The Truly Integrated Integrated Timetable

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Abstract

With current methods, integrated fixed-interval timetables cannot be conclusively constructed for train types of different speeds or different intervals. All interfaces between long-distance, regional and commuter transport need to be defined manually. This jeopardizes the main idea of the integrated timetable, the overall reduction of riding time. The main effort therefore is a unification of these planning layers. The approach presented here does away with the traditional line graph timetable and planar network graphs to make room for a third dimension. While all infrastructure information stays in a plane, all time-related parameters are coded in the third dimension, thus integrating riding time, dwell time, and interval all in one single, infrastructure-independent, parameter. This way the strict principles of the integrated timetable can still be maintained at every level, while the integration between the levels is immanently included in the timetable model. The integrated timetable therefore really becomes integrated all the way through.

Keywords: railway, timetable, integrated timetable

1. INTRODUCTION

It is common consensus by now that the most economical way to design a railway timetable is to offer periodic timetables [1]. However, route networks require more than just a set of periodically repeating departures; they demand a network-wide integrated approach. Since no network can offer only direct rides, transfers across the whole network must be optimized so to reduce overall riding times.

2. EXISTING APPROACHES

Periodic Timetables can be optimized from two sides: (i) by providing riding times that allow for optimal transfer conditions or (ii) by providing an optimized timetable on the basis of existing riding times. Clearly, the second approach allows for short-term implementation, since the first method will likely demand infrastructure upgrades. However, the first approach leads to an enclosed optimization of transfers throughout the whole network.

2.1. Integrated Timetables

The Integrated Timetable as presented by Lichtenegger [5] is based on defined transfer hubs. These need to be linked according to two simple mathematical rules: The riding time between two hubs must be an integer multiple of half the interval, and a journey along any cycle within the network needs to take an integer multiple of the whole interval.

Formally, this leads to

$$t_F = n \cdot \frac{T}{2} \qquad (1)$$

$$\sum t_F = n \cdot T \qquad (2)$$

t_F … riding time between two hubs
$n \in \mathbb{N}$
T … interval

These simple formulae guarantee that (i) transfer points occur only where trains of opposite directions meet each other (see Eqn 1), and (ii) routes do not meet at hubs shifted towards each other (see Eqn 2). A network that fulfils these requirements will automatically present optimal transfer conditions at hubs.

The example network presented in Fig. 1 features two types of hubs. Hubs A, D, and E are shifted to hubs B, C, and F by half an interval. Given an hourly interval, the former could be hubs at the full hour, then the latter would be hubs at the half hour. As can be seen, all routes between the hubs feature riding times of integer multiples of half the interval and all cycles can be travelled in integer multiples of the full interval. Therefore, this network offers optimal transfer conditions at all hubs.

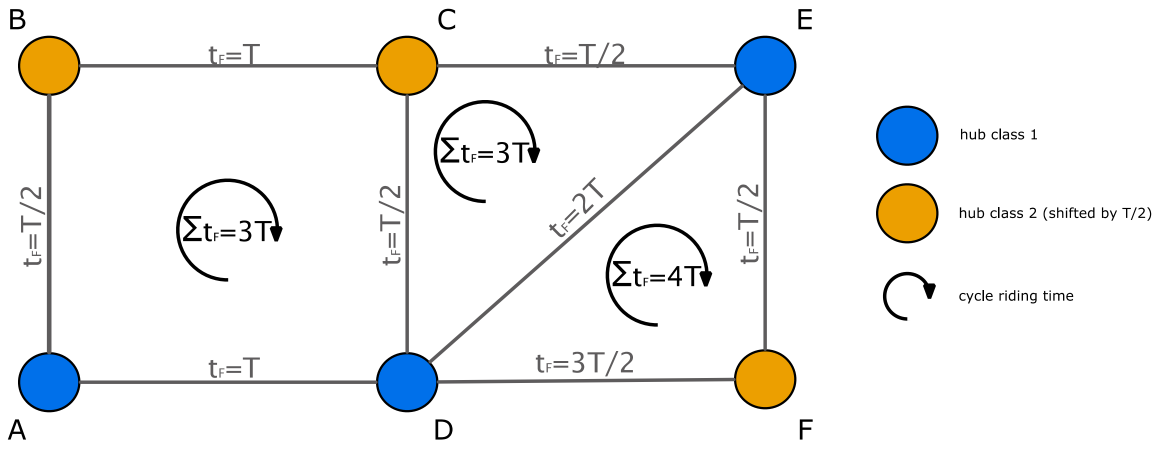

Fig. 1: Sample network with fulfilled riding time requirements

The Integrated Timetable has been implemented in many central European countries such as Switzerland, Austria, the Czech Republic and Hungary for long-distance traffic as well as in most German regional train networks.

The approaches of Weis [11], Uttenthaler [10], Hesse et al. [2], and Kormányos et al. [3] all aim at the implementation of the Integrated Timetable in model regions.

2.2. Periodic Timetable Optimization

Periodic Timetable Optimization as presented by Liebchen [6] aims at avoiding the very tight restrictions of the Integrated Timetable. Especially in urban areas, target riding times and infrastructure upgrades are often unachievable. Furthermore, tightly knit networks do not allow for the installation of hubs at every interchange station. In this approach, the problem is modelled as a so-called *Periodic Event Scheduling Problem* (PESP). With a given infrastructure and given constraints, this model will result in a set of solutions that allow for the best possible transfer conditions and therefore a global travel time minimum across the network.

This approach has successfully been implemented at the Berlin Metro network and has been in operation since 2004. Comparable approaches are presented by Peeters [8], Kroon et al. [4], Schröder and Schüle [9], and Marauli [7] with different methodologies.

3. SHORTCOMINGS

3.1. Coordination of Integrated Timetables with Timetable Optimization

The two approaches towards timetable construction both have reasonable fields of application and both have proven successful within their implementations. Yet interfaces between them do occur wherever densely-knit urban networks meet with long-distance or regional networks. These interfaces can be defined only as static constraints, so an integrated planning process is impossible. This problem can be overcome to a certain extent by a hierarchical planning approach with several iterations.

3.2. Mixed traffic

Train networks on lines with mixed traffic usually feature several different riding times between hubs as well as different intervals for each train type. Therefore, what would work as a timetable solution for one train type usually does not work for another. In the model network in Fig. 2, only at station A is there a full hub, while all the other stations feature a hub shifted by a quarter of the interval, in this case 15 minutes. So both preconditions for an Integrated Timetable are met in the outer network, whereas the inner network does not meet the first precondition for stations B and D (it does fulfill the second condition regarding the denser interval on the local lines B–C and C–D). The networks can be mutually attached at one hub only. Any constraints of connection between the train systems at hubs B, C, and D need to be set manually.

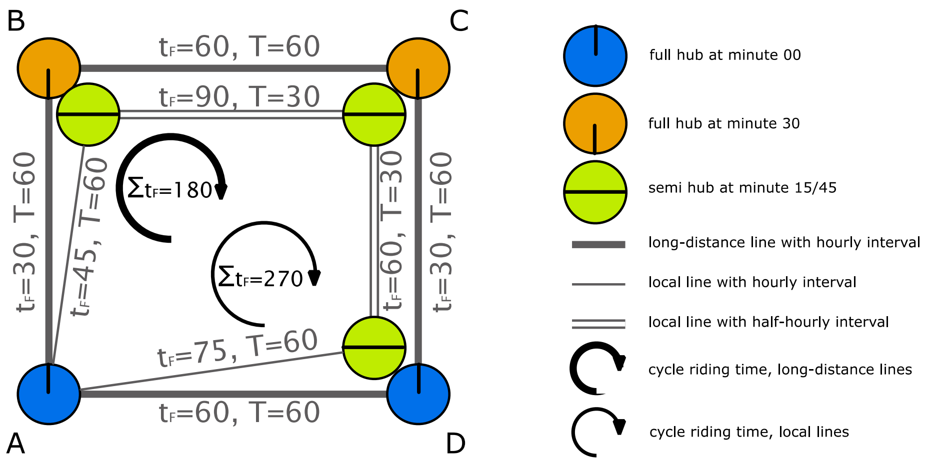

Fig. 2: Part of the sample network with mixed traffic

Generally, different riding times could be modeled by separate routes between hubs. Then, the riding times of the different train types must differ by an integer multiple of the interval, which often results in significantly slowing down the slower train system. Different intervals could be modeled by modeling the whole network with the shortest interval and then successively deleting excess rides, but the solution will not be optimized for transfers between lines with longer intervals. Schröder and Schüle [9] as well as Marauli [7] work with complete enumeration, so their results are independent from the interval, but they cannot obey constraints in transfer conditions or variations in trip riding times. So no present approach can model mixed traffic.

3.3. Semi hubs

As indicated above, Integrated Timetables may consist not only of full hubs (in case of an hourly interval this would be a hub at the full and the half hour) but also of semi hubs (in the case of an hourly interval they are shifted by 15 minutes). “Semi” refers to the fact that only half the connections meet, and only half the transfers are possible in the hub. In Fig. 3, a full hub is displayed on the left and a semi hub on the right. While transfers between all trains are possible in the full hub, the semi hub allows for transfers only in the same direction.

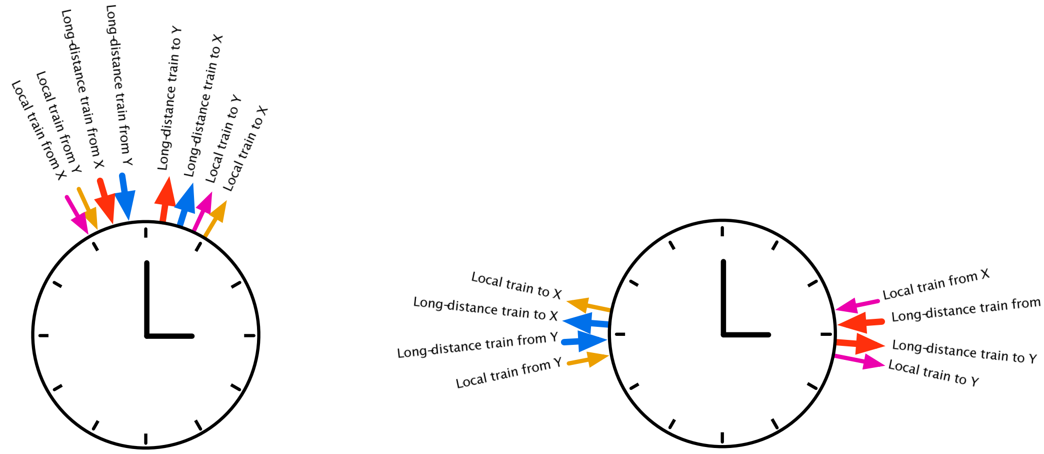

Fig. 3: full hub (left) and semi hub (right)

Semi hubs are a very important additional feature of Integrated Timetables if applied to a station at line branchings: if two routes halve each other's intervals on a combined stretch, they will be shifted by half the interval at any station. If the station at the branching were a full hub, this would mean that a transfer between the branches also takes half an interval. But if the station is a semi hub, this means that a train directed to one branch will meet there with a train coming from the other branch and a transfer becomes possible.

In Fig. 4, the two lines coming from station G (full hub at minutes 00 and 30) will approach the branching station H at minutes 15 and 45. The train directed to I will therefore meet the train coming from J in station H, so a transfer from I to J and vice versa is possible.

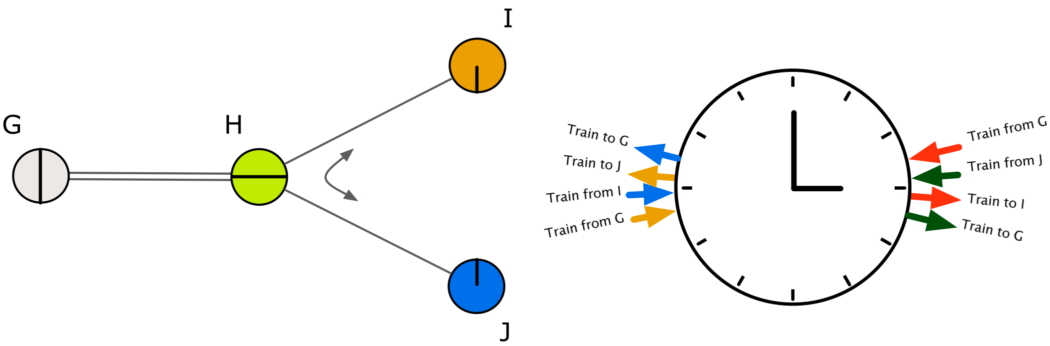

Fig. 4: Semi hub on a line branching

Modelling a semi hub in an Integrated Timetable is currently possible only with additional information outside the basic data. Since the riding time requirements apply to full hubs only, there is no information on which train will serve the semi hub at which time. An integrated consideration of semi hubs is therefore not possible at the moment.

3.4. Selective service of hubs

One principle of the Integrated Timetable is that trains arrive and depart hierarchically: Important trains arrive last and depart first, while local trains will arrive first and depart last. The latter results in a rather long dwell time that is not very attractive for passengers remaining in the vehicle. Furthermore, the early arrival and late departure cut the necessary riding time to the next hub, which may lead to problems achieving the desired timetable structure. One good solution in the first place is to reconstruct station gridirons to allow for parallel arrivals and departures. Nevertheless, the dwell time for hierarchically low trains is also bounded by the minimum transfer time, which can amount to up to ten minutes in bigger stations. If local traffic runs with dense intervals, the dwell time can almost equal the interval.

One solution to reduce this dwell time is not to serve the hub by the local trains, but to arrive *and* depart again before the hub time with one train and to have the next train repeat this pattern after the hub time. The transfer time will not increase significantly if the interval of the local trains is rather dense, and still the dwell time can be reduced to the time necessary for boarding and alighting. In Fig. 5, the long distance trains serve the hub at the full hour, while the urban transport, running at a 15-minute headway, arrives and departs outside the hub time. Transfer time will still not exceed nine minutes in this example.

With current approaches, this situation also cannot be modeled, since the transfer constraints need to be set manually.

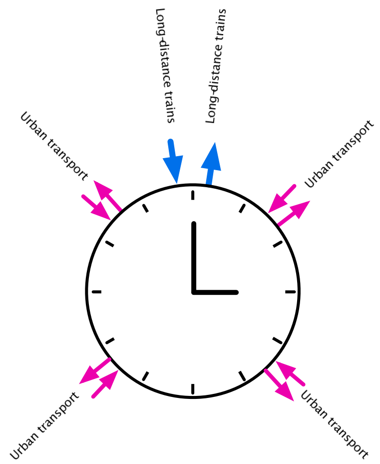

Fig. 5: Selectively served hub

4. THE THREE-DIMENSIONAL APPROACH

Technically, the modeling of a network timetable does not rely on dimensions in a geometrical sense at all. Any timetable model will have time-related events coded separately and the topology of the network modeled as some kind of graph. The problem with this kind of data representation is that the link between the riding time and the network topology is lost, which leads to the problems with mixed traffic as stated above.

The approach presented here builds upon a two-dimensional representation of the network topology and train trajectories in the third dimension. This graph can be imagined like a set of traditional train graphs flipped vertically above the corresponding lines. Therefore, the hitherto separate representations of travel time and interval appear in the same dimension and can be treated simultaneously.

The main advantage of this kind of model is that principal timetable construction rules can now be used for an integrated planning process of several layers of the timetable, not just for only one train type. Any time-related parameters simply add up in the train trajectories and can simply be checked for compatibility with the Integrated Timetable. Axes of symmetry (and therefore the time at which hubs are served) now show up as horizontal planes intersecting the vertical train graphs. Travel chains can be traced along the network and checked for feasibility. To illustrate the major advance within this approach, it will be applied to the three main shortcomings of the Integrated Timetable as mentioned above.

4.1. Mixed traffic

As shown in Fig. 6, the formerly complex hub structure shown for the sample network presented above turns into easily recognizable timetable patterns. The stations now have turned into vertical columns to which the train trajectories are linked. Station A can be identified as a full hub now (all trajectories meet at the same point). At station D, it now becomes apparent that the shift by 15 minutes results in a lost transfer, so a desired transfer from a local train from A (thin, dark blue trajectory) to a long-distance train directed to C (thick, light orange trajectory) at station D results in a waiting time of 45 minutes.

The three-dimensional approach now allows a direct evaluation of the timetable dependencies as well as an improved modeling of the already known rules of the Integrated Timetable. The different train types of mixed traffic (no matter whether they differ in riding time or interval or both) can now be modeled together, as they appear on the time axis together and their different properties are reflected within the time axis together.

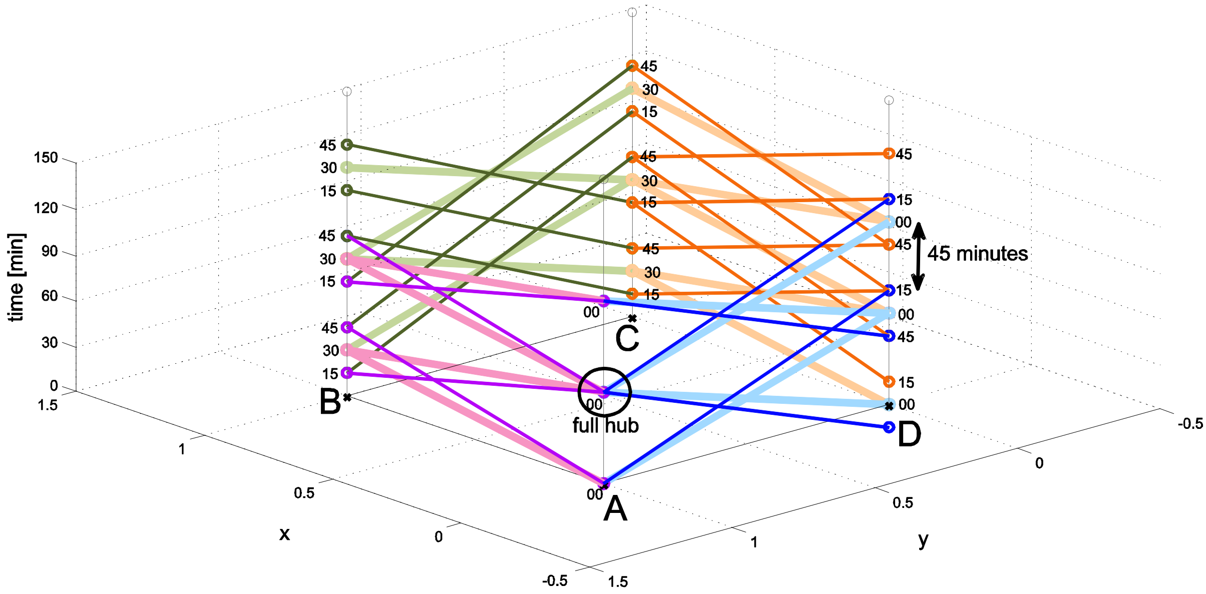

Fig. 6: Sample network with mixed traffic. (Note: x and y denote a schematic representation of 2D space)

4.2. Semi hubs

As indicated in the previous section, the current model of semi hubs does not allow a conclusion of the transfer quality without the knowledge of further parameters and extra manual work. When train trajectories are modeled three-dimensionally, the information about semi hubs does not need any extra work, since it is included in the model itself. Fig. 7 shows two cases of semi hubs: on the left, there are trains going from P to R and from P to S. They share the stretch between P and Q, where they mutually halve each other's intervals. They reach the branching station Q after one quarter of the interval (the train from P to R starts at minute 00, reaches Q at minute 15 and arrives in R at minute 30), where the trains of opposite directions are shifted by 30 minutes (the train from R to P starts at minute 30, reaches Q at minute 45 and arrives at P at minute 60). As the trains between P and S are shifted by half an interval, they serve station Q just the opposite way (the train from P to S reaches Q at minute 45, the train from S to P is there at minute 15). So there are optimal transfer conditions to go from one branch to the other.

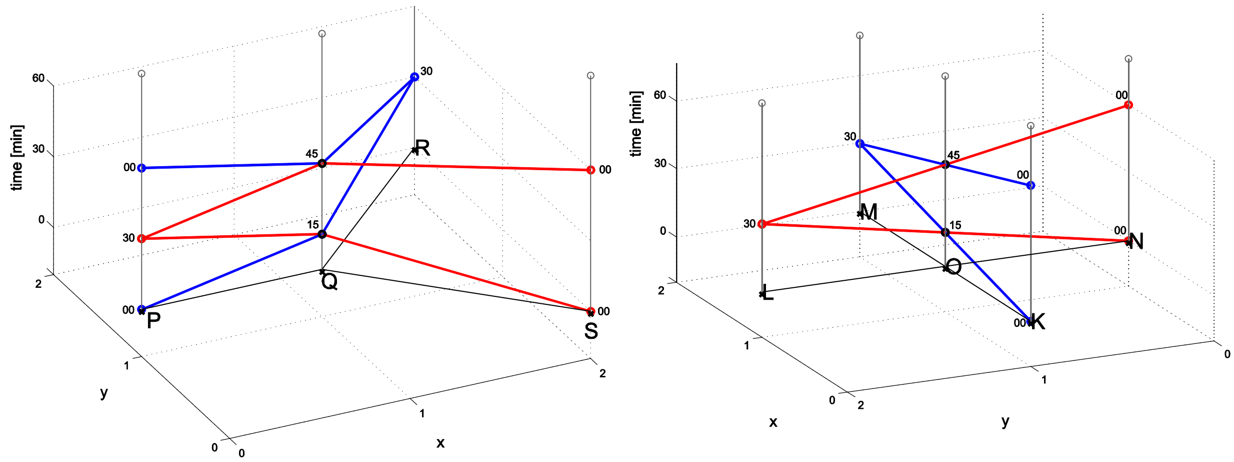

Fig. 7: Semi hub at branchings (left) and interchange stations (right)

The right figure depicts a situation where the network is too densely knit to allow full hubs at every interchange. In this case, semi hubs can used to allow transfers in two preferred directions, while the other two will not work. In the figure, the transfers K⇔L and N⇔M are possible, while L⇔M and K⇔N are not possible. As can easily be seen in the figure, the three-dimensional approach can model this situation without any additional information.

4.3. Selectively served hubs

Finally, the question of selectively served hubs can be solved with the three-dimensional approach: Since the trajectories implicitly contain information about the passage of intermediate stations, the information about the transfer quality at the hub not served by the line with the denser interval can be obtained directly from the timetable model. In Fig. 8, the main line would go from T to V, serving the interchange station X as a full hub. The urban line between U and W crosses the main line at X but serves the hub half its interval before and half its interval afterwards. The transfer times still stay low, while the dwell time is also reduced to the minimum time required for boarding and alighting.

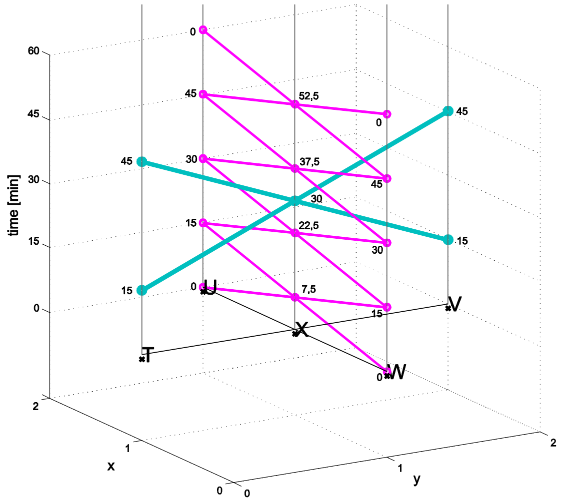

Fig. 8: Selectively served hub

5. OUTLOOK

The three-dimensional approach of the Integrated Timetable has only recently been constructed and is still undergoing development. The approach is a crucial evolution of the Integrated Timetable, so that the development of network timetables can finally be extended to an integrated planning of several train types, regional bus networks and urban transport. As can be seen, this approach effectively tackles the main problems of multi-level timetable integration.

The next step will be the implementation of the presented approach to a much larger, real network as well as the rigid formulation of the timetable construction rules that proved so successful in the last years. With that knowledge, a set of precise design strategies for large networks can be constructed. This achievement will finally lead to a truly integrated Integrated Timetable.

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