Denne artikel er publiceret i det elektroniske tidsskrift
Artikler fra Trafikdage på Aalborg Universitet
(Proceedings from the Annual Transport Conference
at Aalborg University)
ISSN 1603-9696
www.trafikdage.dk/artikelarkiv

Planning With Timetable Supplements in Railway Timetables

Bernd Schittenhelm, bs@transport.dtu.dk & besc@bane.dk
DTU Transport – Department for transport & Rail Net Denmark

Abstract

The use of time supplements in railway timetables is a trade of between attractive travel times and punctuality levels. Punctuality is a key performance indicator for timetables and time supplements are therefore applied in any timetable. Time supplements can be found as running time supplements, dwell time supplements and buffer times between trains. These are described in the paper.

Through analyzing the present valid timetable it is shown that the present size of running time supplements is approximately 50% bigger as recommended by the UIC. Unreliable input data for the timetabling process can be a valid reason for unnecessary high time supplement levels in the timetable.

Making the best use of the applied running time supplement has resulted in several application strategies. Several are presented in the paper. A Danish success story is the use of condensation and compensation zones on the Copenhagen suburban railway network. This is inspired by the approach used in the Swiss Bahn2000 timetable for station hubs.

A political demand for future travel times not higher than or below one hour between the cities of Copenhagen and Odense leads to an investigation of 3 possible scenarios: Applying the existing planning rules in regards to time supplements, using the recommendations from the UIC or making a compromise by adapting the existing rules to fulfill the political demands. It is shown that the existing planning rules cannot provide the necessary reduction in travel time. Critical low levels of running time supplements are the result when using UIC recommendations. A compromise can be the solution. This demands a halving of the presently applied running time supplements and therefore also a new approach to timetabling and railway operation in Denmark.

1 Introduction

Punctuality is one of the key performance indicators (KPI) in public transportation and thereby also for the public railway system. This applies to both passenger and freight traffic. Reliable and punctual trains make passenger trains more attractive towards potential customers and just-in-time delivery for production companies has become more usual within the freight transportation business.

Table 1: Overview of train delay thresholds in Denmark [13]

Train category	Delay threshold [min:sec]	Punctuality target [%]
Long distance passenger train	05:00	95
Copenhagen suburban train (S-tog)	02:30	90
Freight train	10:00	85

Table 1 shows the thresholds for different train categories as being delayed and the political decided punctuality targets for trains in Denmark.

In Denmark the threshold for long distance passenger train being registered as delayed is 05:00minutes at any station or location where trains are being registered either automatically or manually. The punctuality target for long distance passenger trains is that 95% of all trains are running on time. In other countries the delay threshold can be different as can the delay measuring approach. Table 2 gives an overview of selected European countries [4].

Table 2: Overview of delay thresholds for train categories in different countries [4].

Country	Train category	Delay threshold [min:sec]	Measuring approach
Denmark	Long distance + regional passenger trains	05:00	Entire train run. Arrival and departure.
	Copenhagen suburban trains	02:30	Entire train run. Arrival and departure.
	Freight trains	10:00	Entire train run. Arrival and departure.
Holland	Long distance + regional passenger trains	03:00	Selected larger stations. Arrival.
Switzerland	Long distance + regional passenger trains	05:00	Selected larger stations at arrival and at signal boxes.
Germany	Long distance passenger trains	05:00	Selected stations. Arrival.
	Suburban trains (S-Bahn)	02:00	Selected stations. Arrival.
	Freight trains	30:00	
Italy	Long distance + regional passenger trains	15:00	End of line. Arrival.

Trains get delayed because they are subject to stochastic happening incidents that cause train delays. These incidents can be categorized into two groups [2]: Incidents that have the potential to create high levels of train delays and incidents that create low levels of train delays. Table 3 gives an overview of examples for these incidents.

Table 3: Stochastic incidents that can cause train delays [5]

Incident category	Examples
High level of train delays	Infrastructure failure: Track, switch, interlocking, communication
	Passenger: Very extended dwell times, collision, suicide
	Rolling stock: Break down, very reduced traction
	Outside: Bad weather, action by third part
Low level of train delays	Infrastructure: Reduced speed on section
	Passengers: Extended dwell time
	Rolling stock: Reduced traction, single door failure
	Outside: Poor weather

The prepared yearly timetable for a railway system is a static document where changes are made only rarely during the validity period. This makes it necessary to implement time reserves - called time supplements - in the railway timetable in form of running time supplements, dwell time supplements and buffer times between trains. By doing so it becomes possible to avoid or minimize stochastic happening train delays of a certain magnitude [2]. If the consequences of the delay causing incident are to big the use of time supplements will not prevent trains from getting delayed, terminated short or even cancelled – see high level of train delays in Table 3. Time supplements can ensure that a delayed train is able to catch up with the timetable if the delays can be kept within a reasonable scale – see low level of train delays in Table 3.

In a liberalized railway market, such as the Danish, the railway sector is divided into infrastructure managers (IMs), train operating companies (TOCs) and the railway authorities. Interested TOCs apply for the use of capacity – timetable train paths - with the relevant IM who then prepares the timetable trying to accommodate as many wishes from the TOCs as possible. Each IM has a set of planning rules according to which the timetable is prepared. These planning rules include the use of time supplements [3].

In section 2 a set of definitions in regards to train running times and time supplements are presented. These are followed by recommendations for the use of time supplements in railway timetables by the international association of railways – the UIC - in section 3. The planning rules in regards to time supplements applied by infrastructure manger Rail Net Denmark are described in section 4 and a practical example from the present valid timetable is given. In section 5, two recent strategies for placement of time supplements in railway timetables are presented. This is followed by two Danish cases in section 6: The present timetable for the Copenhagen suburban railways (S-tog) and the future "One hour model" between the cities of Copenhagen and Odense. Finally conclusions are made in section 7.

2 Definitions

Scheduled running times of trains in timetables consist of the following four contributions [2][10]:

1. **The minimum running time between locations** – this depends on the driving characteristics of the rolling stock - e.g. acceleration, maximum speed and breaking capabilities, driving style of the train engineer – and the characteristics of the infrastructure – e.g. interlocking system, traction current power supply and maximum allowed line speed.
2. **Dwell times at stops** – stops are normally put into categories according to the number of passengers embarking and/or disembarking trains – e.g. little, medium or large number of passengers. Dwell times are based on empirical data e.g. simple timing of train stops.
3. **Time supplements** – running time supplements, dwell time supplements and buffer times between trains. These are described in detail in the following sections.
4. **Scheduled waiting time** – To be able to create a feasible timetable it can become necessary to increase the scheduled running times of trains. Reasons for this can be synchronization of different train services at an interchange station, synchronization of train services to a clockfaced timetable and to wait for planned passings at crossing stations on single tracked lines or overtakings of slower trains by faster trains. Scheduled waiting time is mostly added as dwell time supplements, extra stops and as running time supplement.

There are three different types of time supplements in a railway timetable [2]:

1. Running time supplements
2. Dwell time supplements
3. Buffer time between timetable train paths

These are defined and described in the following sections.

2.1 Running time supplements

The definition of running time supplement is the following: Running time supplement is the difference between the physically possible minimum running time and the used running time in the timetable – the scheduled running time. See Figure 1.

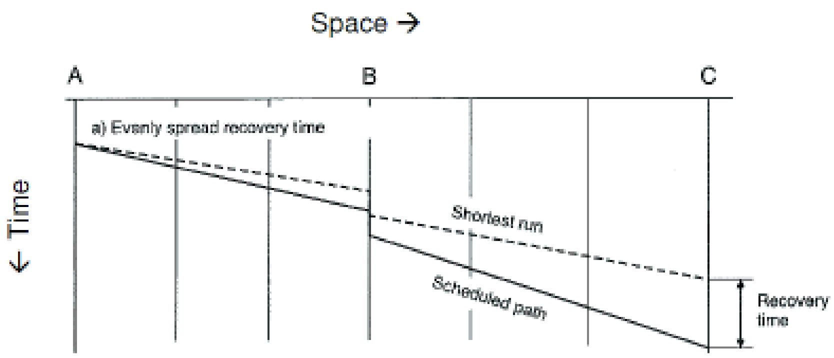

Figure 1: Definition of running time supplements [7]

There exist two kinds of running time supplements [2]:

1. Regular running time supplement
2. Special running time supplement

Regular running time supplements are added to every train path in the timetable. They follow the used planning rules of the given railway infrastructure manager (IM). Running time supplements can be added in three different ways:

1. Based on distance driven [min/km]
2. Based on travel time [%]
3. Fixed supplements per station or junction [min]

Figure 2 shows graphs for both distance and percentage based running time supplements. In most driving speed intervals, methodology 1 and 2 give similar values. In general it can be noticed that the differences increase with the speed [10].

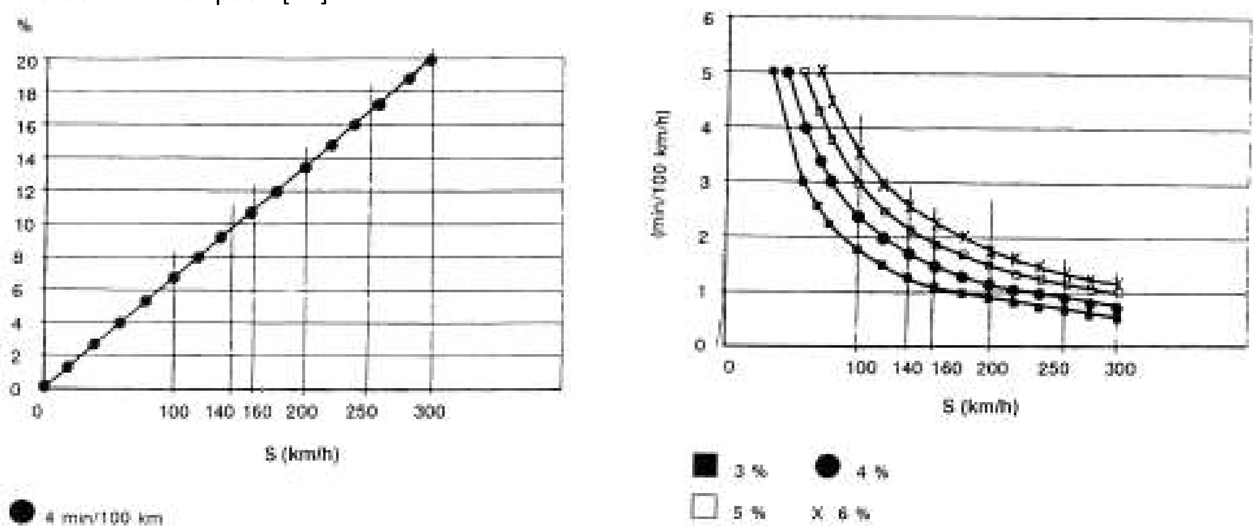

Figure 2: Graph of distance based (left) and percentage based (right) running time supplements [10]

Special running time supplements are added to timetable train paths in case of planned large maintenance/renewal and construction projects. If there are longer line sections with temporarily bad track conditions, special running time supplements are also added. This category of time supplement is a fixed supplement in minutes added to the running time on the relevant railway line sections and is based on premade analyses e.g. simulation of railway traffic [2].

2.2 Dwell time supplements

For the timetable planner it is difficult to know how much dwell time a train needs at a given station. This varies throughout the day and also the weekday. The applied minimum dwell times in timetables are based on empirical data and the supplements are fixed values. Dwell times are not set for each single train but for entire train categories, such as intercity trains. Changes in dwell times can occur between time specific timetable patterns. Typically one timetable pattern is used for the early morning hours and a different pattern for the morning rush hour [3].

Most IMs apply time supplements to the dwell times of trains. This has several advantages:

- Dwell times of trains can be prolonged by school classes or handicapped people embarking or disembarking the train. Time supplements can absorb these variations
- If a train arrives delayed to a station and only needs the planned minimum dwell time it can reduce or eliminate its delay and depart less delayed or on time
- At important transfer stations, dwell time supplements ensure that the planned transfer can be made even though one of the involved trains has a minor delay. See Figure 3.

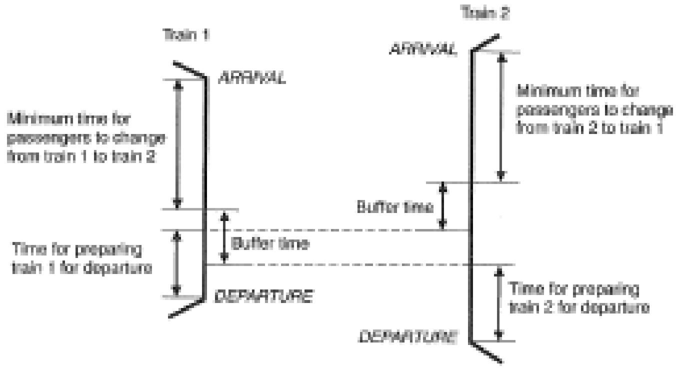

Figure 3: Definition of dwell time supplements [2]

A precondition for being able to apply dwell time supplements is that there is enough station capacity available in form of platform tracks. Dwell time supplements increase the utilization of platform tracks at a given station and can make it necessary to build in scheduled waiting time in the timetable when trains approach stations. This creates longer travel times [9].

Dwell time supplements themselves prolong travel times. As with running time supplements it is a trade of between attractive travel times and a robust timetable. Using a socio economic approach could lead to the finding of an optimal size of dwell time supplements at a given station.

2.3 Buffer times between trains

Additionally to running time and dwell time supplements a timetable contains time buffers between planned timetable train paths. Normally buffer times, t_b, are put between any two pairs of trains following each other on a given railway line. See Figure 4 to the left. Buffer times reduce the risk of transferring delays between trains or they reduce the size of the knock on delay transferred from one train to the following train [2].

On railway lines with homogenous traffic with a high capacity utilization, such as metro systems, buffer times between trains are reduced to achieve a shorter headway between trains and instead a buffer path is introduced. See Figure 4 to the right. If an incident occurs, causing small delays, the trains will run in a later timetable train path. Having one buffer path per periodicity time interval of the timetable gives an opportunity to absorb the delay before it spreads to widely in the railway system [2]. This concept can be seen on the Copenhagen suburban train network (S-banen) between Copenhagen Central station and Svanemøllen station. In a time window of 20 minutes, 9 trains travel on the line with a headway time of 2 minutes, leaving one train path empty as a buffer path.

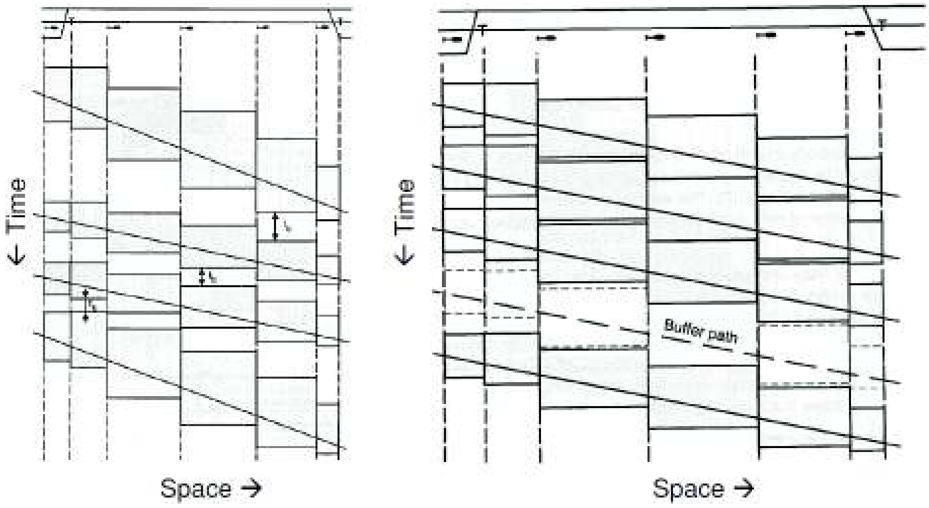

Figure 4: Definition of buffer times, t_b (left) and buffer path (right) between trains [2]

2.4 Size of time supplements in timetables

The use of time supplements in timetables is a trade of between attractive travel times and robustness of the timetable. When using a socioeconomic approach in combination with a railway traffic simulation tool such as RailSys [15]or Open Track [14], it is possible to find an optimal size of the running time, dwell time and buffer time supplements in a given railway timetable for an investigated area. See Figure 5 [4][5][8].

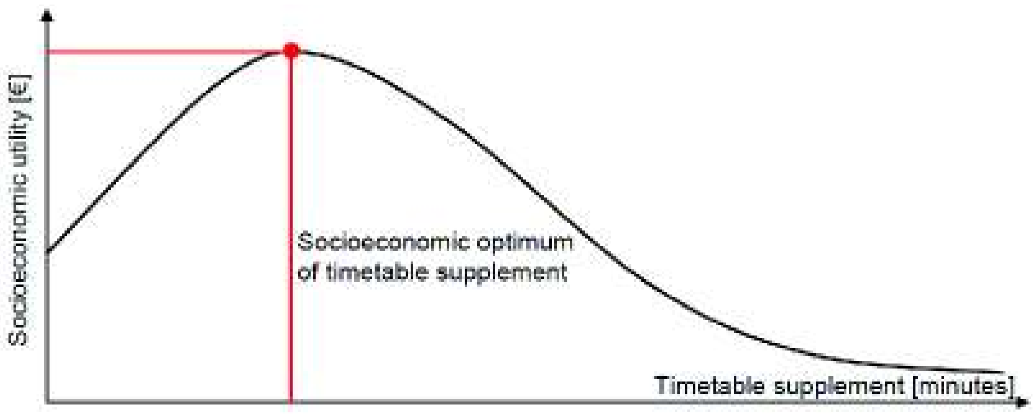

Figure 5: Optimal size of running time supplements with a socioeconomic approach [5]

Socioeconomic utility is calculated from the number of passengers in trains, their segmentation in passenger groups e.g. commuter, education or leisure travellers and the delays they are subjected to. Each passenger group is given a set of time values for one hour of travel time on a train, transfer time and delay. It is not socioeconomic feasible to construct timetables that are able to absorb very high levels of train delays since these occur rarely. A timetable should make it possible for trains to regenerate from smaller delays since these happen more frequently [1][8].

3 UIC Recommendations

The international union of railways (Union International des Chemins de fer = UIC) has produced a leaflet (UIC leaflet 451-1 OR) that provides its members with a series of recommendations in regards to the implementation of running time supplements in timetables. The recommendations are based on empirical data [10]. UIC recommends for all railway traffic the use of a fixed minimum running time supplement Xmin/Ykm and an additional speed dependent percentage running time supplement. The size of supplements increases with speed. Railway traffic has been divided into the following categories:

- Locomotive hauled passenger trains (≤ 300, 301-500, 501-700 and >700tons), see Table 4
- Multiple units passenger trains, see Table 5
- Freight trains, see Table 6

It can be added that a standard diesel locomotive weighs ca. 115tons whereas an electrical locomotive only weighs ca. 80tons. A typical double-decker passenger carriage weighs ca. 50tons where a single-decker carriage weighs ca. 37tons [11].

For locomotive hauled passenger trains the UIC recommends a fixed 1,5min/100km distance based running time supplement plus a percentage increment as shown in Table 4. This train category is divided into sub categories according to the total weight of the train [10].

Table 4: UIC recommended percentage running time supplements for locomotive hauled passenger trains [10]

Weight [tons]	Speed [km/h]			
	≤ 140	141-160	161-200	> 200
≤ 300	3%	3%	4%	5%
301-500	4%	4%	5%	6%
501-700	4%	5%	6%	7%
> 700	5%	5%	6%	7%

Passenger trains run with multiple units are not divided into sub categories according to their weight. The reason for this is that the driving characteristics of the train as a whole do not change if you add one or several multiple units. They all have the same driving performance in contradiction to locomotive hauled trains, where adding carriages primarily reduces the acceleration capabilities and sometimes the maximum achievable speed. Since multiple units in general have better acceleration capabilities than locomotive hauled trains there is a smaller need for running time supplements in the slower speed categories. A fixed running time supplement of 1min/100km with a percentage increment dependent on travel time as shown in Table 5 is recommended by the UIC [10].

Table 5: UIC recommended percentage running time supplements for multiple unit passenger trains [10]

Speed [km/h]				
≤ 140	141-160	161-200	201-250	> 250
3%	4%	5%	6%	7%

Freight trains are divided into trains running up to and above 120km/h by the UIC. See Table 6. Trains running up to 120km/h are recommended to receive a uniform percentage of running time supplement of 4%.

Table 6: UIC recommended running time supplements for freight trains [10]

Speed [km/h]	
≤ 120	> 120
- 1min/100km + 3% running time or - 3min/100km or - 4% running time	As for passenger trains – see Table 4

If using a distance based running time supplement, this should not be less than 3min/100km. Fast freight trains with travelling speeds over 120km/h should be handled as locomotive hauled passenger trains. See Table 4 [10].

4 Rail Net Denmark planning rules

This section describes the planning rules just by IM Rail Net Denmark when preparing the yearly Danish national railway timetable. These planning rules have been drawn up in close cooperation with the most important TOCS: DSB (passenger trains), Arriva (passenger trains), DB Schenker Rail Services Scandinavia (freight trains) and Hector Rail (freight trains).

As with the UIC a speed dependent percentage of travel time approach for running time supplements in the railway timetable is used but with no basic minimum min/km contribution. Table 7 gives an overview of the used percentage of travel time running time supplements by IM Rail Net Denmark and the recommended values by the UIC. It becomes clear that the used values by Rail Net Denmark are higher than the recommendations from the UIC. In speed categories from 120km/h and up the Rail Net Denmark percentages are ca. 50% higher than the recommended values from the UIC. This situation is not unique for Denmark. Most western European countries, e.g. Switzerland and Germany, use larger values than recommended by the UIC [3].

Table 7: Comparison of percentage of travel time running time supplements for passenger trains as used by IM Rail Net Denmark and as recommended by the UIC [3] [10]

Speed interval [km/h]	Time supplements used by IM Rail Net Denmark [%]	UIC recommendations [%]
0-75	3	3 (+ fixed supplement: 1 or1,5min/100km)
76-100	4	3 (+ fixed supplement: 1 or1,5min/100km)
101-120	5	3 (+ fixed supplement: 1 or1,5min/100km)
121-140	7	3 (+ fixed supplement: 1 or1,5min/100km)
141-160	9	4 (+ fixed supplement: 1 or1,5min/100km)
161-180	11	5 (+ fixed supplement: 1 or1,5min/100km)
181-200	13	5 (+ fixed supplement: 1 or1,5min/100km)
201-250	13	6 (+ fixed supplement: 1 or1,5min/100km)
251-300	13	7 (+ fixed supplement: 1 or1,5min/100km)

For freight trains the situation in regards to running time supplements is completely opposite in Denmark. Rail Net Denmark uses one fixed value of 3% for all speed categories when adding running time supplements to freight trains. Almost no freight trains run faster than 120km/h in Denmark. The UIC recommends 4% as a minimum supplement and for travel speeds above 120km/h points towards its recommendations for locomotive hauled passenger trains. See Table 8.

Table 8: Comparison of percentage of travel time running time supplements for freight trains as used by IM Rail Net Denmark and as recommended by the UIC [3] [10]

Speed interval [km/h]	Time supplements used by IM Rail Net Denmark [%]	UIC recommendations [%]
0-120	3	4
121-200	3	See Table 4

In Denmark there has in recent years been an intense political focus on having passenger trains running on time throughout the country. This can have given rise to very high levels of running time supplements in timetables. On the other hand a heavily utilized railway network as the Danish often makes it necessary to reduce the size of running time supplements to be able to run all the requested trains from the TOCS [5].

Rail Net Denmark plans all locomotive hauled freight trains assuming that they are as heavy as permitted. This is seldom the case and freight trains thus often have better driving characteristics than assumed in the timetable. Therefore a lower level of running time supplement than recommended by the UIC has been accepted. Shorter travel times furthermore increase the competiveness of freight trains in the shipping agent business [3].

4.1 A real life example: Intercity express train 27

Above the theoretical planning rules used within Rail Net Denmark have been described, in this section the realised timetable for intercity express train number 27 is analyzed to give an example of the differences between theory and praxis.

Figure 6 shows the detailed timetable for intercity express train (Lyntog) number 27 from Copenhagen central station (KH) to Odense (OD) with departure time 09:50 in Copenhagen and arrival time 10:05 in Odense. In Denmark the precision of the working timetable is 30 seconds. The used timetabling tools have a precision of 1 second. This means that a rounding of times must take place. First the minimum running time is calculated and then the agreed upon running time supplements are added. At Rail Net Denmark an additional technical reaction time for the rolling stock of 10seconds is added after each station where trains are calling at. Following this the timetable times are rounded. This gives the time allowance.

For Intercity express train 27 the rounding of departure, passing and arrival times gives a sum allowance of 5minutes and 51 seconds. It becomes clear that the running times have mostly been rounded up to generate additional running time supplements. In a normal planning situation the timetable planner should try to make sure that the sum of allowances is close to 0seconds (ca. ±1minute). Running time supplements follow the Rail Net Denmark planning rules and add up to 6minutes and 23seconds in total. Inter city express train 27 has a total of 12minutes and 14seconds in running time supplements and a planned travel time of 1hour and 15minutes. The percentage of running time supplements is 16,3% of the travel time.

Depending on the rounding of arrival, departure and passing times a clotting of running time supplements can be caused, instead of having a desired evenly spread running time supplement along the route of the train.

Station	Ankomst	Afgang	Stop	Allowance	Sum Allowance	Type Res.	Sum. Type Res.
KH	08:43:00	50:00	07:00				
VAL	08:43:00	53:30	07:00	00:09	00:09	00:12	00:12
HIF	08:43:00	55:30	07:00	00:45	00:45	00:07	00:07
GL	08:43:00	57:30	07:00	00:22	00:22	00:09	00:09
HTÅ	09:02:00	03:00	01:00	00:53	00:53	00:21	00:21
HH	09:02:00	06:00	01:00	00:03	00:03	00:13	00:13
TRK	09:02:00	08:00	01:00	00:23	00:23	00:09	00:09
RO	09:02:00	09:30	01:00	00:21	00:21	00:06	00:06
VY	09:02:00	14:30	01:00	00:16	00:16	00:28	00:28
BO	09:02:00	17:30	01:00	00:13	00:13	00:16	00:16
KY	09:02:00	21:00	01:00	00:47	00:47	00:16	00:16
RG	09:02:00	24:00	01:00	00:14	00:14	00:16	00:16
FJ	09:02:00	27:30	01:00	-00:06	-00:06	00:21	00:21
SO	09:02:00	30:00	01:00	00:06	00:06	00:14	00:14
SG	09:02:00	35:30	01:00	-00:27	-00:27	00:35	00:35
FO	09:02:00	39:00	01:00	00:05	00:05	00:20	00:20
KØ	09:02:00	42:00	01:00	00:03	00:03	00:17	00:17
SPR	09:02:00	47:00	01:00	-00:13	-00:13	00:31	00:31
NG	09:02:00	52:00	01:00	00:11	00:11	00:28	00:28
JU	09:02:00	54:30	01:00	00:30	00:30	00:11	00:11
UV	09:02:00	57:00	01:00	00:34	00:34	00:11	00:11
MV	09:02:00	10:01:00	01:00	00:43	00:43	00:19	00:19
OD	05:00	07:00	02:00	-00:01	-00:01	00:23	00:23
					05:51		06:23

Figure 6: Timetable for intercity express train (Lyntog) 27 between Copenhagen → Odense

Figure 7 shows the speed profile for intercity express train number 27 between Copenhagen and Odense. Maximum line speed is dependent on the track geometry and the used train protection system. This railway line is equipped with Danish ATC (Automatic Train Control) and allows a maximum speed of 180km/h, see the red line. Minimum running times are achieved by following the speed profile of the blue line and the timetable planned running times are visualized with the green line. The applied running time supplements in the timetable are the areas between the blue and green line. A calculated size of 16,3% is reasonable in regards to Figure 7.

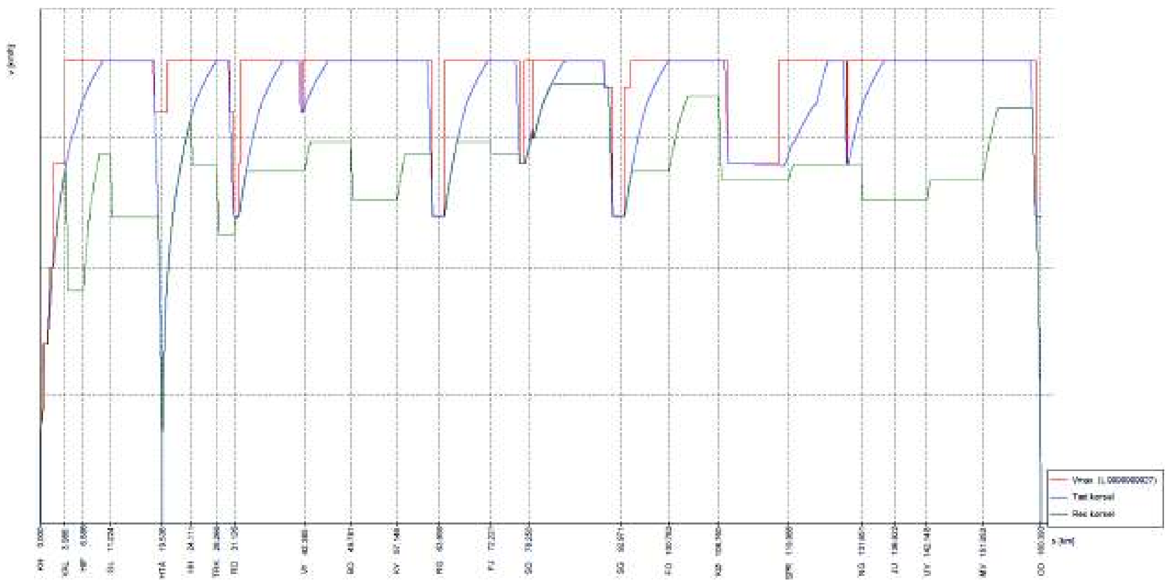

Figure 7: Speed profile for intercity express train (Lyntog) 27 between Copenhagen → Odense

There can be several reasons for planning with larger running time supplements than the planning rules prescribe [3]:

- Political focus on train punctuality
- To be able to prepare a feasible timetable it can become necessary to introduce scheduled waiting time in form of prolonged travel times, e.g. intercity express train 27 would otherwise catch up with a slower train in front of it
- Detailed infrastructure data in the timetabling system can be insufficient or not updated
- Assumed condition of the railway infrastructure, e.g. number of local speed restrictions or availability of the traffic control system, does not correspond to the real world
- Detailed traction effort data for the rolling stock in the timetabling system can be insufficient or not updated
- Assumed condition of rolling stock in the timetabling system, e.g. traction effort or breaking capabilities, does not correspond to the real world
- The train driver is assumed to utilize both rolling stock and infrastructure characteristics in an optimal manner to achieve the shortest possible minimum running times

5 Placement of running time supplements in timetables

It is possible to place running time supplements in railway timetables in several different ways as described above. One key factor has a huge impact on which strategy to apply: The measurement methodology for train punctuality levels. See Table 1. In Italy it would strategically be wise to place a very big running time supplement between the two last stations of a train run. This gives the possibility to catch up with reasonable delays just before the terminus of the train, resulting in an entire train run being registered as being punctual.

Until now only evenly spread running time supplements along the train route have been presented but there exist other strategies for a potentially more optimal placement of running time supplements in railway timetables. In the following two chapters two different strategies for placement of running time supplements are presented.

5.1 Running time supplements added to dwell times

One application strategy of running time supplements in railway timetables suggests that time supplements should be added to dwell times instead of running times. Thereby a train will be able to utilize all of the applied running time supplements between two stops instead of only having a part of the evenly spread running time supplement available to it. Figure 8 illustrates this. This strategy results in scheduled arrival times of trains in the working timetable will be earlier than in the public timetable. By using this approach it becomes possible to reduce the overall amount of time supplements in the timetable due to their optimal availability to trains, thereby creating more attractive travel times, and even increase the punctuality levels of trains [9].

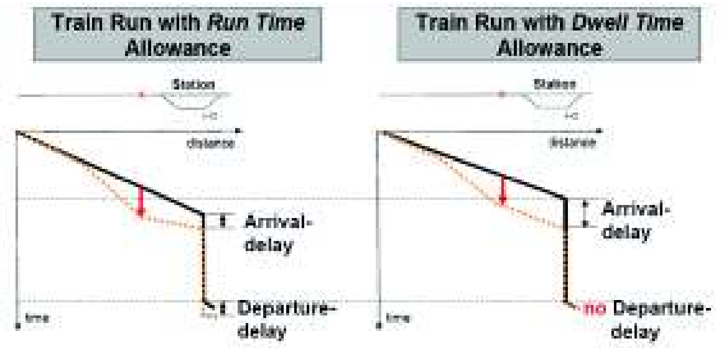

Figure 8: Running time supplements versus dwell time supplements [9]

It must though be emphasized that this strategy requires a certain minimum level of station capacity in form of platform tracks. This can be available to the given timetable planners or not. In Denmark this strategy is not being applied. One reason for this can be that station capacity at larger stations is in general already almost used up.

5.2 Condensation and compensation zones

In Switzerland the state owned TOC Schweizerische Bundesbahn (SBB) has with the introduction of their integrated fixed interval Bahn2000 timetable in December 2004, divided their railway network into two categories of areas [7]:

- Capacity bottleneck areas: Areas operating at or near their capacity limit
- Non capacity bottleneck areas: Areas with spare capacity

To achieve the highest punctuality levels the SBB has used a new application strategy of running time supplements. Capacity bottlenecks are turned into the so called “condensation zones” and non capacity bottlenecks are called “compensation zones”. This is in regards to applying running time supplements. In condensation zones the trains are planned with their maximum allowed speed and a minimum of time supplements in the timetable. This is to ensure that trains take up a minimum of capacity in the bottleneck areas. Whereas in compensation zones they are planned with big time supplements to make sure that the trains arrive on time at the start of the next capacity bottleneck zone [7].

The Bahn2000 timetable is based on the concept of a series of larger station/hubs where all trains meet on the hour, quarter past the hour, half hour, quarter to the hour or combinations hereof. See Figure 9. Scheduled running times between station hubs must fit with the scheduled meeting times of trains.

Figure 9: Map of the hubs and lines in the Swiss Banhn2000 timetable

The selected hubs and their immediate railway sections are defined as condensation zones and the line section between them as compensation zones [7].

6 Two Danish Cases

In the following two sections a presentation of two Danish cases on the topic railway timetable running time supplements is given. Since late 2007 a new strategy for applying running time supplements has been used on the Copenhagen suburban railway network, inspired by the Swiss Bahn2000 timetable. This is followed by an investigation of possible running times between the cities of Copenhagen and Odense in the future Danish one hour timetable model.

6.1 Timetable for the Copenhagen suburban railway (S-tog)

The central part of the Copenhagen suburban railway network, called “Røret”, between Hellerup and Dybølsbro stations was identified as being a capacity bottleneck. All suburban train lines, except the ring line F, pass through here. Line frequencies are A, B, C, and E 10 minutes and H 20minutes. See Figure 10 left. Inspiration was taken from the Swiss Bahn2000 timetable and running time supplements were reduced between stations in the central part and increased between the bottleneck and its neighbouring stations. A buffer zone was created before and after the central part to ensure that trains approaching the capacity bottleneck would reach it on time and if they had received minor delays running through the central part they would recover immediately after. This is illustrated in Figure 10 right. Sections with orange arrows belong to the condensation zone. Red arrows indicate that trains in the relevant driving direction are planned with a speed of 60km/h and 9% of running time supplements to achieve minimal headways. Blue arrows indicate the use of the infrastructure line speed and a running time supplement of 9%. The turquoise boxes show how many seconds are added to the running time as an additional buffer.

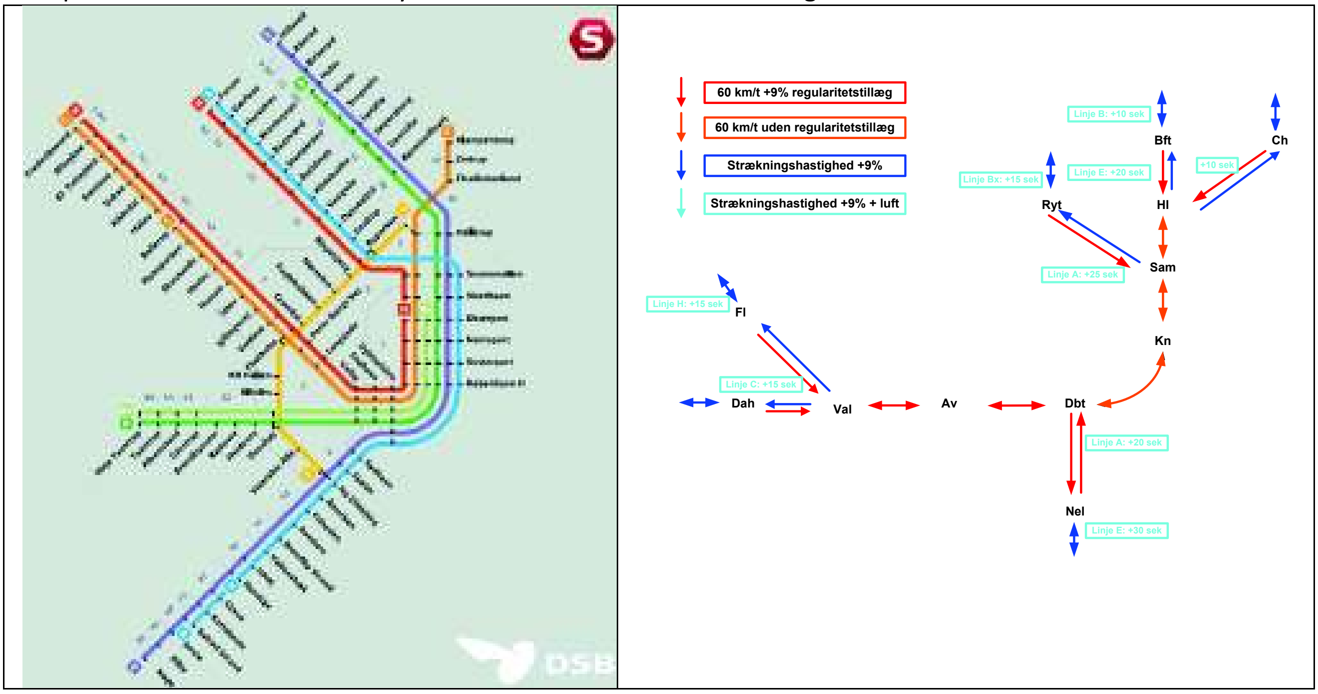

Figure 10: Copenhagen suburban train (S-tog) line map (left) and applied running time supplements (right)

This application strategy of running time supplements has proven very successful. Since 2007 and up till now the political set yearly punctuality targets for the Copenhagen suburban railway network have been reached every year.

6.2 The Danish “One hour model” between Copenhagen - Odense

Since 2006 Danish politicians have talked about improving travel times between the six largest cities in Denmark. The goal is to have a scheduled travel time of maximum one hour between Copenhagen – Odense, Odense – Aarhus, Aarhus – Aalborg and Odense – Esbjerg. The city of Randers lies on the line from Aarhus to Aalborg and will therefore automatically be part of this improvement scheme. It has been decided by the politicians to start the work by reducing the travel time between Copenhagen and Odense to less than one hour. This is done by building a complete new railway line between Copenhagen and Ringsted via Køge, for a maximum allowed speed of 250km/h and upgrade the rest of the line from Ringsted to Odense to a line speed of 200km/h from today's maximum speed of 180km/h. The new railway line will open in the year 2018. A map with the new railway line can be seen in Figure 11. Today there is no rolling stock in Denmark that can run faster than 200km/h. As earlier presented in section 1.5.1 the present shortest possible travel time between the cities of Copenhagen and Odense is 1hour and 15minutes with an intercity express train.

Figure 11: Alignment of the new railway line between Copenhagen and Ringsted via Køge

The new railway line has been modelled in the timetabling tool "Timetable Planning System" (TPS) used by IM Rail Net Denmark and TOC DSB [12].The available infrastructure data from the ongoing project work has been used. This includes the infrastructure speed profile, see Table 9.

Table 9: Maximum allowed infrastructure speed profile for the new line Copenhagen → Ringsted

Location	Milage [km]	Total length [km]	Speed [km/h]
Copenhagen central station	0,000	0,000	40
End of switch zone	0,845	0,845	100
"The Yellow Palace" (obsolete signal post)	2,635	2,635	120
Ny Ellebjerg station	4,566	4,566	120
KØR-project ends	5,269	5,269	120
A1-project start	0,000	5,269	120
Start transition curve	1,191	6,460	150
Start straight line	2,005	7,274	180
After footbridge over motorway	2,570	7,839	200
After road "Søndre Ringvej"	7,264	12,533	250
A1-project end	25,491	30,760	250
A2-project start	0,000	30,760	250
Køge Nord station	4,400	35,160	250
Start transition curve	5,150	35,910	210
End transition curve	7,950	38,710	250
A2-project end	22,963	53,723	250
CR-project start	55,860	53,723	250
Start transition curve at road "Østre Ringvej"	61,400	59,263	200
Entry signal Ringsted station	63,100	60,963	120
Ringsted station	63,900	61,763	120

Travel times including running time supplement have been calculated for the following three scenarios:

1. Existing planning rules, see section 1.5. Figure 12 shows the timetable for a nonstop intercity express. Figure 13 shows the speed profile for the same train.
2. UIC recommendations see section 1.4. Figure 14 shows the timetable for a nonstop intercity express train. Figure 15 shows the speed profile for the same train. The basic fixed minimum running time supplement of 1,5min/100km must be added to the calculated running times in TPS. Odense is 160km away from Copenhagen, which adds 1min36sec in fixed running time supplements.
3. Adjusted existing planning rules to achieve a travel time of 58minutes. A travel time of 58 minutes seems appropriate for being able to depart 2minutes later and making it to the next city within an hour of travel time. The adjustment of the existing planning rules results in a maximum value of percentage running time supplement of 11% instead of 13% as used in the existing planning rules. Figure 16 shows the timetable for a nonstop intercity express train. Figure 17 shows the speed profile for the same train.

Train L 9800000001 (DSB) [? (7971)]:
Model Train: KH - OD: 3 ET (unset)

Station	Ankomst	Afgang	Stop	Allowance	Sum Allowance	Type Res.	Sum. Type Res.
KH	00:59:00	01:00:00	01:00				
NEL	00:59:00	03:30	01:00	-00:08		00:13	
XKJN	00:59:00	14:30	01:00	-00:11		01:17	
RG	00:59:00	24:00	01:00	00:12		01:04	
FJ	00:59:00	27:30	01:00	-00:06		00:24	
SO	00:59:00	30:00	01:00	00:13		00:15	
SG	00:59:00	35:30	01:00	-00:01		00:38	
FO	00:59:00	38:30	01:00	-00:10		00:21	
KØ	00:59:00	41:00	01:00	-00:03		00:17	
SPR	00:59:00	45:00	01:00	00:03		00:27	
NG	00:59:00	49:00	01:00	00:05		00:27	
JU	00:59:00	50:30	01:00	-00:09		00:11	
UV	00:59:00	52:30	01:00	00:20		00:11	
MV	00:59:00	55:30	01:00	-00:15		00:22	
OD	01:59:00	02:01:00	02:00	-00:21	-00:31	00:26	06:33
					-00:31		06:33

Figure 12: Timetable for nonstop intercity express train, existing planning rules

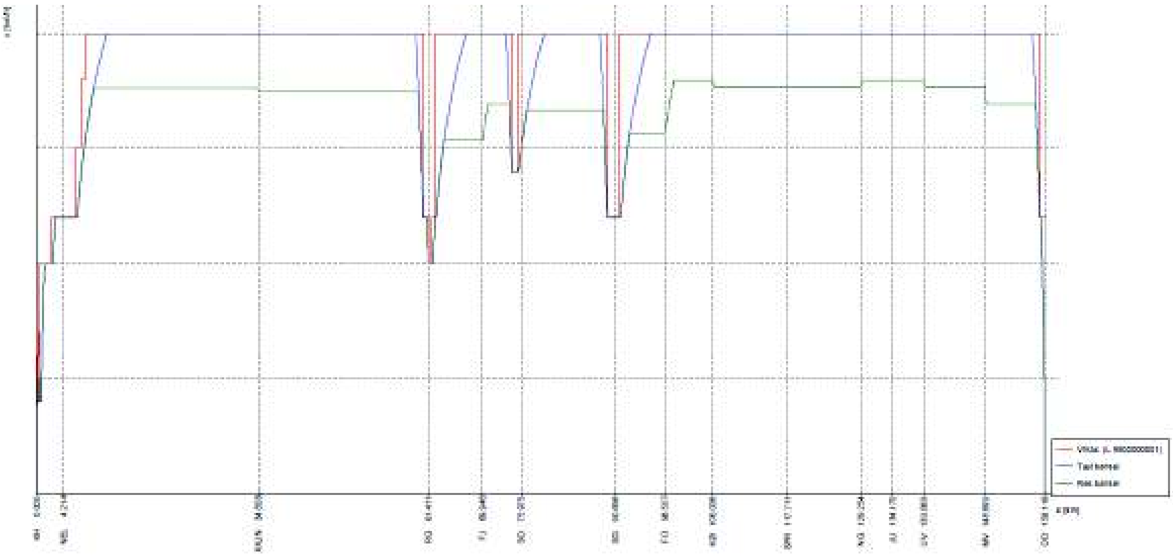

Figure 13: Speed profile for nonstop intercity express train, existing planning rules

Train Y 9800000111 (DSB) [? (7971)]:
Model Train: KH - OD: 3 ET (unset)

Station	Ankomst	Afgang	Stop	Allowance	Sum Allowance	Type Res.	Sum. Type Res.
KH	00:59:00	01:00:00	01:00				
NEL	00:59:00	03:30	01:00	00:00		00:05	
XKJN	00:59:00	14:00	01:00	00:07		00:29	
RG	00:59:00	22:30	01:00	-00:08		00:24	
FJ	00:59:00	26:00	01:00	00:09		00:09	
SO	00:59:00	28:00	01:00	-00:08		00:06	
SG	00:59:00	33:00	01:00	-00:07		00:14	
FO	00:59:00	36:00	01:00	00:03		00:08	
KØ	00:59:00	38:30	01:00	00:08		00:06	
SPR	00:59:00	42:00	01:00	-00:10		00:10	
NG	00:59:00	45:30	01:00	-00:08		00:10	
JU	00:59:00	47:00	01:00	-00:02		00:04	
UV	00:59:00	48:30	01:00	-00:03		00:04	
MV	00:59:00	51:30	01:00	-00:01		00:08	
OD	55:00	57:00	02:00	-00:05	-00:25	00:10	02:27
					-00:25		02:27

Figure 14: Timetable for nonstop intercity express train, UIC recommendations

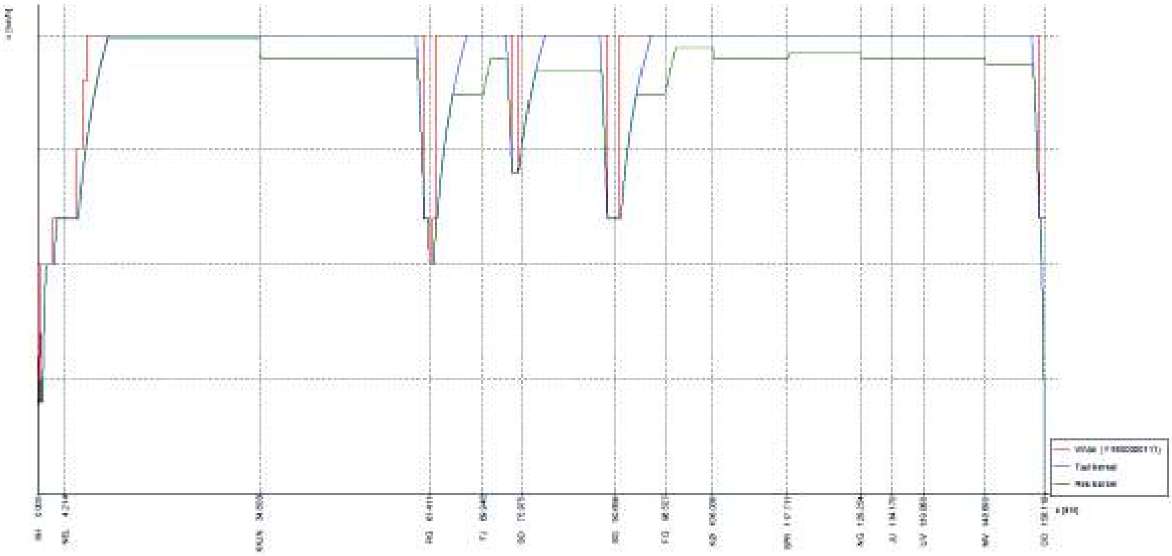

Figure 15: Speed profile for nonstop intercity express train, UIC recommendations

Train X 9800000011 (DSB) [? (7971)]
Model Train: KH - OD: 3 ET (unset)

Station	Ankomst	Afgang	Stop	Allowance	Sum Allowance	Type Res	Sum. Type Res.
KH	00:59:00	01:00:00	01:00				
NEL	00:59:00	03:30	01:00	-00:08		00:13	
XKJN	00:59:00	14:30	01:00	00:07		00:59	
RG	00:59:00	23:30	01:00	-00:03		00:49	
FJ	00:59:00	27:00	01:00	-00:01		00:19	
SO	00:59:00	29:00	01:00	-00:14		00:12	
SG	00:59:00	34:30	01:00	00:08		00:29	
FO	00:59:00	37:30	01:00	-00:05		00:16	
KØ	00:59:00	40:00	01:00	00:01		00:13	
SPR	00:59:00	44:00	01:00	00:09		00:21	
NG	00:59:00	48:00	01:00	00:12		00:20	
JU	00:59:00	49:30	01:00	-00:06		00:08	
UV	00:59:00	51:00	01:00	-00:07		00:08	
MV	00:59:00	54:00	01:00	-00:10		00:17	
OD	01:58:00	02:00:00	02:00	00:15	-00:02	00:20	05:04
					-00:02		05:04

Figure 16: Timetable for nonstop intercity express train, adjusted planning rules

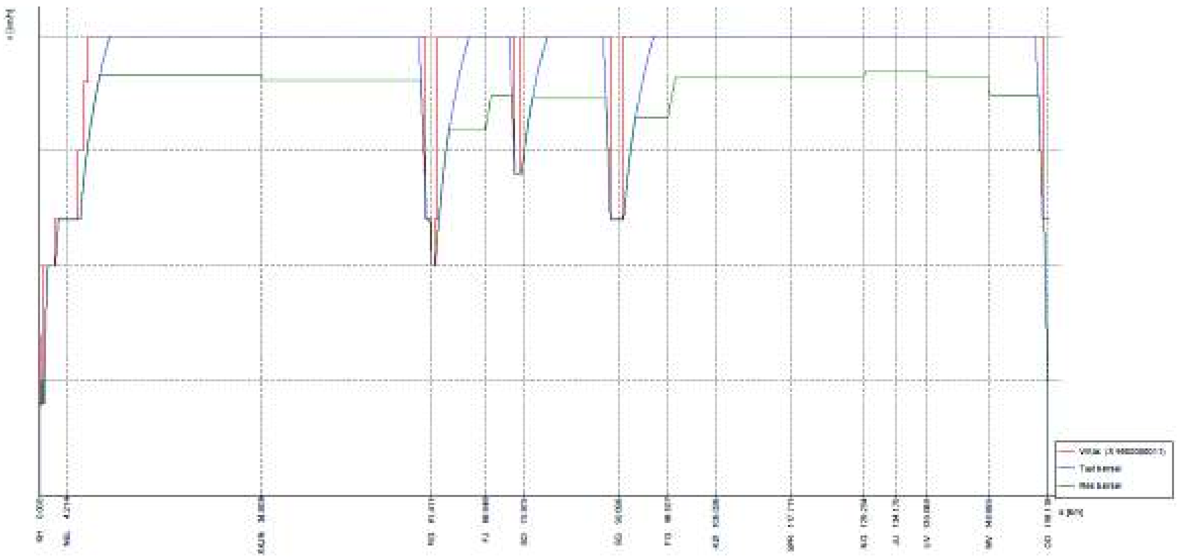

Figure 17: Speed profile for nonstop intercity express train, adjusted planning rules

In Table 10 a comparison of the three investigated scenarios is made. It becomes apparent that using the existing planning rules will result in a too long travel time but with an attractive level of running time supplements in regards to punctuality. Whereas the UIC recommendations will achieve a very attractive short travel time but also a dangerous little amount of running time supplements which increases the risk of delays dramatically.

Table 10: Comparison of scenarios

Scenario	Scheduled travel time [min:sec]	Allowances [min:sec]	Running time supplements [min:sec]	Running time supplements [%]
Existing planning rules	59:00	-00:31	06:33	13
UIC recommendations	56:30	-00:25	04:03	5 (+ fixed)
Adjusted planning rules	58:00	-00:02	05:04	10

A compromise can be made by using the adjusted planning rules. Here a short enough travel time is achieved and with a higher level of running time supplements than recommended by the UIC in case of incidents causing smaller delays.

If today's level of running time supplement of 12minutes and 14seconds (16,3% additional running time) is wanted or needed, large investments in both infrastructure and rolling stock is needed. The railway line between Ringsted and Odense must probably be improved further from 200km/h to maybe 220km/h. A new generation of rolling stock must be brought to Denmark that can run faster than maximum 200km/h as is the case today and thereby being able to utilize the higher maximum speeds provided by the infrastructure. A sensible solution could be a compromise between the scenario with adjusted planning rules and the high investments described above. Faster rolling stock being able to make use of the allowed 250km/h line speed on the new railway line between Copenhagen and Ringsted could be a step in that direction.

If these investments are not feasible, a consequence will be a future reduction of running time supplement levels from today's 16% to 10% in the timetable - a reduction of 37,5%! If no initiatives are taken, this will most probably lead to reduced punctuality levels. This will make the railway as a transportation system less attractive. A demand arises for dramatic changes in train operation philosophy with an intense focus on efforts to keep or even improve punctuality levels with less running time supplements. This can include a new philosophy of applying time supplements in the yearly timetable which can allow for reduced levels of supplements – see the chapter about placement of running time supplements in the timetable. Finally a big continuous effort has to be put into making sure that the detailed input data for the used timetabling systems are reflecting the real world as good as possible - see the earlier calculation example about intercity express train 27.

7 Conclusions

The application of time supplements in railway timetables is a trade of between short and thereby attractive travel times and the achievable punctuality levels with the timetable. Both are very important key performance indicators for timetables and the railway as a transport system, punctuality being regarded as the most important one.

Analyzing the valid yearly timetable for intercity express train 27 between Copenhagen central station and Odense station shows that the size of running time supplements used for this train is approximately 60% bigger as recommended by the international association of railways – UIC. There can be several valid reasons for this situation, amongst others a political focus on train punctuality levels and uncertainty about the validity of detailed input data for the timetable planning system in regards to infrastructure and rolling stock performance levels.

There are several strategies for the placement of running time supplements in the timetable. These are ranging from evenly spread supplements along the route of the train, to concentrating the effort on selected stations or railway sections. With the introduction of a new timetable in 2007 for the Copenhagen suburban train network (S-tog), an optimization of running time supplement placement has begun in Denmark. Inspired by the Swiss Bahn2000 timetable, condensation and compensation zones have been created – with success.

By using the existing planning rules from state owned railway infrastructure manager, Rail Net Denmark, it is not possible to achieve travel times short enough between Copenhagen and Odense that live up to the political demand of a future travel time less than one hour between these cities. Applying the UIC recommendations for running time supplements, results in an attractive short travel time but a very low level of running time supplements compared with today's timetable. A reasonable compromise can be made by introducing an adapted version of the existing planning rules. The adapted planning rules give a reasonable level of running time supplement but this still means a drastic reduction of today's level of running time supplements from 16 to 10% - a reduction of 37,5%. If present punctuality levels are to be kept, a new philosophy for railway timetabling and operations has to be implemented in the Danish railway sector before the introduction of new reduced train travel times between the largest cities in Denmark.

References

[1] Fosgerau, M., Hjorth, K., Lyk-Jensen, S. V., The Danish Value of Time Study, Final Report, Report 5, Danmarks Transportforskning, 2007Caimi, G., Burkholter, D., Herrmann, T., Chudak, F., Laumanns, M., Design of Railway Scheduling Model for Dense Services, *Networks and spatial economics*, Vol. 9, No. 1, 2009

[2] Hansen, I. A., Pachl, J. (editors), "Railway Timetable & Traffic", Eurail Press, 2008

[3] Interview with team leader for timetabling at Rail Net Denmark Ib Flod Johanson (29.04.2011)

[4] Kroon, L. G., Dekker, R., Vromans, M. J. C. M., Cyclic Railway Timetabling: A Stochastic Optimization Approach, Railway Optimization 2004, LNCS 4359, pp 41-66, Springer Verlag 2007

[5] Landex, A., Methods to estimate capacity and passenger delays, PhD-thesis, Department of Transport, Technical University of Denmark, 2008

[6] Landex, A., Nielsen, O. A., 6-by samarbejdet – om hurtige tog mellem byerne, Center for Trafik og Transport, 2006

[7] Lüthi, M., Medeossi, G., Nash, A., Evaluation of an Integrated Real-Time Rescheduling and Train Control System for Heacily Used Areas, Proceedings of the 2nd International Seminar on Railway Operations Modeling and Analysis, RailHannover, 2007

[8] Piester, M., Thorhauge, M., Samfundsøkonomiske fordele i køreplaner ved hjælp af passagerforsinkelsesmodeller (Socio-economic Benefits in Timetables by Implementing Passenger Delay Models), Master thesis (in Danish), Department of Transport, Technical University of Denmark, 2010

[9] Rudolph, R., Radtke, A., "Optimization of allowances in railway scheduling", Proceedings of the World Congress on Railway Research, 2006

[10] Union International des Chemins de fer, UIC CODE 451-1 OR, Timetable recovery margins to guarantee timekeeping – Recovery margins, 4th Edition, 2000

[11] www.dsb.dk/om-dsb/virksomheden/tog-i-drift/personvogne/ (16.05.2011)

[12] www.hacon.de (16.05.2011)

[13] www.trm.dk/da/publikationer/2004/ (13.05.2011)

[14] www.opentrack.ch/opentrack/opentrack_e/opentrack_e.html (12.05.2011)

[15] www.rmcon.de/en.html (12.05.2011)