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Creation of a Framework for Railway Timetable Optimization Criteria

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Abstract

During the last years, much effort has been put into developing mathematical models for timetable creation. All models need an objective function which describes criteria used to optimize and evaluate a timetable. In an attempt to find a Danish list of prioritized railway timetable evaluation criteria, this paper presents the five most important evaluation criteria from the 5 most important Danish railway timetable stakeholders. The criteria are grouped according to overall subjects and a first overview of the prioritization is given. From the criteria descriptions a series of indicators are deduced. This forms the basis for a decision process for finding a common accepted list of prioritized timetable evaluation criteria. This decision process will be accomplished on one or two decision making workshops. A reduction from 13 stated potential timetable evaluation criteria to between 4 and 6 is needed. To make the decision making process as accessible and transparent to the stakeholders as possible the SMARTER technique will be applied. A short description of the technique is given. The deduced indicators for each remaining criterion must also be ranked. Since some of the indicators are not easily quantifiable the "Direct Ranking" methodology will be used for this step in the process. The methodology is briefly described. Hereby the roadmap for a first common Danish list of prioritized railway timetable evaluation criteria is given.

1 Introduction

In the year 2000 Malavasi and Ricci [13] stated that: "Effective and widely tested models for the direct evaluation of the residual carrying capacity of the railway networks and the definition of the most effective actions for the full exploitation of this capacity are not yet available". Since then the picture has changed.

The European railway sector is being liberalized. This creates a railway sector which consists of several interest groups with common and/or conflicting interests – e.g. train operating companies (TOC) for freight and passenger services and infrastructure managers (IM). Even within a single interest group there can be conflicting interests – e.g. competing passenger train operators.

Railway timetables involve all interest groups within the railway sector. By European Union legislation the IM has been given the responsibility for creating a feasible and acceptable timetable [16]. This is not the

case in other parts of the world, where railway companies own and operate both infrastructure and rolling stock and develop their own timetables.
All TOCs have individual wishes for the timetable, based on specific boundary conditions like e.g. traffic contracts with political governments, available rolling stock and crew. Conflicting interests can make it very difficult for IMs to create a timetable that satisfies all stakeholders.

Development and evaluation of railway timetables must be based on accepted optimization criteria by all major timetable stakeholders. If this is not the case, there is no common understanding between stakeholders in regards to timetable optimization and it becomes difficult for the IM to develop and evaluate timetables.

The last years, there has been an intensive research within the area of operations research to develop mathematical models using specialized algorithms for railway timetable construction. In the Netherlands the DONS-software is already being used with great success [9] and in Switzerland advanced models for traffic management in bottlenecks have recently been developed [1]. All these models must have an objective function based on the optimization criterion/criteria wanted for generating a given timetable.

This paper gives the basis for creating a common Danish understanding for timetable optimization and evaluation. Section 2 describes the timetabling process in Rail Net Denmark. For the first time in Denmark, a series of interviews with selected stakeholders was held with the goal to find the parameters for a Danish timetabling objective function. Only long distance railway traffic was discussed. Interviews were held with:

- Infrastructure manager: Rail Net Denmark
- Train operating companies: DSB, Arriva and DB Schenker Rail Scandinavia
- National Transport Authority (Traffic tenders)

No interviews were held with organizations directly representing the end customers – the train passengers and freight customers. It is assumed that the interests of these timetable stakeholders are being represented by the TOCs and the National Transport Authority. The income of the TOCs depending on providing attractive services to their potential customers and the National Transport Authority ensuring a minimum service level for train passengers through their traffic tender policies.

The outcome of these interviews is described in section 3. The results from these interviews make the basis for the decision making process that is needed to reach a Danish list of prioritized railway timetable optimization and evaluation criteria. The roadmap for this process is described in section 4. Finally, conclusions are made and perspectives are given in section 5.

2 Timetabling process in Rail Net Denmark

In the current timetabling process, Rail Net Denmark focus on using the agreed upon planning rules, accommodating all wishes from TOC or reach a fast compromise in case of conflicts and finally keeping the deadline for preparing the timetable. This ensures that most stakeholders are satisfied.

Since Rail Net Denmark is member of Rail Net Europe (RNE) that focus on improving coordination of international train traffic, the timetabling process in Rail Net Denmark follows the guidelines provided by RNE. Figure 1 shows an overview of the RNE timetabling process.

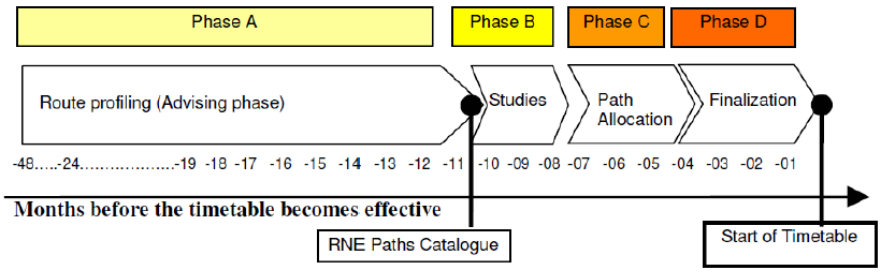

Figure 1: The RNE general timetabling process [18].

It is noticeable that the timetabling process starts 4 years before the timetable becomes effective. A short description of phase A to D follows:

Phase A: From 48 to 12 months before the timetable becomes effective. In the first half of phase A the IM will get an overview of future available capacity and wishes for timetable time slot allocation from TOCs. The IM gathers strategic long term information which may influence railway traffic and infrastructure capacity [18].

In the second half of phase A the IM can help TOCs defining their needs for timetable time slots. Simultaneously RNE works on the international catalogue for train paths [18].

Phase B: Feasibility Studies are performed between 18 to 9 months before the timetable becomes effective. These can also be requested by TOCs to get an overview of which timetable time slots are possible in a future timetable. Requested studies will be based on the results from phase A [18].

Phase C: A detailed time slot allocation for the yearly timetable takes place between 8 to 5 months before the timetable becomes effective. RNE conferences are held to ensure coordination of timetable time slot requests before allocating capacity. At these meetings IM harmonize international timetable time slots at national borders [17][18].

The new timetables are published between 6 to 5 months before they become effective. Information on border crossing timetable time slots is sent to relevant IM hereby ensuring coordination of these [18].

Phase D: From 4 months before to 12 months after the timetable becomes effective, timetable time slot allocation can only be done in free remaining capacity [17][18].

Rail Net Denmark has adjusted its timetabling process to the RNE guidelines. A process chart of the valid timetabling process for the yearly national timetable is shown in Figure 2.

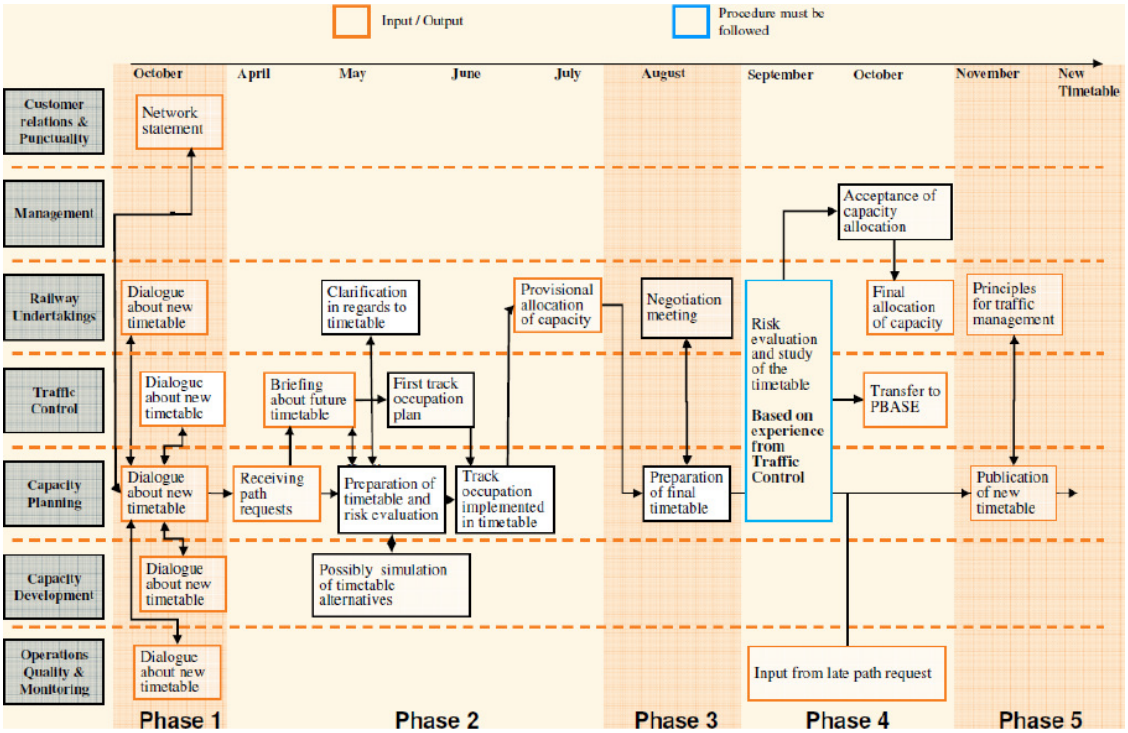

Figure 2: Timetabling process chart for the yearly timetable at Rail Net Denmark [21].

In Figure 2 horizontal lines represent involved organizational units from Rail Net Denmark. Boxes represent involvement from a unit in the timetabling process. Involvement can be giving input, produce output or quality control.

Rail Net Denmark is communicating with other timetable stakeholders during phase 1 from October to April. Timetable time slot applications are received from TOCs and draft versions of feasible timetable variants are made and evaluated in phase 2 -between April and July. In Phase 3 the primary goal is to achieve a compromise between all TOCs by hosting several negotiation meetings. The result is a finalized timetable. This happens around August. During phase 4 the timetable is evaluated in regards to robustness. Two approaches are applied: Simulation of critical parts of the timetable using the railway traffic simulation tool RailSys and utilize local knowledge and experience at the traffic control centers. The timetable is approved by the management of Rail Net Denmark during October. The timetable is made operational in phase 5 lasting from November into December.

The fundamental timetable class used in Denmark is a periodic timetable with a periodicity interval of 1 hour[1]. There are some changes in connection with rush hours and late evening/night time periods. These changes involve higher/lower frequencies of train services, new and stopped train services and a difference in extent of train services on the network.

A future commonly accepted list of timetable evaluation criteria will be used in phase 2, when creating possible timetable variants and during phase 4, in the evaluation process.

3 Interviews with selected timetable stakeholders

A series of interviews have been held with selected timetable stakeholders. These are:

- **DSB:** Passenger train operating company owned by the Danish state
- **Arriva:** Passenger train operating company owned by Deutsche Bahn (and thereby the German state)

[1] For more about timetable classes see Liebchen [12] + Schittenhelm [20].

- **DB Schenker Rail Scandinavia:** Freight train operating company owned by Deutsche Bahn (and thereby the German state) specializing in international transit freight trains through Denmark
- **Rail Net Denmark:** Biggest infrastructure manager owned by the Danish state
- **The National Transport Authority:** Public railway authority in Denmark

The agenda for all interviews was the same and looked as follows:

1. List the most important timetable evaluation criteria for your company.
1.1 Describe/explain each criterion thus making it operational in a timetable context.
1.2 How can each criterion be recognized in the timetable?
1.3 Make suggestions for how to measure the presence of the criterion in the timetable.

2. Prioritize the company's list of timetable evaluation criteria

The outcome from the interviews is presented in the following sections. Each interview states a prioritized list of timetable evaluation criteria, followed by elaboration on each criterion. Based on this each criterion is divided into timetable effects.

3.1 Interview with DSB

The DSB prioritized list of timetable evaluation criteria:

1. Robustness of timetable
2. Fast, high frequent and direct connections
3. Train service for smaller stations
4. Efficient use of the railway infrastructure
5. Scalability of the timetable

Robustness

DSB has committed itself to achieving a punctuality level of 95% of all trains must be on time – less than 5:00min delayed. This is done through traffic contracts with the Ministry of Transport.

It is important to DSB that the timetable is realistic. Calculated running times should be based on realistic rolling stock data and planned stopping times should be based on collected trustworthy data from real life operations. Turnaround times for trains at their terminus must be physically possible and follow any agreements between DSB and relevant unions.

Planned stopping times at stations should be dependent on the time of day and the characteristics of the used rolling stock – e.g. length of the train and/or use of train type.

Fast, high frequent and direct connections

These are the classic wishes for train services from train passengers. Measuring these parameters by using "passenger minutes spent in the train" as an evaluation method is not good enough for DSB. This measurement does not take the frequency of the trains into account. A more sophisticated methodology must be used. DSB focuses on the experienced travel time for the train passengers. This consists of 3 parts:

1. Timetable travel time – given by the valid timetable
2. Average waiting time at stations – this depends on the train frequency and periodicity of the timetable. See equation 1.
3. Time costs with transfers – According to DSB this should minimum be set to 15 minutes of travel time

$$Average\ waiting\ time\ at\ station = \frac{T_{1-2}}{2} \times \frac{T_{1-2}}{I_{periodicity}} \times \ldots \times \frac{T_{x-1'}}{2} \times \frac{T_{x-1'}}{I_{periodicity}} \qquad (1)$$

$T_{1\text{-}2}$ = Time between train 1 and train 2
$T_{X\text{-}1'}$ = Time between train X and the first train of the next periodicity interval
$I_{periodicity}$ = Interval of periodicity in the timetable

DSB's applications for future timetable time slots should be based on available up to date OD-matrices. This gives both TOC and IM the possibility to optimize the timetable based on experienced train passenger travel time.

Train service for smaller stations

DSB has contractual obligations towards the political government to give smaller stations on railway lines serviced by DSB a minimum level of service. This is defined by the number of stopping trains per hour per driving direction. The timetable must allow for DSB to live up to these obligations.

There should be allocated enough capacity in the timetable for trains stopping at smaller stations more often than necessary in regards to contracts to make the train service more attractive.

Future timetables must contain the possibility to (re)open new stations on the railway network. Even on sections of railway lines that are defined as capacity bottlenecks.

Efficient use of the available railway infrastructure

Travelling times for fast service passenger trains must not be affected negatively by slower freight trains. The potential conflicts must be handled by well planned overtakings of freight trains.

There should be no timetable time slots for freight trains during rush hour periods. The available infrastructure capacity should be used for passenger trains. If this is not possible the freight trains should get the lowest priority when creating the rush hour timetable.

Scalability of timetable

It must be possible to increase the frequency of train services during rush hours and reduce frequency again afterwards without changing the timetable structure. This can be done by adding/removing train systems and/or lengthen/shorten the route of train systems in given time periods.

The timetable should allow enough time for changing the composition of trains at relevant stations with depot facilities and also during the route to optimize the seating capacity of trains according to the time period of the day.

3.2 Interview with Arriva Denmark

The Arriva Denmark prioritized list of timetable evaluation criteria:

1. Compliance with traffic tender demands
2. Attractive transfer options to DSB and local busses
3. Periodic timetables are preferable
4. Servicing starting hours of schools and larger workplaces
5. Realistic timetable

Compliance with traffic tender demands

The National Transport Authority -which is the authority for railways in Denmark – has entered a contract with Arriva [22] which contains demands for minimum service levels for all stations in the area covered by the tender. The minimum service level is defined as shown in equation 2.

$$Minimum\ service\ level = \frac{Number\ of\ departures + arrivals}{Station \times Hour \times Driving\ direction} \qquad (2)$$

A tight cooperation between The National Transport Authority, the IM and Arriva exist about the timetabling process. This is to ensure that the timetable complies with the set demands and is feasible.

There is also a close cooperation with DSB to ensure a minimum of conflicting wishes for timetable time slots and attractive transfer options between DSB and Arriva trains.

If there is a station with more than one arrival/departure per driving direction per hour these should be spread evenly during the hour – e.g. 2 departures should give a frequency of 30minutes. The tender documents allow for some flexibility and allow having 20 and 40minutes between trains respectively. Conditions given by the infrastructure (mainly single track) and the wish for running both fast and slower train services necessitate this flexibility.

Attractive transfer options to DSB and local busses

Since Arriva-trains often have the role as feeder trains to DSB's national Intercity systems it is very important to have attractive transfer options. There is a close cooperation with DSB to ensure these attractive transfer options and thereby making the railway system more attractive to passengers as a whole. Arriva allows some scheduled waiting time in the timetable for this[2].

The next step is to expand the cooperation to other parts of the public transport sector. Attractive transfer options to local busses that service stations become important to ensure a coherent journey by public transport.

Periodic timetables are preferable

Arriva's current timetable consists of 3 time periods:

1. Morning rush hour 05:00 to 10:00
2. Day time hours 10:00 to 18:00
3. Evening + night 18:00 to 01:00

During the day time hours the timetable is periodic [12][20]. A market oriented timetable is used for the morning rush hour. Longer and more frequent trains run in the primary traffic directions. In the evening and during the night the frequencies of train services are reduced and do no longer follow an hourly pattern.

Starting hours of schools and larger workplaces

In the mornings a substantial part of Arriva's customers have to be at specific stations to a specific time. These are school children, students and workers in manufacturing companies. This aspect in the timetable is very important to Arriva. The same focus is not given to departure times at selected stations in the afternoon.

Realistic timetable

The cooperation with Rail Net Denmark during the timetable creation process ensures that the final timetable is realistic and feasible. Arriva uses the same approach to running time supplements as DSB and uses the planning rules defined by the IM.

Arriva uses two categories of stopping times for stations, depending on the number of passengers: Large stations = 1minute, and small stations = 30 seconds. Type of rolling stock does not affect the used stopping times.

The minimum layover time for Arriva trains is 4min. This is given by an agreement with the train driver's union. Arriva tries to keep layover times to 4 minutes to achieve an efficient use of the rolling stock.

[2] Longer stopping times than necessary are used in Arriva's timetable to give passengers the optimal transfer conditions to and from DSB trains at selected stations.

3.3 Interview with DB Schenker Rail Scandinavia

DB Schenker Rail Scandinavia assumes that the IM (Rail Net Denmark) is allocating enough infrastructure capacity in the timetable to freight services so that no requests in the application for timetable time slots are rejected. Until now only one TOC was not given the requested capacity [19]. In Denmark more freight TOCs are appearing and therefore this picture can change in the near future.

Prioritized list of timetable evaluation criteria:

1. Coordinated international time slots
2. Time slots give flexibility to where change of train drivers can take place
3. Robustness of timetable
4. Low level of scheduled waiting time
5. Periodic timetables are preferable

Coordinated international time slots

A coordination of international timetable time slots between the IM in different countries ensures no or only little scheduled waiting time for freight trains at border stations. This is an important cost driver and competiveness factor for freight TOCs.

Time slots give flexibility to where a change of train driver can take place

For an international transit freight train to pass through Denmark minimum one train driver change is necessary. The reason for this is a combination of Danish railway safety legislation and agreements between the TOCs and train driver unions.

In Denmark 3 to 5 stations are relevant for changing the train driver. If stations have the necessary staff facilities the change of train driver can optimal be done simultaneously with planned stops for overtaking by faster passenger trains, stops servicing customers and stops caused by technical issues such as changing the settings for the braking system when crossing a national border. In any case the timetable should allow for possible stops at these relevant stations even if no stop is planned. This can be done by concentrating the running time supplements around the relevant stations.

For the traffic planners at DB Schenker Rail Scandinavia it is important to fix the location(s) of train driver changes only just before the yearly timetable becomes effective. This makes planning of staff logistics much more efficient.

Robustness of timetable

If an international transit freight train reaches the Danish border on time it should also be on time when leaving Denmark again [19]. Freight trains must also be able to catch up with minor delays. To ensure this it is important that the agreed upon planning rules are used when constructing the timetable. For freight train time slots a running time supplement of 3% is used.

Low level of scheduled waiting time in the timetable

To increase the competiveness of freight trains towards trucks on the roads the level of scheduled waiting time has to be as low as possible. In accordance with EU recommendations a higher level of priority has to be given to freight trains [2]. Focus must be on keeping the number of necessary stops to be overtaken by faster passenger trains on a minimum and not letting freight trains being caught behind the slowest local passenger trains (resulting in scheduled waiting time) when creating the timetable.

Periodic timetables are preferable

Using periodic timetables and using the concept of “systematic international freight train timetable time slots” through Denmark [19], makes future timetables more predictable. This gives a more efficient traffic planning process at the freight TOC and makes it easier to work out applications for timetable time slots for the IM.

3.4 Interview with the National Transport Authority

A main concern for The National Transport Authority is that the experienced quality of the railway timetable by passengers is part of the timetabling process. This can be quantified by socio economic calculations [15].

The National Transport Authority has 2 tasks regarding railway timetables. Firstly, it undertakes strategic analyses for the future development of the Danish railway infrastructure. Secondly a national traffic plan is prepared in regular intervals of 1-2 years, which defines the minimum service level for all stations. See equation 2. Based on this, traffic tender documents are produced and contracts made with DSB.

The National Transport Authority's prioritized list of timetable evaluation criteria is:

1. Periodic timetable
2. Robustness of timetable
3. Attractive transfer options
4. Travel time for trains
5. Reserve of freight train timetable time slots

A holistic approach to railway timetables is essential for the National Transport Authority. There must be cohesiveness through out the public transport system: Trains, busses and ferries must constitute a seamless network. Inspiration can be taken from the Swiss Rail 2000 (Bahn 2000) traffic master plan [8].

Periodic timetable

In Denmark work has begun to implement "The one hour plan" (Timeplanen) [14]. This means a travel time of maximum one hour between the biggest cities of Denmark. These cities will naturally become transfer hubs where trains and busses meet every hour or half hour – similar to the Swiss Bahn 2000 timetable.

Furthermore the timetable must be easy understandable and easy to remember for passengers. This means that frequencies of exact 10, 15, 20, 30 or 60minutes should be achieved for train services. A service level of 2 trains per hour running with 23/37 minutes between trains is not desirable.

Robustness of timetable

The agreed upon planning rules for timetable construction must be used by the IM. Planning rules should be based as much as possible on international standards and recommendations – e.g. European Norms and UIC leaflets [23][24].

Attractive transfer options

From a Danish socio economic point of view the waiting time in connection with transfers is more valuable than a prolonged travel time [15]. Therefore attractive transfer options are more important than the travel time between 2 cities. Attractive transfers are a very important part of a well functioning public transport system.

Travel time for trains

In the timetable construction process the shortest possible travel times for trains should be achieved. Necessary scheduled waiting time must be kept at a minimum. This is an important factor in the socio economic aspect of timetabling.

Reserve of freight train timetable time slots

The present valid timetable has a pattern of two time slots per driving direction per hour for freight trains between Sweden and Germany – during rush hours this is reduced to one time slot per driving direction per hour. The National Transport Authority recommends increasing this number of time slots to three per driving direction per hour outside rush hours. Not because of expected increasing demand for freight train time slots but to create a reserve of time slots that can be used by freight trains that do not enter the network of Rail Net Denmark in their scheduled time slot. The logistical planning for delayed freight trains

should become more effective since the trains follow a scheduled time slot and the risk of causing consecutive delays could be drastically reduced [19].

3.5 Interview with Rail Net Denmark – Department of Traffic Planning

Rail Net Denmark's prioritized list of timetable evaluation criteria:

1. Robustness of timetable
2. Complexity of traffic in and around stations
3. Utilization of timetable time slots
4. Travel time for trains
5. Timetable prepared within the given deadline

Robustness of timetable

Rail Net Denmark is in the process of writing a "book of planning rules" for timetable planners in Denmark. This manual ensures that both national and local planning rules are known and used by timetable planners at Rail Net Denmark. Parts of this book will be made available to TOCs to improve their future timetable time slot applications.

Since several years often pass between major changes to the national timetable an evaluation project for future timetables has been developed. It is being investigated how well next year's timetable can handle the worst traffic incidents from last year's timetable.

Minimum layover times for trains at their terminus are agreed with TOCs. These or preferable longer times must be used to ensure a robust timetable.

There is a need for differentiating stopping times for trains according to the train type. The length of the train (passengers per door) is a very important factor for exceeding the planned stopping time at a station.

It is the task of Rail Net Denmark to make an efficient use of the railway infrastructure that allows a given number of timetable time slots and gives a wished level of punctuality of trains. The latter is defined by a contract with the Ministry of Transport.

Conflicts between the TOC's applications for timetable time slots should be resolved before the final negotiation meeting between TOCs and IM in the timetabling process takes place, see Figure 2.

Complexity of traffic in and around stations

Rail Net Denmark is working on a traffic complexity index for the busiest stations which depends on the used timetable variant. Several approaches to this subject have been investigated [6][10][11] and Rail Net Denmark wants to build on this. The indexes will partly be based on:

- Track layout of the stations
- Properties of the interlocking system (possible headways of trains)
- Deduced planning rules
- The timetable giving the correct probabilities of conflicting trains paths at the stations

A high traffic complexity index will indicate a negative effect on the punctuality of trains.

Utilization of timetable time slots

An IM is interested in selling as many timetable time slots to TOCs as possible but still keeping the contractual demanded punctuality levels of trains. Rail Net Demark wants to look at the number of sold timetable time slots out of the maximum available in the used periodic timetable structure [19].

It is Rail Net Denmark that defines how the railway infrastructure can be used in the most efficient way under the given circumstances for a given national timetable.

Travel time for trains

Rail Net Denmark has made agreements with all TOCs about standard running time supplements and if relevant also stopping time supplements. Running time supplements depend on the maximum line speed and are a fixed percentage based on the recommendations from the UIC 405 leaflet [24]. The national timetable must follow these agreements.

International transit freight trains are challenging preparing the national timetable. Necessary stops to change train drivers and changing the settings for the braking system to the standard of neighboring countries must be taken into account.

Timetable prepared within the given deadline

Rail Net Denmark is obliged to present a feasible and agreed upon national timetable – including international timetable time slots – within the given deadline by the RNE timetabling process, see Figure 1.

3.6 Criteria and their timetable indicators

Robustness of timetable

- Using realistic train data for running time calculations
- Using empiric measurements for estimating train stopping times at stations
- Differentiating stopping times according to time of day and rolling stock (passengers per door)
- Comply with IM planning rules
- Timetable time slot structure (number and order)
- Using traffic complexity indexes for stations
- Unused freight train time slots are available to delayed trains
- Conflicts between TOCs are solved early

Efficient use of the railway infrastructure

- Low level of scheduled waiting time (stopping trains, slowing fast trains, overtaking of freight trains)
- Priority of freight trains (in/outside rush hours)
- Comply with IM planning rules (running time and stopping time supplements)
- Passenger felt travel time (timetable time + station waiting time + transfers)
- Direct connections/minimizing need for transfers
- Minimizing transfer waiting times
- Transfer conditions (dry transfers)

Periodic timetables are preferable

- Attractive towards passengers
- Predictability of timetable time slot structure gives more efficient planning process for TOCs
- Use of periodic freight train time slots

Compliance with traffic tender demands

- Minimum service level is offered at each station
- Even time intervals between train services

Coordinated international timetable time slots

- Prolonged stopping times (scheduled waiting time) at border stations/shunting yards

Scalability of the timetable

- Easy to adjust the number of train services and frequencies of train services to time of day
- Time to change composition of trains to optimize seating capacity to time of day

Timetable time slots give flexibility to where change of train drivers can take place

- Demand for specific timetable time slot design
- Efficient logistics planning

Service starting hours of schools and larger workplaces

- Trains being at a specific station at a specific requested time

Train service for smaller stations

- Timetable time slot structure allows for better service than minimum service levels for smaller stations
- Timetable allows for opening of new stations

Timetable is prepared within the given deadline

- The timetabling process is based on a realistic time frame

Figure 3: Overview of stakeholder evaluation criteria and the deduced indicators.

Based on the descriptions given by the stakeholders of their prioritized timetable evaluation criteria an attempt has been made to group these and for each criterion timetable indicators have been defined. The indicators can directly affect the timetable and the timetabling process. An overview is given in Figure 3.

3.7 Conclusions on the held interviews

The series of interviews has given a new insight into different railway timetable stakeholders' approaches to the national Danish timetable and the challenges they are facing when preparing/receiving the timetable time slot applications.

Table 1 gives an overview of the chosen evaluation criteria, the stakeholders that stated them and their given prioritization. The listed criteria have been grouped into themes. Hereby the criteria "Reserve of freight train timetable timeslots" and "Complexity of traffic in and around stations" have been put under the overall criterion "Timetable robustness". The criterion "Attractive transfer options to trains and busses" has been integrated into the "Efficient use of the railway infrastructure" criterion. This has been done because these criteria cover the same aspects in timetabling.

Some of the listed criteria are potentially in conflict with each other. These are "Scalability of the timetable" versus "Periodic timetables are preferred" and "Robustness of timetable" versus "Efficient use of the railway infrastructure" [20]. Incorporating flexibility for train driver changes for freight trains is also conflicting with an efficient use of the railway infrastructure.

A simple attempt has been made to show which evaluation criteria show up on more than one list of prioritized criteria and what ranking they got. A criterion gets 5 prioritization points for rank 1 and 4 for rank 2 and so forth. See the far right column in Table 1. The "Robustness of timetable" criterion gets by far the best score with 18 points. It is followed by the "Periodic timetables are preferred" criterion. On third place comes "Low level of scheduled waiting time" and "Attractive Transfer Options to trains and busses" is ranked fourth.

Table 1: Overview of stated timetable criteria, stakeholders and prioritization.

Timetable evaluation criterion	Rail Net Denmark	DSB	Arriva Denmark	DB Schenker	National 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 timeslots	-	-	-	-	5	1
Efficient use of infrastructure						
-Low level of scheduled waiting time	4	4	-	4	4	8
-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 timeslots 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 interviewed people representing the organizations of timetable stakeholders are affected by their present situation regarding e.g. competition, project schedules and the RNE timetabling process. This affects the selected timetable evaluation criteria and especially their prioritization.

4 A roadmap to a common Danish list of prioritized timetable optimization and evaluation criteria

The goal is to reach a common agreed upon list of prioritized timetable optimization and evaluation criteria for the Danish railway sector. The first step was to get prioritized inputs from the stakeholders via interviews. The next step is to prepare the gathered input for a joint decision making event – a workshop – at which a commonly accepted list of prioritized list of timetable evaluation criteria is made. The agenda for the workshop is described in section 4.1. Methodologies used to reach a common acceptable decision are described in section 4.2 and 4.3. The workflow of the process can be seen in Figure 4.

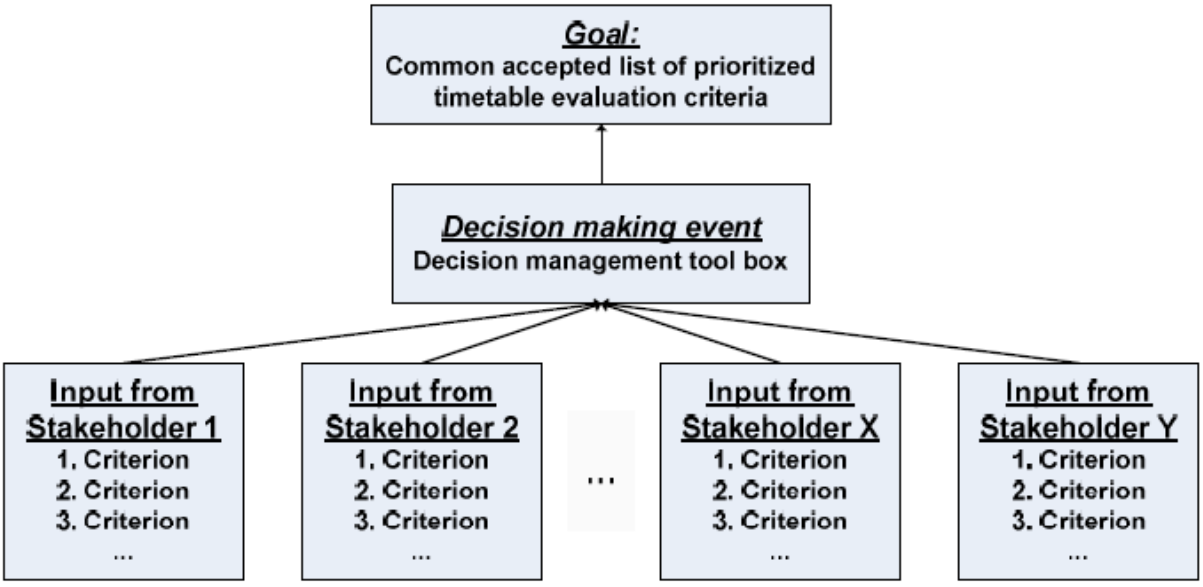

Figure 4: The basis for reaching an agreement on a prioritized list of timetable evaluation and optimization criteria in the Danish railway sector.

4.1 Workshop for decision making

In the end of 2011 all interviewed stakeholders will be invited to participate in a decision making workshop. It is very important for the success of this decision making process that all stakeholders are committed and participate in this workshop. A facilitator – the author – will guide the stakeholders through the agenda of the workshop. When applying decision making methodologies the facilitator will be aided by a specialist from the Technical University of Denmark within the field of decision management.

A minute describing the found results from the interviews will be sent out to the stakeholders before the workshop takes place. At the beginning of the workshop the author will present the found results from the series of interviews and in cooperation with the stakeholders make the necessary corrections and additions to create a common accepted basis for the rest of the workshop.

The stakeholders will use the SMARTER (Simple Multi Attribute Rating Technique Exploiting Ranks) technique to reduce the number of presently 13 stated timetable evaluation criteria to between 4 and 6. Subsequent the “Direct Ranking” method is applied to identify the most important of the criteria indicators/parameters in the timetable and timetabling process that will be in focus on a future Danish list of timetable optimization and evaluation criteria. The workshop is expected to take between 4 and 5 hours.

There is a risk of not reaching a common accepted list of prioritized timetable evaluation criteria at the workshop. Reasons for this can be many e.g. not achieving a matching of expectations or a lack of will to

make compromises from stakeholders. The process can become iterative and it will be necessary to host more than one workshop before a useful result is produced.

4.2 The "SMARTER" technique

The SMARTER technique is a further development of the SMART (Simple Multi Attribute Rating Technique) methodology. In 1971 W. Edwards presented the SMART process [3] and it is based on the following axioms [5]:

1. **Decidability** – The stakeholder(s) has always a preference between 2 options.
2. **Transitivity** – If the stakeholder prefers option A to B and B to C then option A is also preferred to option C.
3. **Summation** – If the stakeholder prefers A to B and B to C then the strength of preference of A over C must be bigger than that of A over B or B over C.
4. **Solvability** – The ability to give value to options in all investigated decision making scenarios.
5. **Finite upper and lower bounds for value** – Values of plus or minus infinity cannot be applied to options.

SMART consists of 8 main stages [5] [7]:

- Stage 1: Identify the stakeholders
- Stage 2: Identify the alternative courses of action – improvement of timetable
- Stage 3: Identify the relevant attributes – timetable evaluation criteria
- Stage 4: Give values to each criterion. The stakeholders must decide on a value function that describes the increase of value when an improvement in regards to the criterion is made. This can be done by bisection. This requires the stakeholder to identify the criterion improvement halfway between the least and most preferred improvement. Same procedure can be used to find new value points between the existing improvement value points. This is done until a general shape is found e.g. exponential growing.
- Stage 5: Apply a weight to each criterion – states the importance of each criterion
- Stage 6: Take a weighted average of the values given to each criterion
- Stage 7: Make a decision
- Stage 8: Perform a sensitivity analysis to investigate the robustness of the decision

Stages 4 to 6 can be a very laborious and complicated approach to overview for the attending stakeholders [25]. Therefore the SMARTER method was developed in 1994 by W. Edwards and F.H. Barron [4]. SMARTER is a simplification of the SMART methodology. Reason for this development was the hypothesis that the loss of quality in the model by making the decision model less realistic is more than made up for by reducing the risk of making errors during the evaluation processes in stages 4-6 [5].

The further development from SMART to SMARTER consists of 2 main parts [5]:

1. Value functions are assumed to be linear in SMARTER. If the difference in increase in value is not more than 100% at the extreme points of the scale for the criterion, then Edwards and Barron state that the use of a linear value function is probably safe. If the difference is higher other approaches must be made e.g. the bisection method is recommended [5].
2. In SMART the decision makers are asked to compare and evaluate swings from worst to best for all criteria giving a relative importance to criteria. In SMARTER the decision makers are only asked to rank the swings from worst to best of each criterion according to their importance. Then SMARTER uses the approach of "Rank Order Centroid" (ROC). This converts the rankings into a set of approximate weights. If you e.g. only work with 2 criteria and have ranked them the approximate weights would be 75 and 25 for rank 1 and 2 respectively.

Table 2 gives an overview of ROC weights according to number of indicators. In depth investigations – including simulations – have shown that SMART and SMARTER techniques agree on which option to recommend in 75-87% of cases. It is therefore recommended to use the SMARTER method to select the 4 to 6 most important timetable evaluation criteria at the workshop [5].

Table 2: Rank Order Centroid (ROC) weights [5].

Rank	Number of indicators					
	2	3	4	5	6	7
1	75.0	61.1	52.1	45.7	40.8	37.0
2	25.0	27.8	27.1	25.7	24.2	22.8
3	-	11.1	14.6	15.7	15.8	15.6
4	-	-	6.3	9.0	10.3	10.9
5	-	-	-	4.0	6.1	7.3
6	-	-	-	-	2.8	4.4
7	-	-	-	-	-	2.0

4.3 The "Direct Ranking" methodology

Some of the found indicators for each evaluation criteria are difficult to represent with common quantifiable variables. Therefore a "Direct Ranking" approach is recommendable to find the importance of each indicator. Stakeholders must rank all indicators of a given criterion. The indicator ranked 1 is given 100points and the indicator with the lowest rank 0points. Now the stakeholders give points to the other indicators in such a fashion that the point intervals represent the strengths of preference between the indicators [5]. An example: Indicator 1 got 0points, indicator 2 got 10points, indicator 3 got 20points, and indicator 4 got 100points. This means that the increase in timetable attractiveness is twice as preferable between indicator 1 and 3 as between indicator 1 and 2. In the same way the improvement between indicator 1 and 4 is seen to be 10 times more valuable for timetable attractiveness as between indicator 1 and 2, see Figure 5: An example of value scale for ranked indicators.

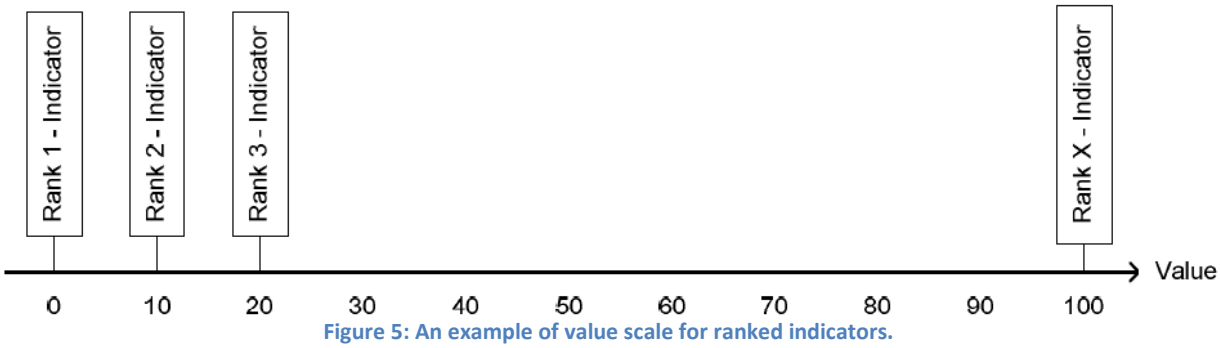

Figure 5: An example of value scale for ranked indicators.

Only intervals between criteria can be compared not their specific amount of given points. The stakeholders must be asked control questions looking at other intervals between criteria to make sure that the allocated points give a correct picture of preference.

4.4 Conclusions on the roadmap

A feasible roadmap for reaching a common agreed upon Danish list of prioritized timetable evaluation and optimization criteria has been presented. The biggest hurdle in the decision making process lies in achieving the necessary commitment amongst the interviewed stakeholders. Firstly they must participate in the decision making workshop in the beginning of 2011 and contribute to the decision making process. Secondly they must accept the outcome of the workshop and implement this in their own timetable creation processes.

The decision making methodologies recommended to be used at the workshop also present an obstacle. It is very important that the stakeholders acknowledge the 2 presented methods and great effort must be put into making the methods as accessible and transparent as possible to the stakeholders. When recommending the SMARTER and Direct Ranking methodologies this was the primary motive.

5 Conclusions and perspectives

This paper has created the basis for reaching a common accepted Danish list of prioritized railway timetable evaluation and optimization criteria for long distance railway traffic. This has been done in two steps: Firstly by conducting successful interviews with the 5 most important railway timetable stakeholders in Denmark. These are The National Transport Authority, state owned infrastructure manager Rail Net Denmark and the train operating companies DSB, Arriva and DB Schenker Rail Scandinavia. Secondly by presenting a roadmap for the decision process necessary for reaching a common accepted list of prioritized timetable evaluation and optimization criteria.

Each interview resulted in a top 5 list of prioritized timetable evaluation criteria and a short description of each. Based on the descriptions a series of criteria indicators were deduced. A first look at the prioritizations shows that the robustness of the timetable is in some degree important to all interviewed stakeholders followed by a preference for a periodic timetable structure, demand for a low level of scheduled waiting time and attractive transfer options to trains and busses.

For the first time in Denmark a series of such interviews addressing this subject have successfully been held. It has become evident that the input from the stakeholders is affected by their present situation regarding the yearly timetabling process and their achieved quality levels of recent and present railway operations.

The results from these interviews form the basis for a roadmap outlining the decision process for reaching a common agreed upon Danish list of prioritized list of timetable evaluation criteria. All interviewed stakeholders will be invited to participate in a decision making workshop in the end of 2011. Here the number of stated timetable evaluation criteria must be brought down to between 4 and 6 by using the SMARTER technique. Following this the deduced indicators for the remaining criteria must be ranked by using the Direct Ranking methodology.

Several potential problems have been identified in the decision making process. It is very important that all stakeholders contribute to the decision making process by participating in the workshop and accepting its outcome. The methodologies applied in the process must be understood and acknowledged by the stakeholders.

The European Union drives a process of liberalization and harmonization in the European railway sector. Looking into the future there will still be national railway authorities and state owned IMs but the group of TOCs can look very differently. One scenario could be that there are several smaller TOCs specializing in servicing specific European countries or regions. Another scenario features a small number of large privatized TOCs who compete on most European railway markets. A third possibility is a combination of the two scenarios above. These potential changes in the boundary conditions for the national timetable creation process can make it necessary to go through a decision making process as described in this paper in regular time intervals.

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References

[1] Caimi, G., Burkholter, D., Herrmann, T., Chudak, F., Laumanns, M., Design of Railway Scheduling Model for Dense Services, Networks and spatial economics, Vol. 9, No. 1, 2009

[2] Commission of the European Communities, Communication From the Commission to the Council and the European Parliament Towards a Rail Network Giving Priority to Freight , 2007

[3] Edwards, W. Social Utilities, Engineering Economist, Summer Symposium Series, 6. 1971

[4] Edwards, W. & Barron, F.H., SMARTs and SMARTER: Improved Simple Methods for Multiattribute Utility

[5] Goodwin, P. & Wright, G., Decision Analysis for Management Judgement, third edition, 2003

[6] Jensen, L.W., Capacity of long distance trains at Copenhagen central station (Fjern og regionaltogskapacitet på Københavns Hovedbanegård), 2009 (in Danish)

[7] Keeney, R.L. & Raiffa, H., Decisions with Multiple Objectives: Preferences and Value Tradeoffs, Wiley, New York, 1976

[8] Keller, M., Frick, R., Sager, F., Rail 2000: Infrastructure Modernization in the Light of the National Transport Policy, Flux 2-3 (n0 72-73), 2008

[9] Kroon, L.G. Huisman, D., Abbinck, E., Fioole, P. J., Fischetti, M., Maróti, G., Schrijver, A., Steenbeek, A., Ybema, R. The New Dutch Timetable: The OR Revolution, Informs, Interfaces Vol. 39, No. 1, January-February 2009

[10] Landex, A., Methods to estimate railway capacity and passengers delays, PhD thesis, Technical University of Denmark, Department of Transport, 2008

[11] Landex, A., Station Capacity, Proc. of the 4th International Seminar on Railway Operations Modelling and Analysis 2011

[12] Liebchen, C., Periodic Timetable Optimization in Public Transport, PhD Thesis, Technical University of Berlin, 2006

[13] Malavasi, G. & Ricci, S. Carrying capacity of railway networks: interaction of line and node models, Computers in Railways VII, pp. 977-986, WIT Press, Southampton, 2000

[14] Ministry of Transport, Aftale mellem regeringen (Venstre og De Konservative), Socialdemokraterne, Dansk Folkeparti, Socialistisk Folkeparti, Det Radikale Venstre og Liberal Alliance om: En grøn transportpolitik, 2009 (in Danish)

[15] Ministry of Transport, Manual for socio economic analyses (Manual for samfundsøkonomisk analyse), 2003 (in Danish)

[16] Official Journal of the European Communities, Directive 2001/14/EC of the European Parliament and of the Council of 26 February 2001, 15.3.2001

[17] Rail Net Europe, Customer Handbook, version of: 06 February 2006

[18] Rail Net Europe, RNE Process Handbook for International Path Allocation – For Infrastructure Managers, 21 November 2005

[19] Richter, T., Systematic Analysis of Transit Freight Train Performance, Proc. of the 4th International Seminar on Railway Operations Modelling and Analysis 2011

[20] Schittenhelm, B. & Landex, A., Quantitative Methods to Evalaute Timetable 3th Attractiveness, Proc. of the International Seminar on Railway Operations Modelling and Analysis 2009

[21] Toylsbjerg-Petersen, L., Presentation for Rail Net Denmark management, 18 May 2009

[22] The National Transport Authority (Trafikstyrelsen), Hovedkontrakt mellem Trafikstyrelsen og Arriva Tog A/S om passagertrafik udført som offentlig service i Midt-og Vestjylland, March 2009 (in Danish)

[23] UIC, Capacity (UIC leaflet 406), International Union of Railways (UIC), Paris, France, 2004

[24] UIC, Links between railway infrastructure capacity and the quality of operations (UIC Code 405 OR). Technical report, International Union of Railways (UIC), 1996

[25] von Winterfeldt, D. & Edwards, W., Decision Analysis and Behavioural Research, Cambridge University Press, Cambridge, 1986