Identification of Timetable Attractiveness Parameters by an International Literature Review

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1 Abstract

Timetable attractiveness is influenced by a set of key parameters which are described in this article. Regarding the superior structure of the timetable, the trend in Europe goes towards periodic regular interval timetables. Regular departures and focus on optimal transfer possibilities make these timetables attractive. The travel time in the timetable depends on characteristics of the infrastructure and rolling stock, heterogeneity of the planned train traffic and the necessary number of transfers on the passenger's journey. Planned interdependencies between trains, such as transfers and heterogeneous traffic, add complexity to the timetable. The risk of spreading initial delays to other trains and parts of the network increases with the level of timetable complexity.

Keywords: Timetable, Railway timetable, timetable attractiveness, timetable structure, timetable complexity, travel time, transfers, punctuality and reliability

2 Introduction

This article summarizes some of the European research on how to create better timetables. This is done by identifying and examining some of the most important parameters that make timetables attractive towards the customers of the railway sector.

If a person wants to travel from one place to another the journey will be made in the most attractive way according to the person. Most attractive meaning the "cheapest" way in respect to journey costs e.g. travel time and number of necessary transfers. The attractiveness of the railway depends on the given valid railway timetable and the reputation of the topical train operating company (TOC).

Looking at a timetable it is possible to examine:

- The scheduled **travel time** when using the railway for the journey or a part hereof
- Number of **needed transfers** to make the railway journey
- Planned **transfer time** at a given transfer station and if the transfer time ensures that the interchange between trains can be made in the most common operational situations

- Number of **departures** per hour and thereby the amount of planned hidden waiting time in the timetable
- Departures in **regular intervals** such as each 10, 15, 20, 30 or 60 minutes
- Trains **available** when needed e.g. late evening or early morning

The reputation of the TOC will depend on:

- The **punctuality** – how many trains arrive on time after a given on time criteria e.g. less than 5 minutes delayed at arrival
- The **reliability** – how many trains are cancelled during a given period of time
- The **seating capacity** of the trains
- The **level of comfort** in the trains

All these parameters come together in the railway timetable. The level of achievable timetable attractiveness depends on several conditions. This is because the railway system consists of infrastructure (e.g. number of tracks, stations and interlocking systems giving the headway times) and traffic (e.g. intercity, local and freight trains) using the infrastructure. Combining the potential of infrastructure with the capability of rolling stock (driving characteristics and size of fleet), possibilities with train staff (number of employees and flexibility) and demand for traffic gives the frame work for, and thereby also the complexity of the timetable. If the goal is to run as many trains as possible on the infrastructure the train traffic has to be 100% homogenous and be running at optimal speed [10][15].

The attractiveness parameters mentioned above will be examined in section 3. Section 3.1 examines the factors that describe the superior timetable structure and advantages/disadvantages of an Integrated Fixed Interval Timetable (IFIT). This is followed by timetable complexity in section 3.2 that describes interdependencies in the timetable and lists advantages/disadvantages of a complex timetable. Possible travel time and benchmarking hereof are described in section 3.3. Factors that influence punctuality and reliability of a railway service are dealt with in section 3.4. This section also describes the existing philosophies to improve punctuality and reliability. In Section 3.5 transfers between trains at stations are examined. This includes optimal transfer time and factors that prolong the transfer time. Finally, section 4 draws up the conclusion and identifies subjects for further research.

3 Timetable attractiveness parameters

A timetable is a compromise between interests of different TOCS and the railway infrastructure manager (IM). TOCS have a range of services, ranging from high speed trains to freight trains and local trains that they want to operate on the infrastructure. On the other side, the IM wants to sell as much infrastructure capacity as possible but also needs to reserve capacity for maintenance activities and buffer times between trains.

In this section, the earlier mentioned attractiveness parameters will be grouped into themes and described further. The themes are timetable structure, timetable complexity, travel time, transfers and punctuality.

3.1 Timetable structure

The superior structure of the timetable can be described by 4 factors [21]:

- **Periodicity/regularity** – The entire timetable, or a part of it, is a repeating pattern over a period of time e.g. 1 hour. Also called a regular interval timetable
- **Symmetry** – the pattern applies for all driving directions for a given train service
- **Constraints on line sections** – the heterogeneity of the train traffic on a given line section is an important parameter for the capacity consumption, travel time, number of needed transfers and traffic punctuality
- **Constraints in stations** – at stations transfer possibilities between trains have to be taken into account. Same goes for train crew and rolling stock scheduling aspects

In Europe the periodicity/regularity parameter has been given much attention since it has been proven that this is one of the most important parameters regarding timetable attractiveness towards customers. Therefore, most countries strive to generate a 100% periodic timetable, also called an IFIT-timetable [2]. One of the best examples is the Swiss "Bahn 2000" timetable. The word "Integrated" refers to special focus on minimal time loss connected with train interchanges in the timetable. This is done by selecting a number of transfer nodes where trains from all connecting railway lines meet at the same time and thereby create optimal transfer possibilities which again ensures optimal travel time [15].

Although more and more countries tend towards implementing periodic timetables there are both advantages and disadvantages associated with this type of timetable structure. In Table 1 are listed the most important advantages and disadvantages associated with a periodic timetable.

Advantages	**Disadvantages**
• Logical and coherent timetable for the entire network • Well defined hierarchy of services • Focus on short transfer times at selected junctions/stations	• Regular interval timetables can be difficult to plan for a railway network with the ongoing liberalization of the railway sector. All involved TOCS have to be interested in achieving this kind of timetable

• Regular service intervals reduces the risk for passengers concerning train interchanges • Regular intervals minimize waiting time for randomly arriving customers at train stations • Best use of capacity because of systematic planning and regularity • Repeating patterns are easy to market and memorize for customers. Thereby reducing customers effort of finding departure times of trains and planning the train journey • Symmetric services in all driving directions	• Difficult to fit the number of departures to time sensitive markets or groups of customers. The basic structure of the timetable will not always give the possibility to run extra trains during specific hours of the day • Achieving absolute periodicity can create a high level of rigidity in the timetable thereby causing loss of business • Transfers are often needed to get through the network resulting in longer travel times

Table 1: Advantages and disadvantages of a periodic timetable [5] [15] [20] [21].

Experience shows that an IFIT-timetable gains most advantage when there are 2 or preferable more departures pr. hour on a given train service. The most attractive departure times at important stations are minute x0 and x5 e.g. 00, 05, 10, 15 etc. These numbers are easy to remember and make it easy to use a given train service. Having a high frequency of trains gives the opportunity for passengers to show up at a station randomly. Less planning is needed before starting the journey [20].

In Germany investigations have been made regarding the improvement of regional railway attractiveness. They conclude that in a long term perspective the potential increase of passengers is at least proportional to the increase in service e.g. train km and/or number of departures pr. hour [3].

3.2 Timetable complexity

Timetables are an agreement and a compromise between several actors and therefore, complicated to work out. In the railway business it is an agreement between TOCS and the IM about how many trains of which type are running and at what time. The TOCS had to make compromises with each other via the IM to get a conflict-free and valid timetable. This has possibly let to a situation where some TOCS did not get all their primary wishes regarding their train services fulfilled.

The complexity of a timetable is characterized by the interdependencies in the timetable. Interdependencies can be found on an open line or a railway station [5][15][21]. Table 2 gives an overview of some of these interdependencies.

Open line	**Station**
• Used capacity per time unit e.g. 1 hour. This depends on the valid timetable, rolling stock and infrastructure • Heterogeneity of the railway operation (the traffic mix on the given line section). A metro like service with frequent trains stopping at all stations is homogenous while a line used by both slow regional trains, fast intercity trains and freight trains has a heterogeneous traffic pattern • Overtaking of trains is part of heterogeneous operation. It increases the heterogeneity of the operation and thereby contributes to more interdependencies – and thereby a more complex timetable	• Layover times for rolling stock and train crew. Scheduled layover times can sometimes be close to the minimum time needed for any needed shunting movements for the rolling stock and for the train crew to get ready for departure in the opposite direction • Rolling stock utilization. The rolling stock can be used on several different train services during the day. If this is the case, a delay can be spread to a big part of a given railway network following the rolling stock • Train crew utilization. A given train crew can work on different train services during their shift. In this case, a delay on one line can spread to another via a train crew • Train connections. The valid timetable can hold several planned connections between the topical train service and other train services. If trains have to wait for each other at connection points, delays can be transferred from one train to another and thereby spread to a larger part of the railway network

Table 2: Interdependencies in the timetable [5][16][19].

Table 3 shows some of the advantages and disadvantages for timetables with a high level of complexity in them.

Advantages	**Disadvantages**
• Adapted product types for different passenger segments e.g. stop trains and fast intercity trains • Focusing on conditions for the largest	• Difficult to find unused attractive train paths in the existing timetable • The timetable becomes rigid and inflexible

passenger flows • Optimizing the need for rolling stock to fulfill given service demands • Make fully use of the driving characteristics of the rolling stock • Reduced costs for breaking and accelerating trains because the number of stops is optimized towards the market segments	• Difficult for train dispatchers to react on disturbances in the planned operation • A complex timetable is more sensitive towards disturbances • The more complex the timetable, the less efficiently the capacity is used

Table 3: Advantages and disadvantages of complex timetables [5][6][21].

The most important advantage in complex timetables, as listed in Table 3, is the possibility to have both slow and fast trains on a railway line and thereby being able to offer attractive travel times to the majority of train passengers.

The structure of a timetable does not necessarily give rise to complexity. Planned interdependencies in the timetable that do cause complexity are based on timetable structure [21].

3.3 Travel time

The travel time of a given journey is an important attractiveness parameter. A potential customer will, in the decision process before the journey, amongst other things compare travel time by train with other competitive means of transport e.g. airplane, bus or car. The scheduled travel time depends on characteristics of infrastructure and rolling stock, on agreed upon running time supplements between IM and TOCS, heterogeneity of operation on the relevant railway lines and on the number of needed transfers to make the journey [4].

In Denmark value of time in regards to transportation is given in a catalogue of key figures published by the Ministry of Transportation. Table 4 shows value of time in public transport for different time segments. Waiting time is estimated to be twice as inconvenient as the travelling time whereas the service headway is weighted only half of the travelling time. These are general values not adjusted to e.g. length of trip or service headway of the trains used. This has been done in other countries, e.g. Sweden, where examinations show that differences between weights decrease when length of trips increase [4][14].

Time segment	Home - Work	Business	Other	Weight
Travel time	59	263	35	1
Waiting time	118	526	70	2
Service Headway (hidden waiting time)	30	132	18	0,5

Table 4: Value of time for different time segments in dkr per hour per person and matching weights [14]

Several countries have developed their own benchmarking methods for journey time by train. As an example the English generalized journey time methodology is used [20].

$$GJT = T + aH + bI \qquad (1)$$

GJT = **G**eneralized **J**ourney **T**ime
T = Station to Station Journey **T**ime
H = Service **H**eadway (frequency)
I = Number of **I**nterchanges Needed
a = frequency penalty factor
b = interchange penalty factor

The penalty factors "a" and "b" are needed to convert service headway and number of transfers into equivalent amount of time.

Scheduled travel times are a compromise between railways being competitive compared with other modes of transport but on the other side also insuring a conflict free timetable and a high level of punctuality. The SBB works with the following motto: "So rasch wie nötig, nicht so schnell wie möglich" (as fast as needed, not as fast as possible). This gives a good understanding of the necessary compromise [6][15].

With the recent focus on climatic changes in the world and reasons behind them, the planned travel time for trains should allow to use an energy efficient driving mode. This consists of an acceleration, cruising, coasting and braking phase. Switching points between phases can be found by using simplified differential equations of motion [1].

3.4 Punctuality and reliability

Timetables should be able to absorb minor disturbances that can occur in most common operational situations to achieve a given level of punctuality. This is done by introducing time supplements and buffer times in the timetable. Time supplements are usually between 3-7% of the calculated minimum running time between 2 stops of a train run. The time span a block section is not occupied between 2 consecutive trains is called buffer time. By using time supplements planned running time is increased which again can increase the need for rolling stock and thereby also personnel to get a feasible roster for the train service [1][7][9][17][19].

Common operational situations are e.g. dwell time delays, reduced speed on part of lines because of poor infrastructure conditions or reduced traction effort on rolling stock. It is necessary to be able to keep planned train interchanges with only minimal transfer time and thereby also the expected timetable travel time [6][7][18].

The scheduled travelling time may differ considerably from the experienced travel time if a customer misses a connection caused by a minor delay. A missed transfer can prolong travel time with up to the frequency of the connecting train service which can be more than 100% of the planned journey time [6].

Time segment	Home - Work	Business	Other	Weight
Delay time	118	526	70	2

Table 5: Value of delay time in dkr per hour per person and matching weight [14]

Table 5 gives an overview of Danish value of time in regards to delays in passenger railway traffic and its weight. Delay time is weighted equally to waiting time.

Punctuality for railways is calculated differently from country to country. This makes it difficult to compare punctuality levels, in e.g. the European Union. One thing most countries have in common is that level of punctuality is based on numbers of trains fulfilling a on time criteria and not e.g. level of passenger or goods delays, which is more meaningful [9][11][22].

Punctuality is not only an important quality parameter for passenger traffic. A competitiveness parameter on the freight market is guaranteed arrival times for freight trains. This is a key factor for companies with production lines that need raw materials or recipients of the company's products [9] [12].

The following factors have a great influence on the punctuality of a train service [1][8][12][13][18][19]:

- **Capacity consumption**. A high level of capacity consumption causes higher risk of consecutive delays
- **Heterogeneity of traffic mix**. The more heterogeneous the railway operation the higher the risk of consecutive delays
- **Allocation of time supplements**. There are several opinions on how to allocate time supplements. The trend goes away from distributing the running time reserves equally on the whole network. One opinion is to add the time supplements to the dwell times at stations. The train will under normal conditions arrive too early. This ensures the availability of the entire time supplement of an open line section to the train before the arrival at the next station, but demands a high level of platform track capacity. Another opinion puts the majority of reserves between capacity bottlenecks which often are larger stations/junctions, e.g. in Switzerland.
- In case of no disruptions in traffic, time supplements can be used to run trains in the most energy efficient driving mode. The optimal allocation of time supplements in regards to

energy efficient driving should be concentrated on the central part of a train run between 2 stops as it will result in a lower speed

- **Train capacity**. If not the TOC has enough train units and/or locomotives and carriages available, trains get crowded. This can cause dwell time extensions as it takes longer time to board and alight trains
- **Station dwell times**. The number of alighting and boarding passengers has to match with the planned dwell time. If a dwell time delay arises this can delay the next train planned to use the same platform track

The railway sector has through time applied 2 philosophies to ensure and improve punctuality [8][9][12]:

- **Slack** – This philosophy is based on use of time supplements in the timetable. Both for running and dwell times. This gives a certain degree of slack that can be used to catch up with minor delays. Experience has shown that punctuality not necessarily increases linear with more slack. Giving more time to a task can make the task take longer time
- **Precision** – Here focus is on high availability of infrastructure and rolling stock together with keeping departure times. The latter is done by teaching passengers how to alight and board trains in an effective manner and creating commitment towards punctuality among the employees of the TOCS and IM

Reliability of a train service can be measured in the number of carried through departures out of the number of scheduled departures. The total or partly cancellation of a train can mainly be caused by 3 reasons:

- Rolling stock break down / massive infrastructure failure – this can be caused by external factors or by lack of maintenance and demand cancellation of one or more train runs
- Train staff failing to turn op at scheduled place and time
- Part of a strategy for restoring normal traffic after a disturbance in the train service – trains can e.g. be turned before reaching their destination and use their planned time slot for the reverse train run. Or train runs can be cancelled completely so the rolling stock can be used elsewhere or wait till the start of the next timetable cycle

3.5 Transfers

The needed number of transfers is an important attractiveness parameter. For passengers with heavy luggage it is not convenient to change trains on their journey. Each transfer can have risk of extending travel time compared to a direct train service. In most cases passengers will experience a scheduled waiting time in connection with transfers. In the best case scenario interchange time p is [6][15][20]:

$$p = h + d \qquad (2)$$

h = the necessary infrastructure dependent **h**eadway between the two trains entering the station

d = the planned **d**well time of trains

Table 6 lists the value of transfer time for different trip classes and the corresponding weight. The time spent on transfers is weighted equal to waiting and delay time.

Time segment	Home - Work	Business	Other	Weight
Transfer time	118	526	70	2

Table 6: Value of transfer time in dkr per hour per person and matching weight [14]

The minimum interchange time depends on the transfer conditions. If the connecting train uses the same track or platform, the planned transfer time can be down to a few minutes. If transferring passengers have to get to a different platform or to a different section of the same platform, then transfer time depends on the station's platform and platform track layout.

Assigning a platform track to a train can depend on different things [15]:

- The same platform is used by connecting train services
- The TOC always uses the same track or platform
- The track is close to ticket sale facilities, station entrances, parking lot, shops or other public transport modes
- The train can be catered when using the given track

When using the regular interval timetable (ITF) concept with focus on selected stations as transfer nodes e.g. Swiss Bahn 2000 timetable, all connecting trains meet once or several times per hour at the same time and station. This gives optimal transfer possibilities but an unbalanced use of the station capacity [2]. The station is either almost empty or full of trains. Numerous simultaneous interdependencies at one station add to the complexity of the timetable drastically because the risk of transferring delays increases.

4 Conclusion and further research

This article has described approaches to increase the timetable attractiveness. There are several parameters that have influence on the experienced timetable attractiveness. Parameters such as travel time, availability and punctuality decide whether the railway is a competitive means of transport. These parameters are dependent on the timetable structure. Periodic regular interval timetables (ITF-Fahrplan) are being adopted by more and more European railway companies. This kind of timetable has proven its attractiveness towards the railway customers. Regularity and focus on optimal transfers make these timetables popular.

Optimal transfer conditions are created by declaring selected stations as transfer nodes and having all connecting trains meet there at the same time. Transfer times depend on actual track allocation to trains, layout of transfer stations and timetable structure.

Scheduled travel time is affected by infrastructure, rolling stock, running time supplements and timetable structure. In the end travel time is a compromise between the railways being competitive compared to other means of transport and achieving a high level of punctuality.

Every timetable contains more or less interdependencies between different trains, and trains and their passengers/train crew. Interdependencies can be planned transfer possibilities, a high level of heterogeneity in the operation, and scheduling aspects for rolling stock and staff. The more interdependencies there exist in a timetable the higher the level of complexity in the timetable.

A high level of complexity increases risk of delays spreading to other trains and thereby to larger parts of the railway network. This has a negative effect on achievable punctuality with a given timetable.

Further research can focus on developing a benchmarking/index methodology for timetable attractiveness and/or complexity. In this way, it will be possible to compare different timetable alternatives regarding timetable attractiveness. The methodology should take the following aspects into account: Possible running time compared to scheduled running time, number of interdependencies attached to a given train run, and the heterogeneity of train traffic.

Another topic for examination is what level of disturbances a new timetable should be able to absorb. First step would be to develop a set of formulas that can identify the socioeconomic optimum when looking at the scheduled travel time, including time supplements, and derived punctuality.

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