TIMETABLING PROBLEM AND INTERVAL SYNCHRONIZATION IN URBAN PUBLIC TRANSPORT

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Abstract

The paper is devoted to the timetabling problem and interval synchronization in urban public communication, which is considered as an important issue in urban transport networks with long overlapping route segments. The main objective of interval synchronization is to determine the timetable of lines sharing route segments, so that the waiting time between arrivals of consecutive buses can be balanced. Although the experts agree on the objective, different approaches to the interval synchronization problem in urban public communication can be observed. In this paper approaches to this problem are reviewed from the perspective of specific goals adopted, models developed for the problem, and methods used for solving them.

Keywords: Interval synchronization, public transport, city transport, timetabling problem, transportation planning

1. INTRODUCTION

Interval synchronization of lines can be considered as a crucial issue in urban public transport (UPT) networks with long overlapping route segments. UPT systems with long overlapping route segments are becoming more often observed as metropolitan areas and agglomerations grow and include suburban residential areas into their territorial administration. Significantly huge mass of people travel every day from home to work and back, and they need to be provided with efficient, comfortable, and robust collective transport, so that they have a real alternative to private cars. Leaving private cars at home and switching to collective transport result in reducing emission, noise, and traffic congestion. Therefore, providing efficient collective transport service is listed among priorities of sustainable urban mobility paradigm [17, 18, 19, 21, 22, 25, 27, 28, 29, 30, 31, 32]. No matter what type of metropolitan or urban public transport network is adopted in modern megapolises, there are route segments - usually considerably long ones - linking ends of the network (e.g. park & ride hubs) with stops of the ring line in the downtown or with intermodal transfer hubs. When such long route segments are served by more than one line, there appears the need to avoid bus (or tram) bunching and to make the waiting time between consecutive arrivals of any line evenly-spaced [4, 7, 16, 20, 24]. That need can be considered to be the foundations of the interval synchronization problem in UPT.

The substantial literature and optimization models for interval synchronization problem in UPT seems to be scarce, e.g. [6, 8, 9, 16, 24,] in contrary to transfer synchronization problem, which is investigated more frequently, e.g. [1, 2, 5, 11, 15, 17, 18, 19, 21, 22, 23]. The main objective of interval synchronization in UPT is to determine the timetable (usually departure time from the first stops) for lines sharing route segments, so that the waiting time between arrivals of consecutive buses at a shared stop can be balanced and bus bunching can be avoided. Although the experts agree on the general objective, different approaches to dealing with interval synchronization problem in urban public communication can be observed.

In this paper selected approaches to interval synchronization problem are reviewed from the perspective of specific goals adopted, models developed for the problem, and methods used for solving them. The paper is organized as follows. We begin with general description of the interval synchronization problem in UTP; we provide the review of formulations of this problem. We put the emphasis here to the importance of interval synchronization in the bigger timetabling and UTP synchronization problems which cover also other aspects of UTP planning. Next, we provide a review of optimization models for interval synchronization problem in UTP. For works, where optimization models for interval synchronization were not presented, we reviewed conceptual models on which algorithms for timetabling generation were based. In conclusions, we collect recommended directions of the interval synchronization problem in UTP development as well as suggested methods to be used for solving this problem in the near future.

2. INTERVAL SYNCHRONIZATION IN URBAN PUBLIC TRANSPORT

Interval synchronization problem in UPT can be defined as finding departure times of all trips of all lines which share overlapping route segments, in order to make time gaps between their arrivals at stops belonging to the shared segments as even as possible. Specific character of interval synchronization can be easily observed when compared to transfer synchronization [1, 6, 16, 24]. In **Figures 1** and **2** we present scratches of network segments, where interval (**Figure 1**) and transfer (**Figure 2**) synchronization is needed. In interval synchronization are interested passengers whose origin and destination belong to the long route segment served by several lines. These passengers can travel with any line serving the route segment, so they do not follow the timetable of lines. The worst synchronization here is the one resulting in bus bunching, while the best timetabling is the one which makes passengers remember only one number - time gap between consecutive arrivals. Interval synchronization becomes even more important at overlapping long route segments served by lines of small ride frequency (e.g. 3 rides per hour); in such case bus bunching results in considerably long waiting time between consecutive bunches. Therefore, the goal of interval synchronization is to obtain even (what is hardly possible) or almost even time gap (the interval) between two consecutive arrivals at the shared stop. Interval synchronization depends significantly on other assumptions - flexible / fixed headways, ride frequency, number of lines to be synchronized etc.

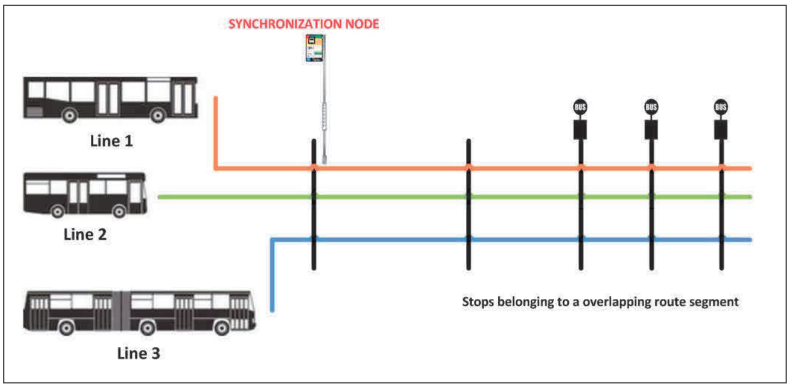

Figure 1 A long route segment where interval synchronization in UTP is needed. Source: [6]

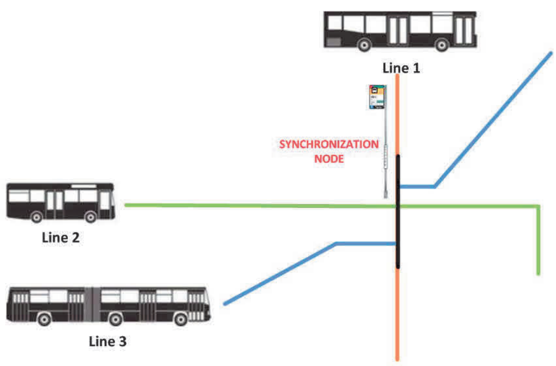

Figure 2 A transfer node where transfer synchronization in UTP is needed. Source: [6]

The main visible result of interval synchronization is preventing buses from bunching. It is typical for long route segments served by more than one line that buses arrive at shared stops simultaneously or almost simultaneously. And it is not caused by traffic congestion, the timetable is just like that - because the timetable was synchronized globally for the whole network according to the superior objective was transfer synchronization at transfer hubs, and timetable at long radial segments was obtained as a consequence of that synchronization. Another result of interval synchronization is the increase of regularity and punctuality of public transport service at long route segments as well as at the entire network. Once time gap between consecutive arrivals at a given stop is even or almost even, the maximal time gap between consecutive arrivals at this stop also decreases. In consequence the distribution of passengers in vehicles serving the stop is more balanced, the number of overcrowded vehicles decreases, and, comfort of travel increases [5, 6].

Interval synchronization problem in UPT is not frequently addresses directly in work on UPT synchronization and timetabling problem - detailed reviews of synchronization and timetabling problems in UPT are to be found in e.g. [3], [6], [10], and [12] Interval synchronization is reduced to bus bunching problem and if a model or a method developed for transfer synchronization prevents buses from bunching, the model / method seems to be considered as well enough for dealing with synchronization at long overlapping route segments [1, 16, 20]. However, these methods do not reach the main goal of interval synchronization: arrivals at shared stops are not evenly spaced in time - it may happen for numerous datasets, but it does not happen on purpose. In such models / methods the goal is to maximize the number of pairs of arrivals of different lines between which time gap is greater than a predefined value [4, 13, 14, 15, 16].

As interval synchronization aims at congestion avoidance, the main objective here is obtaining evenly-spaced intervals between arrivals of lines *A* and *B* as well as between arrivals of lines *B* and *A*. There are works where recommended interval is computed basing on lines' headways and then it is introduced to the model as a parameter [1, 24]. Obviously, this approach is correct for UPT systems with fixed headways, where headways are each other's multiplies [1, 24], and / or in systems with predefined precedence of lines serving shared overlapping route segment [24].

3. MODELS FOR INTERVAL SYNCHRONIZATION PROBLEM IN URBAN PUBLIC TRANSPORT

[1] addresses interval synchronization problem in UPT very briefly. In order to obtain evenly-spaced timetable at the route segment served by one line it is recommended to set and executed fixed headway during the planning period. Fixed headways are also recommended for a group of line serving shared route sector; headways should be equal or be each other multiplies - synchronization cycle is determined by the longest headway. For this predefined sequence of lines, intervals between lines are computed basing on relation between headways. A non-linear programming model is briefly introduced. The objective here is to minimize the average waiting time. The author neither presents it in details nor specifies the algorithm used for searching for solutions.

The inspiration for [1] was [26], where synchronization problem was formulated as the quadratic semi-assignment problem and a tabu search algorithm was proposed for solving it. The model presented in [26] was the objective was to minimize the total transfer waiting time. Nevertheless, interval synchronization was also included in this model, since it also guarantees maintaining the security distances between vehicles sharing route segments.

[24] provides metaheuristics for interval simulation problem with fixed headways - despite the author declares that the model aims at obtaining evenly spaced timetable, the objective implemented in the model in minimization of the total waiting time. Results were obtained with a Monte-Carlo simulation combined with gradient descent.

Although minimization of the total of the average waiting time is an objective in numerous models for UTP synchronization problems, it does not seem to be the best choice. As interval synchronization aims at evenly spacing arrivals over a planning period, time gaps are more likely to exceed than to shorten. More proper objective here would be rather to maximize the total number of consecutive arrivals between which time gap are equal or almost equal.

In [6] multiple-criteria mixed-integer linear models (MCMILP) - Model *V* and Model *R* - are presented. Objectives introduced to the models guarantee maximization of the total number of pairs of arrivals between which time gap is the same (Model V) or equal to the recommended interval (Model R), at the same time the total difference between actual headways and recommended headways is minimized, the total extension of average travel time between nodes is minimized. The non-dominated solution is computed subject to headway flexibility constraints, synchronization constraints, arrival and departure time constraints, and variable non-negativity and integrality conditions. The models cover a wide range of interval synchronization problems; they can be used for obtaining single planning period single node timetables as well as for multiple planning period multiple node networks where headways change between planning periods. In both models flexible headways during each planning period are allowed. Model *V* can be used for finding the optimal interval for a node, which means that in a node the highest number of pairs of subsequent arrivals of different lines are separated from one another by the optimal interval. Model *R* allows the scheduler's intervention in the settings of synchronization: the scheduler defines the recommended interval as a parameter, and the total difference between optimal and recommended interval is minimized. Model *R* is useful especially for multiple node networks, where synchronization depends also on travel time between nodes, as having recommended interval as a parameter can force preferred interval at a chosen node. Model *V* and Model *R* determine the sequence of lines and synchronize trips, which is not typical for models dedicated to interval synchronization.

4. CONCLUSIVE REMARKS

Interval synchronization of radial lines is crucial for providing passengers with reliable collective transport service in networks with long overlapping route segments. Passengers traveling along a route segment served by several lines use so-called joint ride-frequency of the set of lines, so from their perspective a fixed separation time between consecutive arrivals would be perfect.

Due to scarcity of works addressing this problem directly, research in this area of interval synchronization problems in UPT should be continued. All the available models are suitable for simplified interval synchronization problems. A survey on the impact of interval synchronization on other subproblems of urban transport planning and managing on the timetabling problem [4, 12]. Advanced research on models containing precedence constraints [6] should be continued, since it seems to be promising direction for interval synchronization problems. Another direction of development of the interval synchronization problems in UPT is to conduct research with multiple planning periods, where ride frequencies can be different in every planning period [4, 6, 13, 29]. Two issues are faced here: determining the length of a planning period and assuring smooth transition between periods, especially in systems where flexible headways are allowed.

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