

Real-World Patient Transportation

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1 Introduction

All over the world both the health and logistics sectors experience strong growth. Taking into account demographical change, especially the relative increase of the elderly as part of the whole population, the healthcare market as well as the share of logistical applications in health care is expected to rise even further.

In this work, we focus on a patient transportation problem for the Arbeiter Samariter Bund (ASB), an emergency medical service in Vienna. The organization has to perform a large number of patient transports every day and, in addition, has to respond to arising emergency calls. Assigning vehicles of a fleet to given transportation requests is usually modeled as a static dial-a-ride problem (DARP), which is well studied in the literature [1], [2]. However, there are significant differences between the formulations of the DARP in the literature and the real world problem tackled here, which makes the problem interesting and challenging to solve.

In the considered application, a certain number (about 60%) of transportation requests is known in advance, whereas other requests are occurring throughout operations. The ASB aims at planning the allocation of the vehicles to requests for the next day in a way that daily operations run as efficiently as possible. On the day itself, suggestions for allocating requests to vehicles will be given to the dispatchers. Therefore, a stochastic and dynamic variant of the DARP is considered. Based on historical data from ASB, stochastic demand and travel-time models will be used. This extends the model proposed in [3], where only stochastic information about expected return trips of patients is considered. An additional challenge is the sheer size of the problem that has to be solved. The number of requests scheduled at the ASB every day as well as the number of vehicles in the fleet are large compared to the classic DARP instances used in the literature [1]. The problem instances consist of a fleet of around 120 vehicles and the ASB serves approximately 800 - 1000 patient transportation requests a day.

The problem is solved in a two-phase approach, in the first phase known as well as sampled transport requests will be combined in order to build a starting solution for the day of operations. In the second phase, new requests are quickly inserted in the solution replacing the sampled requests, thereby allowing fast response times if reasonable. The solution is then further optimized in a background process. This paper will present two main aspects of the proposed approach: the stochastic models and a restricted dynamic programming approach for solving the initial problem.

2 Problem description

The classic DARP model is adapted to represent the given situation at the ASB. As in the DARP, the aim is to schedule all vehicles to accommodate a number of requests in an optimized way regarding travel time and patient convenience. For each transportation request a time window is given at the pickup location, indicating at what time the patient should be served.

While in the classic DARP the goal is to find an optimal assignment of vehicles to requests regarding the tour length, the overall aim when solving the problem at ASB is to optimize patient convenience and to assign vehicles in an efficient way, such that an increased number of requests could potentially be served per day. The time windows for the requests are seen as soft constraints where violations are penalized, in order to avoid disproportionally long waiting times. Additionally, there is a hard limit on tardiness to preserve a minimal quality standard for patients. Furthermore, some requests are considered high priority where this limit is even tighter which allows patients to keep their appointments. The time a patient spends in the vehicle during transport is also a factor that heavily influences patient convenience: patients should not spend more time en route as necessary. Therefore, the maximum user ride time is limited and detours are only allowed for up to 30 minutes. Another difference between the classic DARP and the problem at hand is that the ASB uses different classes of vehicles. Depending on the needs of the transported patient, sometimes only a certain class of vehicles can be scheduled to conduct an assignment.

3 Stochastic models for estimating demand and travel times

For two input variables into the stochastic optimization procedures, stochastic models were developed. The first model estimates the demand for patient transports per hour from one zip code district to another. The other model estimates the travel time for patient transports from pickup to delivery location.

For the demand model, several types of count models were tested. Amongst them were simple Poisson models, where the mean of the Poisson distribution describing the demand

per zip code pair per hour is modeled as a linear model of several variables, including the time of day, weekday/weekend and demands in previous hours. This was compared to other variants of count models including negative binomial models, giving the advantage of more flexible distribution functions as well as zero inflated models and hurdle models, adding the possibilities to deal with situations where a large number of hours of zero demand are encountered in the data [4]. All the models were estimated using historical demand data from ASB. In most cases Poisson models turned out sufficient for modelling the demands.

The second set of statistical models is used to estimate the travel time of patient transport vehicles. Here we loosely follow ideas developed in [5]. To avoid having to calculate a complete time dependent travel time matrix whenever a new request arrives, reduced 23 x 23 travel time matrices for standard routes between the 23 zip code areas in Vienna with average travel times for each 15 minute interval for four different categories (weekday/no holiday, weekday/holiday, weekend/no holiday, weekend/holiday) are calculated once. Linear models are used to estimate these travel time matrices and floating car data from a Vienna taxi fleet [6] is used as input. These travel time matrices are then used in a second modeling stage that models the travel times for patient transports dependent on the taxi travel time matrices, the actual distance between pick up and drop off and variables like seasons or day of the week. Again, the models are estimated using the historical ASB data. For all the models, an automated stepwise variable selection is performed to avoid over-fitting.

4 Restricted dynamic programming

The size of the instances considered here poses a difficult challenge for most available optimization algorithms for solving the DARP. Thus, in order to be able to construct good solutions in practically acceptable running times, we apply a novel approach that heuristically generates the initial solutions for each day of the ASB operations.

The method we use to solve the problem at hand is based on the dynamic programming (DP) approach for the DARP proposed in [7]. This approach works well for the benchmark instances from the literature but solving the instance sizes from the real world application required the development of a novel way of adapting the DP algorithm to be suitable for large problem sizes. The main concept of this approach is to construct routes by expanding each path by all its possible successors at every iteration. However, in order to restrict the dimension of the problem, we only consider a set of most promising states for further expansion in a restricted DP approach. Specifically, we show how we adapted the objective function in a way that solutions promising high quality are selected during the restriction process.

5 Results and Outlook

The presented stochastic models and the restricted DP algorithm are now part of a comprehensive framework for solving patient transportation problems at the ASB. It encompasses interfaces to various data sources and a user interface for interacting with the dispatchers. Currently, using our method we can already solve practical instances spanning one day of operation with a higher patient satisfaction by reducing delays at the patients pickup locations by up to 40% with comparable total travel times. It is planned to evaluate and further integrate the presented approach at ASB by mid 2012.

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