Doctoral School on Engineering Sciences
Università Politecnica delle Marche

Extended summary

Dynamic allocation and resource planning in the management of a bus terminal

Curriculum: Informatics, Managerial and Automatics Engineering

Author

Gionata Massi

Tutor(s)

Ferdinando Pezzella

Date: 31-January-2011

Abstract. The assignment of buses arriving to available gates is a major issue during the daily operations in a bus station. Such a problem is known in literature as Gate Assignment Problem and consists, given the daily bus schedule, in determining the best feasible assignment of the buses to the gates based on certain preference criteria. In order for a solution to be feasible at least two constraints have to be satisfied: each bus must be assigned to one and only one platform and two buses whose time intervals of platform occupation overlap cannot be assigned to the same platform.

Problems similar to gate assignment in bus stations arise in the management of airports, train stations, ports, freight villages and so on. There are also strong similarities with the register assignment problem in Digital Signal Processors. In the bus station case, manager may require that the bus-platform assignment plan occupies the minimum number of platforms during the planning horizon. For this problem we propose a novel formulation as a list-colouring problem of an interval graph and an integer linear programming model to solve it.

Trip delays such as early or late arrivals and late departures are a frequent occurrence in actual day to day bus station operations and it is often not possible to assign such buses to their original platforms. For this reason we considered a mathematical programming model to increase the robustness of the solutions by the minimization of the probability that buses assigned to the same gate may be "in conflict".

Finally, in order to generate a good solution in a reasonable computation time, we also propose a heuristic algorithm, based on the idea to solve the problem by dividing it into smaller subproblems, using a receding horizon control, and then reconstructing the complete solution.

Computational experiments on a real bus station with 24 platform and more than 200 bus trips have been performed showing the effectiveness of the approach.

Keywords. Bus station management, Gate assignment, Heuristic methods, Interval graphs, List colouring.

1 Problem statement and objectives

Within the transport sector, one of the most widespread decisions that must be taken by those in charge of stations or airports is that of assigning the gate or platform from which each of the offered services must leave. The chosen option is highly relevant in relation to the quality of the service offered, since sub-optimum assignments give rise to dissatisfaction and protests on the part of customers (who must proceed unnecessarily from one part of the station to another), protests from transport companies (which may suffer delays as a result of congestion caused by the lack of correct assignments), etc.
The aim of the thesis is to provide models and algorithm to support the platform manager in taking his choices.
These types of models have been mainly designed so far for airports in an attempt to use gates efficiently (good distribution among companies, minimisation of delays, etc.) since the mid-1980s [5], presents one of the first results for this problem using microcomputers), different gate assignment algorithms have been proposed for airport terminals, with real cases such as Singapore airport [3] or Taiwan [9].
The basic goal in all these cases is to minimise the walk distance of connecting passengers (or baggage collection) at the terminal, thus reducing connecting times. Some authors (for instance [10]) have incorporated passenger waiting time, defining multi-criteria approaches.
Two different approaches have been considered in the literature for solving the gate assignment problem: expert systems and simulation ([7], present a review of the use of ES; Gosling, 1990, introduced one of the first applications in this field, inspiring later papers such as [8]; [11] present a simulation framework tested in Taipei airport able to analyse the effects of stochastic flight delays); and exact procedures (such as [6], using linear programming;[4], and [2], using a QAP with temporal constraints, or [9] using network models). [3] presents a hybrid rule-based system and a heuristic assignment procedure.
In the best of our knowledge, the gate assignment problem has not yet been studied in the bus management case, an environment with distinct requirements and constraints, with the notable exception of [1]. This work illustrates the decision support system of Oviedo bus station, which tackles the bus-platform assignment by means of a rule-based expert system. The goal of reducing the distance passengers walk is not addressed because it becomes secondary, since the size of stations is in general much smaller than that of airports.
However, several new criteria emerge that the station manager must take into consideration because services with destinations in the same geographical area or offered by the same company are usually placed close to one another so that frequent passengers can know their way around the station better and so that the employees of each carrier are near to the place they have to carry out their functions; when a high-demand service is covered by several buses, these must leave in a staggered fashion; if possible, on long-distance services where passengers usually carry luggage, it would be desirable for adjacent platforms to be empty at arrival and departure times so as to avoid a pile-up of luggage on platforms which are normally narrow; not all platforms are valid for all sizes of buses; some platforms must be reserved as temporary parking for the buses which depart sometime after arriving at the station; and so on.
All this must be considered, together with endeavouring (as occurred in the air transport sector) to get high demand services to arrive at and depart from platforms near to the ticket

offices or main doors, and above all attempting to avoid any delay due to a shortage of platforms at the time of offering the service.

2 Research planning and activities

The manager of a bus station may wish that the plan bus-platform assignment is built to minimize the total number of platforms used in a day. A management policy that considers this goal is motivated by the need to make efficient use of the area of the bus station, increasing the density of services. Choosing this objective is motivated also because spare platforms can be used for service stopovers and vehicle parking however, this policy has the disadvantage of determining not very robust plans.
We want to mathematically formalize the problem that can be described as follows. Given a set of rides to be allocated on a typical day (characterized by intervals of platforms occupation and compatibility with platforms), a set of platforms (characterized by unavailable intervals and compatibility with the rides) and a relationship between rides, which combines two rides in case of services carried out with two buses, we want to determine an assignment of the rides to the platforms such that each ride is assigned to a platform, the interfering rides are not assigned to the same platform, the rides are assigned to compatible platforms, the platforms are assigned only to rides compatible and such that the number of platforms that are assigned to at least one ride is minimized.
Such a problem can be solved as a list-coloring of a graph. Each feasible platform allocation corresponds to a good proper coloring of the nodes in the graph in which the color assigned to the node is compatible with the node itself, and vice versa.
Therefore the problem becomes equivalent to the following: given an interval graph $G = (V, E)$, a set of colors C and a family of sets (compatibility lists) $\{L(i)\}_{i \in V}$, we want determine the color of any vertex $i \in V$ such that no two adjacent vertices have the same color (proper coloring), that the color assigned to each node $i \in V$ is present in the compatibility list $L(i)$ and that the number of distinct colors used is minimal.
The above formulation does not consider a minimum time interval that must elapse between two rides on the same platform. Such minimum distance, though small, could cause a chain effect of propagation of delays of the stops assigned to the same platform and may require a reallocation involving many rides. It is therefore proposed a new problem of allocation of platforms whose objective is that the smallest interval of time between the release and the occupation of the same platform is maximum.
Although the maximum time distance is an important indicator of the robustness of an assignment, it is not in itself sufficient to ensure that an optimal solution of the model is in practice the less sensitive to variations of the data input. There are many solutions that have the same minimum distance that, in order to produce a robust assignment, cannot be considered equivalent. It is therefore proposed to minimize a different performance index, which measures in some way the probability that the rides assigned to the same platform are "in conflict".
We then introduced additional constraints: in order to allow passengers of a service to board a vehicle used for a ride carried out by two buses without having to move from one end to the other of the bus station, is desirable that these stops are assigned to adjacent platforms. Furthermore, the presented mathematical models can be extended to consider the exclusion criteria of certain bus-platform assignments. In order to penalize an undesir-

able assignment a penalty (a "soft" constraint) can be added to the objective function of the model. We note that the addition of further constraints and preferences or penalties helps to reduce the symmetries of the models and makes them more suitable for the direct resolution, also for problems with dozens of bus and platforms.

3 Analysis and discussion of main results

The proposed mathematical models can be solved directly by using optimization software libraries for mixed linear programming problems but their algorithms, unfortunately, are poor in proving the solution optimality of a real size instance (due to the models symmetries).

In order to generate a good solution in a shorter time we propose a heuristic algorithm that exploits the idea of solving complex problems by dividing them into smaller subproblems and then reconstructing the complete solution. The planning horizon is divided into time slots (multiple time slot approach) of certain duration and the conflict probability model is solved for each time slot. The duration of a time slot is a critical parameter as it influences solution quality and computational times then it should be calibrated. Test performed on an instance derived from the operation of an existent bus station suggests that a time slot of 120 minutes produces the best tradeoff between quality and time.

A different heuristic approach for quickly determining a robust solution is presented. The algorithms search for a solution with the largest minimum time slack between rides assigned to a same platform by iteratively solving the minimization number of used platforms problem. A variable b symmetrical enlarges the interval during which a platform is reserved by a ride. The algorithm initializes b to zero and iteratively increments it value until fast greedy algorithm cannot determine a feasible solution for the platform assignment problem.

Numerical tests were carried out by extracting a remarkable instance of services run into Bologna bus station. The chosen instance includes 229 rides to be assigned to 24 platforms.

The proposed algorithms were first tested under the same conditions, and therefore complying with the same constraints, of the planning carried out by a commercial software. Different scenario have been considered varying the number of platforms given in the problem and symmetrical enlarging the interval during which a ride is locking a platform. Such range of alternatives allows the station manager to choose between different solutions the one considered most appropriate in his experience.

4 Conclusions

Daily management of a bus station introduces many different types of constraints when assigning platforms to services. The platform assignment problem in bus stations has been analysed in terms of objectives and constraints that the assignment solution should satisfy. Several constraints that are treated as distinct have been unified in a simple compatibility concept that links bus services and platforms. Common characteristics of this problem and others emerging in different context have been identified. Two major problems have been described and formulated. The first one considers the objective of reducing the number of platforms assigned to one or more bus during a planning horizon. The problem is reduced

to a list-colouring problem of an interval graph. The problem deals with the robustness of an assignment plan, which is a relevant problem not well addressed in literature and two ideas are proposed. Three formulations of the described assignment problems as a 0/1 integer linear programming models have been proposed exploiting the interval graph properties. A heuristic method able to find a good solution for the problem has been developed taking advantage of the distribution along the time of the services.
Computational study on a real case has shown the effectiveness of the approach.

References

[1]B. Adenso-Díaz. Rule-based system for platform assignment in bus stations. In G. Kendall, E. K. Burke, S. Petrovic, and M. Gendreau, editors, *Multidisciplinary Scheduling: Theory and Applications*, pages 369–379. Springer US, 2005.
[2] A. Bolat. Procedures for providing robust gate assignments for arriving aircrafts. *European Journal of Operational Research*, 120(1):63–80, 2000.
[3] Y. Cheng. A knowledge-based airport gate assignment system integrated with mathematical programming. *Computers & Industrial Engineering*, 32(4):837–852, 1997.
[4] A. Haghani and M. C. Chen. Optimizing gate assignments at airport terminals. *Transportation Research*, 32(6):437–454, 1998.
[5] S. G. Hamzawi. Management and planning of airport gate capacity: a microcomputer-based gate assignment simulation model. *Transportation Planning and Technology*, 11(3):189–202, 1986.
[6] R. S. Mangoubi and D. F. X. Mathaisel. Optimizing gate assignments at airport terminals. *Transportation Science*, 19(2):173, 1985.
[7] K. Srihari and R. Muthukrishnan. An expert system methodology for aircraft-gate assignment. *Computers & Industrial Engineering*, 21(1-4):101 – 105, 1991.
[8] Y. Su and K. Srihari. A knowledge based aircraft-gate assignment advisor. *Computers & Industrial Engineering*, 25(1-4):123 – 126, 1993.
[9] S. Yan and C. M. Chang. A network model for gate assignment. *Journal of advanced transportation*, 32(2):176–189, 1998.
[10] S. Yan and C. M. Huo. Optimization of multiple objective gate assignments. *Transportation Research*, 35(5):413–432, 2001.
[11] S. Yan, C. Y. Shieh, and M. Chen. A simulation framework for evaluating airport gate assignments. *Transportation Research*, 36(10):885–898, 2002.