Simulation and Optimization of the Pre-hospital Care System of the National University of Mexico using Travelling Salesman Problem algorithms.

Esther Segura Pérez
Secretaría de Posgrado e Investigación, UNAM
esthersp_1976@yahoo.com.mx.

Luis Altamirano Yepez
División de estudios de Posgrado FI, UNAM
altamirano@dctrl.fi-b.unam.mx

Idalia Flores de la Mota
Secretaría de Posgrado e Investigación, UNAM
idalia@servidor.unam.mx

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Abstract

A hybrid methodology was developed in this project, using optimization and simulation techniques to analyze efficiency in a pre-hospital healthcare system offered by Emergency Medical Technicians (TUMs) or paramedics. This healthcare is offered in the North and South of Mexico City while students are sitting their exams for admission to the National Autonomous University of Mexico. This study presents an optimization of the routes of an ambulance in charge of serving 26 security modules installed at schools where students were attending their admission exams. This optimization is done on the basis based on algorithms used to solve the travelling-salesman problem (TSP) and simulation is used to determine the scenarios where calls for the ambulance happen with a greater occurrence probability. Furthermore, the patient´s transfer route from the hospital care module is optimized with the shortest path algorithm. The pre-hospital healthcare system is formed by 11 paramedics and 5 properly equipped ambulances. Heuristic techniques were programmed with the Visual Basic 6 programming language and the simulation was executed using the Arena program.

1 Introduction

Records of the treatment of injured or sick patients go back to biblical times. During the 18th and 19th centuries different methods were used with this purpose, though it was Jean Dominique Larrey who started the first pre-hospital care system.

The National Autonomous University of Mexico (Universidad Nacional Autónoma de México UNAM) has been offering this service since 1982, using vehicles with enough capacity for a multidisciplinary team made up by both professionals and technicians to provide basic and advanced life support. Despite the fact that some studies have been carried out to improve efficiency in patient's transport times in the APH (Pre-hospital care), there is as yet little evidence of any careful study having been made on this subject either in Mexico or elsewhere. The efficiency of the APH system is measured by the system's average response time, which is the time taken by the TUMs to arrive at the scene of the accident, attend to the patient and transfer him or her to hospital if necessary. This study pioneers the use of optimization and simulation techniques to achieve greater efficiency in the system.

2 The Problem

Every year the National University of México (UNAM) organizes three admission exams for three levels: high school, undergraduate level and the open university. On each occasion there are, on average, about 114,462 applicants [6]. In order to guarantee timely medical in cases of emergency, on these occasions the Medical Services Office (DGSM) obtaining with the pre-hospital area (APH) puts a special service in place. This service has five ambulances, four of which each serve one specific area, in order to service 26 modules. The remaining ambulance supervises all the modules. The people in charge of each module require the transfer of patients for the following medical emergencies:

Faints-D, Nervous crisis-CN, Asthmatic crisis-CA, Hypoglycemia-H, Stress-induced colitis-CE, Convulsions-Co, Acute coronary syndrome- I, Metabolic problems: decompensated diabetes-DD, Traffic Accident-A, Status epilepticus –EE, Apendicitis-Ap.

Most of the patients who require the service are applicants or the people accompanying them. For this reason the aim of this research is to reduce the mortality and morbidity resulting from injuries that require medical attention. To achieve this it is necessary to optimize the access routes to the modules and from there to the hospitals where patients will receive proper medical attention. The main index of measurement for the APH is the ambulance response time. This response time includes the call for the ambulance, the care of the patient in the module, and the patient`s transfer to a hospital. Nowadays this takes about 18 minutes.

3 Methodology

This research was developed in three phases. The first consisted of collecting, adapting and sorting the historical information, in the second phase a simulation model was designed in order to generate several scenarios and, finally, the third phase consisted of optimizing routes obtained from the simulation model. These routes were optimized using shortest route algorithms and TSP algorithms.

This project had the support of the APH people who provided the historical information about cases and average response times. These data were fitted into probabilistic functions used in the simulation model.

The scenarios focus on the module requiring the service, the causal agent, patient characteristics and whether or not the patient needs to be transferred to a hospital. Once the simulation gives the scenarios, the stage of routes optimization begins, by taking the module into account as initial input. The Dijkstra shortest route algorithm was used for this stage to find the shortest routes in each scenario.

A heuristic used in the TSP was used for the ambulance that supervises all the modules. Finally, for each scenario, the response time is taken that makes it possible to measure the performance of the APH system and be able to make good decisions.

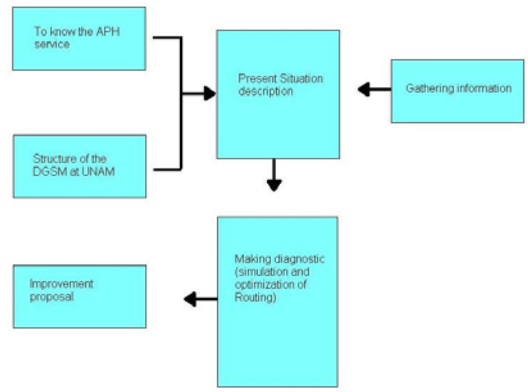

Figure 1. Proposal for improvement

4 Model design

4.1 Phase 1

Stat:Fit software was used with the historical information from the last four years in order to find the probabilistic distribution that best fits in with each module and causal agent (the source of the emergencies).

Table 1 shows the medical events for each module, the Stat:Fit software works with this information as shown in figure 2. Figure 3 shows the curve with the best fit.

This phase gives us probabilistic distribution functions that will be used in the simulation model. The table 2 shows one of the eleven tables for each module and ailment.

Ailment	Event
D	2
CN	1
CA	0
H	3
CE	1
CO	0
I	0
DD	1
A	1
EE	0
AP	0

Table 1. Number of events according to ailment.

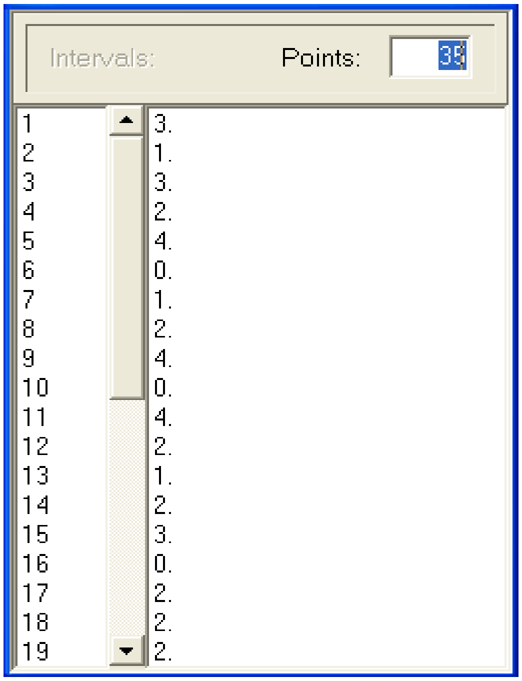

Figure 2. Example of data input for Stat:Fit.

The curve with the best fit:

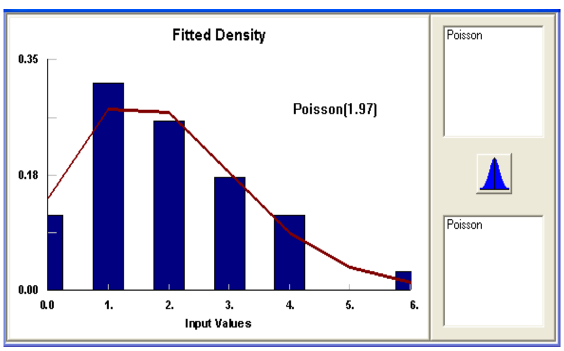

Figure 3. Discrete probability function fit.

Module	Disease	Distrubution	Parameters
1	D	Poisson	mean 0.34
2	D	Poisson	mean 0.19
3	D	Poisson	mean 1.78
4	D	Poisson	mean 0.76
5	D	Poisson	mean 0.64
6	D	Poisson	mean 0.02
7	D	Triangular	0.32,0.62,1.98
8	D	Poisson	mean 0.55
9	D	Triangular	0.05,0.27,1.44
10	D	Triangular	0.01,0.6,1.00
11	D	Poisson	mean 1.87
12	D	Poisson	mean 0.55
13	D	Poisson	mean 0.37
14	D	Poisson	mean 0.21
15	D	Poisson	mean 0.27
16	D	Poisson	mean 0.98
17	D	Poisson	mean 1.89
18	D	Poisson	mean 1.65
19	D	Poisson	mean 1.15
20	D	Triangular	0.08,0.01,1.06
21	D	Poisson	mean 1.52
22	D	Poisson	mean 1.57
23	D	Poisson	mean 1.76
24	D	Poisson	mean 0.04
25	D	Poisson	mean 0.06
26	D	Poisson	mean 1.43

Table 2. Probability distributions for all the causal agents in one module.

4.2 Phase 2

One of the more important advantages of using a simulation model is the possibility of getting information without having to work directly in the system. In this research, the model for the APH considers each module as locations. Patients are represented by entities that enter into the module with certain probability and whose main attribute is a medical emergency.
Different scenarios are obtained from this phase that give us information about which modules need the service, the causal agent, patient characteristics and whether or not a transfer to hospital is required. The choice of hospital depends on whether or not the patient is entitled to any of the public health service schemes, such as the medical service for state employees (ISSSTE) or the medical system for private sector employees (IMSS). If neither of these is the case, he or she is transferred to a hospital that attends patients who fall outside these systems.

The simulation was done using Microsoft Excel. An example is given with five scenarios that are ready for the optimization phase.

Definition of scenarios

Table 3 shows five probable scenarios. For the sake of clarity, scenario three is described in detail and will be optimized in the Phase 3.

Scenario three shows: who asks for the APH system is people from module 26, belongs t ozone IV, causal agent five is an Appendicitis AP (a swollen appendix), the patient is a 20 years old woman, she is entitled to IMSS service and is transferred to IMSS hospital number 32.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
MODULE	4	21	26	16	16
Casual Agent No.	5	11	5	4	9
Casual Agent	CN	H	AP	CA	H
Gender	F	M	M	F	F
Age	19	20	20	19	19
Insurance	NA	NA	IMSS	NA	NA
Tranfer	NO	NO	SI	NO	NO
Hospital	NA	NA	32 IMSS	NA	NA
Zone	I	III	IV	II	II

Table 3. Sample scenarios.

4.3 Phase 3

In this phase, the two problems involved with routes are solved. First the transfer of the patient to the hospital is optimized according to the scenarios given by the simulation. This optimization is done using the Dijkstra algorithm that provides the shortest route in terms of time. On the other hand the number five ambulance tour is optimized for distance, and for this case the TSP algorithms are used.

4.3.1 Optimization of the patient`s transfer time.

Transfer time is one of the more important activities for the APH system in order to lower response time. As we have already mentioned the objective is to find the shortest route in terms of time and the Dijkstra algorithm [7] allows us to find the shortest routes in a set of routes from a source vertex. In the next step, this problem is established.

Shortest Path Problem

Given a connected graph G=(V,E), a weight d:E->R^+ and a fixed vertex s in V, find the shortest path or paths from s to each vertex v in V.

Steps of the algorithm:

1. Set i=0, S_0= {u_0=s}, L(u_0)=0, and L(v)=infinity for v <> u0. If |V| = 1 then stop, otherwise go to step 2.
2. For each v in V\S_i, replace L(v) by min{L(v), L(u_i)+dv_u^i}. If L(v) is replaced, put a label (L(v), u_i) on v.
3. Find a vertex v which minimizes {L(v): v in V\S_i}, say u_i+1.
4. Let S_{i+1} = S_i cup {u_{i+1}}.
5. Replace i by i+1. If i=|V|-1 then stop, otherwise go to step 2.

For this model, vertex s is module 26 and the final vertex v is the hospital number 32. Figure 4 from the Google earth program shows a connected graph.

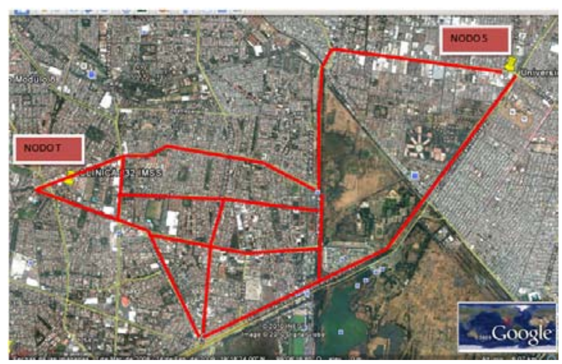

Figure 4. Graph with the edge lengths.

The distances between the vertex are given by the program and they represent the transfer time, so if we choose the longest distances the ambulance will take more time to arrive at the hospital. The algorithm was programmed in C language and the resulting route is given in figure 5.

Figure 5. Resulting route.

The resulting time is 7 minutes on average with a path of 2.67 Km and considering the transfer time with the ambulance using its siren.

4.3.2 Optimization process for ambulance five.

The routing optimization for the supervision ambulance that watches the 26 modules can be established as a symmetric TSP, because the ambulance has to visit all the modules without visiting each one more than once. As it is known that the TSP is an NP-Complete problem the algorithms used to solve it are heuristics, they guarantee a good solution in the short time, but of course not an optimal one.

Consider the symmetric TSP where $c_{ji} = c_{ji} \quad \forall i, j \in V$, then the mathematical model is as follows:

$$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$$

$$s.a. \qquad \sum_{j=1}^{n} x_{ij} = 1 \qquad \forall i = 1,\dots,n \quad i \neq j$$

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad \forall j = 1,\dots,n \quad i \neq j$$

$$\sum_{i \in S} \sum_{j \in S} x_{ij} \geq 1$$

$$x_{ij} = 0,1 \qquad \forall 1 \leq i \neq j \leq n$$

Where:

c_{ij} = transfer time from site i, to site j

x_{ij} = site i is visited after visiting site j

$\min Z = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij}$ = the objective function that minimizes the distance.

$\sum_{j=1}^{n} x_{ij} = 1$ It must leave from just one module

$\sum_{j=1}^{n} x_{ji} = 1$ It must enter just one module.

$\sum_{i \in S} \sum_{j \in S} x_{ij} \geq 1$ Subcircuits are not allowed

$x_{ij} = 0,1$ decision variables are binary, 1 if a module is visited, 0 otherwise.

The closest neighbor heuristic was programmed [8] to propose an initial tour that is improved with the 2-Opt technique [9]

Closest neighbor algorithm pseudocode

Start

Randomly choose a vertex j

To do $t = j$ *y* $W = V \setminus \{j\}$

While $(W \neq 0)$

To take $j \in W / c_{tj} = \min\{c_{ti'} / i \in W\}$

To connect t *a* j

To do $W = W \setminus \{j\} t = j$

As we have already mentioned, the edge-swapping algorithm 2-Opt was used in order to improve the tour given by the closest neighbor algorithm.

2-Opt algorithm Pseudocode

Start

An initial Hamiltonian circuit is considered

For each vertex i *define a set of vertex*

$move = 1$

Label all vertex that have not been explored yet.

While (there are vertex without label)

Choose a vertex i *not explored.*

To examine all the 2-opt movements that delete 2 edges each one of them having at least one vertex $N(i)$.

If one of the examined movements shortens the length of the circuit, chose the best of them and to do $move = 1$. Otherwise label i as explored.

To optimize we had to:

a) Change the geographical coordinates into Cartesian coordinates, using the terrestrial model ED50
b) Adjust the scales in order to run the algorithm.

These algorithms were programmed in Visual Basic 6, and the following results were obtained.

The optimal route consists of visiting the modules as follows: 4-2-6-3-26-20-25-13-11-19-1-22-23-18-21-12-15-14-17-9-16-10-8-5-7-4.

Applying the data to the executable program the next image is obtained that has the optimal tour visiting the 26 modules with a heuristic path of 51.7 km.

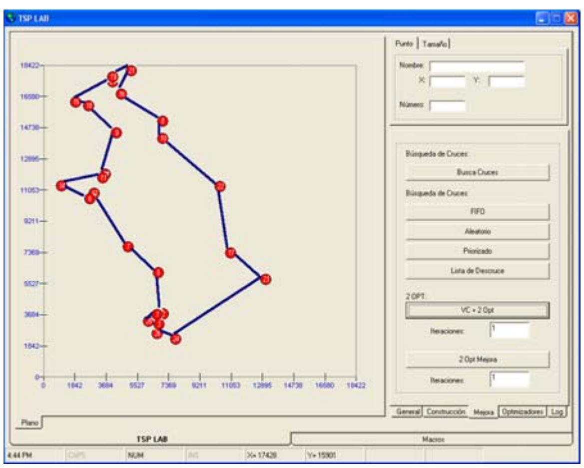

Figure 6. Optimal tour at the TSP Lab.

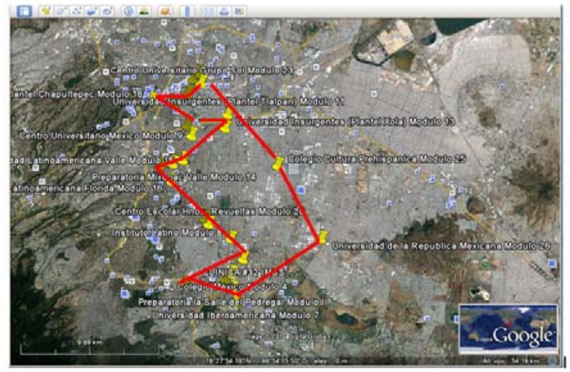

Figure 7. Route on Google Earth.

4 Conclusions

In this research we developed a simulation and worked out the transfer routes for the APH using the Dijkstra algorithm that allows us to determine the shortest route in a connected graph from a vertex s (module that requires the service) to vertex t (the hospital). With this route the response time was reduced to 8 minutes, a very important factor in the outcome for the patient. It was observed that in most cases nervous crises (CN) and stress crises are the causal agents that most often require the service.

The solution obtained by optimizing the route of ambulance five that supervises the 26 modules using an heuristic algorithm was close to the optimal obtained using an exact algorithm that requires a great deal more computational time.

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