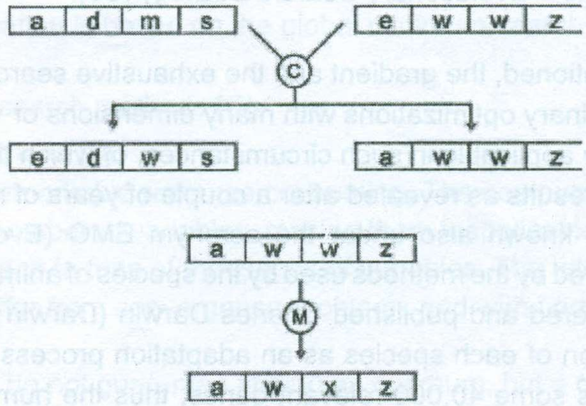

Fig : 3 The chromosome operators cross over and mutation

The **mutation operator** introduces a random evolution in the population, and this is essential to keep the optimization process safe from the local minima traps, allowing it to progress towards the minimum minimorum. The generation may stay segregated (direct inheritance) or may merge (generation overlap). To get results, the objective function needs to be converted into a fitness function, which, besides minimization, ensures the genome diversity. The process is known as scaling, and it may be done in various ways:

- Linear - is a simple rescaling of the objective function;
- Sigma - those individuals who fall outside the standard distribution are eliminated;
- Sharing - introduces a notion of chromosome distance, and an individual is penalized proportionally with the number of similar individuals.

Based on the nature of the hypersurface of the objective function, a combination of the following elimination methods is usually employed:

- Replacing the individuals with the lowest fitness index (least adapted);
- Replacing the most similar or closely related individuals;
- The "revolution" - keeping just the least similar individuals.

These methods may be changed during the process, as the generation index moves forward. Usually we are after a high variety of the genome at the beginning of the optimization process, whereas further on we need to accelerate convergence speed.

The drawbacks of the genetic algorithms are the following:

- There is no theoretical demonstration of their convergence;
- Their convergence is not granted;
- There is no intrinsic stop criterium, the computation may continue to infinity (in other words they are quasi-optimum methods);
- They are big memory consumers (entire populations need to be stored at each generation);
- w Computing time consumption is also an issue;
- In case of insufficient genetic diversity (which could exist from the start, or even occur spontaneously, at least in theory) the genetic algorithm may fail (diverging or entering an infinite cycle).
- These drawbacks are outnumbered by the advantages important to a number of applications:
- There is a statistic proof of their convergence in many types of problems (including all examples from the biology);
- They are adequate for N-dimensional problems where N is big;

- They are also adequate for problems with a variable N;
- They function even if the objective function depends on qualitative variables, provided there is a quantitative representation of those (this facility is particularly useful in business applications);
- They function with Boolean variables (discreet optimization) and with any mixture of variables;
- They do not fall in the "saddle" trap;
- They can handle singularity points or areas in the hypersurface;
- They escape easily from the local minima traps, being suitable for rough or hilly hypersurfaces;
- Genetic algorithms are the fastest convergent nongradient method (definitely faster than Monte-Carlo and Multi-Dimensional Search).

6. Conclusion

Though global standardization can lead to economies of scale, the benefits are offset by the costs of managing the supply chain. Companies that embrace globalization must strike a balance between the standardization and adaptation. The test of globalization is in its ability to understand and respond to the needs and business systems of each market. The non-linear multidisciplinary optimization using genetic algorithms is rich in applications in management, showing a high degree of accuracy in representing the details of the economic phenomenon under all or most aspects. The use of the total costs and risks function (TCR) is an instrumental alternative to the use of more or less arbitrary constraints in the optimization process. The function is expressed directly in currency units, ensuring additivity and allowing aggregation in the optimization of complex, multi-hierarchy systems. The genetic algorithms are the only usable method in many practical situations, due to the large number of variables and to the inadequacy of the linear models. The computing time may be reduced by distributed computing in a LAN, using the distributed processing feature of the genetic algorithms.

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