

# Railway Timetabling Based on Systematic Follow-up on Realized Railway Operations

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## 1 Abstract

This paper shows that the use of systematic follow-up on realized railway operations has potential to improve current and future timetables. After describing the present timetabling process at the main Danish Infrastructure Manager, Rail Net Denmark, it is concluded that systematic follow-up on realized railway operations is not yet a formal integrated part of the timetabling process. As Rail Net Denmark uses timetabling guidelines from the European professional organization of infrastructure managers - Rail Net Europe – the lack of systematic follow-up may very well exist elsewhere in Europe.

Following the introduction, an initial theoretical approach to systematic follow-up on realized operations is described. Focus is on identifying delay patterns in regards to individual train numbers, train categories, time periods and geography or combinations hereof.

Subsequently theory is put into practice. First, the current system for collecting data on operational performance is described as well as methods on how to aggregate this. Six chosen cases are examined to cover the four focus points and combinations hereof. Detailed results are shown in Appendices 1-6. The analyses prove existing ideas about delay patterns in today's railway operations.

Finally it can be concluded that the timetabling process at Rail Net Denmark has a potential for improvements by integrating systematic follow-up on realized operations in the process. By introducing closer cooperation between timetabling and operations monitoring specialists regarding systematic analyses throughout the entire timetabling process there is a potential to improve valid and future timetables.

*Keywords: Railway timetables, timetabling process, systematic follow-up, realized operations*

## 2 Introduction

By legislation of the European Union, it is the duty of the national railway infrastructure manager (IM) to prepare feasible timetables for his railway network. Rail Net Denmark (Banedanmark) is the most important infrastructure manager (IM) in Denmark and is owned by the Danish state [8].

To steadily improve timetable quality IM must learn from identified weaknesses found in earlier prepared timetables. It is thus necessary to look at the timetabling process as a learning loop. Timetable quality can be measured by analyzing recorded performance data from traffic operations. By doing analyses in a systematic way the efficiency of this learning process increases drastically [7, 15].

Systematic follow-up on realized operations gives possibilities to evaluate performance of the entire railway system: Implemented timetables, IM and/or railway undertaking (RU) employees, infrastructure elements and rolling stock.

The performed analyzes are searching for patterns in performance data. Finding patterns in occurring train delays indicates misjudgments or planning in optimums of various kinds. Sometimes it is possible to make corrections in the valid timetable immediately by e.g. changing track occupation plans or running times for trains. In other cases IM have to wait until implementation of next year's timetable [3, 5, 15].

IM timetable planners can use conclusions deduced from the systematic follow up observations to improve the quality of future timetables. To achieve the best input for future timetables a close cooperation between railway operations quality control and timetabling teams is essential. Timetable planners can help define what kind of delay patterns the systematic follow up analyses should look for and help with interpreting the found results.

This paper is outlined as follows. Section 3 describes the general Rail Net Europe (RNE) international timetabling process and the adjusted timetabling process for the yearly national timetable at Rail Net Denmark. A theoretical first approach to systematic follow-up on operations is given in section 4. Section 5 explains possibilities to collect operations performance data and ways to aggregate these. Selected test cases for a systematic analysis approach are described in section 6. Detailed results are shown in appendixes 1-6. Finally section 7 presents some conclusions and an outlook on possible future work within this field at Rail Net Denmark.

## 3 The Timetabling Process at Rail Net Denmark

Rail Net Denmark is a member of the organization Rail Net Europe (RNE). This is a professional body of European railway IM whose main goal is to improve international

passenger and freight railway operations – but with focus on freight traffic. One way to achieve this is by developing and implementing a common timetabling process with all members [11, 12, 17].

After becoming a member of RNE, Rail Net Denmark had to adjust its own timetabling process to adapt it to the general timetabling process by RNE. In the following two sections the general RNE and adjusted Rail Net Denmark timetabling process are presented.

### 3.1 RNE Timetabling process

From conceiving the first thoughts on a future timetable to the day of implementation a time span of 48 months will pass according to the general RNE timetabling process, as shown in Figure 1. The timetable becomes effective on the 2<sup>nd</sup> Sunday in December.

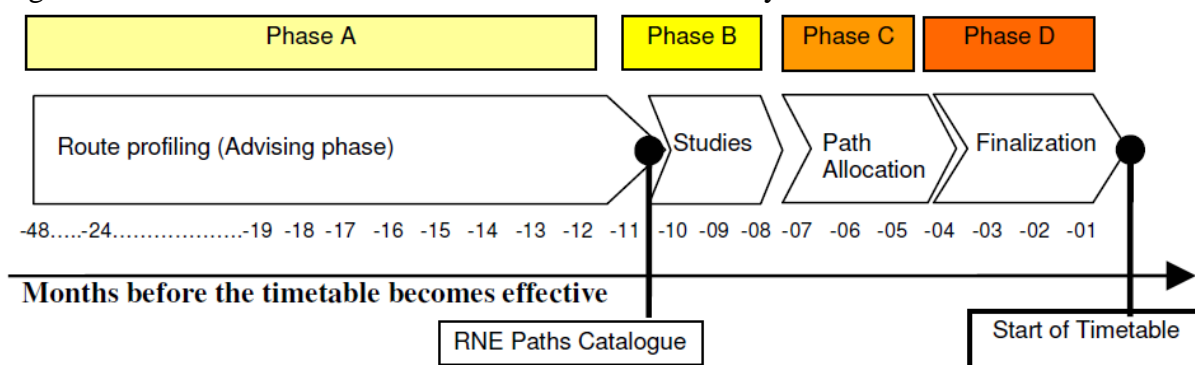


Figure 1: The RNE general timetabling process [12]

Figure 2 shows the actual deadlines in the final part of the timetabling process for the coming yearly timetable valid for 2010.

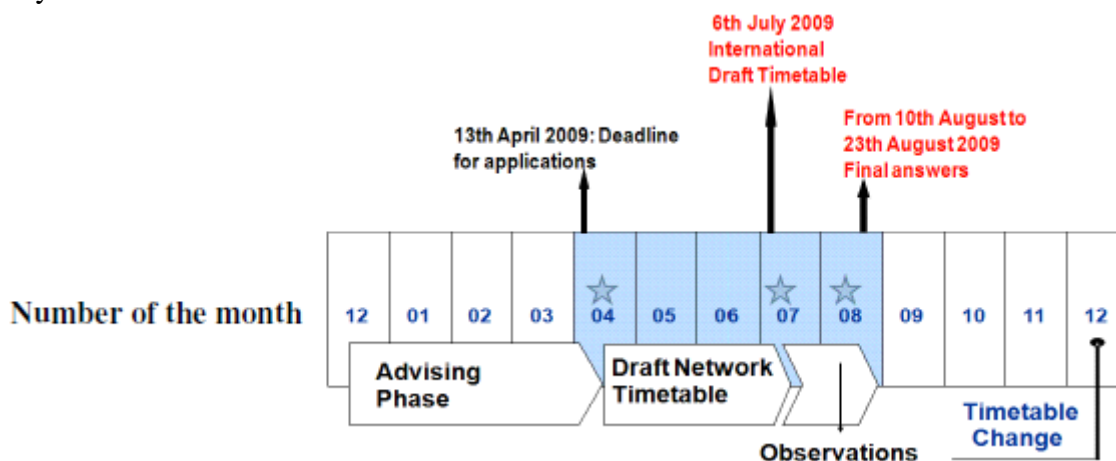


Figure 2: Deadlines in the final part of RNE timetabling process 2010 [11]

The general RNE international timetabling process consists of 4 phases [12].

**Phase A:** Corridor profiling and RU advises - time period from 48 to 12 months before the timetable becomes effective. The first half of phase A the IM needs to get an overview of future available infrastructure capacity and wishes for capacity allocation from RUs. The IM

gathers strategic long term information which may influence railway traffic and infrastructure capacity. This could be changes in traffic pattern by RUs and major maintenance works on the infrastructure [12].

It is important for the IM to try and harmonize corridor capacity profiles by e.g. extending bottlenecks or minimizing constraints for corridors. An example of a capacity profile is shown in

Figure 3. It is less complicated to create a timetable for a corridor with a harmonized capacity profile than without [11, 12].

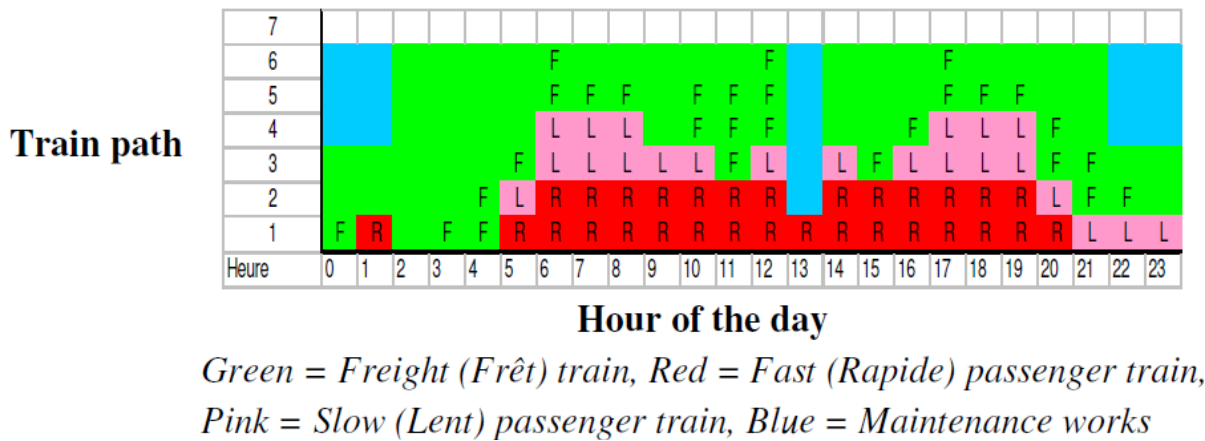


Figure 3: RNE capacity profile for a given corridor section [11, 12]

Figure 3 shows an example of communicating consumption of infrastructure capacity. Each column is one hour (0-23) and each row is a train path (1-7). The later can be allocated to either a category of train service or to maintenance. Train paths marked with a letter are in use according to preliminary path requests. Illustrating use of capacity in this way gives an intuitive understanding of the degree of capacity consumption for both RU and IM [11, 12]. In reality train paths have different capacity consumptions since there are differences in travel speed and stopping pattern between different train types. However during the early stages of timetable planning, simplifications such as in Figure 3 can successfully be used.

In the second half of phase A the IM may help any RUs to define their needs in form of train paths. Simultaneously with this creation of international RNE catalogue train paths takes place. This is done by connecting standard national freight paths at national borders [12].

**Phase B: Feasibility Studies - (18 to 9 months before the timetable becomes effective.)**

Feasibility studies can be requested by a RU to give an insight into how wanted types of train paths can fit into a future timetable. The results may give the RU a better foundation for making decisions in regards to path requests. Requested studies will be carried out by the IM or be based on catalogue paths or prepared schemes from phase A [12].

**Phase C:** Detailed Path Allocation for Yearly Timetable (8 to 5 months before the timetable becomes effective.)

Deadline for path requests delivered to the IM is the 2<sup>nd</sup> Monday in April before implementation of the new yearly timetable. RNE organizes meetings for all involved IMs to ensure coordination of path requests before allocating capacity. At these meetings IMs can gather national path orders for international traffic and make sure they are harmonized for international train paths at national borders [11, 12].

The IM publishes the new timetables between 6 to 5 months before they become effective. Documents containing all trains crossing national borders are prepared and send to all relevant IMs. This makes it possible to check train times at borders [12].

**Phase D:** Path allocation in the remaining capacity (4 months before to 12 months after the timetable becomes effective).

Requests for train paths received 8 months before the timetable is valid are treated on the basis of the remaining available capacity. This includes both all ready ordered train paths and planned possessions. Paths can be allocated by using the RNE path catalogue, national paths or available capacity [11, 12].

### 3.2 Timetabling Process for the National Yearly Timetable

Rail Net Denmark has adjusted its timetabling process to the RNE model. A process chart of the valid timetabling process for the yearly national timetable is shown in Figure 4.

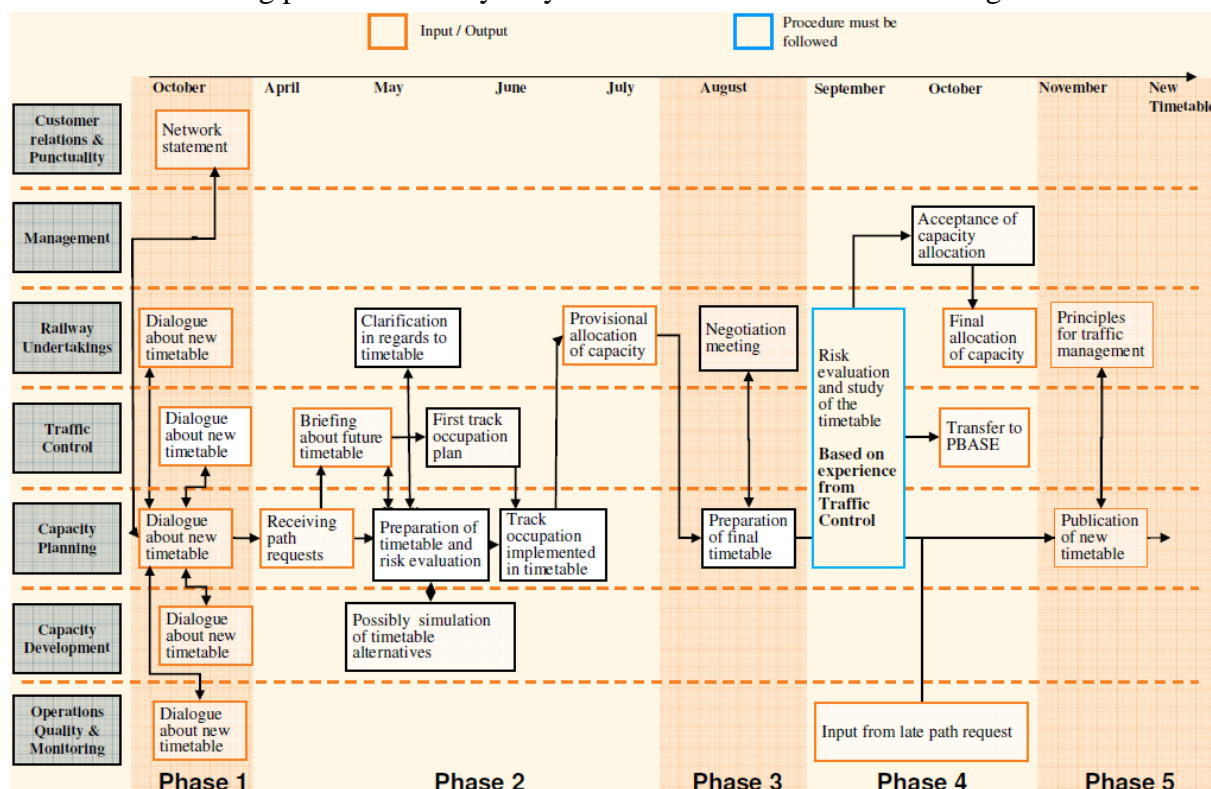


Figure 4: Timetabling process chart for the yearly timetable at Rail Net Denmark [14]

Each horizontal line represents an involved unit within the Rail Net Denmark Operations organization. Every box represents involvement from a given unit in the overall timetabling process. Involvement can be e.g. giving input, produce output or quality control.

The responsibility of preparing the yearly timetable is placed with the organization unit *Capacity Planning*. Dialogue between *Capacity Planning* and all other timetable stakeholders takes place during phase 1 from October to April. This is followed by phase 2 which takes place between April and July. During this phase, path requests are received from RUs and the first draft versions of a feasible timetable are made and evaluated. Phase 3 focuses on achieving a compromise between all RUs through negotiations in order to agree upon a final timetable. This takes place around August. During phase 4 a final risk evaluation of the vulnerability of the timetable to consecutive delays is carried out. This is done locally at the traffic control centers and is based on their detailed local knowledge of the network. This happens during September and the timetable is finally approved by Rail Net Denmark management during October. The prepared timetable is made operational in phase 5 lasting from November into December.

After publication of the timetable both RNE and Rail Net Denmark timetabling processes stop. There is no planned systematic follow-up on realized operations during the first period after implementation of the new timetable or towards the end of a given timetable period. Results from this could be used to adjust existing and improve future timetables. However, in reality there are limited possibilities to make changes to the timetable once it has been published. This applies specially for international train paths. In this case, several IMs have to cooperate on alterations. The normal practice is to introduce minor changes in the middle of June during the timetable period. Focus is mainly on train paths for freight trains. Public timetables are difficult to change because of the risk of confusing the passengers and the costs of communicating the changes [5]. This is part of the explanation for the lack of focus on systematic follow-up on realized operations.

### 3.3 Learning Loops in the Timetabling Process

It is noticeable that the RNE general timetabling process has no build in formal learning loop(s) or in no other ways ensures use of experience from earlier timetables. See Figure 1. Responsibility for learning and using experience is given to each IM from RNE. Systematic follow-up on timetable performance is not an issue dealt with in the RNE general timetabling process [3].

The timetabling process for the yearly national timetable at Rail Net Denmark includes use of practical experience from both traffic control staff and members of the “Operations Quality & Monitoring” section in an early dialogue phase. See Figure 4 (phase 1 and 4). Besides this there are no formal and/or systematic build in learning loops e.g. making use of systematic follow-up on realized operations to improve either valid or future timetables.

## 4 Systematic Follow-up on Realized Railway Operations

Today, the “Check” function in the “Plan – Do – Check – Act” learning loop in creating timetables is based on the experience of the timetable planners. No matter how experienced the timetable planners are, there is a risk of missing patterns which ought to be investigated more closely. With the aim of closing this hole in the loop, methods on how to perform this systematic evaluation of realized operations have been developed. In an initial phase, the analyses can be divided into four categories depending on their focus:

**Single train numbers** - e.g. which trains appear most frequently in delay registrations?

**A train category** - e.g. InterCity trains or international transit freight trains

**Time periods** - e.g. morning rush hour or winter months

**Geography** - e.g. a single station or line section

Not only is it interesting to look at these topics individually but also in possible combinations hereof, e.g. international transit freight trains on a given line section during the Friday afternoon rush hour period.

Creating a “black list” of top 100 (or more) most delayed train numbers on a monthly basis gives a good starting point for systematic analyses. Every week around 11.000 trains run on Rail Net Denmark’s infrastructure. It should be checked if there are train numbers recurring in these prepared train lists. Following this it must be investigated if a major part of these train numbers belong to a certain train category. This is necessary because timetables in most cases consists of periodic traffic patterns, e.g. every hour and therefore problems can be copied to larger parts of the daily timetable.

During morning and afternoon rush hours the railway as a system is under more pressure than off-peak periods. More trains are using the infrastructure and they are often made longer to ensure enough passenger capacity. This increases vulnerability of the entire system. Delays from one train can more easily be transferred to other running trains [4, 6, 15]. Therefore it makes sense to examine if registered delays mainly occur in fixed time windows such as rush hours or e.g. evening and night hours (or adjacent time windows) were the major part of maintenance works takes place which can reduce available infrastructure capacity.

Capacity consumption can differ throughout a railway network. A geographical concentration of delays is most often caused by a high degree of capacity consumption at a station/junction or on a line section. The degree of capacity consumption depends on 2 things [4, 6]:

**Infrastructure specifications** – a double track line has more capacity than a single track line. Railway junctions can be designed as level or flying junctions. Some interlocking systems provide better headway times than others.

**Traffic pattern on given location** – Some railway lines simply carry more trains than others. Rail traffic can consist of only passenger trains that stop at all stations or of several different train categories with different travelling speeds and stopping patterns.

An increase in train path requests from RU for the yearly timetable 2010 has created new capacity bottlenecks on the railway infrastructure of Rail Net Denmark. On several new line sections in and around the Copenhagen area the infrastructure capacity is exhausted. Figure 5 gives an overview of identified capacity bottlenecks on the network of Rail Net Denmark. These identified stations and line sections are obvious candidates for a geographical concentration of delays [4, 6].

If there are no other patterns than a geographical concentration of delay registrations the analysis could indicate returning problems with specific parts of infrastructure elements.



*Figure 5: Overview of identified capacity bottlenecks (marked red) on Rail Net Denmark's network [9]*

If no pattern can be found in examined delay registration data a general timetabling problem may exist. This could be caused by a general data error in the used timetabling tool. Rail Net Denmark uses the tool TPS (Timetable Planning System). Data errors can appear in several modules of a timetabling tool, e.g. infrastructure model or rolling stock characteristics [16].

## 5 Collectable Operations Performance Data

To be able to follow up on the realised operations Rail Net Denmark registers time of passage and deviation from the timetable for every train at a large number of stations. This is done by using measuring points in the infrastructure which either indicates the time of arrival to, departure from or passing through a given station [13]. If the deviation from the timetable



reaches 5:00 minutes or more for long distance and regional trains (2:30 minutes or more for Copenhagen suburban trains), a detailed delay report is created, describing the cause and consequences of the delay. Much work is carried out analysing these reports [13].

A train may very well consequently be a bit late at certain stations but never causing a delay report. Such systematic delays would not be found through the traditional approach to delay analysis within Rail Net Denmark. Analysis of timetable deviations of all train runs and not only of the delay reports can thus prove valuable and give new knowledge to improve punctuality of trains.

The aim of this work is to present a catalogue of reports based on a systematic analysis of deviations. However, organisational implementation of the reports is not covered, since this is the next step in the process. A final goal of this approach is to develop an automated system to evaluate the realized railway operations, where delay patterns are recognised. Result of such analyses could be a list of trains with too little or too much time in the timetable between two measuring points, and thus where there has been allocated too much or too little capacity to a train or category of trains. This automatic evaluation can serve as a feedback/learning loop in the process of planning train timetables.

When a delay report is created, a responsible party for the delay is identified. With this approach, it is neither possible nor relevant to attribute a specific cause for trains systematically being late. It can be argued, that there may be many different reasons for a specific train always being late and that more focus should be on analysis of reasons for the deviations. If a specific train is always late, it should be considered to adjust the timetable, no matter the reason for the delays (unless of course, the reason is known, always the same and will be dealt with soon e.g. local speed restrictions).

A fundamental principle within planning of railway traffic is the train path. The train path allocates a part of the available infrastructure capacity to a train by occupying relevant parts of the railway line at the projected time of passage. A train is expected to stay within its train path throughout its run [4, 6]. However, in reality it often happens that a train leaves its planned train path if it is delayed or runs early. If a train enters the train path of other trains, additional delays occur and this may very well have a domino effect [4, 6].

Since the capacity of the Danish railway network is coming under increasing pressure [10], it is also of great importance to be able to determine the consequences of running additional trains. Perhaps, the consequence on punctuality of an additional train is negligible – or perhaps, infrastructure capacity is already pressed to the limit. A systematic evaluation on the deviations from the timetable can give insight into such considerations.

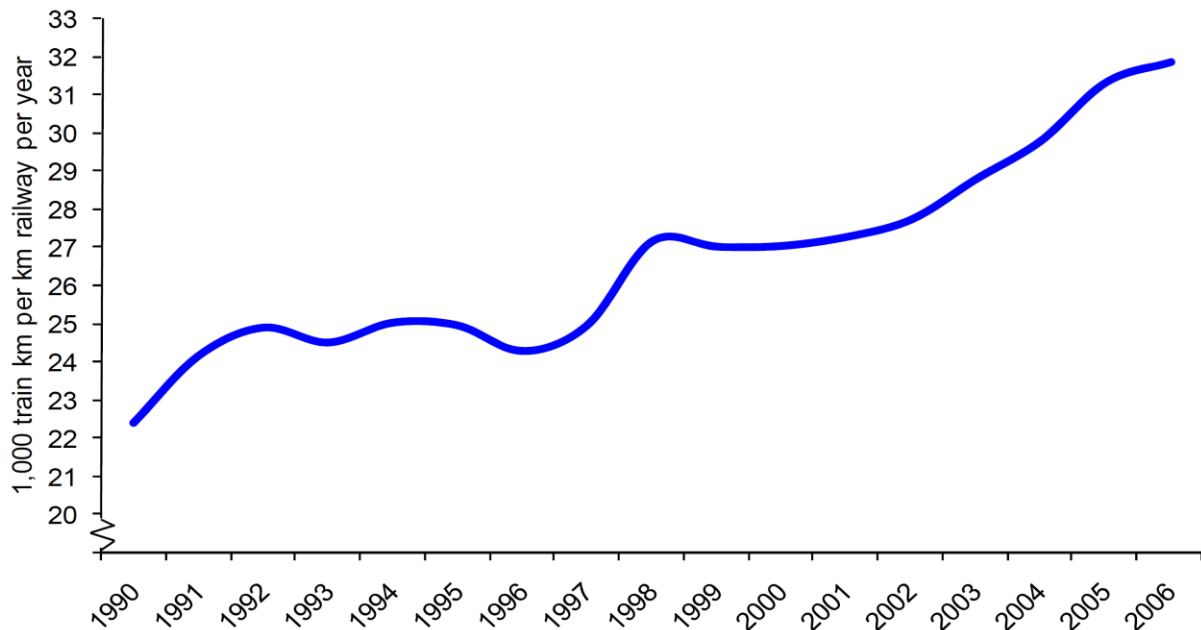


Figure 6: Development in utilization of the Danish railway infrastructure. [6]

## 5.1 Delay Data Acquisition (method)

Two main approaches have been identified to analyse data of train runs:

- Analysis of the timetable deviation at measuring points (A)
- Analysis of the difference in deviation from the timetable between measuring points (B)

In the first approach, data shows the delay at measuring points, which is relevant when evaluating actual performance. The second approach shows the difference in deviation between measuring points and is thus mathematically a derivative of the first approach. The second approach reveals where delays occur whereas the first approach shows the total delay during the train run.

Typically, there tends to be an increase in timetable deviation at stations. There are two technical explanations for this. Passenger trains are typically not allowed to leave early from stations [1], so if they arrive early at the station, which happens frequently, an increase in timetable deviation from arrival to departure will occur. On the network of Rail Net Denmark, the arrival to a station is registered when the platform track block section is occupied and the departure is registered when the block section after the platform track is occupied. As a consequence of this, the registration of arrivals is some seconds earlier than the time when the passenger exchange at the station begins. The registration of departures also happens some seconds later than the trains starts moving. This must be taken into account when analysing delays on stations. On open lines, it is not uncommon for a train to gain time due to the use of running time supplements in timetabling. This may often result in an early arrival at the next station (Running time supplements are evenly distributed on Rail Net Denmark's network).

Rail Net Denmark stores data for train runs for each measuring point (first approach data format). Through usage of a software package/script, data on train runs can easily be transformed into differences in deviation between two measuring points (second approach data format). The choice of data format depends on the analysis wished to be carried out.

The train run data registration system of Rail Net Denmark does not as such store information about which trains caused initial delays and which trains had consecutive delays. This information is however partially available from the delay reports. The trains, which had initial delays, are most relevant to focus on, since this is where an action can prevent trains from being delayed in the first place. A reason for consecutive train delays may be a too tight timetable, and thus those trains do require attention. However, for many analyses and approaches, this information is not necessary [2].

## 5.2 Delay Data Aggregation (method)

Aggregation of data is done using a quantile approach as opposed to a simple average. Using an average on timetable deviations would be very vulnerable to the impact of large single delays. Especially trains running early would significantly impact the result if an average is used. Generally, passenger trains do not run early since they have to respect the public timetable [1]. However freight trains have much fewer constrictions in this respect and are very often seen running both very early and very late. A quantile approach does not have this weakness.

Two different quantile approaches have been developed. In both cases the quantile function is a function of measuring points running over a selected time period. Depending on the needed output, the function can either be run as a function of a specific train number or a group of train numbers. It is only meaningful to aggregate on a group of train numbers with something in common, typically a periodic train system running on the same minutes through the day.

The distribution function for delays of specific train numbers is given by

$$F(x_{r,n}) = p_{r,n} \quad (1)$$

where  $r$  is the measuring point,  $n$  the train number

The corresponding  $p$ -percentile function is

$$F^{-1}(p_{r,n}) = x_{r,n} \quad (2)$$

The distribution function on a group of train numbers is given by

$$F(x_{r,n_{grp}}) = p_{r,n_{grp}} \quad (3)$$

where  $r$  is the measure point,  $n_{grp}$  the group of trains

The corresponding  $p$ -percentile function is

$$F^{-1}(p_{r,n_{grp}}) = x_{r,n_{grp}} \quad (4)$$

Since eqn. (1) only calculates the deviation for a specific train at a specific measuring point over time, input equals output if the function is only run with dataset of one day. A consequence of additional data on which the percentile in eqn. (2) is calculated is that if a single train has a large deviation from the other or if a large deviation exists between the days, this has a greater impact on the result in eqn. (1) than in eqn. (2).

Any additional aggregation is done using averages on the calculated percentiles.

### 5.2.1 Choice of Quantiles

Different quantiles have been used and even though all contribute with relevant information, two have proven to be more useful than others: the 50% quantile, since this is the median and the 80% quantile since this tends to lay around a delay threshold of 5:00 minutes – which matches the delay criteria for creating delay reports used by Rail Net Denmark.

### 5.2.2 Length of Time Period Examined

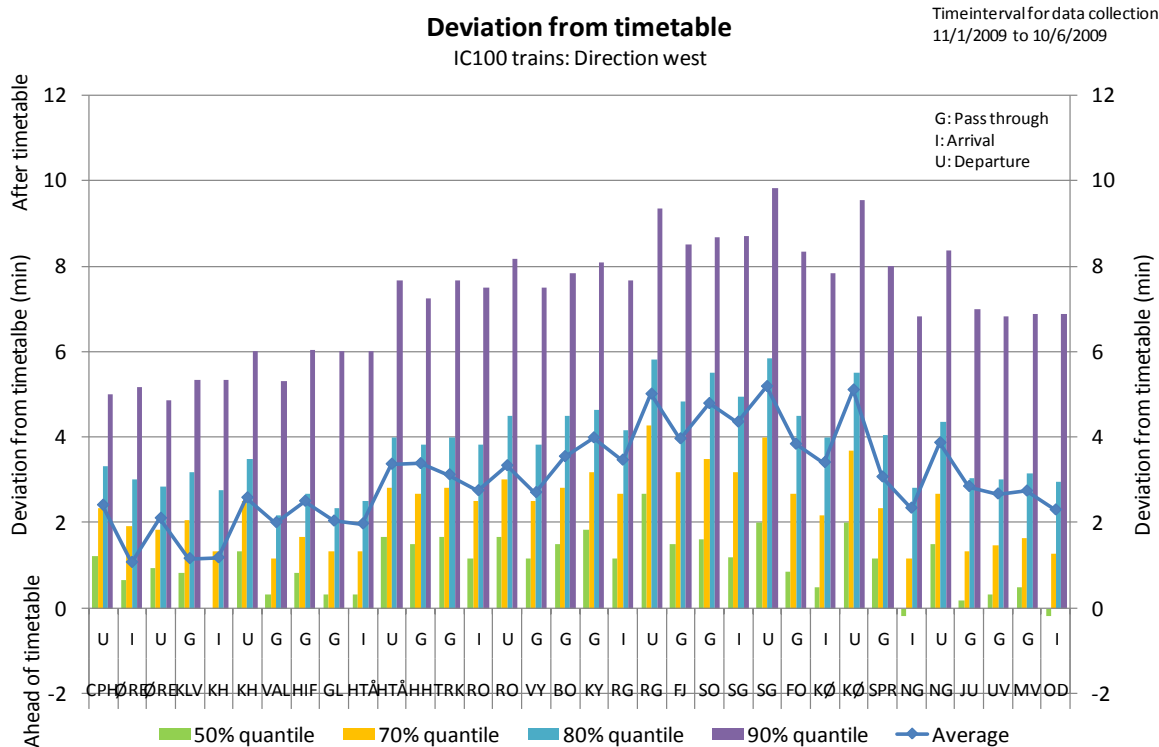
A requirement is that the timetable of trains examined, has no (significantly) changes over the period of time examined. Thus the maximum period of time examined is one year. If the period is too short, single events will have too much influence on the result. A guesstimate for this minimum value is a month depending on the number of trains investigated and the aim of the analysis. If a short period such as a week is used, local infrastructure faults may have a very significant impact on the result

## 6 Delay Data Analysis Used as Feed-back (application)

Based on data on operational performance, the approaches described in the chapter *Systematic Follow-up on Realized Railway Operations* are implemented. Of course the choice of approach depends on the aim of the analysis.

### 6.1 Train Category (accumulated deviations)

With this method, a specific train or groups of trains are evaluated over a time window and network section. This method shows the timetable deviations on during the train runs and thus shows the accumulation of delays as well as the delays experienced by the passengers.



**Figure 7: Example of graph showing the time table deviation for at train system.**

As examples, such an analysis has been carried out on the intercity train (IC) system running hourly between Kastrup (Copenhagen) airport and Lindholm (Aalborg) as well as on high priority transit freight trains (*Appendix 1: Train Category - Case IC100, page 21* and *Appendix 2: Train Category - Case High Priority Transit Freight Trains, page 24*). For the westbound intercity trains delays are registered across Zealand and between the cities Frederica and Århus. The eastbound intercity trains generally seem to be a bit more punctual throughout their run.

This approach has also been used to show consequences of running the Friday supplementary train service from Copenhagen to Århus. These interregional (IR) trains run just before some IC trains between Copenhagen and Århus. A comparison between the train run of those IC trains on Thursdays and Fridays has been carried out (*Appendix 3: Train Category - Case IC/IR, page 27*). This example shows that the Thursday trains are more punctual than the Friday trains. This is due to the IR trains as well as more passengers travelling on a Friday. However, it is not possible to conclude whether the impact of the IR trains on the IC is acceptable or not – this has to be discussed with the train operating companies. Both services are operated by the same RU.

## 6.2 Line Section (occurrence of delays)

Using data on the difference in delays between measuring points, an analysis of the performance of a section of railway line can be carried out. Such an analysis can identify speed restrictions, which are not accounted for in the timetable (LA) or e.g. leaf fall.

However, such an analysis can also reveal sections where the time table supplement seems to be too small or large, which, if this is not done on purpose, may have to be corrected in the next timetable. Passenger trains typically gain time on the open line stretches due to the usage of running time supplements in the timetable, whereas they typically lose time at stations, since they are not allowed to depart early from a station [1].

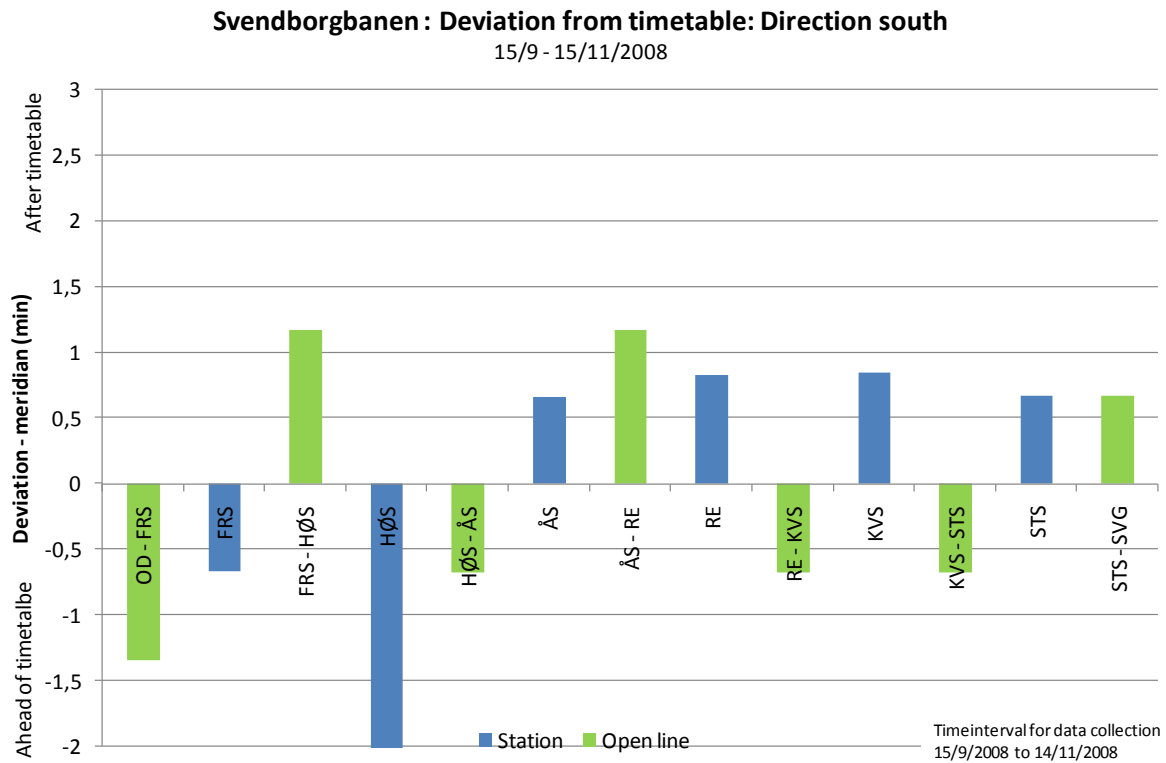


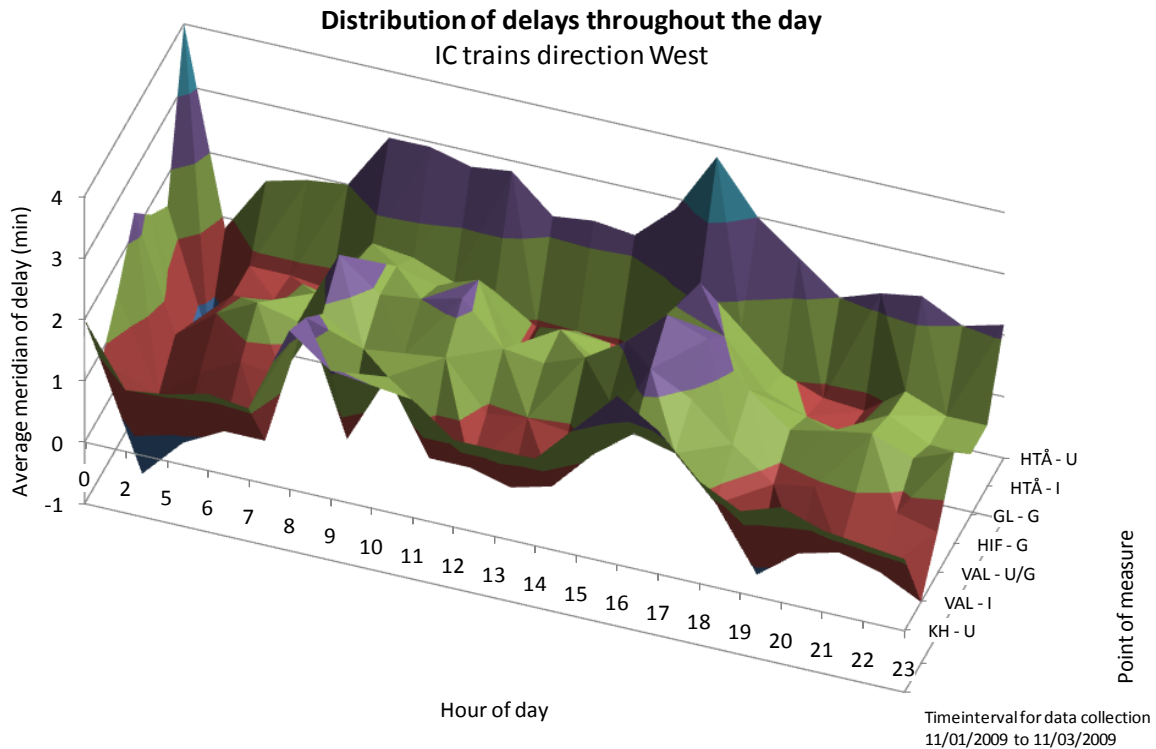
Figure 8: Example of graph showing the occurrence of time table deviation for a train system.

With this approach differences in precision of timetable data compared to registered data becomes even more important. Within Rail Net Denmark, the timetables have a resolution of 30 seconds whereas the actual passage of measuring points has a resolution of 10 seconds where the data is registered automatically. Where it is done manually, the resolution is 1 minute. Using this approach, it is thus very important to take into account that some of the deviations may be due to technical reasons. Secondly, the timetable may also deliberately be too tight at specific points due to capacity considerations.

The railway line between Odense and Svendborg has been used as an example of this approach (Appendix 4: Line Section - Case Svendborgbanen page 29). This shows that there are some significant losses of time for the northbound trains between Årslev and Fruens Bøge on Sundays. The period of time examined was during the leaf fall season and the leaf fall treatment vehicles were not operating on the night after Saturday due to work hour restrictions. This may be the explanation.

### 6.3 Time Period

Another approach is the time window approach plotting the deviations on a section as a function of time of the day. This approach may reveal information on consequences of nightly maintenance work or the effect of additional rush hour trains.



*Figure 9: Example of graph showing deviation as a function of hour of the day.*

This method has been tested on the railway section Copenhagen – Høje Taastrup, which is one of the most heavily used in Denmark (*Appendix 5: Time Period - Case Line Section Copenhagen Central Station – Høje Taastrup, page 32*). As expected the delays are much higher during rush hour. However, during the night hours, delays also occur. This is due to maintenance works.

## 6.4 Top 100 List - Most Delayed Trains

A final approach is the identification of the most delayed combination of trains and measuring points (*Top 100 List - Most Delayed Trains, page 33*). With this method, particular care has to be taken querying the results. E.g. freight trains have by the nature of their operation more deviations from the timetable and they may then very well out mask other trains.

Reports using this “black list” approach could both be made over a long examination period systematically identifying structural timetable weaknesses but also over shorter periods of time such as a week showing a “last 7 days” status. Here local speed restrictions may very well be the cause of many of the trains / measuring points which come out worst. This kind of data can e.g. help rank speed restrictions according to their influence on realized operations.



## 7 Conclusion and Perspective

Presently, systematic follow-up on realized railway operations is not an integrated part of the timetabling process at the IM Rail Net Denmark. This paper has shown that an introduction of systematic follow-up has potential to improve the timetabling processes as a supplement to the experience based processes today. The presented theoretical approach to systematic follow-up has been applied to real operations data and results proved promising to both railway operations analysts and timetable planners. Next step is an organisational implementation of this approach in the Rail Net Denmark timetabling process.

The presented test cases have not revealed information which was fundamentally unexpected within Rail Net Denmark. However, the cases have quantified and documented many issues which were common beliefs and perceptions, thus making it much easier to act since the issues have been quantified. The feedback/learning loop in the timetable process can thus now be based not only on experience amongst planners but also on quantifiable evidence.

The aim of the methods is to expose delay patterns and derived train operation problems so that further analysis can be carried out and corrective actions devised if appropriate. Those corrective actions may include changes to the timetable. The methods are thus “just” a first step in the follow up process answering the question of “where are the problems?” The questions of “why” and “what to do” are to be answered by other analyses.

As in many other cases, the interpretation of the analysis results requires a certain amount of knowledge about railway operations. In many cases there may be logical reasons to what at first appears as large time losses on railway sections. Therein lies a future challenge in developing an automatic method which identifies problematic train runs for further analysis. An aim could be to develop a tool which automatically evaluates the timetable of a given train over a period of time and gives it a single grade as well as a similar tool which does the same for timetables for line sections.

Further work could also be the usage of Geographic Information Systems (GIS) to visualise analysis data e.g. for displaying the average meridian of deviations from the timetable on a map of the railway network. This could be a powerful tool to spot delay patterns and increase the level of understanding for train delays amongst timetable planners and other railway personnel. The advantage of GIS maps is that they are intuitively understandable even for layman.

As opposed to the traditional delay report approach, which only allows analysis of trains delays of 5:00 minutes or more (2½ minutes on S-banen), this approach permits the analysis of all timetable deviations, thus giving completely new information on timetable deviations. Within the classical follow-up paradigm, a train could remain unnoticed by the follow up

processes even though it daily was delayed 4 minutes or always ended up on delay reports with different responsible parties. The new approach makes sure that such trains will be identified. This new approach should not be regarded as a substitute to the classical threshold based approach but as a supplement giving valuable new information on timetable deviations and thus creating a better basis for future timetable development.

## 8 References

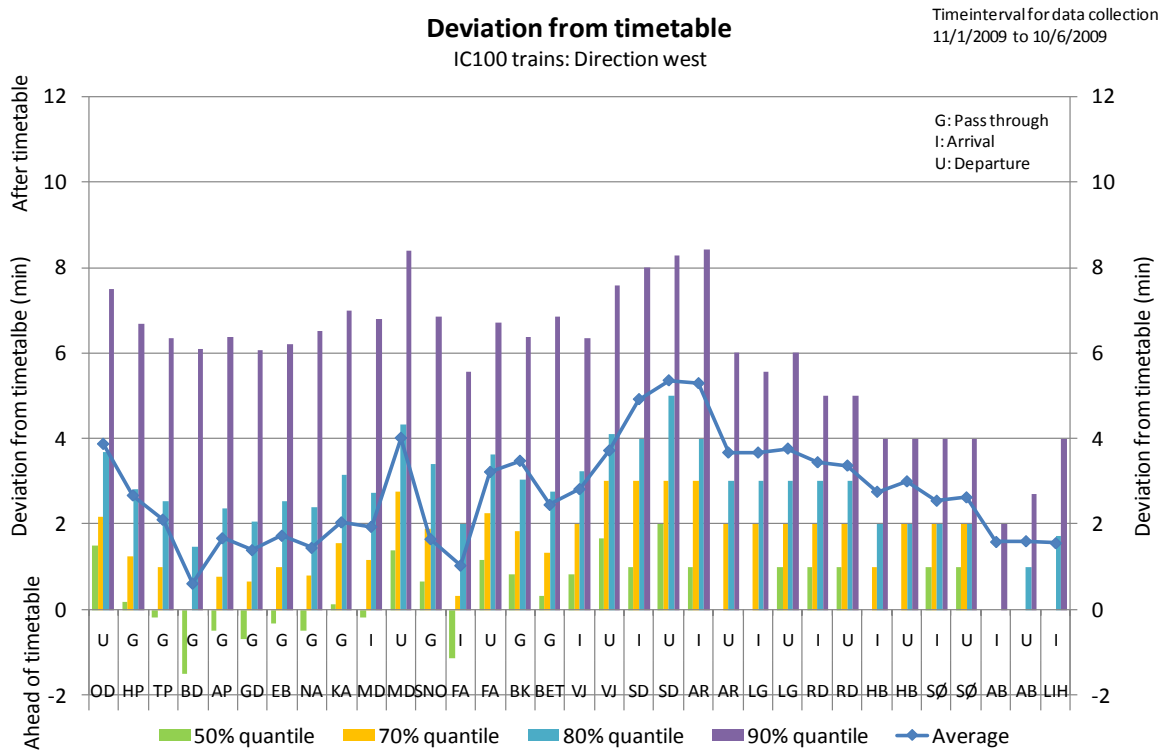
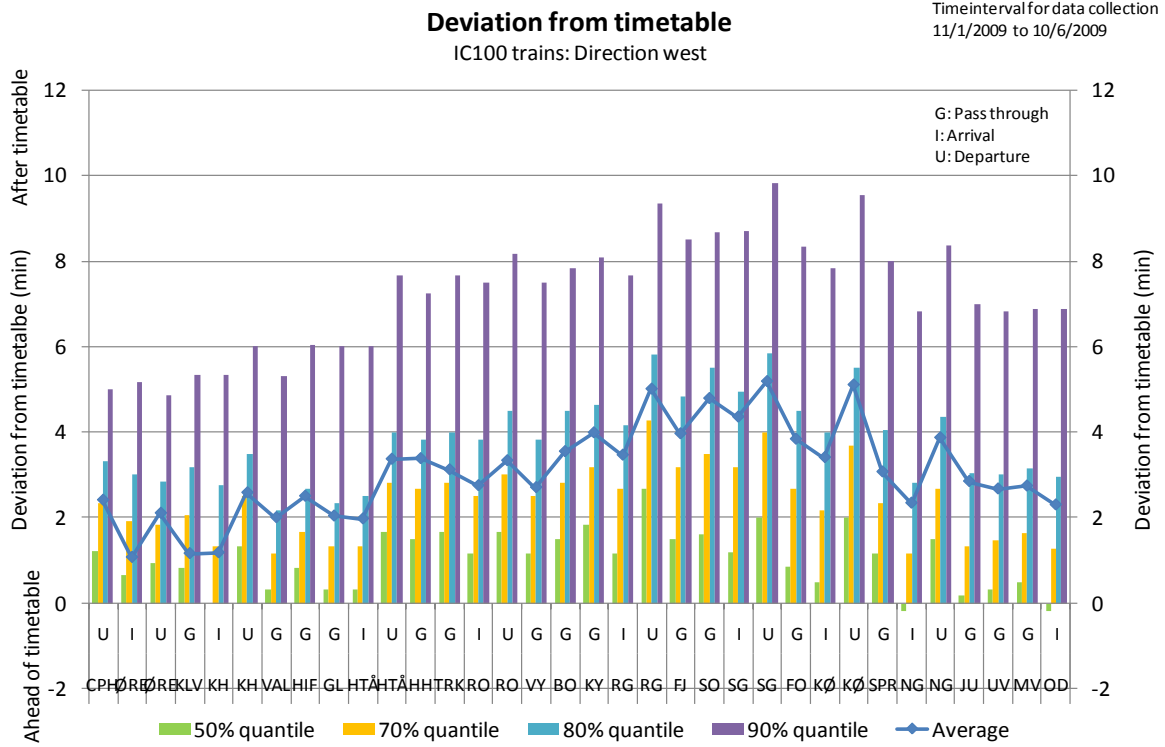
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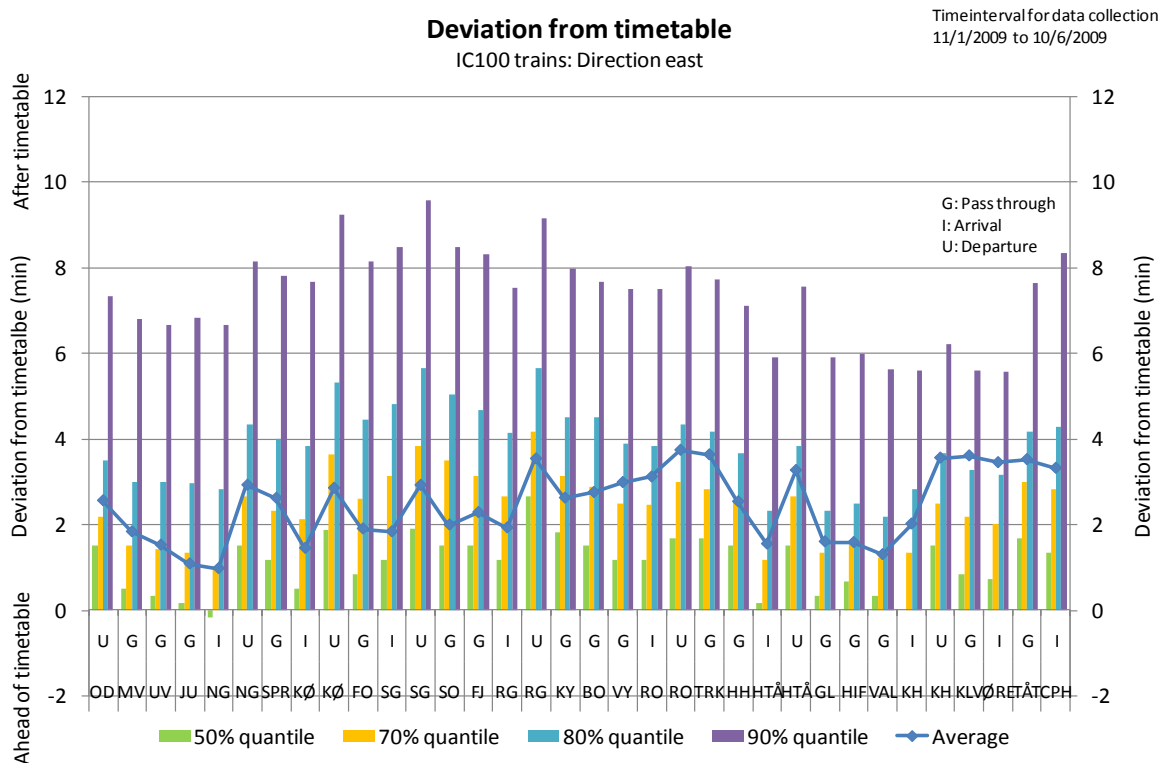
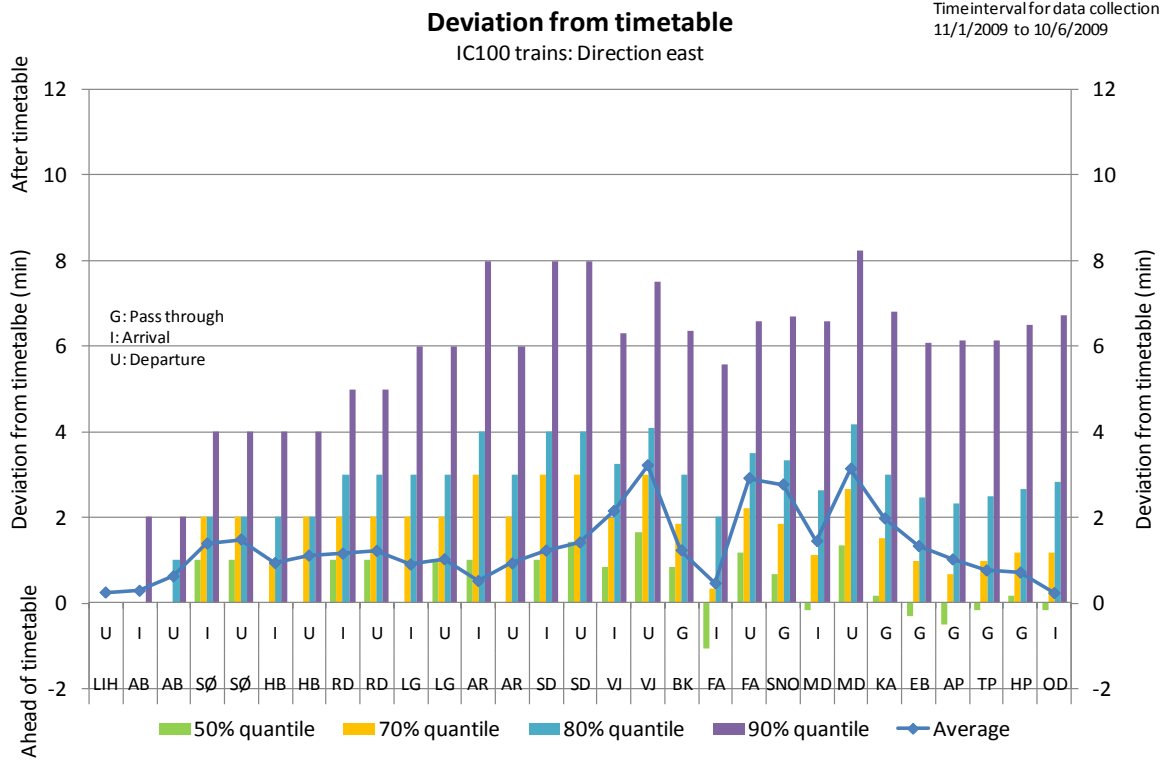
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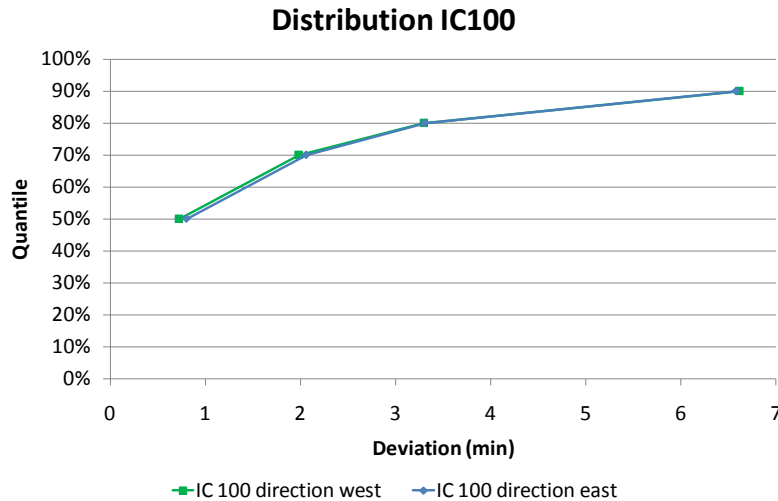
## Appendix 1: Train Category - Case IC100

The Intercity service connecting Copenhagen and Aalborg, referred to as IC100 since the trains have numbers in the 100 series, pick up delays crossing Zealand towards west. Delays diminish when trains pass the island of Funen. The 70% quantile is below 2 min on most of Funen. Across Jutland the on-time performance deteriorates again especially between Vejle (VJ) and Århus (AR). In the opposite direction, towards east, generally fewer delays occur. However, trains pick up delays at Vejle (VJ) but lose them again before arriving at Frederica (FA). On Funen, performance improves but then deteriorates on Zealand. Having arrived at the capacity bottleneck Høje Taastrup (HTÅ), the delays diminishes until arriving at Copenhagen Central station (KH).

Capacity constraints, technicalities in data-registration as well as timetabling considerations can explain the majority of the observations. However speed restrictions may also have impacted the train runs. Especially the slightly higher delays between Ringsted (RG) and Slagelse (SG) and vice versa compared to Roskilde (RO) – Ringsted (RG) are most likely explained by local speed restrictions. In order to explain the exact reasons for the observations, a further analysis is needed.







Over the entire run and including both arrivals, departures and passing throughs, approximately 86% of all registrations fall within a 5 minute maximum.

## Appendix 2: Train Category - Case High Priority Transit Freight Trains

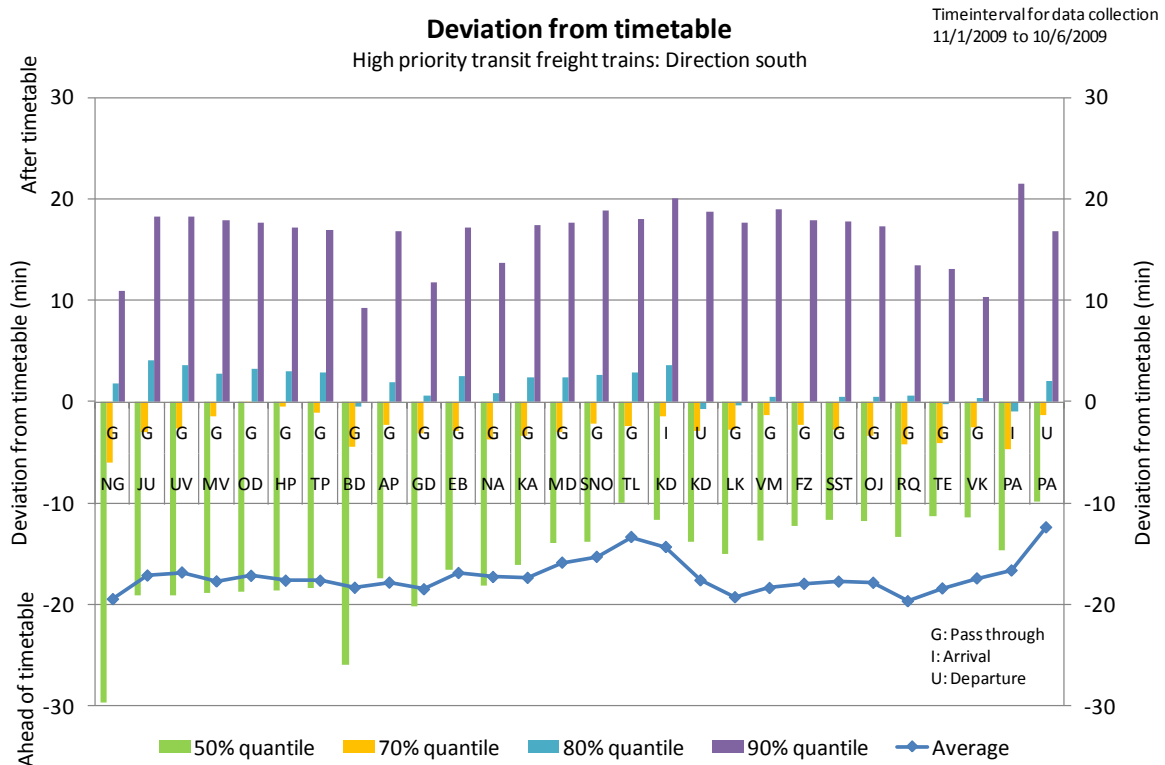
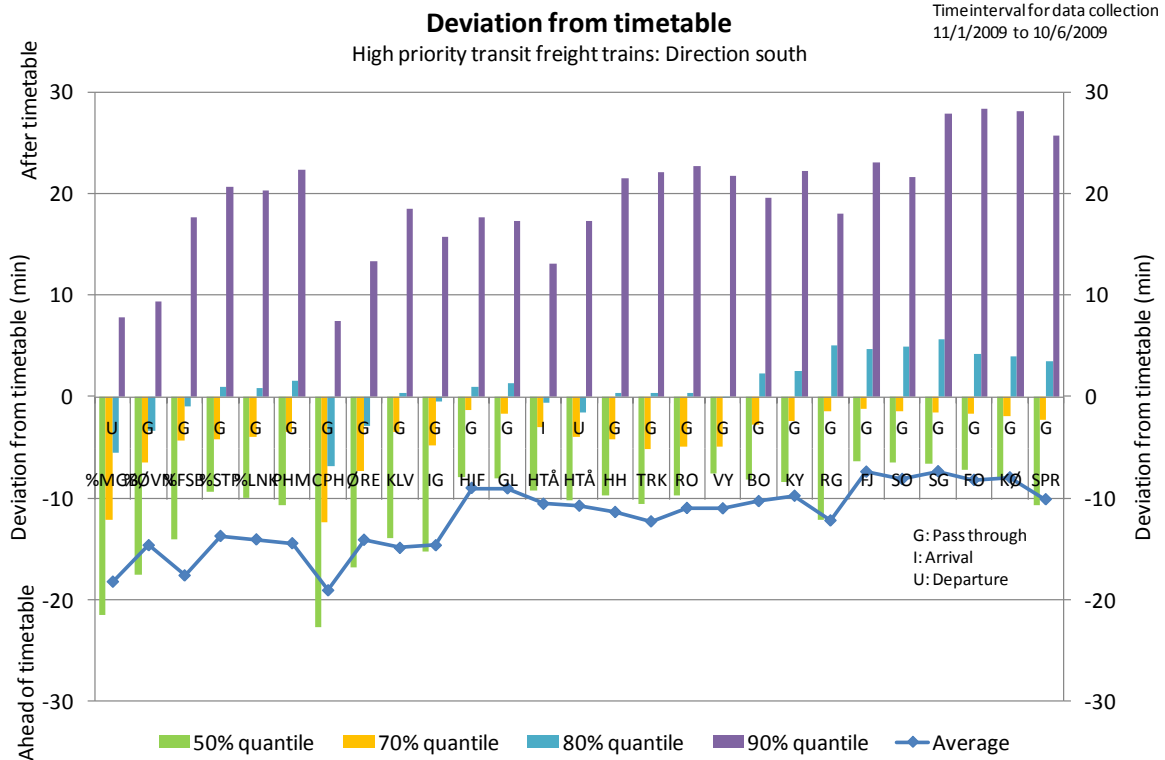
The nature of freight train operations is different from passenger trains as they do not follow the timetable in the same strict manner as passenger trains do: If capacity is available on the railway network, the freight train often departs when ready at the terminal and then travels as fast as possible towards its destination: generally freight trains are allowed to run prior to their timetable. However, freight trains may also be much more delayed than passenger trains since they might have to wait for freight as well as the preparation process of the train is more complicated. Secondly, the aim of the service is somewhat different. If a passenger train is sufficiently late, the passengers might have the possibility to choose another train or an entirely different mean of transport. Then the train run might lose the objective and the train might be cancelled. With freight trains, this happens rarely and thus very late freight trains occur more frequently than very late passenger trains.

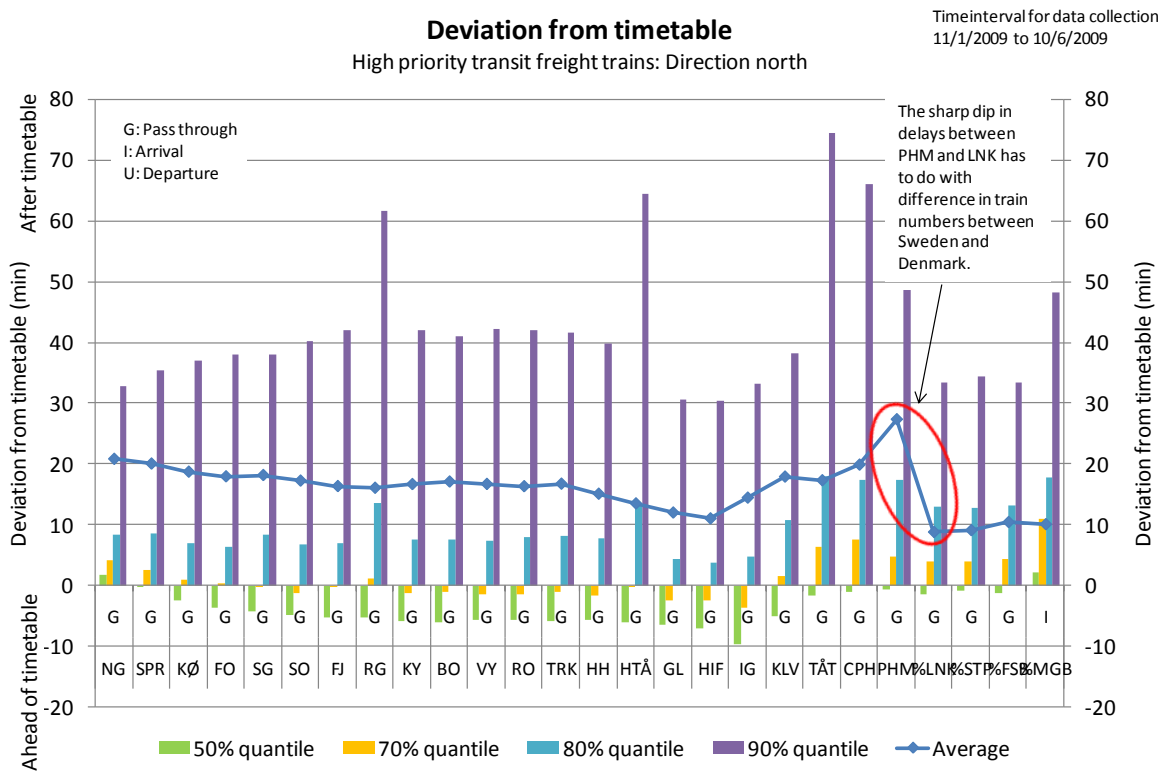
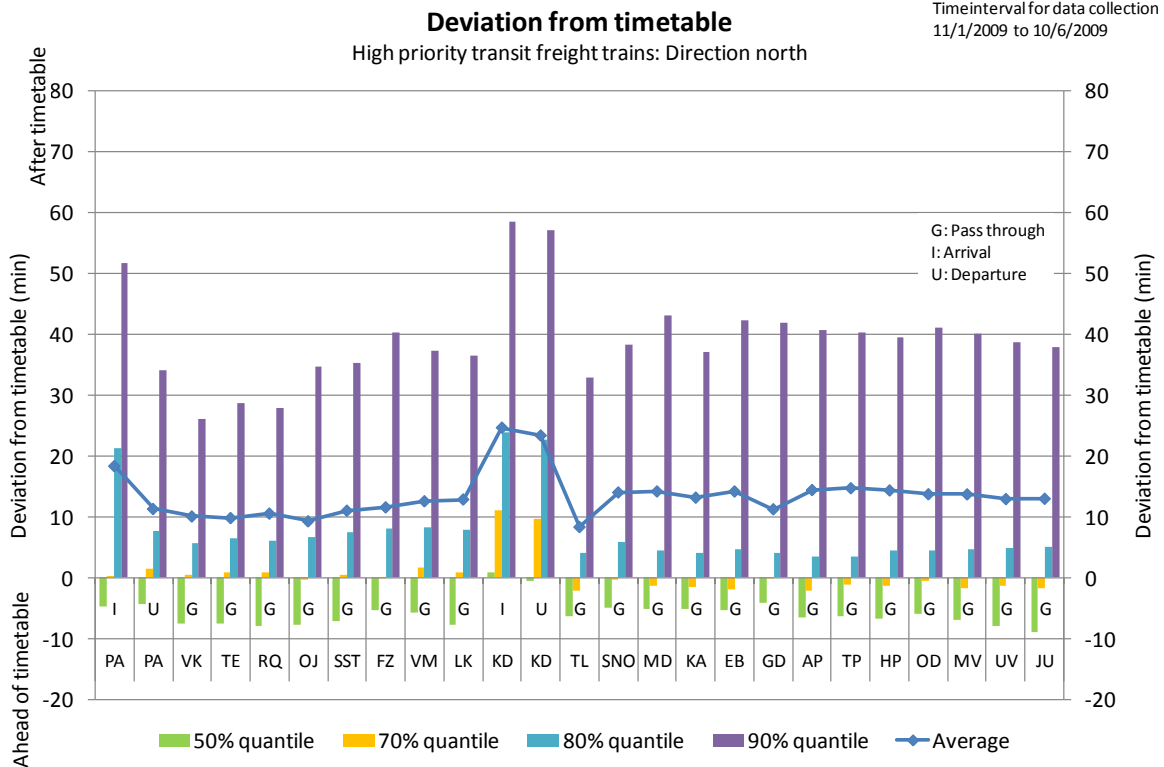
In order to illustrate this difference in nature, an analysis has been carried out on the high priority transit freight train service operated between Gent, Belgium and Älmhult, Sweden. Generally - and not surprisingly - trains seem to be picking up delays where it is possible for them to be passed by passenger trains. Overall, the south bound trains are more punctual than the north bound trains. This can be explained with traffic density in Germany compared to Sweden as well as distance from origin of the train (Gent versus Älmhult).

Compared to the IC100 case, the vast difference between the dynamics of the freight train run compared to a passenger train run is clear.



# Railway Timetabling Based on Systematic Follow-up on Realized Railway Operations





## Appendix 3: Train Category - Case IC/IR

On Fridays and Sundays an Interregional service is offered between Copenhagen and Århus / Esbjerg.

These trains leave 4 minutes prior to the normal IC trains for Jutland from Copenhagen central station. 3 minutes before them, the regional train towards Kalundborg has departed. The interregional trains are thus tightly squeezed in between two other trains.

Not surprisingly, this tight timetable together with the high number of travellers on Fridays, contributes to more delays of the IC trains on Fridays compared to Thursdays.

### Departure Copenhagen Central station (KH)

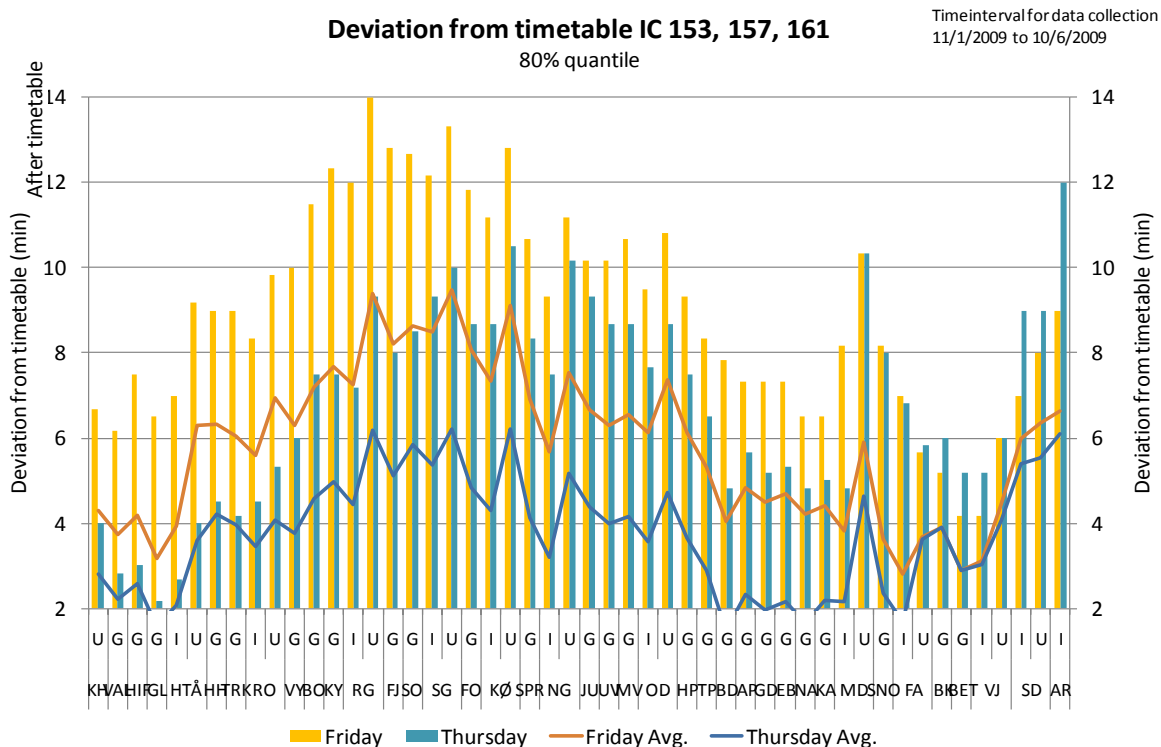
Product	No	Departure	Towards
L	51	14:50	Frederikshavn
RØ	1553	14:53	Kalundborg
IR	1679	14:56	Esbjerg
IC	153	15:00	Lindholm

L	55	15:50	Frederikshavn
RØ	1557	15:53	Kalundborg
IR	6555	15:56	Århus
IC	157	16:00	Lindholm

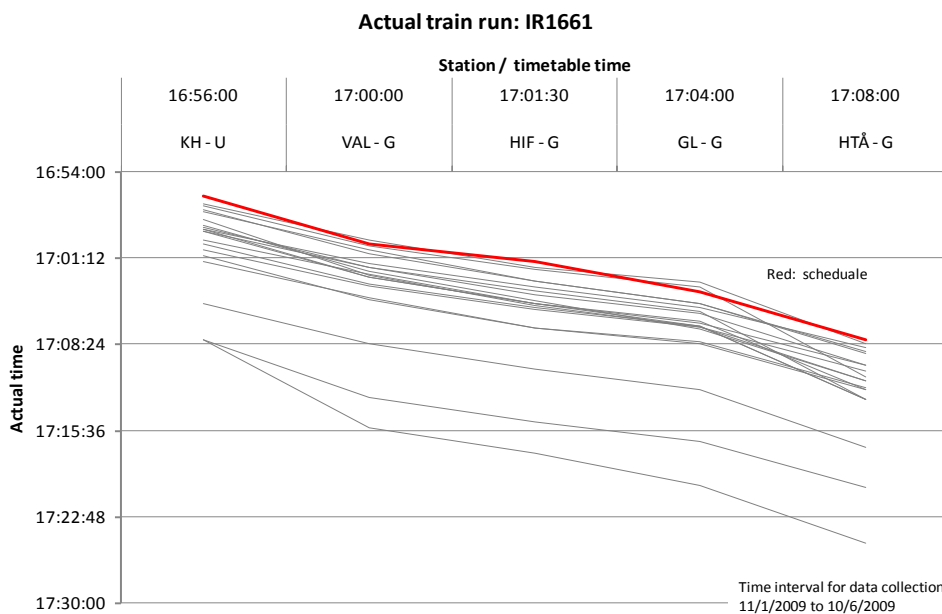
L	59	16:50	Frederikshavn
IR	1661	16:56	Århus
IC	161	17:00	Lindholm

### Stopping pattern for selected trains

	L 51	RØ1661	IR1679	IC153
KH	X	X	X	X
VAL				
HTÅ		X		X
HH				
TRK				
RO		X	X	X
VY				
BO				
RG				X
SO				
SG			X	X
KØ				X
NG				X
OD	X		X	X
HP				
TP				
BD				
AP				
GD				
EB				
NA				
KA				
MD				X
FA	X		X	X
VJ	X		X	X
SD	X		X	X
AR	X		X	X

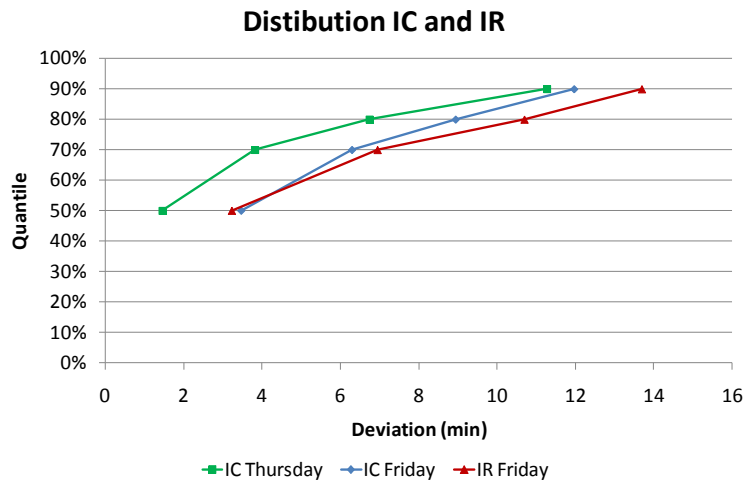


A closer look at one of the trains, IR1661, shows that it was significantly late out of Copenhagen central station (KH) in only 3 cases and in no cases did it leave Copenhagen Central before the published departure time.



Comparing the different quantiles for IC trains on Fridays to those on Thursdays clearly shows a better performance on Thursdays.

We cannot, however, conclude that this is only because of the IR train: On Fridays there are a higher number of travellers than on Thursdays which results in longer stops at stations. This consequently results in a worse on time performance.

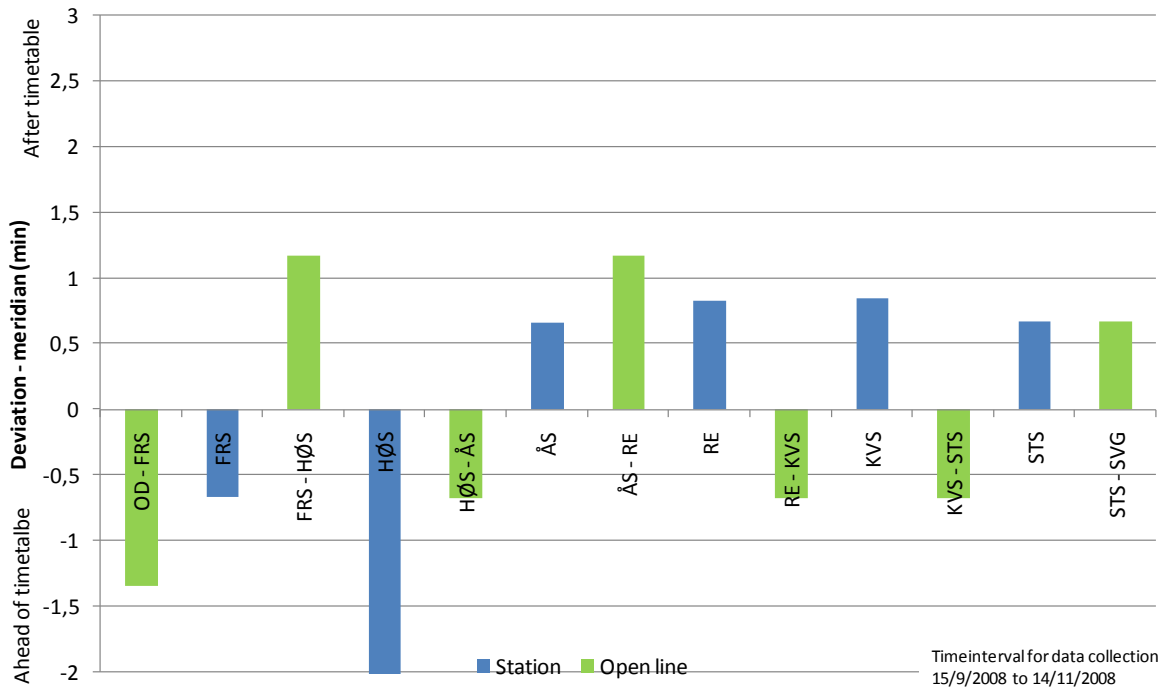


## Appendix 4: Line Section - Case Svendborgbanen

This single track line runs between the cities of Odense and Svendborg on the island of Funen. As expected, the trains gain time on the open line stretches where as they lose time on stations due to the occurrence of early arrivals. However, there seems to be some significant losses of time between Fruens Bøge (FRA) and Højby (HØ) in northbound direction, which then are recuperated at Højby station (HØ). The likely reason for this is a local speed restriction. In order to confirm this, further analysis is needed. The loss of time between Svendborg (SVG) and Svendborg Vest (SVV) are due to technical circumstances with the data registrations (Technically Svendborg Vest is a halt on the open line and not a station which reduces the precision on data registered).

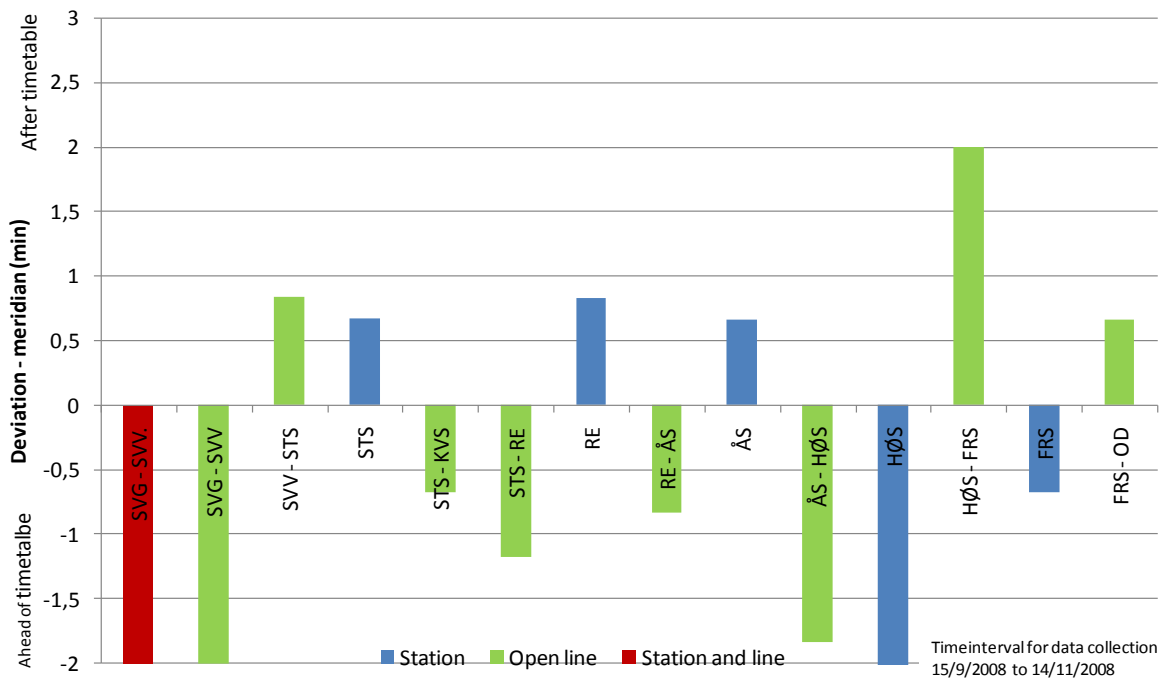
**Svendborgbanen : Deviation from timetable: Direction south**

15/9 - 15/11/2008



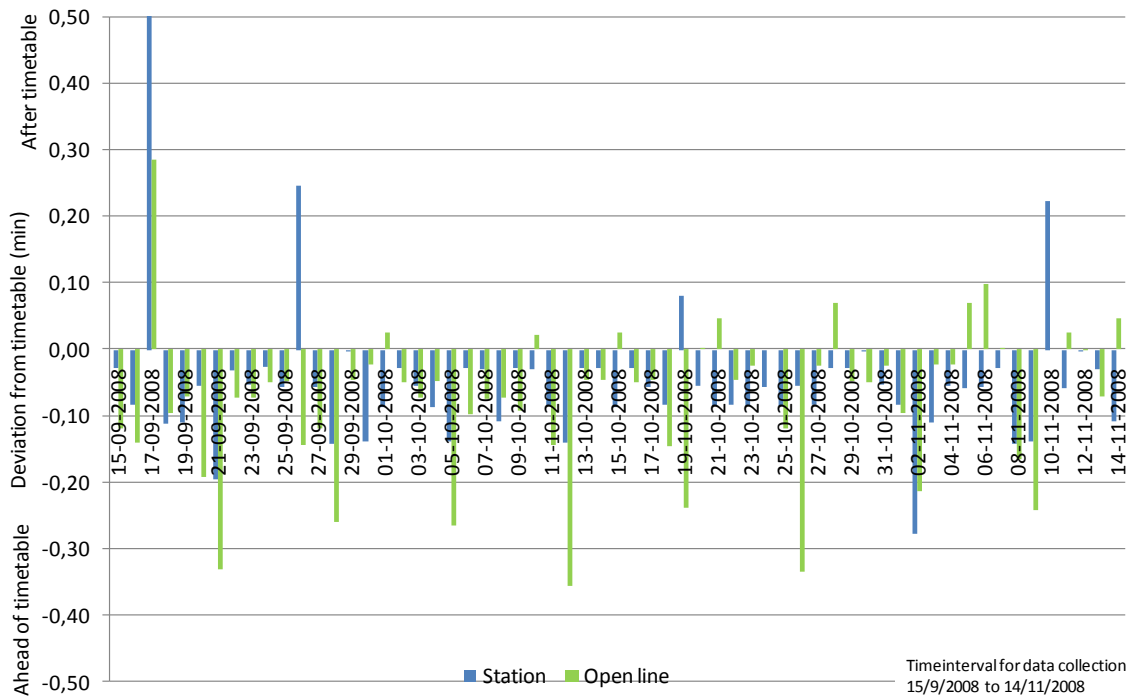
**Svendborgbanen : Deviation from timetable: Direction north**

15/9 - 15/11/2008

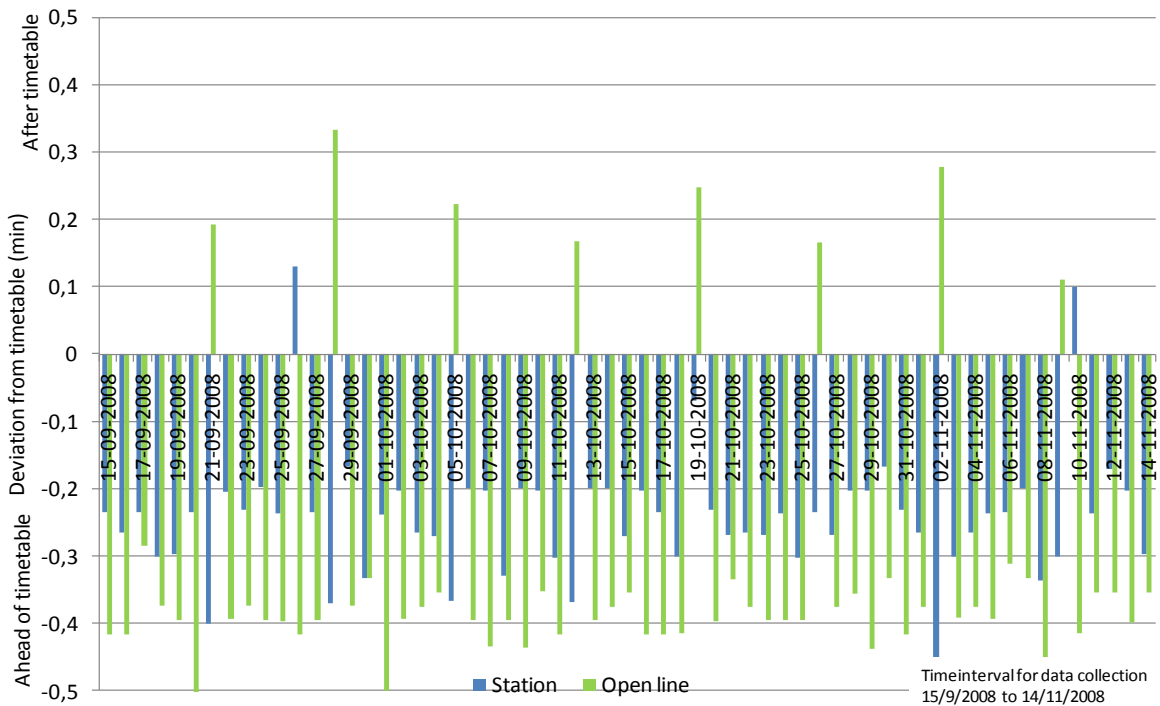


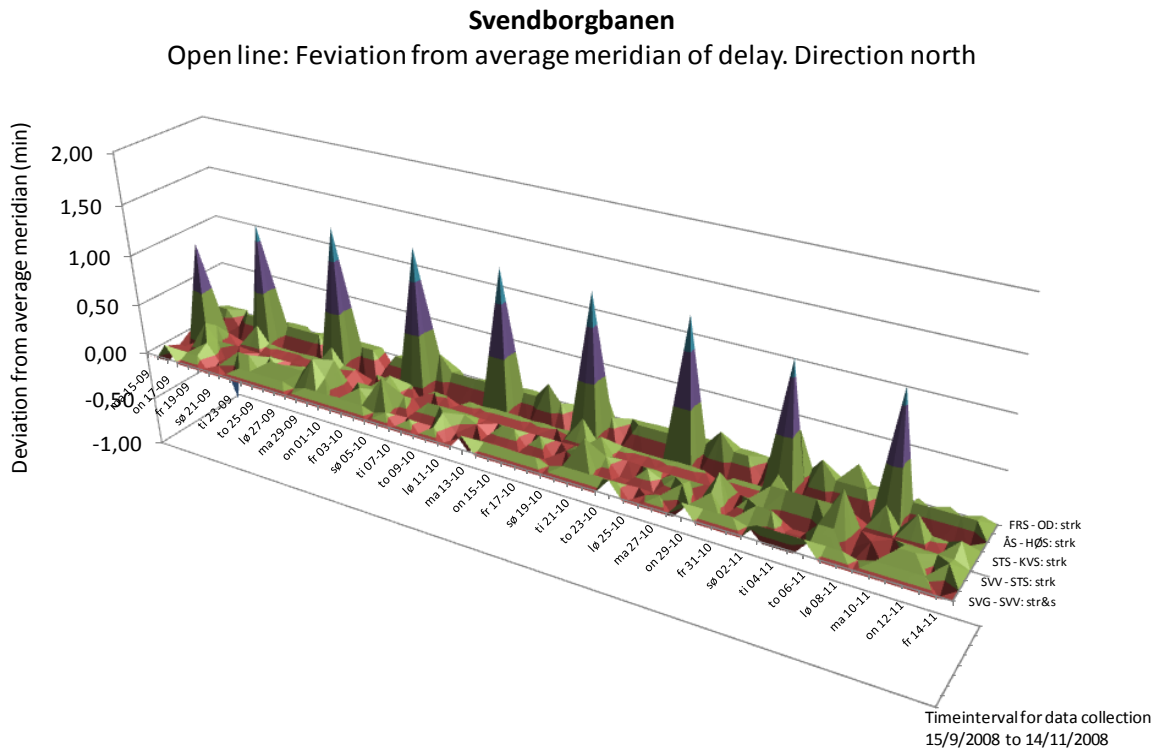
Time wise, there generally seems to be a loss of time on the open line sections in direction north on Sundays compared to the other days. More specifically, this delay occurs between Årslev (ÅS) and Fruens Bøge (FRS) in northbound direction. A further analysis is needed in order to explain why this loss of time occurs here.

**Svendborgbanen, Deviation from average meridian of delay. Direction south**



**Svendborgbanen, deviation from average meridian of delay. Direction north**

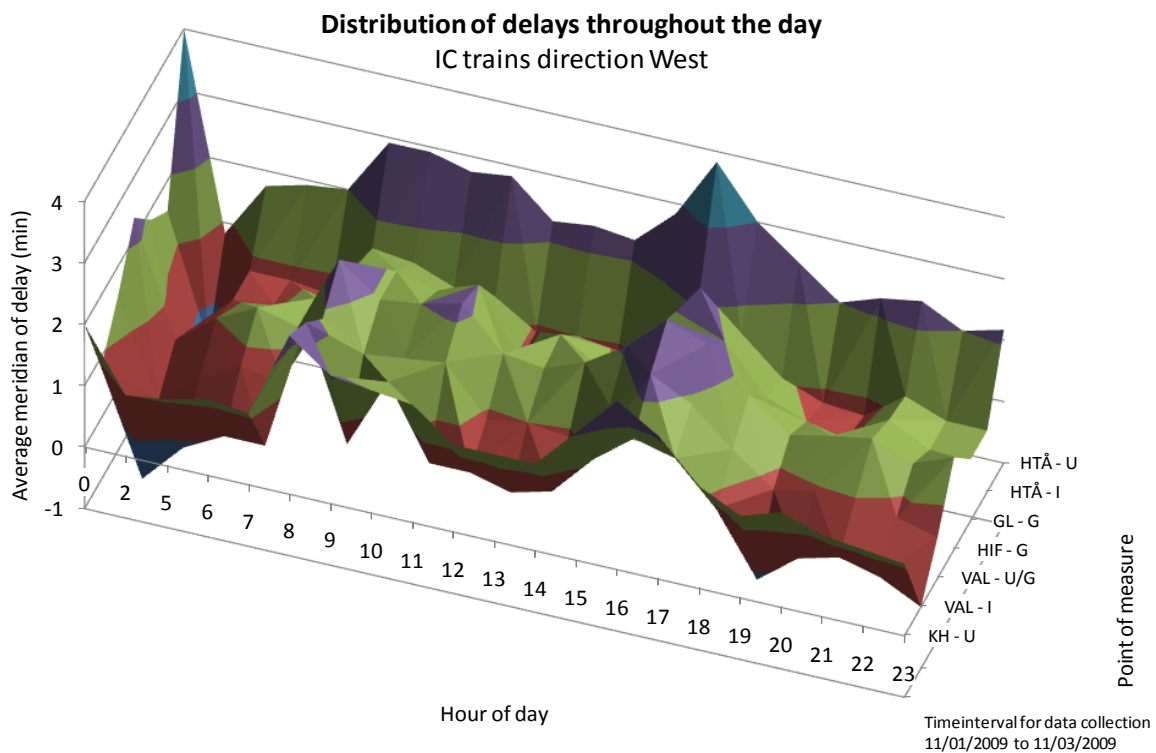






## Appendix 5: Time Period - Case Line Section Copenhagen Central Station – Høje Taastrup

An analysis of the line section between Copenhagen central station and Høje Taastrup station shows the expected patterns of an increase in delays during rush hours. As expected, the delays at arrivals are lower than at departures since trains may arrive early but do not leave before their planned departure time in the timetable. Delays after midnight are due to commencing maintenance works on the railway network. Number of trains influenced is not very high since there are not many trains running at this time. Furthermore, Rail Net Denmark incorporates the maintenance work in the timetables as much as possible.



## Appendix 6: Top 100 List – Most Delayed Trains

Examined data are from time period 1/5/2009 to 1/7/2009 for the long distance network. A top 100 list over most delayed combinations of train and location have been identified. Freight trains and Euronight trains have been omitted from the list since they otherwise would have dominated the list. This is since those trains typically have much higher deviations from the timetable than passenger services.

Station	Train	Product	Type	50% quantile	Average	Train runs
HH	172	IC	Arrival	-17,2	-16,9	33
TRK	172	IC	Departure	-16	-15,3	33
HTÅ	172	IC	Departure	-11,8	-13,3	61
HTÅ	172	IC	Arrival	-11,2	-12,4	61
KH	172	IC	Arrival	-11,2	-10,7	61
PA	482	EN	Arrival	-11	-30,3	61
HIF	172	IC	Pass through	-10,2	-10,9	61
VO	4759	RØ	Departure	-10	-9,3	39
KN	1512	RØ	Departure	-10	-10,5	37
VY	172	IC	Departure	-10	-13,9	34
KK	1512	RØ	Arrival	-9,7	-9,8	37
GL	172	IC	Pass through	-9,7	-11,3	61
VY	172	IC	Arrival	-9,5	-12,4	34
RO	172	IC	Departure	-9,3	-11,6	60
KN	1512	RØ	Arrival	-9,3	-9,4	37

Similarly, a top 100 of most delayed trains has been produced for Copenhagen central station (KH).

Train nr	Product	Type	50%quantile	Average	Train runs
80482	EN	Arrival	-10,8	-27,7	44
1512	RØ	Departure	-9	-8,8	37
4550	RØ	Arrival	-7,5	-7	37
4550	RØ	Departure	-6,7	-6,8	37
906	L	Departure	-6	-8,4	39
1512	RØ	Arrival	-6	-7,2	38
4600	RØ	Arrival	-5	-5,3	36
828	IC	Departure	-4,8	-6,5	58
4025	RØ	Departure	-4,7	-5,4	38
4554	RØ	Arrival	-4,7	-5,8	39
820	IC	Departure	-4,5	-8,3	60
26	L	Arrival	-4,3	-9,2	59

Few surprises are on either list. 172 is the last IC normal train of the day running and may get delayed by maintenance work / track possessions. 482 / 80482 is the Euronight coming from Munich / Basel thus having a very long run.

Careful analysis of the trains on the list is necessary in order to explain why the train is on the list; whether it is due to local and temporary circumstances that will be corrected or whether it is due to timetabling deficiencies.