OPTIMAL SINGLE-ROUTE VEHICLE SCHEDULING

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Abstract: The efficiency of the operator performing mass passenger transport services, from one side, depends on the usage of the service by passengers and from other side - from the optimal planning of the vehicles, moving on the route line. The schedule and spaces of movement of every bus is pre-set. This study investigates only the optimization of the number of rolling stock traveling on fixed routes of urban passenger transport. The problem to be solved by the determining of the optimal distribution of vehicles, performing all trips on a given line with a fixed schedule, is in their correct planning. The travel chain is designed for all vehicles running on the line. The planning of the vehicles in the urban passenger transport is based on their distribution in the hours of the day and as a result is determined the type of them, arranged in descending order according to their expenses. In the public transport, the schedule of vehicle necessary t o meet the needs of passengers, as well as to increase their number by the using of this service. In order to achieve optimality of the fixed schedules, there may be empty trips to the place of stay of the vehicles, as the departure times and stops along the route cannot be changed. The study aims to suggest a technique easy for implementation, to meets the practical problems and leads to optimization of traffic on the line from mass passenger transport in one direction. The achievement of it, need to define minimum number of vehicles, optimal for the route is determined. The described model is a step function, called the deficit-function, with the introduction of vehicle traffic control along a predetermined schedule and shows such optimization. For creation of set of deficit-functions, information needed is a schedule of the exact number of the trip. As a result, capital spending for vehicles is significantly lower than such for fuel, repair and maintenance of rolling stock decrese, as well as the number of drivers optimal. And as a final result, the company increases its profitable.
Keywords: Vehicle, optimal size of the fleet, deficit-function model

1. INTRODUCTION

The operation planning process commonly includes four basic activities, usually performed in sequence: (1) network route design, (2) timetable development, (3) vehicle scheduling, and (4) crew scheduling. The output of each activity positioned higher in the sequence becomes an important input for lower-level decisions. However it is desirable for all four activities to be planned simultaneously in order to exploit the system's capability to the greatest extent and to maximize the system's productivity and efficiency. In fixed schedules, departure times cannot be changed. A method to construct timetables with the combination of both even-headway and even-load concepts is developed for multi-vehicle sizes. The scheduling problem is based on given sets of trips and vehicle types arranged in decreasing order of vehicle cost. The vehicle-scheduling activity is aimed at creating chains of trips; each is referred to as a vehicle schedule according to given timetables. This chaining process is often called vehicle blocking (a block is a sequence of revenue and non-revenue activities for an individual vehicle). A trip can be planned either to transport passengers along its route or to make a deadheading trip in order to connect two service trips efficiently.

This research has the aim to proffer a graphical technique that is easy to interact with and responds to practical concerns. It contains two main parts following an introductory section, and a literature review section. First, a formula is derived to find the minimum fleet size required for a single route without deadheading (DH) trips and for a fixed schedule. Second, a graphical person-computer interactive approach, based on a step function called deficit function, is proffered for minimizing single-route fleet size and creating vehicle schedules with DH trip insertions.

2. LITERATURE REVIEW

The group of studies that are related directly to vehicle scheduling, was researched by, for example, Dell Amico et al. (1993), Löbel (1998, 1999), Mesquita and Paixao (1999), Banihashemi and Haghani (2000), Freling et al. (2001), Haghani and Banihashemi (2002), Haghani et al. (2003), and Huisman et al. (2004).

Dell Amico et al. (1993) developed several heuristic formulations, based on a shortest-path problem, that seek to minimize the number of required vehicles in a multiple-depot schedule. The algorithm presented is performed in stages, in each of them the duty of a new vehicle is determined. In each such stage, a set of forbidden arcs is defined, and then a feasible circuit through the network is sought that does not use any of the forbidden arcs.

Löbel (1998, 1999) discussed the multiple-depot vehicle scheduling problem and its relaxation into a linear programming formulation that can be tackled using the branch-and-cut method. A special multi-commodity flow formulation is presented, which, unlike most other such formulations, is not arc-oriented. A column-generation solution technique is developed, called Lagrangean pricing; it is based on two different Lagrangean relaxations.

Heuristics are used within the procedure to determine the upper and lower bounds of the solution, but the final solution is proved to be the real optimum.
Mesquita and Paixao (1999) used a tree-search procedure, based on a multi-commodity network flow formulation, to obtain an exact solution for the multi-depot vehicle scheduling problem. The methodology employs two different types of decision variables. The first type describes connections between trips in order to obtain the vehicle blocks, and the other relates to the assignment of trips to depots. The procedure includes creating a more compact, multicommodity network flow formulation that contains just one type of variables and a smaller amount of constraints, which are then solved using a branch-and-bound algorithm.
Banihashemi and Haghani (2000) and Haghani and Banihashemi (2002) focused on the solvability of real-world, large-scale, multiple-depot vehicle scheduling problems. The case presented includes additional constraints on route time in order to account for realistic operational restrictions such as fuel consumption. The authors proposed a formulation of the problem and the constraints, as well as an exact solution algorithm.
Freling et al. (2001) discussed the case of single-depot with identical vehicles, concentrating on quasi-assignment formulations and auction algorithms.
Haghani et al. (2003) compared three vehicle scheduling models: one multiple-depot (presented by Banihashemi and Haghani, 2002) and two single-depot formulations which are special cases of the multiple-depot problem. The analysis showed that a single-depot vehicle scheduling model performed better under certain conditions.
Huisman et al. (2004) proposed a dynamic formulation of the multi-depot vehicle scheduling problem. The traditional, static vehicle scheduling problem assumes that travel times are a fixed input that enters the solution procedure only once; the dynamic formulation relaxes this assumption by solving a sequence of optimization problems for shorter periods.

3. FLEET SIZE REQUIRED FOR A SINGLE ROUTE

Here considers a case in which interlinings and deadheading (DH) trips are not allowed and each route operates separately. Let T_r be the average round-trip time, including layover and turn-around times, of a radial route r (departure and arrival points are same). The minimum fleet size is equal to the largest number of vehicles that departs within T_r.
Although Salzborn's model provides the base for fleet-size calculation, it relies on three assumptions that do not hold up in practice: (i) vehicle-departure rate is a continuous function of time, (ii) Tr is the same throughout the period under consideration, and (iii) route *r* is *a* radial route starting at a major point (e.g., CBD). In practice, departure times are discrete, average trip time is usually dependent on time-of-day, and a single transit route usually has different timetables for each direction of travel. For that reason, this section broadens Salzborn's model to account for practical operations planning.

4. DEFICIT-FUNCTION MODEL WITH DEAD-HEADING TRIP

The minimum-fleet-size problem may be approached with and without DH trips. A DH trip is an empty trip between two terminuses and is usually inserted into the schedule (*i*) to ensure that the schedule is balanced at the start and end of the day and (*ii*) to transfer a vehicle from one terminal where it is not needed to another where it is needed to service a required trip.

4.1 Definitions and Minimum Fleet Size

Let I = {i: i = l, ..., n} denote a set of required trips. The trips are conducted between a set of terminals K = {k: k = l, …,q}, each trip to be serviced by a single vehicle, and each vehicle able to service any trip. Each trip i can be represented as a 4-tuple $(p^i,\ t_s^i,\ q^i,\ t_e^i)$, in which the ordered elements denote departure terminal, departure (start) time, arrival terminal, and arrival (end) time. It is assumed that each trip i lies within a schedule horizon $[T_1, T_2]$ i.e., $T_1 \leq t_s^i \leq t_e^i \leq T_2$. The set of all trips S = { $(p^i,\ t_s^i,\ q^i,\ t_e^i) : p^i,\ q^i \in K$, $i \in I$ } constitutes the timetable. Two trips *i*, *j* may be serviced sequentially (feasibly joined) by the same vehicle if and only if (a) $t_e^i \leq t_s^j$ and (b) $q^i = p^j$.
If *i* is feasibly joined to *j*, then i is said to be the predecessor of *j*, and j the successor of *i*. A sequence of trips i_1, i_2,…, i_w ordered in such a way that each adjacent pair of trips satisfies (a) and (b) is called a chain or block. It follows that a chain is a set of trips that can be serviced by a single vehicle. A set of chains in which each trip i is included in I exactly once is said to constitute a vehicle schedule. The problem of finding the minimum number of chains for a fixed schedule S is defined as the minimum fleet- size problem.
Let us define a DH trip as an empty trip from some terminal p to some terminal q in time $\tau(p,q)$. If it is permissible to introduce DH trips into the schedule, then conditions (a) and (b) for the feasible joining of two trips, i, j, may be replaced by the following:

$t_e^i + \tau\,(q^i,\ p^i) \le t_s^j$ (1)

Let us introduce a deficit-function-based model.

4.2 Deficit-Function Model

A deficit function (DF) is a step function defined across the schedule horizon increases by one at the time of each trip departure and decreases by one at the time of each trip arrival. This step function is called a deficit function (DF) because it represents the deficit number of vehicles, required at a particular terminal in a multi-terminal transit system. To construct a set of DFs, the only information needed is a timetable of required trips. The main advantage of the DF is its visual nature. Let d(k,t,S) denote the DF for terminal k at time t for schedule S. The value of d(k,t,S) represents the total number of departures minus the total number of trip arrivals at terminal k, up to and including time t. The maximum value of d(k,t,S) over the schedule horizon [T_1, T_2], designated D(k,S), depicts the deficit number of vehicles required at k.

The DF notations are presented in Figure 1 below, in which [T_1, T_2] = [5:00, 8:30]. It is possible to partition the schedule horizon of d(k,t) into a sequence of alternating hollow and maximum intervals (H_0^k, M_1^k, H_1^k,…, H_j^k, M_{j+1}^k,$M_{n(k)}^k$,

$H_{n(k)}^k$). Note that S will be deleted when it is clear which underlying schedule is being considered. Maximum intervals $M_j^k = [\ s_j^k,\ e_j^k]$, *j* = 1, 2,..., *n*(*k*) define the intervals of time over which d(*k*,*t*) takes on its maximum value. Index *j* represents the *j*-th maximum intervals from the left; n(*k*) represents the total number of maximal intervals in d(*k*,*t*), where s_j^k is the departure time for a trip leaving terminal *k* and e_j^k is the time of arrival at terminal *k* for this trip. The one exception occurs when the DF reaches its maximum value at M_j^k and is not followed by an arrival, in which case $e_j^k = T_2$.

A hollow interval H_j^k, *j* = 0,1,2,…,n(*k*) is defined as the interval between two maximum times: this includes the first hollow, from T_1 to the first maximum interval, $H_0^k = [T_1, s_1^k]$; and the last hollow, which is from the last interval to T_2, $H_{n(k)}^k = [\ e_{n(k)}^k, T_2]$. Hollows may contain only one point; if this case is not on the schedule horizon boundaries (T_1 or T_2), the graphical representation of d(*k*,*t*) is emphasized by a clear dot.

The sum of all DFs over k is defined as the overall DF, g(t) $= \sum_{k\in K} d(k,t)$. This function g(t) represents the number of trips that are simultaneously in operation; i.e., a count, from a bird's-eye view at time *t*, of the number of vehicles in actual service over the entire transit network of routes. The maximum value of g(t), G(S), is exploited for a determination of the lower bound on the fleet size. An example of a two-terminal operation, a fixed schedule of trips, and the corresponding set of DFs and notations is illustrated in Figure 2.

Determining the minimum fleet size, D(S), from the set of DFs is simple enough - one merely adds up the deficits of all the terminals. In the example in Figure 1below without DH trips, D(S) = D(a) + D(b).

When F_k = the number of vehicles present in terminal *k* at the start of the schedule horizon T_1; let s(*k, t*) and e(*k, t*) be the cumulative number of trips starting and ending at *k* from T_1 up to and including time t. The number of vehicles remaining at *k* at time t ≥ T_1 is F_k - s(*k, t*) + e(*k, t*).

In order to service all trips leaving *k*, the above expression must be non-negative; i.e., $F_k \ge$ s(*k, t*) - e(*k, t*), $T_1 \le t \le T_2$. The minimum number of vehicles required at *k* is then equal to the maximum deficit at *k*. Min F_k = Max_t [s(*k, t*) - e(*k, t*)] = Max_t d(*k, t*). Therefore, the minimum number of vehicles required for all terminals in the system is equal to the total deficit

$$Min\ N = \sum_{k\in K} MinF_k = \sum_{k\in K} d(k) = D(S)$$
(2)

or

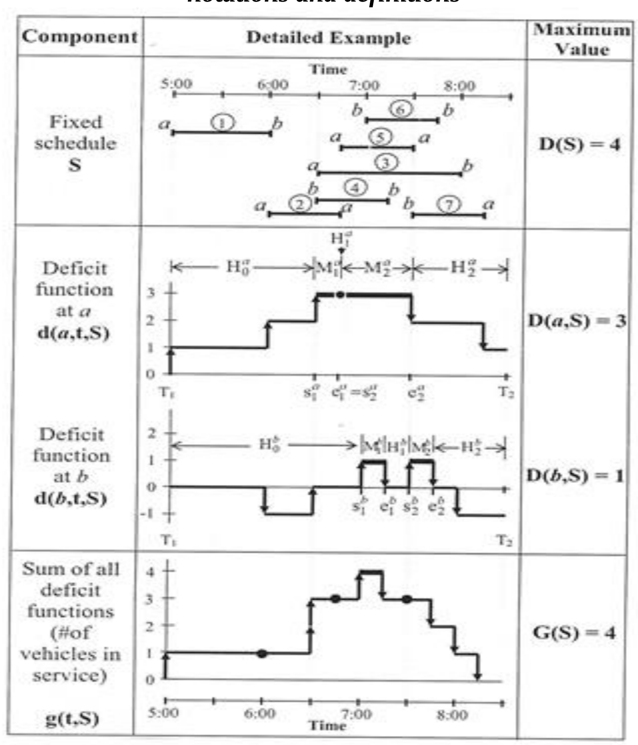
$$Min\ N = \sum_{k\in K} D(k) = \sum_{\substack{t\in[T1,T2]\\ k\in K}} max\ d(k,t) \quad (3)$$

4.3 DH Trip Insertion

A DH trip is an empty trip between the ends of a single route. Always, a trip schedule received from operating personnel includes such deadheading trips, and it is easy to apply the fleet-size formula to determine the minimum fleet size, followed by the first in-first out rule to construct each vehicle's schedule. The assumption is that the trip schedule S has been purged of all DH trips, leaving only required trips. From this point, the question of how to insert deadheading trips into the schedule in order to further reduce the fleet size will be examined. At first, it seems counterintuitive it can be achieved, since it implies that increased work (adding trips to the schedule) can be carried out with decreased resources (fewer vehicles). This section will show through an examination of the effect of such deadheading trip insertions on deficit functions that it is indeed possible. When given configuration, according to the fleet-size formula, five vehicles are required at terminal a, and six at terminal b for a fleet size of eleven. After the introduction of this DH trip into the schedule, the net effect is a reduction in fleet size by one unit at terminal b. Ceder (2002, 2003) shows that a chain of DH trips may be required for the reductionof the fleet size by one. All successful DH trip chains follow a common pattern. The initial DH trip is introduced to arrive in the first hollow of a terminal in which a reduction is desired. This DH trip must depart from some hollow of another terminal. Moving to the end of this hollow, another DH trip is inserted, such that its arrival epoch will compensate for the departure epoch added by the first DH trip. This is followed by additional compensating trips; however, in order to avoid looping, no more than one DH trip will be allowed to depart from the same empty. Each time a DH trip is inserted (from p to q) to arrive at the end of a hollow H_i^q from the start of a hollow H_j^q, it must pass a feasibility test; i.e., $e_j^q + \tau\ (p.q) \le s_{i+1}^k$. If the inequality is true with smaller, then there will be some slack time, during which the DH trip can be shifted. Let this slack time be defined as $\delta_{pq} = s_{i+1}^k - [e_j^p + \tau\ (p.q)]$. In practice, if the DH time plus the slack time are greate r than or equal to the average service travel time, then a service trip may replace the DH trip. In this way, an additional service trip is introduced, thereby resulting in higher frequency (i.e., an improved level of service) at usually the same operational cost.

The process ends when a final hollow of some terminal q is reached (i.e., $H_i^q = H_{n(q)}^q$), after which no compensation is necessary. It is possible to arrive at a point where no feasible compensating DH trips can be inserted, in which case the procedure terminates or one may back track to the arrival point of the last DH trip added and try to replace it with another. This procedure results in a sequence of DH trips known as a unit reduction dead-heading chain (URDHC) if it ends successfully (i.e., if it reduces the fleet size by a unit amount). Clearly, the continued reward for such a search must stop, and the Lower Bound Theorem (Ceder, 2002) provides a condition when it is futile to continue this search; this lower bound is based on the sum of DFs, g(t), and its maximum value G(S).

Fig. 1: Illustration of two-terminal fixed schedule with associated deficit functions and their sum, including notations and definitions



5. CONCLUSION

This study examined the effect of vehicle planning on an urban passenger transport line with a fixed schedule. In the model described above, two variants of optimizing the number of rolling stock are considered. In the research is showns that the minimum-fleet-size problem may be approached with and without DH trip. In the case of no deadheading (DH) trips, departures must be performed by different vehicles at both final stops. In case there are no entanglements (between the routes) and there are no trips with DH, the minimum the size of the fleet required for the route is the maximum departing from the final bus stops. A small amount of shifting in scheduled departure times becomes almost common in practice when attempting to minimize fleet size or the number of vehicles required. A common practice in vehicle scheduling is to use time-space diagrams. Each line in the diagram represents a trip moving over time (x-axis). Although many schedulers became accustomed to this description, it is cumbersome, if not impossible, to use these diagrams to make changes and improvements in the scheduling. It is also difficult to use different average speeds for different route segments, in which the lines in the time-space diagram can cross one another; this is not to mention the inconvenience of using these diagrams manually for inserting deadheading trips and/or shifting departure times. These limitations of the time-space diagram caused us to look more closely into more appealing approaches – those that are presented in this research.

In practical single-route transit-vehicle scheduling, schedulers should attempt to allocate vehicles in the most efficient manner possible, including the insertion of deadheading (DH) trips and the employment of small shifts in departure times. Moreover, some DH trip insertions are combined with small shifts in the departure times to allow these insertions; thus, reducing the fleet size and vehicle cost required. Finally, it is believed that prudent usage of vehicles by the consideration of different can support making the need for travel more economical and saving resources.

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