Expert Systems With Applications 61 (2016) 262–271

Contents lists available at ScienceDirect

Expert Systems With Applications

journal homepage: www.elsevier.com/locate/eswa

Non-emergency patient transport services planning through genetic algorithms

Manuel Fogue, Julio A. Sanguesa, Fernando Naranjo, Jesus Gallardo, Piedad Garrido, Francisco J. Martinez*

University of Zaragoza, Spain

ARTICLE INFO

Article history:
Received 18 September 2015
Revised 6 November 2015
Accepted 17 May 2016
Available online 20 May 2016

Keywords:
Genetic algorithms
Intelligent transportation systems
Non-emergency patient transport Services

ABSTRACT

Non-emergency Patient Transport Services (PTS) are provided by ambulance companies for patients who do not require urgent and emergency transport. These patients require transport to or from a health facility like a hospital, but due to clinical requirements are unable to use private or public transport. This task is performed nowadays mainly by human operators, spending a high amount of time and resources to obtain solutions that are suboptimal in most cases. To overcome this limitation, in this paper we present NURA (Non-Urgent transport Routing Algorithm), a novel algorithm aimed at ambulance route planning. In particular, NURA relies on a genetic algorithm to explore the solution space, and it includes a scheduling algorithm to generate detailed routes for ambulances. Experimental results show that NURA is able to outperform human experts in several real scenarios, reducing the time spent by patients in ambulances during non-emergency transportations, increasing ambulance usage, while saving time and money for ambulance companies.

1. Introduction

Route planning is a classic problem with remarkable importance in multiple environments, with a wide range of applications in the fields of Intelligent Transportation Systems (Di Lecce & Amato, 2011; Fontanelli, Bini, & Santi, 2010; Liu, 2002), autonomous robotics (Latombe, 1991; Makhal, Raj, Singh, Chakraborty, & Nandi, 2012), aerospace environments (Hui, Zhong, & Weihua, 2008; Tulum, Durak, & Yder, 2009) and military guidance and navigation systems (Lei, Qing, Zheng, & Yu, 2010; Ruuben & Kreison, 2013; Zafar, Qazi, & Baig, 2006).

An important application of route planning involves determining optimal routes for ambulances in both emergency and non-emergency transport services. Specifically, the Non-emergency Patient Transport Services (PTS) are provided by ambulance companies for patients who do not require emergency transport. These patients require transport to or from a health facility like a hospital, but due to clinical requirements are unable to use private or public transport.

Computing optimal routes for ambulances is a non-trivial problem that depends on the number and characteristics of the available ambulances, as well as their location. Several incompatibilities may arise due to the limited number of positions available in each ambulance, the equipment included, or depending on the legislation related to patient transport and minimum service conditions in each country. The main objective in this environment is, in general, to reduce the amount of time a patient spends in an ambulance which could be negative for their comfort and produce additional related health problems.

The Non-emergency Patient Transport Services Route Planning problem could be defined as the determination of the daily schedule for each available ambulance indicating the stops to be performed during the day, including the estimated time for the ambulance to arrive to each point of the route, and the patients that should be get on or off the ambulance at the stop. Most companies perform the service assignment by means of experts that are aware of the limitations of the system and the constraints that should be addressed in order to have a feasible solution, which is often a suboptimal one since human experts are not able to test enough combinations in an adequate time. The main planning unit in this problem is called *service*, which includes any single transportation of patients to or from a health center or a home address. For example, a return trip of a patient from his home to a hospital for a medical check would require two services: transferring the patient to the hospital, and another transportation to bring him home.

To solve the limitations of traditional systems, in this paper we propose the *Non-Urgent transport Routing Algorithm* (NURA), a route

* Corresponding author. Fax: +0034978618104.
E-mail addresses: mfogue@unizar.es (M. Fogue), jsanguesa@unizar.es (J.A. Sanguesa), fnaranjo@unizar.es (F. Naranjo), jesusgal@unizar.es (J. Gallardo), piedad@unizar.es (P. Garrido), f.martinez@unizar.es (F.J. Martinez).

http://dx.doi.org/10.1016/j.eswa.2016.05.028
0957-4174/

planning algorithm for non-emergency patient transport based on two main components: (i) an evolutionary algorithm (specifically, a genetic algorithm) to assign the services to be completed during a day to the set of available ambulances, and (ii) a scheduling algorithm based on solutions provided by human experts that, given the assigned services to a specific ambulance, determines the schedule for that ambulance including the times when the ambulance should pass through each point of the route, and ensures that the schedule provided is feasible.

Evolutionary Algorithms imitate the principles of natural evolution as a method to solve parameter optimization problems. They have been successfully used to solve various types of optimization problems (Greenwood, Lang, & Hurley, 1995), since they provide an optimal solution without checking all the possible solutions, reducing the execution time drastically. In this work, we compared the results obtained by our proposal with real planning obtained by human experts working in an existing ambulance company, and proved how our algorithm is able to provide better solutions, saving the time required by the experts.

This paper is organized as follows: Section 2 reviews the related work regarding non-emergency medical transport and the Vehicle Routing Problem (VRP). In Section 3 we present NURA, our proposed Non-Urgent transport Routing Algorithm which allows automatically obtaining a complete schedule for each available ambulance including all the stops to perform during the day. Section 4 introduces the structure and main parameters of the Genetic Algorithm (GA) used to explore the solution space. Section 5 presents the scheduling algorithm used to evaluate each solution. Section 6 shows the obtained results compared to those generated by human experts. Finally, Section 7 concludes this paper.

2. Related work

In this section, we are going to deal with some some approaches that are similar to the one we are introducing in this paper. This section is divided into two subsections: In the first one, we are going to mention how non-emergency medical transport has been faced by several authors when applied to different medical services around the world. In particular, we focus in the main problems that have been addressed in this field. In the second subsection we are going to review some approaches regarding the Vehicle Routing Problem (VRP) that use genetic algorithms, apart from medical transport issues.

2.1. Approaches for non-emergency medical transport

Non-emergency medical transport has been faced from different points of view, giving importance to different issues each time. The first thing to have in mind is that non-emergency medical transport has to be faced separately from emergency medical transport. For example, Huggins and Shugg (2008) made clear this need, and explained how non-emergency medical transport started to be treated in a separate way from the emergency one in a specific case. Also, authors remarked that the non-emergency sector would grow in size and the scope of practice would change as the population ages, and health needs change. Despite such studies, specific non-emergency medical transportation services are not often found, so novel approaches are appearing in the last years, such as the one by Safaei (2011). The specific approach mentioned in that paper, however, did not provide details about vehicle routing problems when carrying out the patients' transport.

Further studies have analyzed the quality and safety issues that have to be taken into account when dealing with non-emergency patient transport, for instance the one by Hains, Marks, Georgiou, and Westbrook (2011). As this paper states, quality and safety issues relating to non-emergency patient transport services have rarely been discussed compared to the transport of emergency patients. Therefore, authors identified communication, efficiency and appropriateness as the key factors that are advanced as impacting on the quality and safety of non-emergency transport services. Lastly, it is worth noting that vehicular networks are having a great importance recently, and of course, they are being used in patient transport situations. However, they are mostly found in emergency transport, as stated by Lee et al. (2014). In this paper, the literature is searched for suggested methods for assisting emergency vehicles, and evaluations are used simulations to evaluate them.

Thus, from this review we can conclude that non-emergency medical transport is a relevant field, which should be treated in a separate way from the emergency one, as it owns some very specific features. Non-emergency medical transport should be made as efficient as possible so that medical care is given properly to patients who make use of such service.

2.2. Genetic algorithms applied to the vehicle routing problem

Genetic algorithms (GAs) have found usefulness in several problems in which a complex solution must be found in a wide range of options. The Vehicle Routing Problem (VRP) is one of such problems. The basic Vehicle Routing Problem consists of a number of customers, each requiring a specified weight of goods to be delivered (Baker & Ayechew, 2003). Vehicles dispatched from a single depot must deliver the goods required, and then return to the depot. Thus, medical transport can be seen as a specific application of the VRP where patients are being transported to medical centers, instead of goods to customers.

In particular, Baker and Ayechew (2003) considered the application of a genetic algorithm to the VRP and compared it to both tabu search and simulated annealing, which are the two techniques that have usually been used to solve the VRP. In their paper, authors show that genetic algorithms are an effective approach to solve the basic VRP, although they give more value to genetic algorithms as a means of diversifying the exploration of the solution space rather than being the only way of solving the problem. This is one of several approaches that apply genetic algorithm to the VRP. Another remarkable one is the approach proposed by Prins (2004), in which the author tried to develop some effective metaheuristics for hard combinatorial optimization problems faced in vehicle routing. Thus, he presented a hybrid genetic algorithm for the VRP able to compete with powerful tabu search algorithms in terms of average solution cost.

There are also some approaches that focused on solving some variations of the VRP, such as the VRP modified with additional time constraints. More specifically, Hwang (2002) tried to improve a genetic algorithm in order to solve such a problem. Thus, the author found that the proposed model could be potentially efficient and useful in certain conditions. More recently, Pisinger and Ropke (2007) tried to give a solution to such problems by defining a unified heuristic. In this work, authors conclude that a mixture of good and less good heuristics lead to better solutions than using good heuristics solely.

According to this, we consider that the Vehicle Routing Problem adapted to medical transport issues is a problem that can be solved by means of genetic algorithms or similar approaches. Therefore, in the following sections we are going to explain how we have addressed the problem of non-emergency medical transport. Our solution, namely NURA, consists of a route planning algorithm for non-emergency patient transport. In particular, NURA uses a genetic algorithm to assign the services to the set of available ambulances, and provides a scheduling algorithm that,