# Evolutionary Multiobjective Optimization for Emergency Medical Services

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## ABSTRACT
In this paper, the use of evolutionary metaheuristics for the optimization of emergency medical services (EMS) applied to a real-world case in Argentina is analyzed.

The problem requires the simultaneous optimization of two opposing objectives – reducing service delay time and minimizing the use of third-party medical vehicle. Therefore, a multiobjective technique was implemented.

Several multiobjective techniques that had good results reported in the literature were assessed. The techniques that presented the best indicators in this case were selected. Also, a disturbance operator that improves the results found by the assessed algorithms was developed.

The objectives were achieved. A process to dispatch medical vehicles to home medical services based on evolutionary computing was successfully carried out, maximizing the use of the available installed capacity, improving response time rates and using a smaller amount of resources.

## Categories and Subject Descriptors
I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search – *Heuristic methods.*

## General Terms
Management

## Keywords
Evolutionary Computing, Emergency Medical Services, Multiobjective Optimization, Real World Problem, Automation, Disturbance Operator

## 1. Emergency Medical Services
These companies provide home medical care services for the immediate and efficient medical care of people who suffer an illness or have been injured. Each incident that is reported to this type of companies is classified based on its severity in some of the following categories, red → imminent death risk, yellow → serious emergency, no death risk and green: → home medical visit, non-serious event.


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In the case of medical emergencies, the vehicle dispatching process can be summarized as follows: sending the suitable ambulance that is available at the nearest location of the emergency. In the case of non-urgent services (green), the problem is of a different nature – the previous location of the medical vehicles is not as relevant as the existence of an optimized dispatch process that is economically sustainable for the service provider and, at the same time, minimizes the time elapsed since receiving the request until medical care arrives. This problem can be considered as a variation of the classic Vehicle Routing Problem (VRP), and is one of the most significant combination optimization problems introduced by Dantzig and Ramser more than five decades ago [1].

## 2. MULTIOBJECTIVE OPTIMIZATION
A multi-objective problem implies the simultaneous optimization of several objective functions. In this type of problems, the solution consists in a set of optimum solutions. There is a set of solutions, rather than a unique solution, because no single solution can be considered to be better than the rest when considering all the objective functions, since the best solution for one of the objective functions can be worse for another function [6].

## 3. PROBLEM MODELING

### 3.1 Representation
Each individual is represented as a vector of real numbers. The dimension of that vector corresponds to the number of services to provide. Therefore, the size of the vector varies with the instance of the problem to solve. The domain of the values for all dimensions is the same and is related to the number of available vehicles.

### 3.2 Vector Decoding
Each vector dimension represents a service. The real value corresponding to each dimension represents the vehicle (medical team) that will be used to provide the service by applying the function *round()* to the real value. Each vehicle can provide more than one service. The order in which each vehicle provides these services is defined by the real value, no function applied, and is considered in an ascending manner.

### 3.3 Fitness Function
The two objective functions to minimize are the average delay time **(TE)** and the number of services provided by third-party mobiles **(PT).**

Delay time ***(TE)*** is calculated as follows:

For the first service provided by the vehicle

$$TL = M2 + TV1$$

$$TE = TL + P2$$

***TV1*** being the travel time, in seconds, ***M2*** the time from which the medical vehicle will be available (shift start) and ***P2*** the time elapsed since the call was received

For the services provided by the vehicle other than the first service

$$TL = TE_{ant} + P4 + TV2$$

$$TE = TL + P2$$

***TEant*** being the ***TE*** of the service provided previously, ***TV2*** the travel time from the location of the previous service and ***P4*** the service estimated average time in patient home

To calculate ***PT***, the services that are provided by third-parties are counted.

## 3.4 Restrictions

To handle restrictions, a penalization function was created. This penalization is added to the waiting time ***(TE)***.

$$Penalization = \begin{cases} 0 & M2 \le TL \le M3 \\ (M2 - TL)^2 & TL < M2 \\ (M3 - TL)^2 & TL > M3 \end{cases}$$

***M3*** is the time from which the medical vehicle will not be available (shift end).

## 3.5 Disturbance Operator

To improve the search capabilities of the metaheuristics used, a disturbance operator was added. Before the assessment of an individual for 1% of the cases, changes are made in the values of the individual. These changes consist in randomly selecting 5% of the individual's vector dimensions and interchange the value of that dimension with that of another, randomly selected dimension.

# 4. EXPERIMENTAL TESTS

To solve the problem presented, six multiobjective metaheuristics were selected to compare performances and select the one that yields the best result for the problem being analyzed. The metaheuristics selected were NSGA II [2], SPEA2 [8], PAES [3], varMOPSO [4], OMOPSO [7], and SMPSO [5]. The former three are reference techniques in this field, the latter three have been reported to yield good results.

**Table 1. Hypervolume. Median and IQR. All Instances.**

***pl* → algorithm + disturbance operator**

| | Large | Medium | Small |
|---|---|---|---|
| NSGAII | *5.74E-02*<br>*1.50E-01* | *6.27E-02*<br>*1.60E-01* | *6.42E-01*<br>*3.10E-02* |
| NSGAII-pl | *8.55E-02*<br>*1.00E-01* | *1.00E+00*<br>*0.00E+00* | *6.94E-01*<br>*7.00E-02* |
| SPEA | *2.41E-01*<br>*1.50E-01* | *2.81E-02*<br>*3.10E-01* | *6.35E-01*<br>*7.40E-02* |
| SPEA-pl | *2.37E-01*<br>*1.20E-01* | *1.00E+00*<br>*0.00E+00* | *7.15E-01*<br>*6.20E-02* |
| PAES | *7.04E-01*<br>*6.10E-02* | *2.55E-01*<br>*5.50E-01* | *5.53E-01*<br>*8.50E-02* |
| PAES-pl | *0.00E+00*<br>*0.00E+00* | *0.00E+00*<br>*0.00E+00* | *1.08E-01*<br>*1.00E-01* |

Three instances of the problem were assessed, corresponding to real situations provided by the company. The UCMQSmall problem corresponds to an instance with 37 services and 10 vehicles. The UCMQMedium problem corresponds to an instance with 79 services and 18 vehicles. The UCMQLarge problem corresponds to an instance with 237 services and 33 vehicles.

Due to space restrictions, only the results obtained with NSGAII, SPEA2 and PAES for the Hypervolume indicator are presented, since these are the ones that performed better in these instances.

# 5. CONCLUSIONS

An application of evolutionary metaheuristics to a real-world case in relation to the real-time automation of the medical vehicle dispatch process was presented.

An extensive set of optimization techniques, representative of the state of the art, was assessed. Based on the problem to solve, those algorithms capable of finding the best solutions for this particular problem were selected.

The use of research technology in business applications is considered to be extremely important. There was a real transfer of knowledge between the scientific world and the private sector.

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