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Discrete Optimization

A heuristic algorithm for the free newspaper delivery problem

Claudia Archetti [a,*], Karl F. Doerner [b], Fabien Tricoire [c,d]

[a] Department of Economics and Management, University of Brescia, Brescia, Italy
[b] Institute for Production and Logistics Management, Johannes Kepler University, Linz, Austria
[c] Department of Business Administration, University of Vienna, Vienna, Austria
[d] NICTA/UNSW, Sydney, Australia

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ABSTRACT

This paper addresses the problem of finding an effective distribution plan to deliver free newspapers from a production plant to subway, bus, or tram stations. The overall goal is to combine two factors: first, the free newspaper producing company wants to minimize the number of vehicle trips needed to distribute all newspapers produced at the production plant. Second, the company is interested in minimizing the time needed to consume all newspapers, i.e., the time needed to get all the newspapers taken by the final readers. The resulting routing problem combines aspects of the vehicle routing problem with time windows, the inventory routing problem, and additional constraints related to the production schedule. We propose a formulation and different heuristic approaches, as well as a hybrid method. Computational tests with real world data show that the hybrid method is the best in various problem settings.

1. Introduction

In the context of large public transport networks, free newspaper companies produce daily newspapers that public transport users (consumers) can read while commuting in the morning. Consumers take the newspapers for free from distribution boxes located at underground, tramway and bus stations, so advertisements are the only source of revenue for these companies. However, advertising rates depend on the market share of the free newspaper companies, such that the company with the highest number of daily consumed newspapers can charge the highest rates for its advertising space. It is therefore crucial for these companies to maximize their market share, as measured by their daily consumption, which in turn requires increased production (printing). However, the potential for consumption is not infinite, and newspapers must be present at the right place and right time to be consumed; otherwise, large quantities of printed newspapers remain unconsumed. For marketing reasons, the newspaper companies prefer to avoid unconsumed newspapers left in the boxes at the end of the day, which is likely to damage users' opinions of the newspaper and possibly decrease its market share. Thus, the company deals with the trade-off between producing as many newspapers as possible while avoiding unconsumed newspapers at the end of the day. In practice, production aims to attain the level of a portion of the estimated demand, even if doing so runs the risk of stockouts, such that some portion of the demand will not be satisfied.

Consumer traffic at public transport stations is quite regular; most people go to work every day at the same time. Predictive consumption thus can be derived from traffic information. Stochasticity is not really an issue, as long as the consumers are used to seeing newspapers in the boxes and are always able to pick up newspapers if they so choose. If the boxes are alternately full and empty during the morning, consumers who want to pick up a copy but find an empty box lose interest in the long term. Therefore, it is a sensible policy to avoid temporary stockouts during the consumption period, to retain consumer interest in the long term and support high, predictable consumption.

The free newspapers arrive at the various public transport stations on vehicles that depart from the production factory. Because they want to maximize consumption, the newspaper companies provide interesting news to the readers and attempt to print the latest, most up-to-date stories. In this sense, newspapers are highly perishable, and the later a print run starts, the better. However, printing capabilities are limited, and the number of copies demanded can be quite high. In practice then, the delivery trips start while the printing is still continuing, and the companies must synchronize production at the factory with delivery trips. The vehicles must wait until the newspapers they are supposed to deliver are

* Corresponding author. Tel.: +39 0302988587; fax: +39 0302400925.
E-mail addresses: archetti@eco.unibs.it (C. Archetti), karl.doerner@jku.at (K.F. Doerner), fabien.tricoire@univie.ac.at (F. Tricoire).

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printed, and the trips have to be scheduled according to the production schedule.

Maximizing the profit of such a company is therefore a complex process with many decisions, including pricing, production scheduling, and combined routing and scheduling. For this study, we assume that decisions about pricing and printing already have been made and that the production schedule is a given. We thus can concentrate on the combined routing and scheduling problem. On the one hand, a tactical objective is to consume all produced newspapers as quickly as possible, which helps the company justify high advertising prices. On the other hand, the delivery trips are typically outsourced to a company that bills a fixed price for each trip, so minimizing the total number of trips required is an operational objective.

The contribution of this paper is twofold. First, we introduce a new problem, the Free Newspaper Delivery Problem (FNDP), that reflects a compelling trait of modern societies; we provide a mathematical model for this problem and study its peculiarities. Second, we propose solution techniques for the FNDP. These methods involve a decomposition, heuristic and exact approaches for the subproblems, as well as a hybrid method.

The remainder of this paper is organized as follows: In the next section, we give a more detailed description of the FNDP and the application we consider, which concerns a free newspaper company working in Vienna. In Section 3, we review publications dealing with problems that are related to the FNDP. After we discuss the peculiarities of the problem in Section 4, we present an extended formulation in Section 5. In Section 6 we describe the solution approaches we propose for the FNDP. Finally, computational tests on real data are presented in Section 7.

2. Problem description

A central depot is given which corresponds to the production plant where the newspapers are produced and stored. The starting production time and the production rate are constant over time. Once the total amount of newspapers prescribed has been produced, production stops. The distribution of the newspapers to subway and tramway stations relies on a fleet of identical vehicles. Each vehicle can perform one or several trips; we define a trip as a tour that starts at the production plant (or depot), visits a certain number of stations, and returns to the production plant. Time gets consumed by vehicles when they travel from one station to another (travel time) and when they perform the deliveries (service time). Additionally, vehicles can wait at stations before performing a delivery (waiting time). Therefore the total duration of a trip is the sum of the total travel time, total service time, and total waiting time. The time at which the distribution starts is established and constant over time (and obviously later than the starting production time), and all the newspapers must be delivered within a fixed due time, typically fixed at 9:00 am, when the last demand peak occurs. The demand occuring after this last peak appears so small that it can be ignored. Thus, the time horizon spans from the start of the distribution operations to their end. The newspaper consumption rate is not stationary over time and space, meaning that it varies on the basis of the stations and on time. For example, central stations typically exhibit a higher consumption rate than suburb stations, and during the time horizon, consumption typically shows two peaks at 7:00 am and 9:00 am. At the stations, newspapers are stored in boxes with a given capacity, such that the number of boxes at a station indicates its total capacity. The goal is thus (i) to satisfy demand by distributing all the produced newspapers to the stations where they are actually consumed, as well as (ii) to minimize the number of vehicle trips used to deliver the newspapers.

Alternating between empty and full boxes can have a negative impact on consumer's interest on the long term though and lead to lower and/or unpredictable consumption. The company rather wants to avoid alternating stockout and replenishment at each station, instead demand needs to be satisfied continuously, and stockout has to occur only once (at the end of the time horizon or even before). Once a station has incurred a stockout situation, it will not be replenished. In practice, the company plans its distribution on the basis of forecasted demands. Each station keeps receiving a quantity that is sufficient to cover the forecasted demand in each period until the deliveries stop. At this point, the station should face a stockout situation, though it does not necessarily occur at every station at the same time.

We now present the problem input as well as the resources available.

The fleet is homogeneous. Each vehicle performs only one route, but one route can be formed by a sequence of several consecutive trips. The capacity volume is fixed, but because the thickness of newspapers can change from day to day, vehicle capacity in terms of the number of newspapers carried also changes daily. Moreover, newspapers are grouped into *batches* with a set number of copies. Because the thickness of one newspaper copy can change, the volume of one batch also differs on a daily basis. These batches are the standard unit used in capacity measures in the following. Each station has a set of boxes, which may be of four types, each with different capacities. The number of boxes and their capacities determine the total capacity of a station. Some stations also offer the possibility of delivering newspapers outside of a box, such as leaving them on a table or a bench. These stations typically have a small demand, and an infinite capacity is assumed in such a case. The consumption rate changes for every (station, period) pair.

The planning horizon starts at 4:00 am and ends at 9:00 am, divided into *periods* (e.g., 10 periods of 30 minutes). Consumption at the stations starts only after 5:00 am, and finishes at 9:00 am. Newspapers consumed at a given station at period t have to be delivered to this station within period t. All stations that are not visited during or before the first period of consumption (between 5:00 am and 5:30 am) enter stockout, such that their consumption is lost for the whole horizon. However, in the application considered herein, for contractual reasons, the company must serve each station at least once, so all stations will be served in the first period of consumption.

The central depot produces newspapers from 1:00 am to 7:00 am. It produces 40,000 newspapers per hour, and fresh production is only available at the end of the hour. For instance, nothing is available at 1:59 am, but 40,000 newspapers are available at 2:00 am. In practice, the distribution operations start at 4:00 am with an available stock of 120,000 newspapers. In total, 240,000 newspapers are produced; they must all be consumed by the end of the horizon, which is at 9:00 am.

It is important to notice that some stations need to be visited only once. These are typically small suburb stations, distant from the depot. Their capacity allows them to handle their total consumption over the whole horizon.

Moreover, newspapers thickness changes everyday and thus has an impact on capacity, both of the vehicles and at the stations. Thus, the problem differs from one day to another. We will focus on this daily problem and the need to organize the distribution operations of a single day.