Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 22 (2017) 222–231

Transportation Research Procedia

www.elsevier.com/locate/procedia

19th EURO Working Group on Transportation Meeting, EWGT2016, 5-7 September 2016, Istanbul, Turkey

A Bus Crew Scheduling Problem with Eligibility Constraints and Time Limitations

Hande Öztop[a]* , Uğur Eliiyi[b,c], Deniz Türsel Eliiyi[a], Levent Kandiller[a]

[a] *Yaşar University, Department of Industrial Engineering, Izmir 35100, Turkey*
[b] *Dokuz Eylül University, Department of Computer Science, Izmir 35160, Turkey*
[c] *ESHOT General Directorate, Department of Transport Planning, Izmir 35380, Turkey*

Abstract

In this study, we consider a real life crew scheduling problem (CSP) of a public bus transportation authority, where the objective is to determine the optimal number of different types of crew members with a minimum cost that cover a given set of tasks regarding working and spread time limitations. Each driver has a spread time limit from the start time to the end time of his/her shift, including the idle times. Additionally, a driver cannot exceed the maximum total working time limit. The processing times of the tasks assigned to each driver are included in his/her working time, as well as the sequence-dependent setup times. As our study is inspired from a real life CSP, the tasks can require different types of vehicles that require different crew capabilities. Therefore, there are several crew classes based on the competencies required to use certain vehicle types inducing eligibility constraints in the problem. We formulate a Tactical Fixed Job Scheduling Problem based binary programming model for the problem. In the formulation, we consider only processing times of tasks as working time. In order to avoid defining an additional sequence control variable that explodes the model size and in turn ruins solution performance, we develop an iterative valid inequality generation scheme, which eliminates task sequences exceeding the total working time when setup times are included. The performance of the developed model is investigated through a comprehensive experimentation and the numerical results are reported. The results show that our optimal seeking solution procedure is quite effective in terms of solution time for instances with up to 120 tasks.

Peer-review under responsibility of the Scientific Committee of EWGT2016.

Keywords: Crew Scheduling; Public Transportation; Tactical Fixed Job Scheduling; Time Limitations; Eligibility Constraints

* Corresponding author. Tel.: +90-232-411-50-00; fax: +90-374-54-74.
E-mail address: hande.oztop@yasar.edu.tr

2214-241X © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Scientific Committee of EWGT2016.
10.1016/j.trpro.2017.03.029

1. Introduction

The impact of planning systems in public transportation has been increasing, as significant cost savings are possible if the available resources such as crew and vehicles are used efficiently. The public transit-operation planning process includes five basic activities, usually performed in sequence: network route design, timetable development, vehicle scheduling, crew scheduling and crew rostering (Ceder, 2007).

In network route design stage, the bus stops, terminals and interchanges are determined, as well as the route of each bus line. Then, the frequency of each bus line is determined based on public demand. Consequently, timetables are constructed, which lead to *trips* having start and end termini, along with departure and destination times. In the vehicle scheduling problem (VSP), the vehicles are assigned to trips. Each daily vehicle schedule, known as *vehicle block*, is defined as a bus journey starting at a depot, and returning to the same or a different one. The crew rostering problem (CRP) includes the long term crew planning, where crew rosters are generated from crew shifts. This stage consists of the days-off scheduling and shift scheduling. Days-off scheduling deals with the assignment of rest days to the crew over a planning horizon, while shift scheduling deals with the assignment of the crew to shifts.

In this study, the crew scheduling stage of the planning process is considered for public bus transportation. The crew scheduling problem (CSP) is the short term crew planning, where daily shifts are formed for the crew. There is a set of tasks corresponding to the vehicle blocks, and the aim is to define the sequence of these tasks as *shifts* in such a way that every task must be assigned into a shift without any overlaps. The feasibility of a crew shift depends on a set of rules such as the maximum driving time limit, minimum break time duration, etc.

We consider the problem of determining the optimal number of different types of crew members with the minimum cost in order to cover a given set of tasks. A *task* is defined as an activity performed on a single vehicle by a single crew member (driver) without an interruption. A task can be a *d-trip*, created by dividing the trips at relief points; or a *deadhead*, which is a driving activity between two relief points without passengers. The *relief points* are the planned locations and times where and when a change of driver may happen. Thus, there are predetermined start and end location, as well as start and end times for each task. A task can be assigned to a driver depending on the previous tasks assigned to that driver. Due to this reason, the traveling times between tasks differ from any start location to any end location leading to sequence-dependent setup times between tasks.

Our study is motivated by a real life crew scheduling problem of a public bus transportation authority and operator, which has many operational constraints. Each driver has a spread time limit from the start time to the end time of his/her shift, including the idle times. Furthermore, a driver cannot exceed the maximum total working time limit. The processing times of the tasks assigned to each driver are included in his/her working time, as well as the sequence-dependent setup times. As our study is inspired from a real life CSP, the tasks can require different types of vehicles that require different crew capabilities. Therefore, there are several crew classes based on the competencies required to use certain vehicle types corresponding to eligibility constraints in the problem.

Based on these characteristics, the CSP problem in our study can be formulated as a Tactical Fixed Job Scheduling Problem (TFJSP), as the ready times and deadlines of the tasks are fixed in advance, and the objective is to minimize the total cost of crew to cover all tasks. In the basic Fixed Job Scheduling Problem (FJSP), there are n independent tasks ready to be processed on m parallel resources. The time window of each task is defined by a ready time and a deadline. The tasks cannot be delayed after their ready times, meaning that the processing times of the tasks are equal to their corresponding time windows. The TFJSP is a variant of the FJSP where the objective is to minimize the total fixed cost of the resources required to process all tasks. Additional operational constraints in our study such as working time, spread time and eligibility complicate the problem. Moreover, the existence of sequence-dependent setup times diverge the problem from a typical TFJSP, further complicating the structure.

2. Literature Review

Fischetti *et al.* (1987) proved that the FJSP with spread time constraints is NP-hard, and in a later study, Fischetti *et al.* (1989) proved that the FJSP with working time constraints is also NP-hard. As these two special cases of the CSP with spread and working time constraints are NP-hard, the problem studied in this study is also NP-hard.

Wren and Rousseau (1995) provided an overview of the Bus Driver Scheduling Problem (BDSP), which is a kind of the CSP for public bus transportation, and its several variants. The authors presented constraints and conditions in different environments, and proposed various solution approaches for the BDSP. Ernst *et al.* (2004) provided a detailed bibliography about crew scheduling and crew rostering. They classified the studies related to these two problems according to problem type, application area and solution methodology.

In the literature, one of the most commonly used approaches for the CSP is column generation, introduced by