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Multiobjective Optimization Applied to the Distribution of Petroleum Products in Pipelines Networks

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Abstract

Constraints satisfaction and multiobjective optimization are very common in
real-world optimization scenarios and cannot be handled independently of the
underlying optimizer. Heuristics methods are especially well suited to solve
these complex problems. Genetic algorithms can be very robust and easy to be
implemented if compared to a numerical method. In this paper, a problem of
petroleum products distribution through pipelines networks is proposed. It
considers a simplified model of a real network. The methodology uses a GA
with an elitism strategy to find a set of feasible solutions. The Global Criterion
Method and an approaching of Weighing Objectives Method were used to
calculate the fitness of each individual in this set

Keywords: Optimization, Multiobjective, Genetic Algorithm, Global Criterion,
Petroleum Distribution, Pipelines Network.

1. Introduction

Genetic algorithms (GAs) were inspired by the principle of natural
selection of individuals, where the most "capable" tends to remain in the
population and reproduce, passing its genetic code onto the next generation. In

almost cases, this method can achieve good solution when compared with conventional methods of optimization.

2. Model of the network

A problem of distribution of petroleum products through pipelines networks is proposed. It considers a simplified model of a real network. The network is composed by two sources (Node 1 and Node 2) that represent refineries, two intermediate connection (Node 3 and Node 4) that ac as sinks or sources with storage capacity and three terminals (Node 5, Node 6 and Node 7). The arrows represent the polyducts that connect the nodes each others and its respective direction. A bidirectional pipe is introduced to connect the two intermediates nodes. Figure 1 shows the model of this network.
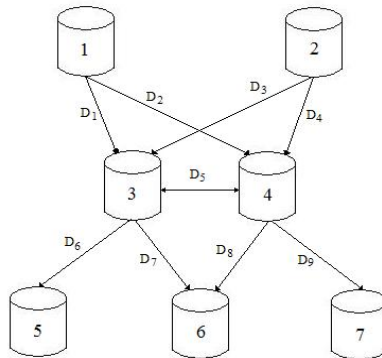

Figure 1 - Distribution network

It is assumed that the products are delivered as discrete batch, each terminal or intermediate node have as many tanks as products it can receive, to store the different products. All the connections have the same characteristics as diameter, volume, flow speed and etc. A batch is a product volume delivered by a source or intermediate node. D_1, D_2, …, D_9 are normalized distance in terms of unit time needed to a batch to be delivered from one node to another one. It means the time that a batch takes to be transported from one node to another one.

3. Solution Codification

The solution of the problem is given by the type of the batch sent by every node at every instant. To code the solution, a matrix is used to represent the population, where each row represents an individual. The individual is divided by time instants and each instant divided by the number of connections. Each element stored in the matrix represent the type of the batch sent through

the connections. For example, the first n elements of an individual will represent the batch type sent through the n connections in the first time instant. The follow n elements the batch type sent during the second time instant, and so on.

The figure 2 shows the individual codification for 10 instants. The values are in the range [0; number of products], where 0 represents an empty connection.

Time	Instant 1			...		Instant 10		
Connection	1	...	10		...		1	...	10
Solution	1 0 1 2 2 3 3 0 2 3				...		2 4 3 0 2 2 2 3 0 3		

Figure 2 - Solution codification

A mask is used to handle nodes that produce different types of products. In the model, node 1 produces type 1 and 2, and node 2 produces type 3 and 4. Therefore connections D_1 and D_2 can handle only product type 1 and 2, and so on. Table 1 shows the entry values of mask.

Connection	1	2	3	4	5	6	7	8	9	10
Mask	2	2	2	2	4	4	4	4	4	4

Table 1 – Mask product codification

Using the mask, the range for connection 1 to 4 is in [0; 2]. Then, just values inside this range can be found in the solution codification for connection 1 to 4. A matrix containing 'i' connections and 'j' products is used to decode the mask as show in table 2. The stored value of the decoder matrix is the batch type. Therefore, the pair (i,j) gives the batch type, where the '*i*' is the connection and '*j*' the element stored in the code solution.

Coding values	0	1	2	3	4
Connection D_1	0	1	2		
Connection D_2	0	1	2		
…	…	…	…	…	…
Connection D_9	0	1	2	3	4

Table 2 – Decoder matrix

4. Genetic Operators

Genetic operations are the tools allowing the exploration of search space, and they are responsible to find new solutions and to converge the model to a good solution. The main genetic operations are the crossover, mutation and selection and in this paper, they are implemented as described in [1]. Moreover, we use an elitism strategy where a set of good solution is kept generation by generation. This strategy avoids to loose good solution during the generation [2] and in the end of evolution, the decision-maker can choose a solution from a set

of potential solutions for the multiobjective optimization problem in addition to the best individual representing the final unique solution. Figure 3 shows the selection method used in this work.
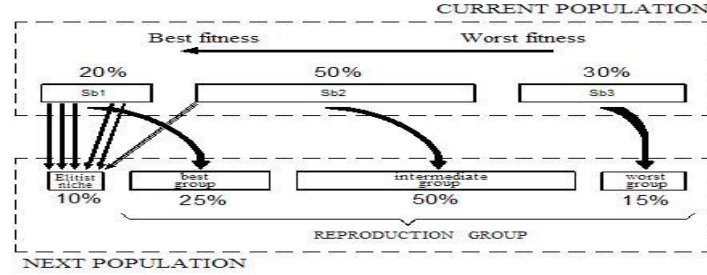

Figure 3 – Selection method

5. Multiobjective Optimization

To calculate the fitness, it was used the Global Criterion Method and an approaching of Weighing Objectives Method [3] as following:

$$fitness = \frac{\sum_{i=0}^{No} w_i \cdot f_i}{\sum_{i=0}^{No} w_i} \text{, to } w_i \geq 0$$

$$Eq.(1)$$

w_i is the weigh for each objective 'i'.

The best fitness has the value 0 and the worst fitness has the value 1. The model is subject as the following constraints:

1. There must be no collisions of batches in the bidirectional connection.

$$NC = 0 \qquad Eq.(2)$$

2. The number of batches in the tanks can not violate the lower and upper limit for each node 'i' and product 'j'.

$$LCm_{ij} \leq C_{ij} \leq LCM_{ij} \qquad Eq.(3)$$

The constraints are fulfilled by reparation function as described in [4].

The objectives number 1 and 2 are constraints that are treated as objectives. The objectives are the follow equations:

1. Satisfy the minimal production:

$$mim\left(\frac{\sum_{j=0}^{N_f}\sum_{i=0}^{Nt_j}\begin{cases}1-\dfrac{E_{ij}}{P_{ij}} &, E_{ij} \leq P_{ij}\\ 0 &, E_{ij} > P_{ij}\end{cases}}{\dfrac{Nt_j}{N_f}}\right)$$

$$Eq.(4)$$

P_{ij} is the minimal number of batches to be sent from the source and E_{ij} is the amount of batch sent, for each source 'i' and product 'j'.

2. Receive the amount of batches demanded (D_{ij}) by terminals:

$$mim\left(\frac{\sum_{j=0}^{Nd}\frac{\sum_{i=0}^{Nt_j}1-\frac{R_{ij}}{D_{ij}}}{Nt_j}}{N_d}\right) \qquad Eq.(5)$$

R_{ij} is the number of batches of product 'i' in the terminal 'j' received.

3. Minimize the time of delivery for batches. The portion "$D_{ij} - R_{ij}$" is a penalty in case of the demand won't be fulfilled.

$$mim\left(\frac{\sum_{j=0}^{Nd}\frac{\sum_{i=0}^{Nt_j}\frac{\frac{Tarrival_{ij}-Tmim_j}{T\,max-Tmim_j}+(D_{ij}-R_{ij})}{(D_{ij}-R_{ij})+1}}{Nt_j}}{N_d}\right) \qquad Eq.(6)$$

Tarrival$_{ij}$ is the arrival time of a batch of the product 'i' in the terminal 'j', *Tmax* is the horizontal time and *Tmin* is the smallest time for a batch to be received in a terminal.

4. Minimize the batches changes or fragmentations:

$$mim\left(\frac{\sum_{i=0}^{Nconex}\begin{cases}\frac{Frag_i-(Mask[i]-1)}{Frag_i} & ,Frag_i \geq Mask[i]\\0 & ,Frag_i < Mask[i]\end{cases}}{N_{conex}}\right) \qquad Eq.(7)$$

Frag$_i$ is the number batches changes in the connection 'i'.

6. Results

To run the model it is necessary to configure the upper and lower tank limit, the time distance of each connection and horizontal time. These configurations are a project decision. Figure 4 shows the evolution of the global objective function and objective 1 during the generations.
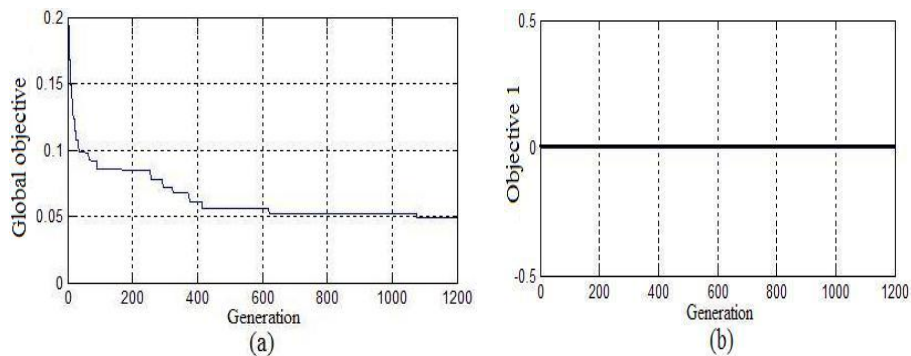

Figure 4 – (a) Global objective fitness, (b) Objective 1

Figure 5 shows the evolution of objective 2 and objective 3 during the generations.
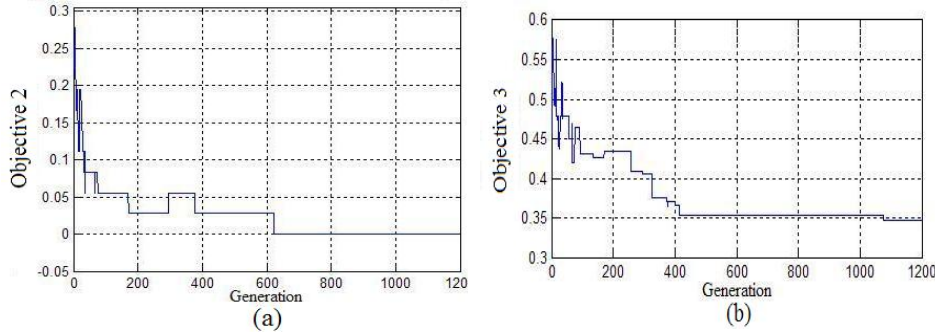

Figure 5 – (a) Objective 2, (b) Objective 3

Table 3 shows the values of all objectives achieved after the simulation.

Objective	Global	1	2	3	4
Fitness value	0.049	0	0	0.34	0.03

Table 3 – Final values of the objectives

The global objective is very close to zero, it means a result close to the optimum. Objective 1 and 3 were accomplished, but objective 3 and 4 were partially achieved. It can be noted that the model converges quickly and good solution are not loosed during the generations because the selection method implemented.

7. Conclusions

A distribution problem of petroleum through pipelines network was presented and optimization methods were described. Genetic algorithm can be a powerful tool to solve complex problems as show in this work and good solution can be achieved.

References

1. M. Cruz, B. Andrés-toro, A. Herrán, E. P. Besada, P. F. Blanco, IEEE International conference on Emerging Technologies and Factory Automation, Vol. 1 (2003) 566.
2. M. C. Szpak, Master Dissertation. Federal University of Technology - Paraná, Brazil, 2005. (in portuguese).
3. C. A. Coelho and A. D. Christiansen, Intelligent Engineering Systems Through Artificial Neural Networks, Vol. 5 (1995) 411.
4. H. Westphal, Master Dissertation. Federal University of Technology - Paraná, Brazil, 2006. (in portuguese).