Non Emergency Patients Transport
A Mixed Integer Linear Programming

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Abstract: This work presents a model and a heuristic to solve the non-emergency patients transport (NEPT) service issues given the new rules recently established in Portugal. The model follows the same principle of the Team Orienteering Problem by selecting the patients to be included in the routes attending the maximum reduction in costs when compared with individual transportation. This model establishes the best sets of patients to be transported together. The model was implemented in AMPL and a compact formulation was solved using NEOS Server. A heuristic procedure based on iteratively solving problems with one vehicle was presented, and this heuristic provides good results in terms of accuracy and computation time.

1 INTRODUCTION

In 2012, Portugal published several official documents about the non-emergency patient transport (NEPT) service in “Diário da República” (DRE). The legislative motivation was based on a requirement laid down in the Memorandum of Understanding signed between the Portuguese Government and the International Monetary Fund, the European Central Bank and the European Union to reduce the cost of NEPT services (DRE, 2011). This legislation mandates the minimum requirements for the quality and safety of care delivered to patients by NEPT services, (DRE, 2012a).

In 2011, the Northern Department of Health (ARSN, 2011) reported the implementation of a computer system to optimize the management of NEPT services. The published documents state that the computer system "will allow greater accuracy in terms of prescription and simultaneously ensures your organization rationally, promoting the transport of multiple users whenever appropriate and possible." The Northern Department of Health expected to achieve a reduction of transport costs in the region of €3 million related to a reduction of 20% of costs.

The current paper is composed of five sections. After the introduction, Section 2 presents a description of the problem, the main topics referred by the law, and a brief literature review. Section 3 describes the model and presents the mathematical formulation. Section 4 includes a discussion of the heuristic and its results. Section 5 summarizes the main conclusions of this work.

2 TRANSPORT PROBLEM

2.1 NEPT Definition

In light of the legislation in 2014 in Portugal (DRE, 2012b-h), and with regard to access by the users to the services of the National Health Service (NHS), NEPT is considered the associated transport system for the health care system, where the origin or destination are the medical centres and services within the NHS, private entities or social entities with a contract or agreement for the provision of health care under the following conditions: consultations for inpatient or outpatient surgery, diagnostic procedures and therapeutic treatments, transporting the patient after discharge from hospital (with prior prescription) and transporting the patient after discharge from the emergency room (with prior prescription).

2.2 Transport Prescription

Prescription of transportation is solely the

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responsibility of the attending physician, who shall record the following information in the support doctor system or equivalent system: the clinical justification, or reasons for needing transport, and verification of the economic condition. Where there is a need to make the ambulance transport, the following is required: the justification of the mode of transport; the conditions under which the transport should occur, particularly if the patient requires ventilation, oxygen, wheelchair or is sick in bed or isolated, the justification of the need for a companion, and the justification of the need for monitoring a health professional. After the shipping prescription by the physician is completed, a member of the administrative services staff validates the economic condition of the patient and proceeds to request transportation.

The requisition of transport satisfies the criteria of minimizing the distance between the place of origin, which must match the address from which the transportation is effected, and the place of destination, which must take into account the location of the nearest place of origin. The NEPT is performed by ambulance or by ambulette (simple vehicle for patient transport - SVPT), which is a passenger car, with a maximum capacity of five or nine people, for the NEPT service whose clinical condition does not impose the need for health care during the transport.

The non-emergency patient transport is carried out, where possible, in SVPT, taking into account the need to optimize the capacity of the vehicle against the following criteria: a) Grouping of clients, regardless of origin, within the same route; b) intended for health facility and preferably in the same county or geographical area; c) users for the same time period for consultation or treatment.

The attending physician shall justify the use of individual transport ambulances, in a reasoned manner. To further the grouping of users, the NEPT may allow deviations of less than 10 km or 30 minutes journey, considering the travelling of the first patient. The first patient assumes a critical importance to define the route and to define the cost of the transportation service. The first patient should be the most distant patient to destination. A transport on SVPT may carry a single patient in cases where there are no other patients in the same time period or along the same route, but this is an exception, and an effort must be made to carry additional patients where possible.

2.3 Transport Organization

Transportation must be ordered and scheduled at least 48 hours before the journey. In individual situations of an exceptional nature where this time limit cannot be observed since no agreement has been authorized between the requesting entity and the carrier, the time limit of tacit acceptance and approval of daily transportation requests is determined by the computer system, at 15 hours and 30 minutes.

Requests for transportation are grouped according to the schedules of supply of care to which patients are intended, according to the following guidelines:

• If the destination is within the geographic boundaries of the patient's county of origin or within a radius of 10 km, these requests are grouped at one hour intervals between delivery of the first and the last patient;

• If the destination is outside the patient's county of origin, the interval between the delivery of the first patient and the last can be two or four hours, depending on the distance which, according to geographical features, can be a range of 100 km to 130 km. This time is to be determined by the entity responsible for organizing the transport.

The law states that the rule of the maximum deviation should be applied to the "Optimization of routes". Patients can be grouped for a journey, regardless of parish or municipality, provided that there is no deviation more than 10 km or 30 minutes, provided the previous guidelines are observed.

The costs resulting from NEPT are the responsibility of the requesting entity. Thus it becomes important for the requesting entity to optimize and streamline the process of transporting non-emergency patients. It is not known how the requesting entity must make the optimization of NEPT, so this study hopes to be an important and timely contribution.

2.4 Literature Review

The health care industry is rife with problems of management and organization which have been studied over the past several decades (Stiver et al., 1982, Begur, Miller and Weaver, 1997). The research attention to such problems is increasing and, in the Western world, results from increased demand for health care and the need to keep the social cost of health care as low as possible. The increased demand for health care has two vectors justifying its growth: the democratization of access to healthcare in developed societies and an aging population. The increased demand for health care causes transporting patients an important problem in the logistics of the health systems, since it is a significant portion of operating costs. As far as health logistic problems are concerned, an effective transport service is now becoming an extremely complex problem that has to be solved efficiently, so it requires the best solution methodologies. Bellamy et al. (2003) defines non-emergency transport needs including ordinary situations in which a patient simply cannot get to and from a healthcare facility under their own power.

According to Wilken et al. (2005), patient transportation is a critical part in providing healthcare services. The authors discuss non-emergency transportation in rural southern Illinois, and they point out the importance of this issue. Many individuals do not have the funds to pay for public transportation and often public transportation is not available or easily accessible to them so they may miss regular doctor's appointments, treatments, and so on. As a consequence, the patient may become more ill and then must be transported to a medical facility by emergency transportation. Safei (2011) studied the non-emergency medical transportation services available in rural British Columbia, and he reported the success of the "Connections service" in enhancing rural and northern communities' access to healthcare services, in particular among those with limited means and resources.

Health authorities and health managers rely on knowledge and state of the art technology to address the logistic of health systems. Today, information systems provide support for making the decision, allowing gains in effectiveness and efficiency. Transport in health care is a subject which has been studied in the literature of optimization of logistic processes for many years. Vaisblat and Albert (2013) carried out one study which focused on the scheduling of a special fleet serving the needs of patients. Hains et al. (2011) addressed the issue of safety and quality in NEPT. Recently Díaz-Parra et al. (2014) published a state of the art review on the problem of transport which included several variants of problems, mathematical formulas, and techniques used in problem solving.

One of the most studied routing problems is the vehicle routing problem (VRP), which basically aims to define a set of vehicle routes which are optimized to visit a series of well-defined locations. This problem presents a large number of variants which address more specific situations. Berbeglia et al. (2010) refer to the static or dynamic nature of routing problems. In the static case, all the information is known in advance and does not change during the construction and implementation phases. In the dynamic case, the available information is updated (changed) during both the construction phase and the implementation phase, by virtue of new user requests. In these problems, the proposed solution is a solution strategy that can be changed with the passage of time. Typically, dynamic situations of this kind occur in transport at the request of users with special needs, which need to be sent to the car which will transport them to their destination. The dynamic aspect of this problem stems from the fact that transportation requests sometimes arise on the same day they need to be met: this type of problem is called a DARP (Dial-A-Ride Problem).

Both the static and dynamic versions of DARP have received significant contributions, such as a review of Cordeau and Laporte (2007) about models and algorithms. Psaraftis (1988) examined a single route of this problem in which clients request a service to be made available as soon as possible. Whenever a new order is entered, the system updates the proceedings and attempts to accommodate the new request on an existing, but only partially complete, route. Meanwhile, Madsen et al. (1995) presented an algorithm to a real case of the dynamic DARP with multiple vehicles that met up to 300 requests daily to transport people with special needs.

One VRP variant is the "Vehicle routing problems with profits" (Archetti et al., 2013). In this type of problem, two different decisions have to be made simultaneously—which which customers to serve and how to sequence them in one or several routes. In general, a profit is associated with each customer that makes the customer more or less attractive. The majority of real-world applications require systems that are more flexible in order to overcome some imposed constraints that may lead to the selection of customers. To deal with the selection of customers, the Team Orienteering Problem (TOP) models can be used. The main difference between the TOP and the VRP is related to the fact that not all the TOP vertices of the graph (clients) must be visited, as in the VRP. In the TOP, each customer has an associated profit, and the routes have maximum durations or distances. The choice of customers is made by balancing their profits and their contributions to the route duration or distance. The objective is to maximize the total reward collected by all routes while satisfying the time limit.

The TOP is a fairly recent concept, first suggested by Butt and Cavalier (1994) under the name Multiple Tour Maximum Collection Problem.

Later, Chao et al. (1996) formally introduced the problem and designed one of the most frequently used sets of benchmark instances. TOP has recieved significant attention from the scientific community (Vansteenwegen, Souffriau, Oudheusden, 2011; Archetti, Speranza and Vigo, 2013) either in presenting exact solution methodology (Archetti, Bianchessi and Speranza, 2013) or in approximate solution methodology (Hu and Lim, 2014). Vansteenwegen and his team maintain a repository of public instances (The Orienteering Problem: Test Instances, 2014).

Gutiérrez-Jarpa et al. (2009) studied the problem with fixed delivery and optional collections, utilizing a mixed solution which uses VRP for delivery and TOP for collection. The authors studied the particular case of a single vehicle and presented a new branch-and-cut method that allows the system to solve larger instances. The method can solve instances which include up to 90 vertices. The authors refer to the need to extend the investigation to cases with multiple vehicles and the development of heuristics to solve large scale instances. Despite the great practical interest that this modelling system has for reverse logistics, the authors report they found only study, Gribkovskaia et al. (2008) that have applied tabu search to the single vehicle pickup and delivery problem with selective pickups.

3 THE MODEL

The real problem studied in this article concerns the non-emergency transport of patients from their homes to the hospital and from the hospital back to their homes. Currently, in Portugal the shuttle typically collects patients from their homes to the hospital for treatment and back again. This system creates the situation – "many (origins)-to-one (target)-to-many (destinations)." The way to organize this transport is not clearly established in law, which means that money is being wasted on the waiting time of the vehicle, and patients often waste time waiting for their transportation.

We decided by modelling the NEPT problem with the TOP point of view. What will happen is that given a list of non-urgent patients for whom transportation was requested and given a fleet of vehicles available with a capacity of eight seats, it is the allocation of transport services to maximize the occupancy of the vehicle and minimizing the distance travelled. Patients who can not be included in the routes of these vehicles will be transported in specially requested for this ambulances service.

3.1 Mathematical Model

Since the group of patients is a severely constrained situation, it is our choice to model the real problem presented by the NHS as a Team Orienteering Problem, solving for the set of available vehicles. Vertices not included in the routes of the problem are the users who will make the path by individual transport.

Our model is based on the Team Orienteering Problem and we follow the mathematical model presented by Labadie et al (2012). We define the search of different paths from a common start point (i=1) to a common ending point (i=n). If we want the start point to be the same ending point, we use the same coordinates for both points.

We have established the following variables:

x_{ij}^k - set of binary variables that is equal to 1 if arc (i, j) is selected in the path *k* and 0 otherwise.

y_j^k - set of binary variables that is equal to 1 if vertex *j* is in path *k* and 0 otherwise.

w_j^k - set of binary variables that is equal to 1 if vertex *j* is the first vertex in the path after the start point.

W^k - is the maximum value for the length of the path that is a function of the distance of the first vertex to terminal vertex and an allowed increase.

X_j - a variable the controls a sequential number for the vertices in the path.

TPS_{ij}^k - is an auxiliary variable to linearize the product of $w_i^k * y_j^k$.

To define the objective function we define three parcels. TIC is the Total Individual Cost, equivalent to transporting each patient individually. CIP is the Cost of Individual Transport for patients who are transported together with some other patient. This parcel is the main savings when a patient is not transported individually. APC is Additional Patient Cost (incremental cost) related to patients who are transported together in same vehicle with the first patient. This parcel is to pay the additional deviations to collect patients in the route of the first patient. By law, this cost is nowadays 20% of the cost of the first patient in the route. In a solution with an individual transport for all patients, *CIP* and *APC* are equal to zero.

$$TIC = \sum_{i=2}^{n-1} c_{1i} + c_{in}$$

$$CIP = \sum_{k}^{m} \sum_{j=2}^{n-1} \sum_{i=2}^{n-1} (c_{1,j} + c_{jn}) x_{ij}^k$$

$$APC = \sum_{k=1}^{m}\sum_{j=2}^{n}\sum_{i=1}^{n-1} s\left(c_{1i} + c_{in}\right) TPS_{ij}^{k}$$

Figure 1 explains these calculations considering the transportation of two patients: A and B. COST1 is the solution cost using two vehicles/routes, both starting at S and ending at E; COST2 is the solution cost using only one vehicle, where A is first patient in the route; while COST3 is the solution cost using one vehicle, where B is the first patient in the route.

It is possible to establish the following relations:
COST1=TIC;
CIP(A)=a1+a2; CIP(B)=b1+b2;
COST2=TIC-CIP(B)+APC(B);
COST2=TIC-CIP(B)+20%CIP(A);
COST3=TIC-CIP(A)+APC(A);
COST3=TIC-CIP(B)+20%CIP(B).

Obviously, APC(A) and APC(B) depends on which is the first patient in the route where they are included.

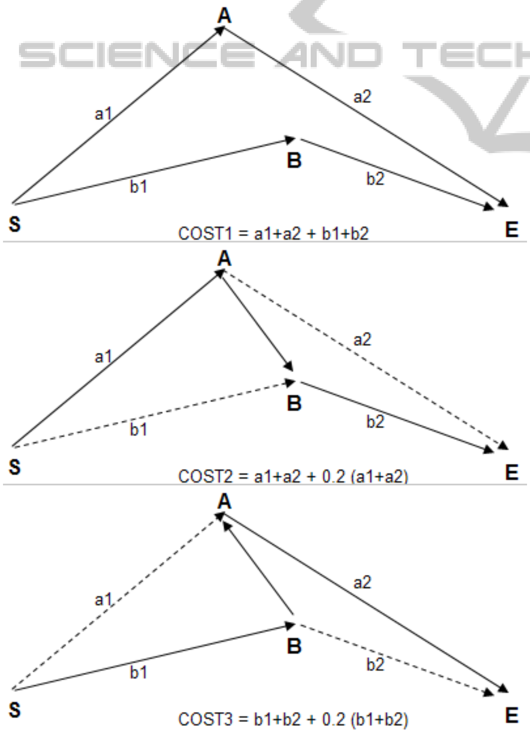

Figure 1: Cost parcelles.

The mathematical formulation of the Mixed Integer Linear Programming (MILP) is presented next:

$$\min\left(TIC - CIP + APC\right) \tag{1}$$

subject to:

$$\sum_{i=2}^{n-1} x_{ij}^{k} = y_{j}^{k} \quad j = 1,\ldots,n-1; k = 1,\ldots,m \tag{2}$$

$$\sum_{i=1}^{n-1} x_{ij}^{k} = \sum_{i=2}^{n} x_{ji}^{k} \quad j = 2,\ldots,n; k = 1,\ldots,m \tag{3}$$

$$\sum_{j=2}^{n} x_{1j}^{k} = \sum_{i=1}^{n-1} x_{in}^{k} = 1 \quad k = 1,\ldots,m \tag{4}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n-1} x_{ij}^{k} \le 1 \quad j = 2,\ldots,n-1 \tag{5}$$

$$w_{j}^{k} = x_{1j}^{k} \quad k = 1,\ldots,m \tag{6}$$

$$W^{k} = \sum_{j=2}^{n-1} c_{jn} x_{1j}^{k} + dMax \quad k = 1,\ldots,m \tag{7}$$

$$\sum_{i=2}^{n-1}\sum_{j=2}^{n} c_{ij} x_{ij}^{k} \le W^{k} \quad k = 1,\ldots,m \tag{8}$$

$$X_1 = 1 \tag{9}$$

$$X_j \ge X_i + x_{ij}^{k} - M\left(1 - x_{ij}^{k}\right) \quad \begin{array}{l} i = 1,\ldots,n-1; \\ j = 2,\ldots,n; \\ k = 1,\ldots,m \end{array} \tag{10}$$

$$\sum_{i=2}^{n-1} w_{i}^{k} + \sum_{i=2}^{n-1} y_{i}^{k} \le L_{\max} \quad k = 1,\ldots,m \tag{11}$$

$$\begin{array}{l} TPS_{ij}^{k} \le w_{i}^{k} \\ TPS_{ij}^{k} \le y_{j}^{k} \\ TPS_{ij}^{k} \ge w_{i}^{k} + y_{j}^{k} - 1 \end{array} \quad \begin{cases} i = 2,\ldots,n-1 \\ j = 2,\ldots,n-1 \\ k = 1,\ldots,m \end{cases} \tag{12}$$

Expression (1) represents the objective function to be minimized. It is intended to diminish the total transport cost removing individual transportation as much as possible, paying the necessary deviations to collect patients in shared routes.

In terms of constraints, expression (2) assign visited patients to only one route, and in expression (5) patients could be visited by only one route. Expression (3) ensures the flow conservation in each node. Expression (4) ensures that a vehicle starts the route from node 1. Expressions (6) (7) and (8) establish the first patient in the route and calculate the maximum length for the route according to the distance from the first patient to the destination. The law allows an increase in the length of the route to collect additional patients, but this is currently limited ($dMax$) to 10 km or 30 minutes.

Expressions (9) and (10) eliminate sub tours, and the capacity of vehicle is verified in expression (11). Expression (12) linearizes the objective function.

3.2 NEOS Server Experiments

The model was implemented in AMPL language and submitted to the NEOS Server to evaluate the quality of solutions provided by this compact formulation. Sixty-four Euclidean instances were randomly created to perform the computational experiments. The instances are divided into two sets, based on the capacity of the vehicle: four places and eight places available to transport the patients. The size of the instances varies from twenty to one hundred patients, and from three to ten vehicles.

Table 1: Experimental results (capacity = 4).

	vehicles x capacity			
nodes	3x4	4x4	7x4	10x4
20	1272.65	1184.0	1055.93	1055.93
30	1840.37	1693.42	1383.03 gap 5.43%	1299.10 gap 34.16%
40	2671.87	2498.09	2048.70 gap 20.73%	1776.02 gap 70.69%
50	3478.46	3248.65	2709.00 gap 17.63%	2362.49 gap 47.45%
60	4311.22	4074.27 gap 3.42%	3455.71 gap 17.67%	2987.28 gap 36.01%
70	5043.11	4802.52 gap 3.29%	4131.28 gap 12.73%	3718.51 gap 31.35%
80	5818.70	--- mem_error	4931.43 gap 12.31%	4507.76 gap 30.52%
100	---- mem_error	7155.63 gap 4.55%	---- mem_error	8198.99 gap 77.61%

Table 2: Experimental results (capacity = 8).

	vehicles x capacity			
nodes	3x8	4x8	7x8	10x8
20	1245.22	1156.65	1048.91	1048.91
30	1812.94	1665.99	1376.02	1299.10 gap 30.13%
40	2561.95	2362.82	1915.61 gap 23.26%	1706.82 gap 66.38%
50	3238.03	2974.04	2362.52 gap 31.87%	2075.69 gap 68.38%
60	4003.97	3702.97	2932.47 gap 34.77%	2523.03 gap 83.67%
70	4693.05	4389.54 gap 6.88%	3682.41 gap 36.55%	3135.39 gap 81.95%
80	5450.52	---- mem_error	4332.84 gap 32.28%	3686.95 gap 70.91%
100	6785.59	6505.46 gap 13.98%	---- mem_error	---- mem_error

Using the NEOS Server with AMPL/ Gurobi/MINTO/scip/XpressMP, the MILP could not find a solution for all instances. Experiments with instances of different sizes were performed to find the maximum number of vertices that it is possible to solve optimally. Memory errors ("mem_error") were reported when the solution exceed 3GB of memory limit. Also, it is only possible to dispose a maximum of eight hours of computation with the NEOS Server. When the maximum time was achieved, it reported the best solution founded and the correspondent gap. Tables 1-2 present these results.

Apparently solving instances with vehicles with larger capacity becomes easier and it was possible to solve an instance with one hundred patients and three vehicles.

4 HEURISTIC PROCEDURE

As expected, the compact model could not be used to solve for large instances using the NEOS Server. However, the NEOS Server can solve the large instance's terms of vertices using only one vehicle (Orienteering Problem - OP). Considering this situation, we developed a heuristic procedure to solve the TOP that is based in successive OP solutions. Iteratively, to the remaining unvisited vertices, we solve the problem using the compact formulation with one vehicle.

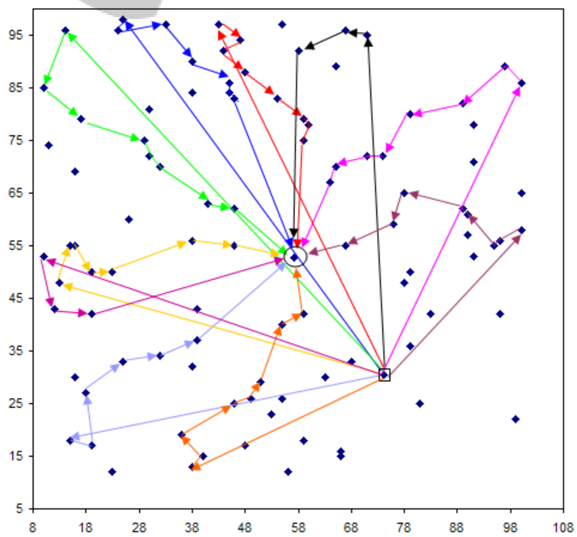

Figure 2: Heuristic Solution (100 nodes_10x8).

Figure 2 presents the solution obtained with heuristic procedure to solve the large instance (one hundred patients with ten vehicles each with capacity of eight patients). The patients not included in these ten routes must be transported individually. In terms of computational time, 198 seconds was required to produce the 10 routes.

To confirm the results obtained with this heuristic, we solved the 32 instances with capacity equal 8. Table 3 compares the results obtained with NEOS Server ("NeosS" line) and heuristic ("heur" line) in this set of instances.

Table 3: Experimental results (capacity = 8).

nodes		vehicles x capacity 3x8	4x8	7x8	10x8
20	NeosS	1245.22	1156.65	1048.91	1048.91
	heur	**1245.22**	**1156.65**	**1048.91**	**1048.91**
30	NeosS	1812.94	1665.99	1376.02	1299.10*
	heur	**1812.94**	**1665.99**	**1376.02**	1311,43
40	NeosS	2561.95	2362.82	1915.61*	1706.82*
	heur	**2561.95**	**2362.82**	1930,27	1748,65
50	NeosS	3238.03	2974.04	2362.52*	2075.69*
	heur	3240.36	2994.45	2382.93	2118,02
60	NeosS	4003.97	3702.97	2932.47*	2523.03*
	heur	**4003.97**	3707.29	**2917.65**	**2478.83**
70	NeosS	4693.05	4389.54*	3682.41*	3135.39*
	heur	**4693.05**	**4389.54**	**3624.17**	3163.34
80	NeosS	5450.52	----	4332.84*	3686.95*
	heur	**5450.52**	**5141.44**	**4240,82**	**3627,75**
100	NeosS	6785.59	6505.46*	----	----
	heur	**6785.59**	**6403.38**	**5398.40**	**4801.58**

The heuristic obtained the optimal solution in 13 instances, and obtained better or equal result than NEOS Server in 23 of 32 instances, representing around 70%. We recall that for some instances we present the values obtained by the NEOS Server at the end of available computation time. These instances are signalized with an asterisk "*" .

5 CONCLUSIONS

This work presents a model and a heuristic to solve the problems posed by the non-emergency patient transport in Portugal, given the new rules recently established. The model follows the same principle of the Team Orienteering Problem to select the patients to be included and the routes providing the maximum reduction in the costs. This approach is different from VRP strategies because some vertices are not visited. Particularly in this problem a patient that it is not visited by the routes means that the patient must be transported individually. Indeed, this model establishes the best sets of patients that should be transported jointly.

In this study, several Euclidean instances were generated to test our approach. The model was implemented in AMPL and our compact formulation was used to solve the instances using the NEOS Server. Instances with one hundred patients and ten vehicles with a capacity for eight patients each could not be solved within available computation time provided by the NEOS Server.

A heuristic procedure based on iteratively solving problems with one vehicle was presented, and this heuristic provides good results in terms of accuracy and computation time. Taking into account the knowledge provided by this study, a greedy heuristic and a genetic algorithm will be developed to solve this problem.

In this work, it is assumed the transport is the type "1 to many to 1", meaning the all patients have the same destination. For further work, we will study the situation of several destinations. Also, this study assumes an equal due date for all patients, but future work will consider different due dates for patients.

Finally, our model was tested with real instances with distances provide by Google Maps and generates promising preliminary results.

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