Danish Key Performance Indicators for Railway Timetables

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Abstract

Based on the first common list of Danish railway timetable evaluation criteria this paper presents a series of existing and newly developed key performance indicators (KPI) for railway timetables. Measuring the level of timetable capacity consumption is done by the well-known UIC 406 methodology. By introducing the concept of timetable patterns it becomes possible to measure how systematic a given timetable is. Robustness of the timetable depends much on the complexity of the planned railway traffic. With the application of timetable fix points a new powerful tool becomes available to measure the robustness potential of a timetable. Societal acceptance of an implemented timetable is crucial for its success. It can be measured with satisfaction surveys. These must be conducted by an independent non-departmental organization to ensure objectivity, as it is done by "Passenger Focus" in the United Kingdom. Short travel and transfer times make the railway competitive. The degree of deviation from the shortest possible travel and transfer time gives an overview of the socio-economic attractiveness of a given timetable.

The new KPI have proven useful in their first trial. Most of the presented KPI must be calculated manually but have a high potential to be automated and integrated into future timetabling software packages. Few of the KPI demand a high level of knowledge about railway infrastructure characteristics and basic timetable train path structures. This makes a future automation more difficult. The first trial of the recommended timetable KPI has shown further development possibilities by e.g. looking separately at railway stations when applying the UIC 406 methodology and considering timetable pattern differences when calculating how systematic a timetable is.

1. Introduction

In today' society every business process has to be made measurable to evaluate a company's performance level. Both infrastructure managers (IM) and train operating companies (TOC) are under political pressure to make their businesses more effective, by improving their product but reducing their costs at the same time. One important tool that is used to achieve this goal is the use of Key Performance Indicators (KPI). The most important process for both TOC and IM is to create a feasible and attractive railway timetable. One of the possibilities to measure the success of the timetabling process is to measure the quality of produced timetable variants.

This paper starts with a brief presentation of the process that would lead to the creation of a common Danish list of prioritized timetabling evaluation and optimization criteria in section 2. The list was the result of a long process including individual interviews with the presently most important Danish railway timetable stakeholders and a joined timetabling criteria workshop that resulted in a consensus about a set of common timetabling criteria. These are described in section 2.1 and 2.2 respectively.

KPI for Danish railway timetables must be based on this common list of Danish timetabling criteria. For each criterion one or more KPI are recommended. Some of these are already in use today; others are improved versions of earlier used KPI and some are completely new KPI. Each KPI and the calculation of it, is presented in detail through sections 3.1 to 3.6.

A first attempt to implement the KPI recommended in this paper for Danish railway timetables is made in appendix 1 to 6. The present valid national timetable 2012 (K12) is used for illustrating the use of the developed timetable KPI. In appendix 1 the systematic timetable indicator is calculated for the Coastal railway line between Copenhagen and Elsinore. The UIC 406 methodology has been applied for the railway network of Rail Net Denmark in appendix 2. A timetable fix point approach is used on the regional train 4111 between Copenhagen and Ringsted during the morning rush hour in appendix 3. Appendix 4 shows a few examples of results from the half yearly published railway passenger satisfaction survey conducted by the organization "Passenger Focus" in United Kingdom. Deviations from the shortest possible travel time in the 2012 timetable are presented for the travel relations between the six largest Danish cities in appendix 5. Odense station is used as location for calculating the degree of transfer time prolongation and the degree of optimal transfer conditions in appendix 6.

The achieved results with the applied KPI on the timetable 2012 are discussed in section 4. Some KPI have proved themselves and others need further development to become more useful. Finally conclusions on the presented results are made and perspectives for future improvements and research are presented in section 5.

2. The common Danish railway timetabling criteria
A first version of a common Danish list of prioritized railway timetable evaluation and optimization criteria was the result of a long working process. The process consisted of two basic working steps:
1. Individual interviews with the most important Danish railway timetable stakeholders
2. A joined timetable criteria workshop

These two working steps are described briefly in the following two sections. A detailed exposition of the two working steps in the process are given in the papers "Creation of a Framework for Railway Timetable Optimization Criteria" [15] and "Creating a common Danish list of railway timetable evaluation criteria and revising the timetabling process accordingly" respectively [16].

2.1. Interviews with selected stakeholders
DSB, Arriva, DB Schenker Rail, The Danish Transport Authority (Trafikstyrelsen) and Rail Net Denmark (Banedanmark) were according to [15] identified as being the most important Danish railway timetable stakeholders.

Each stakeholder was interviewed at their offices or by phone (Arriva). The results of the interviews described in [15] are summarized in Table 2. Following this the interviewees were asked to give a detailed description of the criteria both to avoid misunderstandings and to make the criteria operational and thereby recognizable in a given timetable. Finally the interviewees had to rank their selected five criteria according to importance.

The results from the individual stakeholder interviews needed further processing to get a better overview of the achieved results. Some criteria could be grouped under the same overall timetabling topic and

others were unique. Table 2 shows the synthesized results from the interviews. A simple attempt was made to get a first picture of the overall ranking of identified criteria by using a concept of prioritization points, based on the stakeholder made prioritizations. A top ranking gave five points and a fifth priority only one point. The by far highest point score, with 18 points, was achieved by the criterion "Robustness of the timetable". This was followed by "Periodic timetables are preferable" with 9 points, "Efficient use of infrastructure" with 8 points and "Capacity consumption of infrastructure" with 7 points. Rank five was shared between "Compliance with traffic tender documents" and "Coordinated international timetable train paths" with 5 points.

Table 1: Synthesized overview of interview results and prioritization of criteria

Timetable evaluation criterion	Rail Net Denmark	DSB	Arriva	DB Schenker Rail	Danish Transport Authority	Prioritization points
Robustness of timetable	1	1	5	3	2	18
- Complexity of traffic in/around stations	2	-	-	-	-	4
- Reserve freight train timetable train paths	-	-	-	-	5	1
Efficient use of infrastructure	4	4	-	4	4	8
- Low level of scheduled waiting time						
- Capacity consumption of infrastructure	3	-	-	-	-	3
- Attractive transfer options for trains and busses	-	-	2	-	3	7
- Fast, high frequent and direct connections	-	2	-	-	-	4
Periodic timetable is preferable	-	-	3	5	1	9
Compliance with traffic tender demands	-	-	1	-	-	5
Coordinated international timetable time slots	-	-	-	1	-	5
Timetable train paths give flexibility to where change of train driver can take place	-	-	-	2	-	4
Train service for smaller stations	-	3	-	-	-	3
Servicing starting hours of schools and larger workplaces	-	-	4	-	-	2
Scalability of timetable	-	5	-	-	-	1
Timetable is prepared within given deadline	5	-	-	-	-	1

The presented not-synthesized results from the individual stakeholder interviews formed the starting point for the following timetabling criteria workshop.

2.2. Timetable criteria workshop

The timetable criteria workshop was held on neutral ground at DTU Transport - Department of Transport at the Technical University of Denmark. Figure 1 gives an overview of the overall workshop process. The stakeholder lists of prioritized timetabling criteria formed the basic input for the workshop, which should lead to a common accepted list of timetable evaluation criteria.
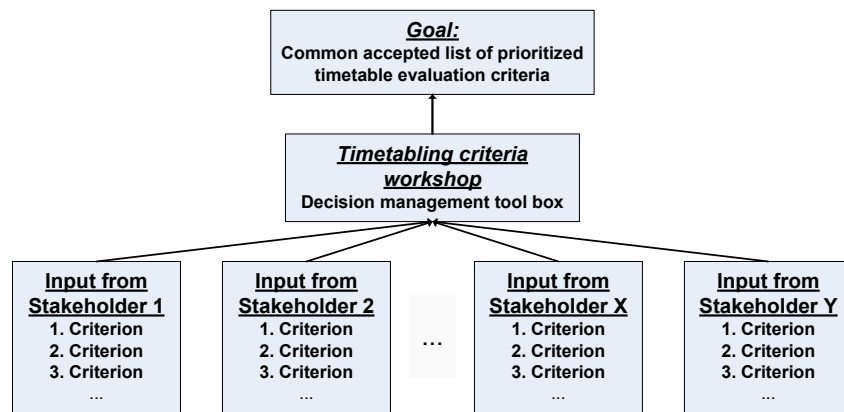
Figure 1: Timetabling criteria workshop process

A condensed version of the timetabling criteria workshop agenda can be seen in Figure 2. Unfortunately a last minute cancellation was received by Arriva, who stated that their interests would be covered by the representatives from DSB! All other stakeholder participated. There were several changes in company representatives. An overview is given in Table 3. Amongst the participants of the workshop there was consensus about that Arriva's list of prioritized timetabling criteria should be presented. This was done without any stakeholder comments.

1. Presentation of all stakeholder lists with prioritized criteria to all stakeholders	4. Ranking and reducing pool of criteria according to their score
2. Adding/removing criteria if wanted by stakeholders	5. Individual ranking of remaining criteria. Stakeholders must state arguments
3. Simple scoring of criteria. Each stakeholder has five votes. One vote for five criteria	6. Achieving consensus on a prioritized list of criteria

Figure 2: Timetabling criteria workshop agenda

Table 2: Company representatives for interviews and the timetabling criteria workshop

Company	Representatives	
	Workshop	**Interview**
DSB	Lars Christian Krogsdam (timetabling project manager) Per Elgaard (senior timetable planner)	Niklas Kohl (director of the timetabling department) Per Elgaard (senior timetable planner)
Arriva Denmark	▓▓▓▓▓▓▓▓▓	Kent Nielsen (by phone) (senior timetable planner)
DB Schenker Rail Scandinavia	Claus Jensen (planning manager) Thomas Vestergaard (strategic planner)	Susanne Olling Nielsen (timetable planner)
Danish Transport Authority	Benny Mølgaard (senior consultant) Claus Jørgensen (senior consultant)	Benny Mølgaard (senior consultant) Claus Jørgensen (senior consultant) Jacob Møldrup Petersen (consultant)
Rail Net Denmark	Lasse Toylsbjerg-Petersen (director of capacity planning) Ib Flod Johansson (team leader of timetabling)	Lasse Toylsbjerg-Petersen (director of capacity planning) Ib Flod Johansson (team leader of timetabling)

While presenting the first list of prioritized timetabling criteria, it became apparent that any changes to the criteria lists would be made during the presentations and not after all lists had been presented. During

these presentations the participants of the workshop by themselves started working on creating a common list of timetable evaluation and optimization criteria from the presented lists of timetabling criteria. This spontaneous deviation from the agenda was not opposed by the facilitators of the workshop since the dialogue between participants could improve the chances of reaching a reduced list of timetabling criteria based on a consensus rather than the application of the simple ranking methodology often applied within the field of decision management [5].

During this phase of dialogue several questions arose: Such as which criteria are controlled by stakeholders and which are controlled by contractual obligations towards the Danish Ministry of Transport, and what is the length of the periodicity interval in a periodic timetable. The Danish Transport Authority could give answers to the first part and the facilitators to the second part by stating that a periodicity interval could be as little as 10 minutes and as long as 2 hours [9]. It was also decided by the participants to generally use the term "Systematic timetable" as replacement for "Periodic timetable", hereby avoiding the uncertainty in regards to the use of the wording "periodicity intervals of a given timetable".

The representatives from Rail Net Denmark wanted their criterion "Utilization of timetable train paths" renamed to "capacity consumption for a railway line section".

Following the last presentation of the Danish Transport Authority's list of timetabling criteria, an uncertainty in regards to the difference in socio-economic value of "transfer time" and "travel time" arose. It was clarified that a reduction in transfer time is given double the value than the same reduction in travel time [4]. This was as a surprise for several the participants.

After the presentations there was a general uncertainty amongst the participants about the application of timetabling evaluation and optimization criteria. Since some of the stated criteria are given demands from the Danish Ministry of Transport. The Danish Transport Authority is the link between the ministry and the railway sector and must both fulfill several contractual obligations towards the ministry and must handle the interests of the ministry towards all other railway stakeholders.

Several participants considered the robust timetable criterion as being a basic precondition and therefore it should always be ensured by the applied planning rules of the IM. The ensuing discussion proved that the uncertainty connected to the timetable robustness criterion originates from the more or less loose definitions within the group of the other timetabling criteria.

This lead to a discussion about the achievability of the workshop goal and it was stated by the author that the goal was to get a snapshot of today's situation and that this kind of workshop could and should be repeated every time larger changes take place in the preconditions for railway timetabling in Denmark. It then became apparent for all stakeholders, that an intelligent surveillance and evaluation system for railway timetables was needed in the future.

All this lead to workshop participants agreeing on that the criterion "Societal acceptance of the timetable" was missing and had to be added to a first version of a common list of timetabling criteria. The reduced list of common accepted timetable evaluation and optimization criteria included the following criteria:
- Attractive transfer options (to other train and bus services)
- Robustness of the timetable
- Societal acceptance of the timetable
- Systematic timetables are preferable (earlier periodic timetables)
- Travel time of trains
- Consumption of capacity on railway line sections

A ranking of these timetabling criteria according to their importance was the next step. The facilitators of the workshop decided that the simple ranking methodology would now be applied. Every stakeholder was

given three votes and should reward three criteria with one vote each. The criteria were listed on a marker board and the votes were given by sticking post-it stickers next to each timetabling criteria. See Table 4.

Level of importance	Timetable evaluation and optimization criteria
High (3 votes)	Consumption of capacity on railway line sections & Systematic timetables are preferable
Medium (2 votes)	Robustness of the timetable & Societal acceptance of the timetable
Low (1 vote)	Travel time of trains & Attractive transfer options

The criteria could be placed in three layers with two criteria in each. First rank criteria received three votes each, second rank criteria got two votes and third rank criteria ended up with one vote each.

This approach had not given a unique ranking of timetabling criteria. The facilitators asked the participants to rank the two criteria in each layer according to their mutual importance. After a short discussion among the participants, they decided unanimously against ranking the criteria in each layer, since the difference in criterion importance was too small. This was accepted by the facilitators and therefore the result of the workshop

3. Development of key performance indicators

Based on the identified railway timetable evaluation and optimization criteria the use of selected timetable KPI is recommended. For each timetabling criteria this paper develops a set of KPI. In the following sections these KPI are described in detail.

3.1. Systematic timetable

In a systematic railway timetable one or more traffic patterns are repeated through an operational day. There can be small or big differences between the single traffic patterns. This paper recommends introducing the concept of timetable patterns. The definition of the term "timetable pattern" used in this paper is given below.

Definition of a timetable pattern:

A timetable pattern is the shortest time period for which the regularity index for a given travel relation, a railway line or an entire network, including all relevant train services, is 100%. Starting from the beginning of the investigation time period or the end of the previous timetable pattern.

Timetable patterns should not have a periodicity time period of more than one hour – an absolute maximum of two hours is recommended.

A timetable pattern can be repeated several times – with or without interruption from other timetable patterns.

The mentioned regularity index in the definition of a timetable pattern is presented in equation (1) [21].

$$\text{Regularity Index (RI):} \qquad RI = \frac{A}{A+B} \qquad (1)$$

A = Number of timetabled train paths belonging to a service planned at regular time intervals
B = Number of missing train paths that would exist if a service was planned at regular intervals

When working with timetable patterns it must be decided if one only looks at passenger train services or also includes timetable train paths allocated to freight trains. From a passenger point of view, freight trains are not important for timetable analyses, whereas an IM might want to consider all trains in his analyses. Therefore, it has been chosen to use the word "relevant" in regards to trains that should be considered in the definition above.

To measure how systematic a timetable is this paper recommends a revised version of the RI-index as KPI. The calculation of the systematic timetable index (STI) can be seen in equation (2).

$$STI = \frac{\sum TS_{mtp}}{TS_{inv}} \ x \ 100\% \quad (2)$$

Where:

STI = Systematic Timetable Index - based on the time wise most used timetable pattern

TS_{mtp} = Time Span for the most used timetable pattern

TS_{inv} = Time Span for the investigated time frame

Here the time wise most used timetable pattern will indicate how systematic an investigated timetable is. If a timetable uses one pattern throughout the operational hours the STI will be 100%. If the pattern changes every hour during a 20 hour operational day the result will be 5%. The later could be considered a non-systematic timetable. Please notice that the low index values for non-systematic timetables depend on the length of the investigated time span.

In appendix 1 an example is given for the application of equation (1) and (2) to measure how systematic the timetable for the Coastal Line (Kystbanen) between Copenhagen and Elsinore (Helsingør) is. Here a RI-index value of 60% and STI-index value of 55% are achieved.

3.2. Capacity consumption on railway line sections

The International Union of Railways (UIC) recommends performing railway capacity analyses according to the method described in their leaflet UIC 406 [22]. This approach, also called the UIC 406 methodology, has gained acceptance in most of Europe. Based on the time that a train occupies a block section in the investigation area, a percentage of used and available minutes is calculated. Strengths and weaknesses of this methodology are described in detail by Landex [7]. It is recommended to investigate the consumption of railway capacity on railway line sections by using the UIC 406 methodology and use the results as KPI for this criterion. The methodology provides guidelines based on current practices of IM for capacity consumption levels [22]. An example of a network capacity analysis can be seen in appendix 1, Figure 6.

Presently stations, including switch zones and platform tracks, are included in the sections of analysis that begin/end here. An approach where stations are considered separately has been investigated by Landex but has not yet been introduced in Denmark [8].

3.3. Robustness of the timetable

This topic has many aspects and therefore several approaches of analysis with their own KPI are needed. In the following sections, issues that affect the robustness of the timetable are addressed. Each aspect can require one or several KPI to make a thorough analysis.

3.3.1 Time supplements

The primary method to ensure the robustness of the timetable towards stochastic delays up to a certain magnitude is to add time reserves to both running times and stopping times of trains. In Denmark the running time supplements are speed dependent and described in detail in the paper "Planning with time supplements in railway timetables" [6][18].

Each timetabled train paths must be checked to see if it contains time supplements according to the IM timetable planning rules used or if deviations occur. The following KPI "Degree of deviation from planning rule running time" is recommended. See equation (3):

$$Degree \ of \ deviation \ from \ planning \ rules = \frac{Timetable \ running \ time \ [sec] - Planning \ rule \ running \ time \ [sec]}{Planning \ rule \ running \ time \ [sec]} \quad (3)$$

The currently used timetabling tools calculate train running times with an accuracy of seconds therefore the times should be entered as seconds. If the result is 0.0 then timetabled running times are in accordance

with planning rule times. If the timetabled time is 25% larger than the planning rule time, then the degree would be 0,25. If the timetabled time was less than the planning rule time the result would be negative. This calculation can be made for a single train path, a train service, a train class or all timetabled train paths. Geographically the analysis can be made for a specific railway line section, a region of the railway network and the entire railway network. See appendix 3 for an application of this KPI for a single train path. The example train path has a degree of deviation from planning rules between 0.04 and 0.47.

3.3.2. Timetable complexity
The complexity of the timetable can be subdivided into several topics:
- Complexity of train traffic at a station or junction – potential for conflicting train paths
- Complexity of a timetabled train path – for the entire path or a section of it
- Complexity of rostering plans for rolling stock – for the TOC overall, a given train service or a single piece of rolling stock
- Complexity of rostering plans for train staff – for the TOC overall, a given train service or a single train staff member

Complexity of train traffic at a station or junction
This topic has been investigated several times in Denmark [7][8][14]. A high level of traffic complexity at a station or junction indicates that the potential for conflicting train paths is high. In Denmark the traffic complexity is defined as the conflict potential between timetabled train paths at a given station. But how many planned train paths can potentially be in conflict with each other and how much buffer time is there between them to avoid a potential conflict? Based on Landex [8], a risk index for train conflicts at a given station or junction has been developed, based on the infrastructure layout, minimum headway times given by the interlocking system and a detailed timetable. A conflict risk index can be calculated with a value between 0 and 1 as shown in equation (4):

$$CRI_s = \frac{NHRC_s}{PC_s} \quad (4)$$

Where:
CRI_s = Conflict Risk Index for a given station
$NHRC_s$ = Number of High Risk Conflicts at a given station
PC_s = Number of Potential Conflicts at a given station

If there is no buffer time or only maximum 50% of the possible minimum headway time between two potentially conflicting train paths, this paper defines this as a high risk conflict. A low value indicates a low conflict risk at a given station. This paper recommends to us this as KPI for measuring the complexity of train traffic at a station/location [14].

Complexity of a timetabled train path
In the timetable, a train path is surrounded by other planned train paths. Train paths in front of the analyzed train path can potentially become conflicting train paths. This risk is especially high at train path fix points. Train path fix points for traffic complexity are:
- Crossing stations on single tracked railway lines where the analyzed train path is scheduled to cross with another timetabled train path
- Transition stations between single and double tracked line sections. The analyzed train path goes from a double tracked to single tracked section and is scheduled to cross a train path in the opposite direction.
- Stations where the analyzed train path is planned to overtake another train path
- Level railway junctions where the analyzed train path has potential conflicts with other train paths
- Stations where the order of departing trains due to their travel speed must be kept
- Stations where the analyzed train path is scheduled to catch up with a slower train path

A different category of fix points for train paths are transfers. Transfer fix points are:
- Stations where there is one or more planned transfer options to other trains that must be kept
- Stations with transfer options to other means of transportation e.g. ferries that must be kept

The higher the number of train path fix points is in a timetable, the higher is the level of complexity of the timetable. A high level of timetable complexity generally leads to a lower level of timetable robustness. See appendix 3 for the identification of fix points for a train path.

This paper recommends using the following KPI approach for measuring the train path complexity:
- **Number of fix points for a given train path**
  - To get a more varied picture this can be normalized to a number of fix points according to the length of the train path - fix points per train path kilometer - or to the train path running time – fix points per train path running time minute
- **Number of fix points for a group of train paths**
  - A train path group can be a train class such as InterCity-trains or train paths that are within a selected geographical area within a selected time span
  - An overall train path group average of fix points can be calculated
  - This can be normalized to a number of fix points per train path group kilometer or per train path running time minute to get a more varied picture
- **Risk profile for a train path**
  - Amount of time supplements (both running time and dwell time) between individual identified train path fix points
  - An average of time supplements between one train path's fix points
- **Risk profile for a group of train paths**
  - The average amount of time supplements between fix points for a group of train paths

Generally the more fix points a train path has the higher is the potential for being delayed by another train path. A simple KPI approach is to calculate a train path average of fix points for the investigation area which can be anything from a single train path, a railway line section to the entire railway network. A time span for such an investigation must also be applied, e.g. rush hours. No previous data of this kind exists for Danish railway timetables and therefore a given fix point average for train paths in a given timetable can presently not tell us much. This category of data will become more and more available for future timetable variant evaluation and over time become more and more useful.

In case train path fix points are geographically situated closely together, the quantity of timetabled time supplements between them is not big, if the general Rail Net Denmark timetable planning rules are followed. This increases the risk of transferring a given train delay from one fix point to the next and thereby potentially creating new conflicts between train paths, delaying even more trains. See appendix 3 for an example of this approach.

Some timetable classes may require more transfers between trains to get through a given railway network, e.g. such as an integrated fixed interval timetable with selected station hubs [17]. Planned transfer options between trains are easy recognizable in a modern software timetabling tool since a data connection is made between the relevant trains. Some transfer times include a buffer time to ensure the transfer option in case of minor delays. Other planned train to train transfers are just feasible. If there is issued a traffic dispatching rule saying that trains do not wait for delayed transfer feeder trains, timetable complexity wise it means that there are no planned transfer possibilities. Hereby no delays can be transferred from delayed trains to on time trains. If trains have to wait for delayed transfer trains, the risk of transferring delays increases with the number of planned transfers to a train path at a given station and the risk further increases if there are no buffer times included in the scheduled transfer times.

Complexity of rostering plans for rolling stock
Train services can be run with dedicated rolling stock for only one service or the rolling stock can be shared

amongst several train services. The first can be found within subway systems e.g. some lines of the London underground and the later is the normal situation in railway traffic, since a higher utilization level of rolling stock can be achieved [10].

Due to the basic tree like structure of the Danish railway network most Long distance passenger train services are running in combined train runs on the main railway line between Copenhagen and Jutland. Here the train runs are split up into individual train services that run on different railway lines. Furthermore the length of trains is changed during their runs to adapt the available seating capacity to the passenger demand along the railway line. This intricate use of rolling stock increase the complexity of the rolling stock rostering plans drastically.

Sharing rolling stock covers both receiving and handing over rolling stock. Receiving rolling stock is critical in regards to carrying through a given train service. The rostering of rolling stock can be a very intricate issue, why it is not necessarily all timetabled train paths that are run with shared rolling stock. This can be taken into account by looking at the fraction of train paths that are run with shared rolling stock out of the total number of train paths. If no train paths are run with shared rolling stock, there are no interdependencies between trains. Rolling stock wise the timetable is then as simple as possible. See equation (5):

$$Degree\ of\ train\ paths\ with\ shared\ rolling\ stock =$$

$$\frac{Number\ of\ total\ train\ paths - Number\ of\ train\ paths\ with\ not\ shared\ rolling\ stock}{Number\ of\ total\ train\ paths} \quad (5)$$

This KPI can be calculated for a single station, a region of the railway network or the entire network for a defined time span. Additionally this KPI can be calculated for one single TOC, a group of TOC or all TOC running trains on the network. Unfortunate the needed data to calculate this KPI is most often not available. This is due to missing interfaces between timetabling software and the software tools used to create rostering plans for rolling stock. Furthermore, the TOC might consider this information as classified, since rostering plans for rolling stock is an important competition parameter when entering a bid for running public service railway traffic.

When a train reaches its terminus station a turnaround time for the rolling stock is planned. The turnaround time depends on the class of rolling stock and what operations have to be done to the rolling stock at the terminus station, e.g. cleaning and/or refueling. If there is no buffer time included in this turnaround time, then the risk increases of transferring delays from one train service to another or from one driving direction to another if the rolling stock stays with the same train service. A degree of buffer time for turnaround times for rolling stock can be calculated. See equation (6):

$$Degree\ of\ buffer\ time\ in\ turnaround\ time\ for\ rolling\ stock =$$

$$\frac{Timetabled\ turnaround\ time\ for\ rolling\ stock[min] - minimum\ turnaround\ time\ for\ rolling\ stock\ [min]}{minimum\ turnaround\ time\ for\ rolling\ stock[min]} \quad (6)$$

This KPI can be calculated for a single train service, a single terminus station and up to all train services and the entire railway network. For long distance train services the needed data to calculate this KPI is likely not available due to the same reasons as mentioned in regards to equation (5). If looking at bounded suburban or metro railway systems, such as the Copenhagen suburban trains (S-tog), there should be good possibilities to be able to calculate this KPI based on the public timetable.

Complexity of rostering plans for train staff
As for rolling stock, train services can be manned with dedicated train crews or the crew members can be shared with other train services. The later is most common in railway crew rostering. On long distance train services the crew can change several times en route. It is not necessarily the entire crew that is shared with

other train services [10]. The KPI: Degree of train paths with shared train staff can be calculated as show in equation (7):

$$Degree\ of\ train\ paths\ with\ shared\ train\ staff\ =$$

$$\frac{Number\ of\ total\ train\ paths - Number\ of\ train\ paths\ with\ not\ shared\ train\ staff}{Number\ of\ total\ train\ paths} \tag{7}$$

Similar to rolling stock the scheduled turnaround times for train staff at terminus stations for train services can contain more or less buffer time and thereby decreasing or increasing the risk of transferring a delay from one train service to another. The minimum turnaround time for train staff can differ from the minimum turnaround time for rolling stock due to agreements between labor unions and TOC. A degree of buffer time in turnaround times for train staff can be calculated as shown in equation (8):

$$Degree\ of\ buffer\ time\ in\ turnaround\ time\ for\ train\ staff =$$

$$\frac{Timetabled\ turnaround\ time\ for\ train\ staff[min] - minimum\ turnaround\ time\ for\ train\ staff\ [min]}{minimum\ turnaround\ time\ for\ train\ staff[min]} \tag{8}$$

Calculation of these KPI is again made difficult due to the unavailability of this category of timetable data. Rostering plans for train staff is also an important parameter for TOC when competing with other TOC to win bids to run public service railway traffic. Furthermore, the detailed rostering plans for train staff are made in separate software systems which most often do not have an interface to timetabling software.

3.4. Societal acceptance of the timetable

To achieve success with a railway timetable it must be acceptable to society, both to political decision makers and normal customers of the railway transportation system. Measuring the societal acceptance level of a timetable is difficult. This paper recommends conducting regular satisfaction surveys amongst railway customers (both passengers and freight clients) and parliamentarian transportation politicians as a KPI for societal acceptance of the timetable. The timetable must obtain a minimum agreed upon score in these surveys to achieve the label "accepted by society".

Key timetable aspects that must be covered in the satisfaction survey include:
- **Punctuality levels of train services** – is the punctuality satisfactory to customers and politicians?
- **Travel time of train services** – are travel times attractive for customers and society?
- **Frequency of train services** – is the number of departures per hour at a given time of day suitable?
- **Connections with other train services** – does the timetable provide attractive transfer options?

Inspiration for such a satisfaction survey could be taken from Great Britain where an independent non-departmental public body named "Passenger Focus" since 2005 has performed half yearly satisfaction surveys. Here train passengers are asked to evaluate several railway transport issues covering everything from train comfort to the timetable. Passengers are faced with a number of statements and must give one of the following grades: Good ☺☺ – satisfied ☺ – neither nor ☺ – dissatisfied ☹ – poor ☹☹. These surveys are conducted to ensure that passengers get high value for their money and the money spend by the government on railway transportation. The results are then drawn up per TOC, train service/route, per region and a national total. Survey data is also drawn up according to journey purpose, age and gender. All this is made public in a report twice a year – spring and autumn [10][23].

In Denmark the TOC are requested to make satisfaction surveys according to their public service traffic contracts with the Danish Ministry of Transport. Doubt can arise about the objectivity of results from these surveys since the TOC evaluates its own train services. This paper therefore recommends introducing the British model in Denmark by creating a non-departmental body to carry out satisfaction surveys for the entire railway system but also for other means of public transport such as busses and ferries. Hereby

objectivity is ensured and it is possible to compare different TOC. Appendix 4 shows a few examples of the presented results from the British rail passenger satisfaction survey from spring 2012.

3.5. Train travel time

Based on infrastructure characteristics, rolling stock characteristics and agreed upon timetabling planning rules between TOC and IM, a minimum travel time for a direct non-stop train service between two stations can be calculated in today's timetable planning systems [18], e.g. TPS [24], Roman D [28], RailSys [27] and Open Track [25]. This theoretical possible minimum travel time can then be compared to the timetabled train travel time in a given timetable variant. A degree of timetabled travel time prolongation can be calculated for every travel relation or a group of selected travel relations covering the biggest passenger and freight flows. This paper recommends using the degree of prolonged travel time as a timetable KPI. See equation (9).

$$Degree\ of\ travel\ time\ prolongation =$$

$$\frac{Shortest\ timetable\ travel\ time\ [min] - Shortest\ possbile\ direct\ non-stop\ travel\ time [min]}{shortest\ possible\ direct\ non-stop\ travel\ time\ [min]} \quad (9)$$

In appendix 5 the degree of travel time prolongation has been calculated between the six biggest Danish cities: Copenhagen, Odense, Esbjerg, Aarhus, Randers and Aalborg. The results vary between 0.12 and 0.54. A non-weighted average can be calculated to be 0.22.

The timetabled travel time can be prolonged due to several reasons: Homogenization of travel speed for rail traffic is needed due to capacity restrictions. If one wants to run both more fast and slow trains on the same railway track a solution is to make the fast train less fast so they do not catch up with the slower trains. On single tracked railway lines, travel time prolongation can occur due to the location of crossing stations. Travel time prolongation can be present in a timetable train path in the following ways [7]:
- Not wanted stops (needs knowledge of TOC capacity application)
- Prolonged running times
- Prolonged stopping times

When investigating a timetable variant It is impossible to detect if a stop in a given timetable train path is wanted or not by the TOC. Full knowledge of the TOC capacity application to the IM is needed. A large necessary prolongation of running time can be converted into an extra stop [7].

If a transfer is unavoidable on a travel relation then a possibility arises to experience a longer than necessary transfer time at the transfer station. The railway timetable planning rules hold a minimum required transfer time for all train to train transfer stations. This must also be taken into consideration when calculating minimum and scheduled travel times for equation (9).

3.6. Attractive transfer options

For every railway station where a timetable planned train to train transfer takes place, a minimum transfer time is defined. This is the minimum time between the arrival of the first train and departure of the second train, which ensures that it is physically possible to make the transfer. Minimum transfer times for Danish railway stations are between 4-6minutes. Larger stations such as Copenhagen central station and Aarhus central station need the longest minimum transfer times [1].

Transfers also hold the possibility for prolongation of the travel time. This paper recommends the KPI: Degree of transfer time prolongation. This can be calculated according to equation (10):

$$Degree\ of\ transfer\ time\ prolongation = \frac{Timetabled\ tranfer\ time\ [min] - Minimum\ transfer\ time\ [min]}{Minimum\ tranfer\ time\ [min]} \quad (10)$$

The necessary input data for calculating the degree of transfer time prolongation can be found in both public and working timetables. This KPI can be calculated for a single transfer. An average value can be calculated for all transfers taking place at a station, for a group of stations or for the entire network. To get a more varied picture a passenger number weighted average can be calculated. A necessary transfer often prolongs the total travel time. This can be caused by limitations in the railway infrastructure within and around the transfer station area and by the time needed to get from one train to the other. The later is influenced by the station layout.
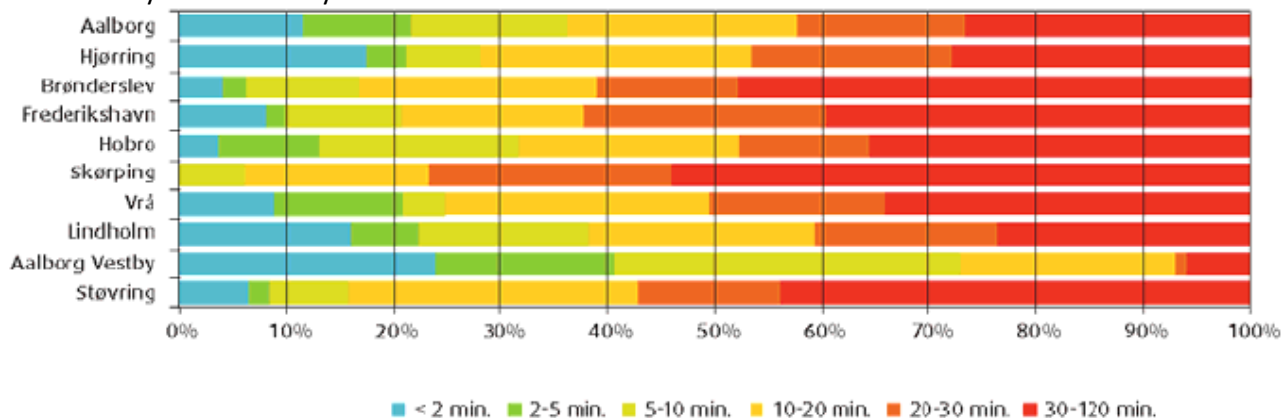

Figure 3: Transfer times at selected stations in Northern Jutland from regional and long distance trains to busses [20].

The Danish Transport Authority (Trafikstyrelsen) has prepared a national traffic plan for the state owned railway for the years 2008-2018. In this report transfers times from trains to busses at the largest stations in each region have been investigated. The transfer times take into consideration the minimum physically needed transfer time and show the additional time needed to make the transfer. Time intervals are: <2, 2-5, 6-10, 11-20, 21-30 and >30 minutes. Figure 3 gives an example of such an investigation for Northern Jutland [20]. See appendix 6 for a calculation example from Odense station. At Odense station the degree of transfer time prolongation varies between -0.2 and up to 9.6. Resulting in a non-weighted average of 4.2.

For a train to train transfer there are some key aspects that have a high influence on the degree of transfer time prolongation. If the connecting train uses the opposite track at the same platform, the prolongation of transfer time can be kept on a minimum or even create no prolongation. If the connecting train uses the same track, travel time prolongation can be down to a few minutes. If transferring passengers have to go to a different platform, the degree of transfer time prolongation depends on station layout and station facilities such as escalators and elevators. This paper recommends introducing the following KPI for optimal train to train transfer conditions in a timetable. See equation (11).

$$Degree\ of\ optimal\ transfer\ conditions = \frac{Number\ of\ timetabled\ train\ to\ train\ transfers\ taking\ place\ at\ the\ same\ platform}{Total\ number\ of\ timetabled\ train\ to\ train\ tranfers} \quad (11)$$

Current timetabling software based on microscopic infrastructure models does take the use of specific platform tracks into account when preparing a timetable variant. The needed data to calculate the degree of optimal transfer options at a given station is available from these systems. This KPI can be calculated in the same ways as equation (10) for a single station, a group of stations or the entire railway network. Calculation of the degree of optimal transfer options for Odense station can be seen in appendix 6. Odense station achieves a value of 0.25.

4. Discussion

The calculation of the recommended timetable evaluation KPI in this paper is generally a work heavy process, if done manually. Only the calculation of the capacity consumption percentage on railway line sections with the UIC 406 methodology has been automated in railway timetabling and simulation software, such as TPS, RailSys and OpenTrack. Since there are several different opinions about how to apply the UIC 406 methodology, calculation results for a given railway line section can potentially vary from user to user and from country to country.

The application of the UIC 406 methodology to measuring the capacity consumption levels on railway line sections is almost inevitable since it is used all over the world and has achieved a general acceptance. Being able to conduct UIC 406 methodology investigations automatically in software timetabling systems makes this approach even more attractive. A weakness of the methodology is that it does not show where in the railway line section of analysis the capacity consumption is highest. It could be at a station.

Analyzing timetable data to recognize a series of timetable patterns during an operational day for sections of a railway network or the entire network demands a high work effort and is further complicated by that it needs a high level of background knowledge on timetable data from the analyst. The KPI for systematic timetables has though proven to give a good and varied picture of how systematic the timetable is by looking at the length of the time span of the most used timetable pattern.

Robustness of the railway timetable depends on many aspects. Therefore, several KPI are needed to cover this topic. Making sure that the agreed upon timetable planning rules between TOC and IM are complied with in regards to train running times between stations is a classical approach and still needed. The degree of deviation from planning rule running times gives an insight into the robustness of the individual train path. The calculation of this KPI can easily be automated in a given software system.

Analysis of the traffic complexity level in a given railway timetable will indicate a risk level for, if the basic timetable structures are supporting timetable robustness or make it easily receptive towards secondary delays. Using the concept of timetable fix points has proven to be a fruitful approach to measuring the traffic complexity level in a railway timetable. This approach gives a very high level of flexibility when preparing analyses for e.g. an individual train path, train paths following a railway line section during the morning rush hour or the entire railway network for the entire day. Automated identification of fix points in timetable data is assumed to be easy to develop. Unfortunately today there exist no available data to compare different timetables according to their timetable fix point statistics.

Investigating the complexity levels of rostering plans for both rolling stock and train staff is difficult since rostering plans are generated in different software tools than timetables are. Most often there is no interface between these systems. Furthermore, rostering plan data is considered to be classified by TOC, since it is a very important competiveness parameter in todays liberalized railway sector. The recommended KPI for number of train departures with shared rolling stock and train staff and the KPI analyzing turnaround buffer times for rolling stock and train staff have therefore not been tested yet. An automation of KPI calculation seems difficult.

Determining if a given railway timetable is acceptable to society can only be done by asking the customers of the railway system, both passengers and freight, and traffic political decision makers. Satisfaction surveys are being carried out today by TOC in Denmark. But this does not ensure an objective approach and presentation of results. In the United Kingdom the task of carrying out satisfaction surveys for railway passengers is done by an independent non-departmental organization called "Passenger Focus". A similar approach is recommendable to be made in Denmark. Such a future organization should also cover the freight part of the Danish railway sector, both present and potential future customers and TOC.

The degree of timetabled travel time prolongation compared to a direct non-stop train gives an insight into which travel relations suffer the most from travel time prolongation in a given timetable. From a socio-economic perspective there should be a correlation between the number of passengers on a given travel relation and the degree of travel time prolongation in the timetable. High numbers of passengers should entail low degrees of travel time prolongation. It is assumed that the automated calculation of this KPI can be implemented in a future timetabling system.

The need for attractive train to train transfer options depends on how heavily the railway timetable is based on necessary transfers to get through the railway network. In a normal situation a train to train

transfer will prolong the travel time. The degree of transfer time prolongation gives an insight into how much the travel time will be prolonged compared to a predefined theoretical minimum possible transfer time at a given station. This value is predefined and ensures that all possible train to train transfers are physically possible. Best possible transfer conditions are achieved if passengers do not have to move to a different platform to make a train to train transfer. The KPI measuring the degree of transfers that fulfill this criterion out of the total number of planned transfers at a given station gives a good overview of this. A transfer taking place at the same platform only demands the minimum transfer time. Creating an automated calculation method for this KPI is possible. The hindrances are that it demands knowledge of the predefined minimum transfer time for stations and which relevant and planned train to train transfers are present in the timetable.

5. Conclusions and perspective

This paper has presented a series of existing and newly developed railway timetable evaluation KPI. Each KPI is attached to one of the six railway timetable evaluation criteria from the first version of a common Danish list of railway timetabling criteria.

Using the concept of timetable patterns to measure how systematic a given timetable is has proven to be a very useful approach. Based on a Swiss regularity index for train services, a refinement is presented that uses the time span of the most used timetable pattern during an operational day to measure how systematic a timetable is. A further development of this KPI could be to have two separate approaches: One for big differences between timetable patterns and one for small differences.

The suggested use of the widely accepted UIC 406 methodology for measuring the capacity consumption makes cooperation and communication easier between IM and TOC, also on an international level. Strengths and weaknesses of the methodology are well known and tested. Automatic UIC 406 methodology capacity analysis modules are already available in timetabling software tools and therefore the use of this KPI is widely implemented in the European railway sector. A future improvement of the UIC 406 methodology should be to handle stations bordering to railway line sections of analysis separately and not as being a part of the analyzed railway line section.

Applying the concept of timetable fix points for measuring the level of traffic complexity in regards to timetable robustness is very promising. This form of analysis contains a high level of flexibility since the area of analysis can go from a single train path to the entire railway network and time wise from one hour to an entire operational day. The identification of timetable fix points was time consuming since it was done manually. To be able to identify fix points, one needs a high level of knowledge about timetabling and the railway infrastructure characteristics. When an automated approach is developed it can also improve the overall quality control of the entire timetable when scanning the timetable for fix points.

To measure the societal acceptance level of an implemented railway timetable one must ask the railway customers and the traffic political decision makers. Good inspiration can be taken from the United Kingdom, where an independent non-departmental organization named "Passenger Focus" conducts half yearly satisfaction surveys amongst train passengers. A future improvement of this concept is to include railway freight customers as well, both existing clients and potential future ones.

Measuring the degree of travel time prolongation in a railway timetable as a KPI is very useful in a socio economic context. There should be a correlation between the number of passengers and the degree of travel time prolongation for a travel relation.

Calculation of the degree of timetabled transfer time prolongation is also important for a socio-economic evaluation of a given timetable variant. The calculations are made complicated since it is manual work to identify which train to train transfer possibilities are relevant and which are not at a given station. Today, each station has its own predefined minimum needed transfer time between two trains. This time covers

the worst case scenario where a slow walking passenger must cover the longest possible distance to make a transfer. A future improvement would be to make the minimum needed train to train transfer time at a given station dependent on the track usage of the involved trains.

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Appendix 1: Systematic timetables are preferable

The public timetable for the Coastal Line between Copenhagen and Elsinore is shown in Figure 4. An overview of identified timetable patterns for the travel relation between Østerport and Helsingør (Elsinore) stations can be seen in Table 5.

	dagtimer					aftentimer			nattetimer	
køredage	ma-fr	ma-sø	ma-sø	ma-fr: 6.22-9.02	ma-fr	ma-sø	ma-sø	ma-sø	ma-sø	nat efter
tidsinterval	6.09-7.09	4.13-18.53	4.42-19.22	15.42-18.22	15.09-17.49	19.42-22.42	19.13-23.33			fr og lø
				lø: 11.02-12.02					0.33-3.33	0.33-3.33
Malmö C		13 33 53		22 42 02			13 33 53		33	33
Triangeln		17 37 57		26 46 06			17 37 57		37	37
Hyllie		22 42 02		31 51 11			22 42 02		42	42
Kbh./Kastrup✈		34 54 14	42 02 22	42 02 22		42 02 22	34 54 14		54	54
Tårnby		38 58 18	46 06 26	46 06 26		46 06 26	38 58 18		58	58
Ørestad		40 00 20	48 08 28	48 08 28		48 08 28	40 00 20		00	00
København H ank.		47 07 27	55 15 35	55 15 35		55 15 35	47 07 27		07	07
København H	09 29 49	56 16 36	59 19 39	59 19 39	09 29 49	58 18 38	49 09 29	0.29 0.49	09	09
Nørreport	13 33 53	00 20 40	03 23 43	03 23 43	13 33 53	02 22 42	53 13 33	0.33 0.53	13	13
Østerport	16 36 56	03 23 43	06 26 46	06 26 46	16 36 56	05 25 45	56 16 36	0.36 0.56	16	16
Hellerup	| | |	08 28 48	11 31 51	11 31 51	| | |		01 21 41	0.41 1.01		21
Klampenborg	| | |	| | |	17 37 57	17 37 57	| | |		05 25 45	0.45 1.05		25
Skodsborg	| | |	| | |	21 41 01	21 41 01	| | |		10 30 50	0.50 1.10		30
Vedbæk	| | |	| | |	25 45 05	25 45 05	| | |		13 33 53	0.53 1.13		33
Rungsted Kyst	33 53 13	| | |	29 49 09	29 49 09	34 54 14		17 37 57	0.57 1.17		37
Kokkedal	37 57 17	22 42 02	33 53 13	33 53 13	| | |		20 40 00	1.00 1.20		40
Nivå	| | |	26 46 06	36 56 16	36 56 16	| | |		24 44 04	1.04 1.24		44
Humlebæk	43 03 23	29 49 09			43 03 23		27 47 07	1.07 1.27		47
Espergærde	46 06 26	33 53 13			46 06 26		31 51 11	1.11 1.31		51
Snekkersten	50 10 30	36 56 16			50 10 30		34 54 14	1.14 1.34		54
Helsingør ank.	54 14 34	41 01 21			54 14 34		38 58 18	1.18 1.38		58

Figure 4: Public timetable for the Coastal Line, driving direction Østerport → Helsingør (Elsinore) [3]

The difference between timetable patterns 1 and 2 is the additional rush hour trains with departure in minute 16, 36 and 56 at Østerport station. The stopping pattern for the rush hour trains is not the same as the regular train service but the travel time is 38minutes for both train services. In timetable pattern 3 there is only one train service running on the line calling at all stations thereby increasing travel time to 42 minutes. There are bigger differences between timetable pattern 3 and timetable patterns 1 and 2.

Table 4: Overview of timetable patterns for the travel relation Østerport → Helsingør (Elsinore)

Timetable pattern ID	Time span [hour]	Departure times from Østerport station [min]					
1	05 - 06	03	-	23	-	43	-
2	06 - 07	03	16	23	36	43	56
1	07 - 15	03	-	23	-	43	-
2	15 - 18	03	16	23	36	43	56
1	18 - 20	03	-	23	-	43	-
3	20 - 01	-	16	-	36	-	56

Now the regularity index for the timetable can be calculated by equation (1) and (2).

$$RI = \frac{A}{A+B} \; X \; 100\% = \frac{72}{72+48} \; X \; 100\% = \mathbf{60}\% \qquad (1)$$

Where A = 15 hours with 3 departures in minute 3, 23 and 43 + 9 hours with departures in minute 16, 36 and 56 = 72
Where B = 5 hours without departures in minute 3, 23 and 43 + 11 hours without departures in minute 16, 36 and 56 = 48

$$STI = \frac{\sum TS_{mtp}}{TS_{inv}} \; x \; 100\% = \frac{11}{20} \; X \; 100\% = \mathbf{55}\% \qquad (2)$$

Where TS_{mtp} is 11 hours since timetable pattern 1 is time wise the most used. It is in use from hour 05-06, 07-15 and 18-20 = 11 hours

TS_{inv} = 20 hours since the investigation time span is from hour 05 to 01 = 20 hours

The Swiss RI-index indicates a regularity of the example timetable about 60%. The systematic timetable index using the sum of hours for the most used timetable pattern gives 55%. It can be argued for that the index values are to low since the train service with departure times in minute 03 23 and 43 is present in 15 of the 20 hours that the timetable covers and therefore should be closer to 75%. It is noticeable that timetable pattern 2 contains the entire timetable pattern 1. Therefore it can be discussed if timetable pattern 1 is present in 15 of the 20 investigated hours and the result should be 75% instead of 55%.

Appendix 2: Consumption of capacity on railway line sections

Figure 5 shows a map illustrating the division of the railway network of Rail Net Denmark into line sections according to the guidelines given in UIC leaflet 406. The division of the network depends on the route structure of the train services and is therefore not static. The map is from the year 2008 but is still valid today.
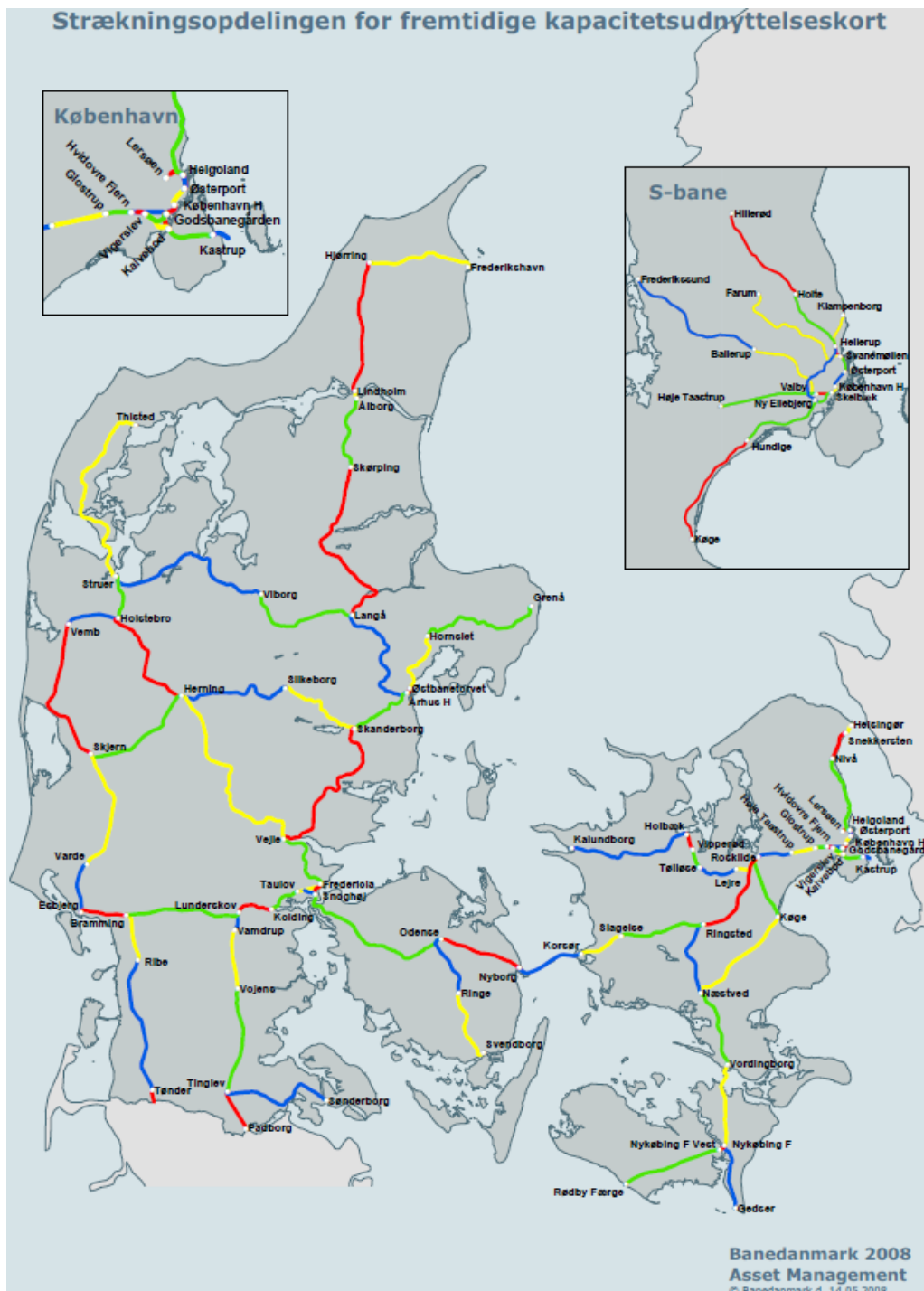
Figure 5: Division of the railway network of Rail Net Denmark into line sections for capacity analysis [11]

Notice that the division of the railway network focuses on changes in number of running trains (junctions and terminus stations for train services) and major changes in infrastructure (going from single to double track or vice versa and changes in interlocking systems e.g. going from automatic train control to manual train control).

Figure 6 shows the capacity consumption for a peak hour in the 2010 timetable. Double track lines are analyzed by using the UIC 406 methodology and single tracked railway lines are investigated by looking at the number of available standard train paths per hour that are used. The later approach can be used since the traffic is mostly very homogenous on single tracked lines whereas traffic on the double tracked main lines most often is heterogeneous.

Figure 6: Peak hour capacity consumption of railway line sections for the 2010 timetable [13]

Appendix 3: Robustness of the timetable – train RØ 4111

As an example for the use of some of the proposed KPI for timetable robustness, regional train RØ 4111 running between Copenhagen and Ringsted with stop at all immediate stations has been selected for a first analysis of timetable robustness.

Figure 7 shows the train graph for the railway line between Ringsted station (Rg) and Copenhagen central station (Kh). The train path to be analyzed, train RØ 4111, is marked with red circles. The train graph is a screenshot from Rail Net Denmark's train production database software "P-base".
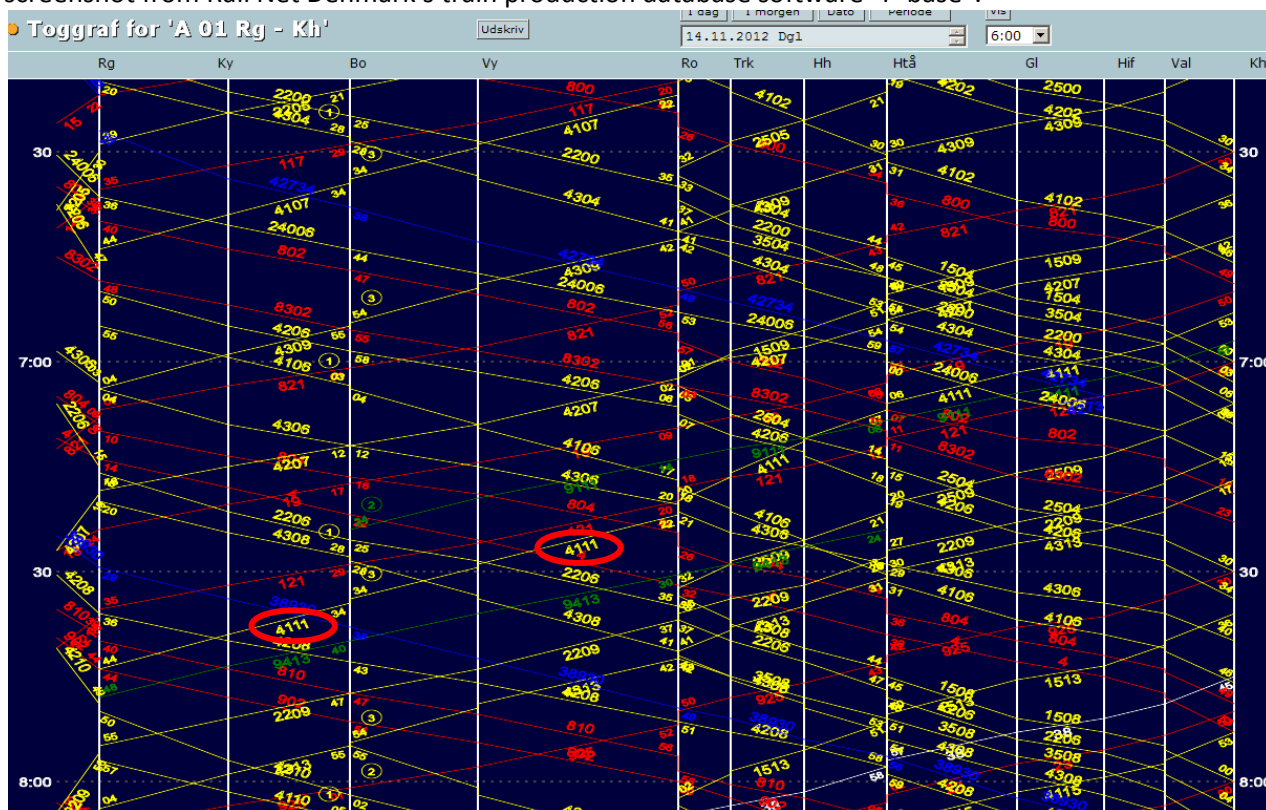
Figure 7: Train graph for the railway line Ringsted (Rg) and Copenhagen central station (Kh). Train RØ 4111 is marked with red

The detailed timetable for train RØ 4111 can be seen in Table 6. Data are taken from the TPS timetabling system. From the two columns to the right, it becomes clear that this train only has positive deviations from the timetable planning rules used at Rail Net Denmark, and has been given substantial running time reserves. Considering the complex traffic pattern around this train, this makes sense from a timetabling point of view.

Table 5: Detailed timetable data for train RØ 4111 - including deviation and degree of deviation from planning rules

Station	Arrival [hr:min:sec]	Departure [hr:min:sec]	Deviation from planning rules [min:sec]	Degree of deviation from planning rules
Copenhagen central station (Kh)	-	06:53:00	-	-
Valby (Val)	06:57:00	06:57:30	+ 00:27	0.13
Høje Taastrup (Htå)	07:06:00	07:07:00	+ 00:18	0.04
Hedehusene (Hh)	07:11:00	07:11:30	+ 00:42	0.20
Trekroner (Trk)	07:16:00	07:16:30	+ 01:24	0.47
Roskilde (Ro)	07:20:00	07:22:00	+ 00:58	0.39
Viby Sjælland (Vy)	07:29:00	07:29:30	+ 00:45	0.12
Borup (Bo)	07:34:00	07:34:30	+ 00:14	0.06
Ringsted (Rg)	07:44:00	-	+ 00:59	0.12

The train path of train 4111 has three identified timetable fix points on the route between Copenhagen central station and Ringsted station. These are:

1. Copenhagen central station (km 0.0) – the order of departing trains must be kept. InterCityExpress-train L 19 is departing at 06:50 and train RØ 4111 at 06:53. This is the minimum planning headway time between two following trains.
2. Roskilde station (km 31.3) – change of train order. Train RØ 4111 is overtaken between Høje Taastrup station and Roskilde station (4 track section) by empty train M 9111 and InterCity-train IC 121.
3. Ringsted station (63.9) – this is a level junction and train RØ 4111 must cross the train path of InterCity-train IC 810 and morning rush hour InterCityExpress train L 902.

This gives an average of a timetable fix point every 21.3km for train RØ 4111. There are unfortunately no available data on average values for timetable fix points for train paths or per kilometer.

Table 7 gives an overview of the potential train path conflicts that train RØ 4111 may experience on its run between Copenhagen central station and Ringsted station. Train paths in front of train RØ 4111 are listed at the relevant fix point and the conflict category stated and evaluated according to its risk level.

Table 6: Overview of potential conflicts at identified fix points foer train RØ 4111

Train number	Fix point	Arrival Departure	Conflicting train number	Arrival Departure	Conflict category	Risk level of conflict
RØ 4111	Copenhagen central station	- 06:53	L 19	- 06:50	Train order	High
			M 9111	- 06:57	Train order	-
			IC 121	- 07:00	Train order	-
	Roskilde	07:20 07:22	M 9111	- 07:14	Overtaking / train order	Low
			IC 121	07:18 07:20	Overtaking / train order	High
	Ringsted	07:44 -	IC 810	07:39 07:40	Crossing train paths	Medium
			L 902	07:43 07:44	Crossing train paths	Very high

When looking at the further most right column in Table 7, a first impression would be that the risk of train RØ 4111 getting delayed is rather high. However one must remember the deviations from the timetable planning rules shown presented in Table 6. If the timetable planner added the substantial running time reserves to train RØ 4111 because of the complexity in the timetable concerning train RØ 4111 and the neighboring train paths or if it was simply to make the timetable feasible is unsaid. The overall evaluation of the planned train path of train RØ 4111 is that the robustness level is adequate.

Appendix 4: Societal acceptance of the timetable

On the following pages some examples from the railway passenger satisfaction survey conducted in spring 2012 by the British Passenger Focus organization are presented. Such surveys give a better understanding about the societal acceptance level of the investigated timetable. Please notice the results marked with a red box in Figure 8. These are particularly interesting in this context.

Improved ⬆ (green)
Unchanged ⊖ (orange)
Declined ⬇ (red)

National total

Overall sample size 28832	sample size	Spring 2012 % satisfied or good	Spring 2012 % neither/ nor	Spring 2012 % dissatisfied or poor	Improvement/decline in % satisfied or good since Autumn 2011 % change	significant change	Improvement/decline in % satisfied or good since Spring 2011 % change	significant change
Overall satisfaction	28407	83	10	7	-1	⬇	-1	⊖
STATION FACILITIES								
Overall satisfaction with the station	28128	77	16	7	-1	⬇	1	⬆
Ticket buying facilities	14973	73	14	12	0	⊖	1	⊖
Provision of information about train times/platforms	27092	81	11	8	0	⊖	2	⬆
The upkeep/repair of the station buildings/platforms	27081	67	20	13	0	⊖	2	⬆
Cleanliness	26930	71	19	10	-1	⊖	1	⊖
The facilities and services	23377	50	22	29	-1	⊖	0	⊖
The attitudes and helpfulness of the staff	20520	71	19	10	0	⊖	1	⊖
Connections with other forms of public transport	20037	73	16	12	0	⊖	0	⊖
Facilities for car parking	10934	49	19	33	-2	⬇	0	⊖
Overall environment	27564	67	22	11	-1	⊖	2	⬆
Your personal security whilst using	24544	68	26	6	1	⊖	2	⬆
The availability of staff	23542	60	23	18	1	⊖	2	⬆
How request to station staff was handled	4348	83	6	10	-3	⬇	0	⊖
TRAIN FACILITIES								
The frequency of the trains on that route	27722	78	8	13	0	⊖	1	⊖
Punctuality/reliability (i.e. the train arriving/departing on time)	27651	81	8	11	0	⊖	1	⊖
The length of time the journey was scheduled to take (speed)	27325	85	9	6	0	⊖	0	⊖
Connections with other train services	16111	77	16	7	1	⊖	1	⊖
The value for money for the price of your ticket	26437	42	21	37	-4	⬇	-2	⬇
Upkeep and repair of the train	27927	75	15	10	0	⊖	2	⬆
The provision of information during the journey	25330	70	19	10	1	⊖	1	⊖
The helpfulness and attitude of staff on train	16867	64	26	9	0	⊖	0	⊖
The space for luggage	21958	55	22	24	1	⊖	2	⬆
The toilet facilities	12008	37	23	40	-1	⊖	1	⊖
Sufficient room for all passengers to sit/stand	27441	69	13	18	1	⊖	2	⬆
The comfort of the seating area	27346	72	17	11	0	⊖	2	⬆
The ease of being able to get on and off	27764	80	13	7	0	⊖	0	⊖
Your personal security on board	26147	77	19	4	0	⊖	1	⬆
The cleanliness of the inside	28044	75	15	11	0	⊖	2	⬆
The cleanliness of the outside	24032	71	20	9	-3	⬇	3	⬆
The availability of staff	20768	47	29	25	1	⊖	1	⊖
How well train company deals with delays	4517	37	37	26	-2	⊖	1	⊖

Figure 8: Example of results on a national level from Passenger Focus satisfaction survey in Great Britain [10]

Punctuality/reliability (i.e. the train arriving/departing on time)

Improved ⬆
Unchanged ⊖
Declined ⬇

% of passengers satisfied/good by sector:
London and South East - 79%
Long Distance - 87%
Regional - 85%

	sample size	% satisfied or good	% neither/ nor	% dissatisfied or poor	% change	significant change	% change	significant change
		Spring 2012			Improvement/decline in % satisfied or good since Autumn 2011		Improvement/decline in % satisfied or good since Spring 2011	
Arriva Trains Wales	1133	87	5	8	0	⊖	3	⊖
c2c	1072	92	5	3	0	⊖	0	⊖
Chiltern Railways	1148	86	6	8	5	⬆	-2	⊖
CrossCountry	1131	85	5	10	6	⬆	1	⊖
East Coast	1178	88	5	7	9	⬆	3	⊖
East Midlands Trains	1178	88	5	7	0	⊖	1	⊖
First Capital Connect	1927	76	9	15	-1	⊖	1	⊖
First Great Western	2911	78	8	14	-1	⊖	1	⊖
First Hull Trains	550	93	4	3	8	⬆	4	⊖
First TransPennine Express	1122	88	5	7	4	⬆	1	⊖
Greater Anglia*	2341	70	9	22	-7	⬇	-5	⬇
Heathrow Connect	578	91	7	2	1	⊖	4	⊖
Heathrow Express	529	93	5	2	-1	⊖	-3	⊖
London Midland	1142	81	8	10	3	⊖	6	⬆
London Overground	1145	88	8	5	4	⬆	9	⬆
Merseyrail	606	94	3	3	-1	⊖	1	⊖
Northern Rail	1222	78	9	13	-2	⊖	0	⊖
ScotRail	1192	87	6	7	1	⊖	6	⬆
South West Trains	2240	82	8	10	-2	⊖	-4	⬇
Southeastern	1651	79	9	12	-1	⊖	1	⊖
Southern	2228	78	8	14	0	⊖	0	⊖
Virgin Trains	1084	89	4	7	4	⬆	-3	⊖

Figure 9: Example of results on a train operating company level from Passenger Focus satisfaction survey in Great Britain [10]

Figure 9 shows the results from a train operating company point of view. Such an overview makes it possible to see if a specific company experiences problems in fulfilling passenger expectations or has developed a new approach that is appreciated by passengers. These results are made public and therefore train operating companies also get an insight into how they are perceived by their customers.

Such a survey should also be conducted for the railway freight sector, with its train operating companies and customers. In the best case the survey should also include potential future customers. This would give the freight train operating companies a valuable insight into what services they must provide to attract new clients.

The value for money for the price of your ticket by route

Route	sample size	% satisfied or good	significant change
Arriva Trains Wales - North Wales	439	55	Declined
Arriva Trains Wales - South Wales	314	55	Unchanged
Arriva Trains Wales - Valley	361	57	Unchanged
c2c	1030	42	Unchanged
Chiltern Railways - North	269	54	Unchanged
Chiltern Railways - South	839	46	Unchanged
CrossCountry - Birmingham - Manchester	145	46	Declined
CrossCountry - Birmingham - North East And Scotland	266	49	Unchanged
CrossCountry - Birmingham - South Coast	207	48	Unchanged
CrossCountry - Birmingham - South West	196	49	Unchanged
CrossCountry - Birmingham - Stansted	187	50	Unchanged
CrossCountry - Nottingham - Cardiff	116	46	Unchanged
East Coast - London - East Midlands/East Of England	234	54	Unchanged
East Coast - London - North East & Scotland	250	58	Unchanged
East Coast - London - Yorkshire	306	50	Unchanged
East Coast - Non-London journeys	377	62	Unchanged
East Midlands Trains - Liverpool - Norwich	233	53	Declined
East Midlands Trains - Local	275	58	Unchanged
East Midlands Trains - London	647	48	Unchanged
First Capital Connect - Great Northern	584	33	Unchanged
First Capital Connect - Thameslink Loop	272	36	
First Capital Connect - Thameslink North	609	32	Unchanged
First Capital Connect - Thameslink South	359	39	Unchanged
First Great Western - Long Distance	1091	49	Unchanged
First Great Western - London Thames Valley	1101	42	Unchanged
First Great Western - West	675	54	Unchanged
First Hull Trains	543	56	Unchanged
First TransPennine Express - North	613	54	Unchanged
First TransPennine Express - North West	306	60	Unchanged

Route	sample size	% satisfied or good	significant change
First TransPennine Express - South	179	61	Unchanged
Greater Anglia* - Intercity	400	44	Unchanged
Greater Anglia* - Mainline	464	23	Declined
Greater Anglia* - Metro	408	29	Unchanged
Greater Anglia* - Rural	220	51	Unchanged
Greater Anglia* - Stansted Express	196	29	Unchanged
Greater Anglia* - West Anglia	563	27	Unchanged
Heathrow Connect	530	56	Unchanged
Heathrow Express	526	33	Unchanged
London Midland - London Commuter	312	42	Unchanged
London Midland - West Coast	205	59	Unchanged
London Midland - West Midlands	535	55	Unchanged
London Overground - Gospel Oak - Barking	208	56	Unchanged
London Overground - Richmond/Clapham - Stratford	281	52	Unchanged
London Overground - Watford - Euston	305	48	Declined
London Overground - Dalston - Croydon	224	43	Unchanged
Merseyrail - Northern	231	64	Unchanged
Merseyrail - Wirral	230	71	Unchanged
Northern - Lancashire & Cumbria	139	48	Unchanged
Northern - Manchester & Liverpool	327	50	Unchanged
Northern - South & East Yorkshire	203	43	Declined
Northern - Tyne Tees & Wear	139	65	Unchanged
Northern - West & North Yorkshire	348	52	Declined
Scotrail - Interurban	475	53	Unchanged
Scotrail - Rural	115	75	Unchanged
Scotrail - Strathclyde	294	50	Declined
Scotrail - Urban	274	50	Unchanged
Southeastern - High Speed	353	34	Unchanged
Southeastern - Mainline	384	34	Unchanged
Southeastern - Metro	797	31	Unchanged
Southern - Gatwick Express	450	31	Unchanged

Route	sample size	% satisfied or good	significant change
Southern - Sussex Coast	1029	41	Unchanged
Southern - Metro	649	35	Unchanged
South West Trains - Island Line	100	54	Unchanged
South West Trains - London	586	40	Unchanged
South West Trains - Mainline	228	32	Unchanged
South West Trains - Metro	243	37	Unchanged
South West Trains - Not Managed By South West Trains	219	40	Unchanged
South West Trains - Portsmouth	137	26	Declined
South West Trains - Reading/Windsor	195	35	Unchanged
South West Trains - Suburban	259	31	Unchanged
South West Trains - West Of England	176	41	Declined
Virgin - Birmingham - Scotland	124	61	Unchanged
Virgin - London - Liverpool	145	62	Unchanged
Virgin - London - Manchester	319	60	Unchanged
Virgin - London - North Wales	63	52	Unchanged
Virgin - London - Scotland	213	54	Unchanged
Virgin - London - Wolverhampton	192	60	Unchanged

Figure 10: Example of results on a train service/railway route level from Passenger Focus satisfaction survey in Great Britain [10]

One of the most important parameters for societal acceptance of a given timetable is if the railway customers feel that they get good value for their money. This aspect has been analyzed in the satisfaction survey and is presented on a railway route level in Figure 10.

Appendix 5: Train travel time

An overview of train travel times between the biggest cities in Denmark is given in Table 8. First row in each cell is the shortest possible travel time in the current 2012 timetable. Second row is the fastest possible travel time with direct non-stop train scheduled according to the agreed upon planning rules between IM and TOC. Third row is the calculated degree of travel time prolongation in the timetable 2012. The degree of prolongation is calculated as shown in the following equation:

$$Degree\ of\ travel\ time\ prolongation = \frac{Shortest\ timetable\ travel\ time - Shortest\ possbile\ travel\ time}{shortest\ possible\ travel\ time}$$

The timetabled travel times are collected from the online travel planner service: www.rejseplanen.dk (05.07.2012) and from Rail Net Denmark's timetable production software system TPS. Here the valid 2012 timetable and infrastructure version are used.

Table 7: Overview of train travel times for selected travel relations. First row: Shortest timetable travel time [hour:min:sec]. Second row: Shortest possible travel time with non-stop train following planning rules [hour:min:sec]. Third row: Degree of travel time prolongation in the 2012 timetable

Origin \ Destination	Copenhagen	Odense	Esbjerg	Aarhus	Randers	Aalborg
Copenhagen		01:15:00 01:07:00 **0.12**	02:53:00 02:17:00 **0.26**	02:43:00 02:26:00 **0.12**	03:29:00 02:59:00 **0.17**	04:19:00 03:42:00 **0.17**
Odense	-		01:20:00 01:08:00 **0.18**	01:23:00 01:17:00 **0.08**	02:12:00 01:50:00 **0.20**	03:02:00 02:33:30 **0.19**
Esbjerg	-	-		02:29:00 01:37:00 **0.54**	03:08:00 02:10:00 **0.45**	04:03:00 02:53:30 **0.40**
Aarhus	-	-	-		00:31:00 00:28:00 **0.11**	01:21:00 01:11:30 **0.13**
Randers	-	-	-	-		00:49:00 00:42:30 **0.15**
Aalborg	-	-	-	-	-	

A non-weighted average can be calculated to be 0.22.

In the 2012 timetable there are planned direct InterCityExpress (almost) non-stop trains between Copenhagen and Aarhus via Odense. Normal InterCityExpress trains continue on to Randers and Aalborg. These travel relations also show the smallest degree of travel time prolongation in the timetable.

There are InterCity trains running between Copenhagen and Esbjerg via Odense. These have several stops on their route and the degree of travel time prolongation therefore is higher.

There is only a direct regional train service between Esbjerg and Aarhus. Continuing on to Randers and Aalborg requires a train to train transfer. These travel options result in much higher levels of travel time prolongation.

Appendix 6: Attractive transfer options at Odense station

Table 9 shows transfer waiting times (timetabled transfer time – minimum transfer time) and the matching degree of transfer time prolongation for Odense station. The predefined minimum transfer time at this station is 5minutes. Not all transfer combinations are calculated since they are not relevant due to e.g. an earlier departure servicing the same stations. Please be aware of that the non-stop IL-trains overtake IC-trains on their way to Copenhagen and Aarhus from Odense. As well that the station Sorø is only serviced by the IC-train service between Copenhagen and Esbjerg.

Table 8: Transfer waiting times and degree of transfer time prolongation at Odense station for the yearly timetable 2012, weekdays 16-17 [1]

Departure	Train class	IC	Lyn	Lyn	RV	IC	RV	IL	IC	RV	IL	IC	RV *
Arrival	Destination	Es-bjerg / Flens-borg	Frede-riks-havn	Copen-hagen	Ringe	Øster-port	Svend-borg	Copen-hagen	Lind-holm / Aal-borg	Frede-ricia	Aarhus	Copen-hagen Air-port	Svend-borg
Train	Origin	Minute	03	07	07	09	15	23	25	33	37	42	45	54
IC	Østerport	01		1 / 0.2	-	3 / 0.6	-	17 / 3.4	-	27 / 5.4	31 / 6.2	36 / 7.2	-	-
Lyn	Copenhagen	05	-		-	-1 / -0.2	-	13 / 2.6	-	23 / 4.6	27 / 5.4	-	-	-
Lyn	Frederikshavn	05		-		-1 / -0.2	5 / 1.0	13 / 2.6	-	-	-	-	-	-
RV	Ringe	07	-	-	-		3 / 0.6	-	13 / 2.6	21 / 4.2	25 / 5.0	30 / 6.0	-	-
IC	Esbjerg / Sønderborg	11	-	-	-	53/10.6		7/ 1.4	9 / 1.8	-	-	-	-	-
RV *	Svendborg	21	-	-	-	-	-		-1 / 0.2	7 / 1.4	11 / 2.1	16 / 3.2	19 / 3.8	28 / 5.6
Il	Aarhus	23	-	-	-	41 / 8.2	47 / 9.4	-		-	-	-	-	26 / 5.2
IC	Copenhagen Airport	30	-	-	-	34 / 6.8	-	48 / 9.6	-		2 / 0.4	7 / 1.4	-	19 / 3.8
RV	Fredericia	32	-	-	-	32 / 6.4	38 / 7.6	46 / 9.2	-	-		-	8 / 1.6	17 / 3.4
IL	Copenhagen	40	18 / 3.6	-	-	24 / 4.8	-	38 / 7.6	-	-	52/10.4		-	9 / 1.8
IC	Lindholm / Aalborg	43	-	-	-	21 / 4.2	27 / 5.4	35 / 7.0	-	-	-	-		6 / 1.2
RV	Svendborg	55	3 / 0.6	7 / 1.4	7 / 1.4	-	15 / 3.0	-	25 / 5.0	33 / 6.6	37 / 7.4	42 / 8.4	-	

An attempt has been made to give an overview of the transfer waiting times at Odense station in Table 10. This is inspired by the Danish Transport Authority's (Trafikstyrelsen) national traffic plan for the state owned railways. The transfer waiting times have been put into time intervals and a number of transfers has been calculated. An accumulated percentage is shown to the most right column.

Table 9: Overview of transfer waiting times at Odense station

Transfer waiting time interval [min:sec]	Number of transfers	Accumulated percentage [%]
<2:00	4	7.0
2:00 - 4:59	4	14.0
5:00 - 9:59	10	31.6
10:00 - 19:59	11	50.9
20:00 − 29:59	11	70.2
30 ≥	17	100.0
Non-weighted average degree of transfer time prolongation		**4.2**

When looking at the degree of optimal transfer conditions, one most know the station layout and the timetabled platform track usage for train services. Figure 11 shows the schematic track plan of Odense station. Platform tracks 3 and 4 are used by IL, Lyn and IC-trains from Esbjerg / Flensborg / Sønderborg / Aarhus / Aalborg and Frederikshavn towards Copenhagen. The RV-train service from Fredericia to Odense terminates at track 3. Tracks 5 and 6 are used by IL, Lyn and IC-train from Copenhagen and towards Esbjerg / Flensborg / Sønderborg / Aarhus / Aalborg and Frederikshavn. Departures with RV-train towards Fredericia take place on track 6. Trains to/from Ringe and Svendborg use tracks 7 and 8.
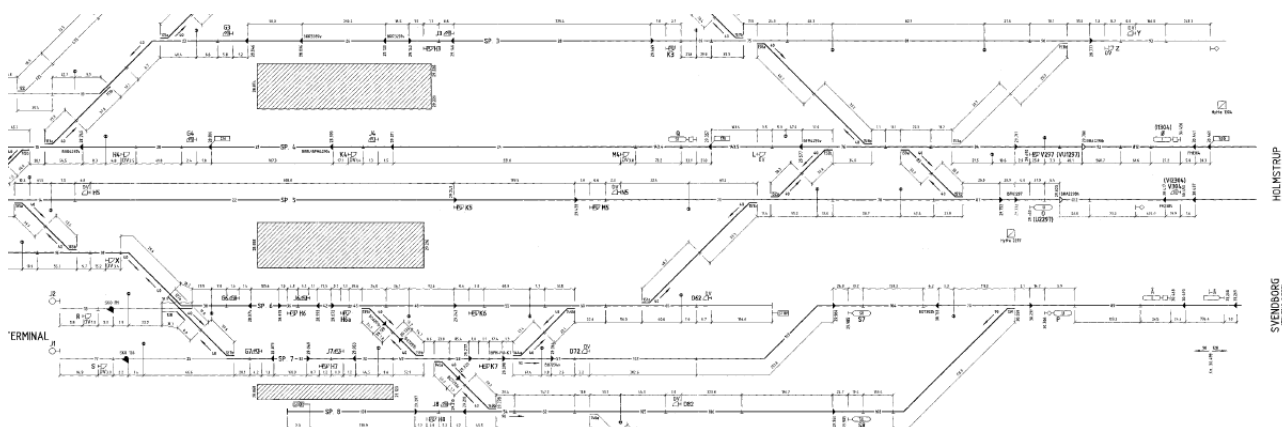

Figure 11: Schematic track plan with platforms for Odense station [12]

The degree of optimal transfer conditions at Odense station can then be calculated to:

$$\frac{Number\ of\ timetabled\ train\ to\ train\ transfers\ taking\ place\ at\ the\ same\ platform}{Total\ number\ of\ timetabled\ train\ to\ train\ tranfers} = Degree\ of\ optimal\ transfer\ conditions$$

➔ $\frac{14}{57} = \mathbf{0.25}$