High-speed Railway Assessment - Rail Specific Planning and Development Analysis

APPENDIX 1

REPORT

Acceptance Criteria for punctuality

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Background

Punctuality is an important factor in railway operations. It is a central measure of performance and it is widely used to evaluate effectiveness of infrastructure investments and timetable adjustments.

This PM gives a review of previous studies of punctuality. Delay statistics from existing lines has been compiled and are presented. These statistics give useful insights of delay and punctuality levels achieved on existing lines. In some sense these levels form lower limits on the delay and punctuality scale that is to be considered during planning and design of new high speed lines.

The knowledge gained through this study will be used directly throughout the following assignments in which different infrastructure designs will be evaluated with regard to knock-on delays and punctuality.

Definition of punctuality and delays

Punctuality is a measure of the deviation in time (delay) between actual and predefined train arrivals, passes and departures at defined locations of the rail network, according to timetables. Punctuality can be also expressed as a ratio (percentage) between the number of trains delayed a certain amount of time to the total number of trains at defined locations.

The cause for delays can be divided into two main categories [1,2]

1. Primary, also called initial or direct delays not caused by interacting trains
2. Knock-on or consecutive delays caused by interacting trains. Knock-on delays are in this category.

Primary delays affecting a single train are typically caused by weather conditions, malfunctioning equipment (vehicles, infrastructure), driver behavior, fluctuations in boarding and passenger embarkment etc.

Knock-on delays are caused by interaction from other trains, normally delayed.

A train is normally not allowed to depart earlier than scheduled. Therefore a train will always depart ‘’on time’’ or delayed. It is very difficult to arrive and depart exactly ‘’on time’’ due to various reasons. Therefore, trains are always departing more or less delayed. For practical reasons, threshold time values are used by operators to allow for these subtle delays.

Punctuality is normally measured for

- Arrival delays
- Departure delays, including dwell time delays.

The threshold values chosen by the operators decide if a train is on time or delayed.

Typical threshold values are shown in Table 1. Different threshold values are used by different operators in different countries. Also, it differs among the countries where the delay is measured. For example in Holland is the departure delay measured, while in Norway is the arrival delay at terminal station measured.

Table 1 Some threshold time values. The train is delayed if arrived later than threshold value.

		IC long distance
Norway		6 min [3] (international)
Denmark		6 min (S-trains 2,5 min) [5]
Holland		3 min [1]
Spain (conventional train)		5min regional 10 min (long distance) [7,8,9]
Spain (High speed line AVE)		5 min
Sweden		5 min

In many European countries delays smaller than 5 minutes are not considered as delays (threshold value 5 min). Figure 1 shows average delay statistics from various European countries (year 2003)

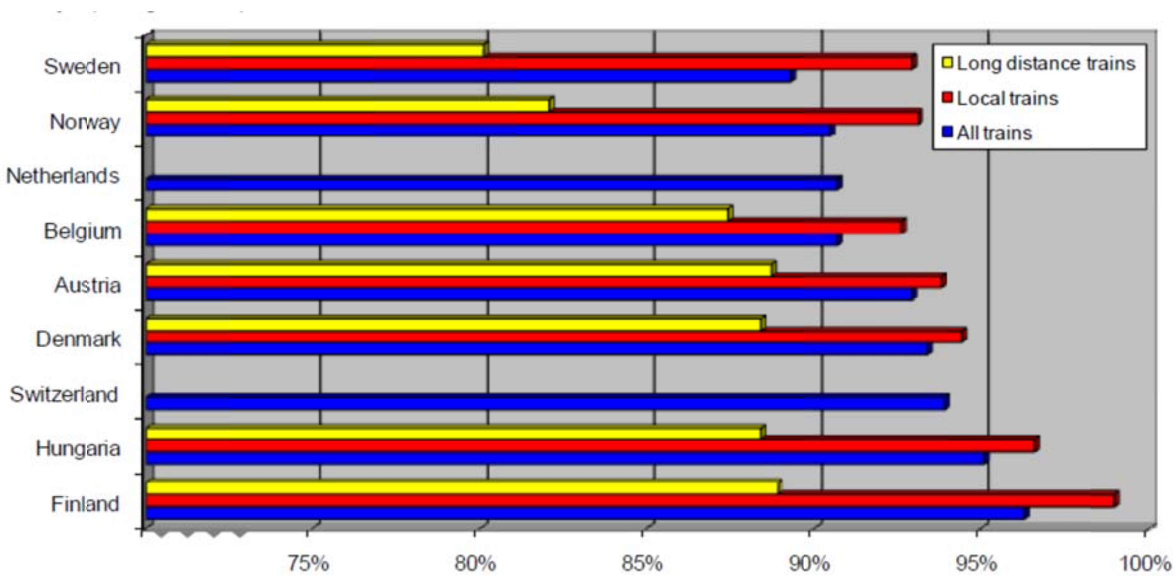

Figure 1 Trains arriving less than 5 minutes late in 1992-2002. Data from NEA 2003 [5]

However, the threshold values are decided by the railway operators taking also into consideration political and marketing aspects. This is not always suitable from a scientific point of view for performing just and independent analysis on delays.

The public timetable schedules the trains with a minute precision. This could make it possible to define threshold values of 1, 2, 3 minutes etc. Computerized timetables and trains operated with driver assistance systems (DAS) or automatic train operation

(ATO) can have even higher precision in steps of 15 or 30 seconds like in Japan or in internal timetables utilized by some operators in Europe.

Therefore it is suggested by [1] to define punctuality as:

‘’ Trains are considered delayed if they arrive, pass or depart later than scheduled at the stopping position of the platform or stabling track. Early or late arrivals and departures are treated separately. Punctuality of train services is expressed as the percentage of trains that arrived, passed or departed no later than 60 sec compared to all train movements in the same time period at predefined representative network locations.’’

It is worth noting that punctuality is also considered to express the overall quality in rail operations, not least by the public.

Punctuality is considered so important that many countries have refund programs if trains are late at their destinations. For instance, Renfe in Spain, refunds in general:

- Over 60 minutes late: 50% refund.
- Over 90 minutes late: 100% refund.

However, the long distance high speed lines (AVE larga distancia) have an even more ambitious refund programme. On the specific line Madrid - Seville (with Alta Velocidad–Larga Distancia) the refund is **100% if the train arrives more than 5 minutes late** from scheduled.

Other Ave trains (high speed, long distance)

- Over 15 minutes late: 50% refund.
- Over 30 minutes late: 100% refund.

Models for analysing delay propagation

General

Delay propagation, knock-on delays, occur because of a large number of trains are sharing the same infrastructure. The train operation is restricted by safety regulations and the signaling system. If one train is late to a certain level, the delay propagates to other trains. The punctuality of the system can be improved by preventing or reducing delay propagation. Typical bottlenecks in railway systems are stations and single tracks.

From the literature [1,2,3,4,5,6] the following general approaches for analyzing delay propagation are identified

- Process algebra. Process Algebra is an active area of research in computer science and corresponds to an algebraic approach to the study of concurrent processes to ensure that they are correctly designed.

- Markov Chain. A special case of random processes which can be used to model various processes in queuing theory and statistics.

- Linear regression

- Wakob's approach [2]. ''Wakob has proposed an analytical framework for capacity assessment of railway stations which is based on queuing theory. More precisely, he applies queuing theory to predict the waiting time incurred by the simultaneous arrival and random processing of two trains as isolated part of the infrastructure. Wakob's approach does not provide a queuing model for an entire railway station, but it proposes an analytical framework for capacity planning''.

- Statistical methods. Delay data is collected from real operation or retrieved by means of simulations, where primary delays are introduced stochastically.

This work deals with statistical analysis of delays.

Statistical analysis

Statistical data can be collected from

- Arrival times
- Dwell times
- Departure times

It is shown in the literature that arrival times, delays, can vary randomly and fluctuates considerably during the day. Also, there is an indication on that arrival delays follow a log-normal distribution. An example of this is shown in Figure 2.

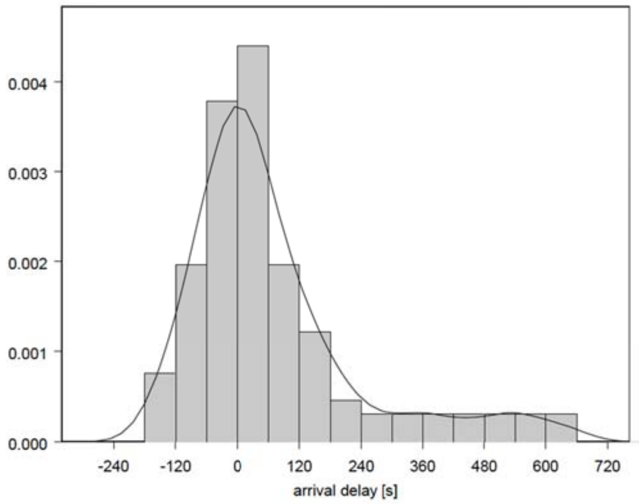

Figure 2 Example of log-normal arrival delay distribution [1].

Dwell delay times can also be fitted and explained by normal distributions. However, early arrivals cause large dwell times. The scheduled dwell time in Sweden is typically 2 minutes.

The departure delays are found to be well explained and fitted by exponential distributions. This is exemplified by Figure 3 by [1].

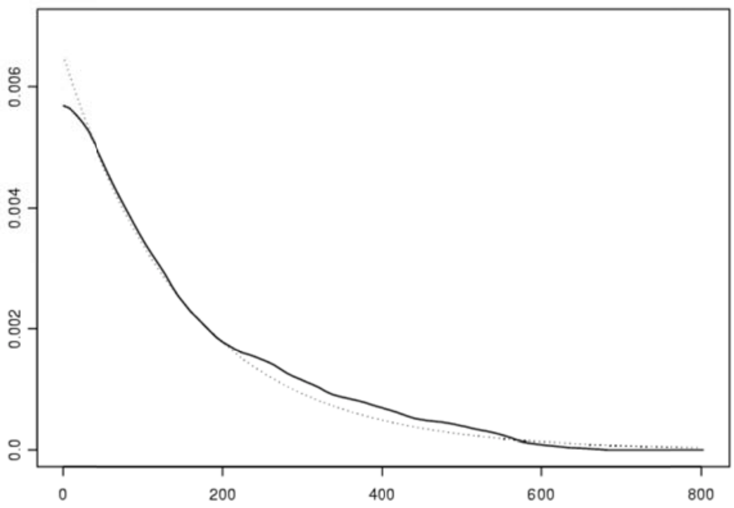

Figure 3 Example of exponential departure delay distribution [1].

Delays are to be considered during design of new railway lines

Delays and punctuality affect the benefit of railway lines directly. Care has to be taken to design the infrastructure so that the delays and delay propagation is kept on reasonable levels.

Primary delays can be kept at low levels through frequent maintenance of infrastructure and vehicles, but also through thought solutions and designs with a limited number of components that can malfunction and cause delays.

Knock-on delays, i.e. delay propagation, can be avoided and kept at low level through well designed infrastructure solutions. This includes design and location of crossing loops, passing loops and track loops. The subsequent analysis will show how different infrastructure solutions, vehicles and primary delays affect the knock-on delays.

The subsequent assignments will make use of different techniques to estimate and reduce delay propagation. These calculations need entry delays and acceptance criteria as input. The evaluation of single-track solutions will be performed as a multifactor analysis. The calculations aim at finding out how the delay distribution is affected by crossings. Using acceptance criteria it is then possible to estimate the amount of time supplement that needs to be added to the timetable in order to keep the delays (and punctuality) on a reasonable level.

Statistics

Punctuality and delays play important roles when new railway lines are planned and constructed. The infrastructure has to be designed for a certain degree of robustness so that the traffic reaches the goals for punctuality.

One way to determine possible and reasonable criteria for punctuality is to compile and compare delay and punctuality data from existing railway lines. This PM presents delay statistics from two countries with similar climate: Norway and Sweden. Data from the northern countries show punctuality levels for conventional trains, but with the impact of weather conditions, maintenance policies, traffic conditions etc that occur in these countries.

Data from Spain on punctuality are included for reference. The data show achievable punctuality levels for high-speed railway lines (AVE) operated under conditions that differ significantly from the northern countries. Due to data collection problems, data from other countries such as Germany and Japan could not be included in this compilation.

Norway

Norwegian railways are not operated by any high-speed trains. Instead data from long-distance Intercity trains between Oslo and Gothenburg are used to give an idea of reasonable delay and punctuality levels. On the way between Oslo and Gothenburg these trains pass Halden and Kornsjø. The following figures show delay statistics for all IC-trains operated during 2009 from these stations.

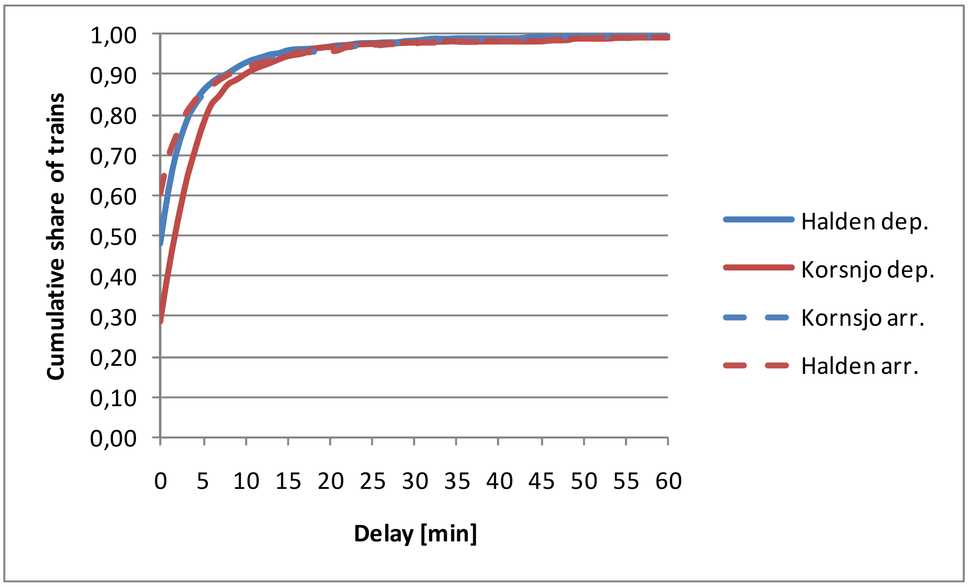

Figure 4 Delay distributions for Halden and Kornsjo. All trains operated during 2009 included.

The figure shows that trains from Halden to Kornsjø do not suffer any additional delay between these stations. The departure distribution in Halden coincides with the arrival distribution in Kornsjø. The opposite direction shows an interesting fact. The arrival distribution in Halden is better (less delays) than the departure distribution in Kornsjø. This means that the trains in this direction catch up delays and increase their punctuality.

The shape of the curves reminds of a negative exponential distribution. However, the probability of great delays tends to be higher in real operation and so the tail of the distribution is thicker.

The following figure shows the mean delay values that correspond to the distributions above.

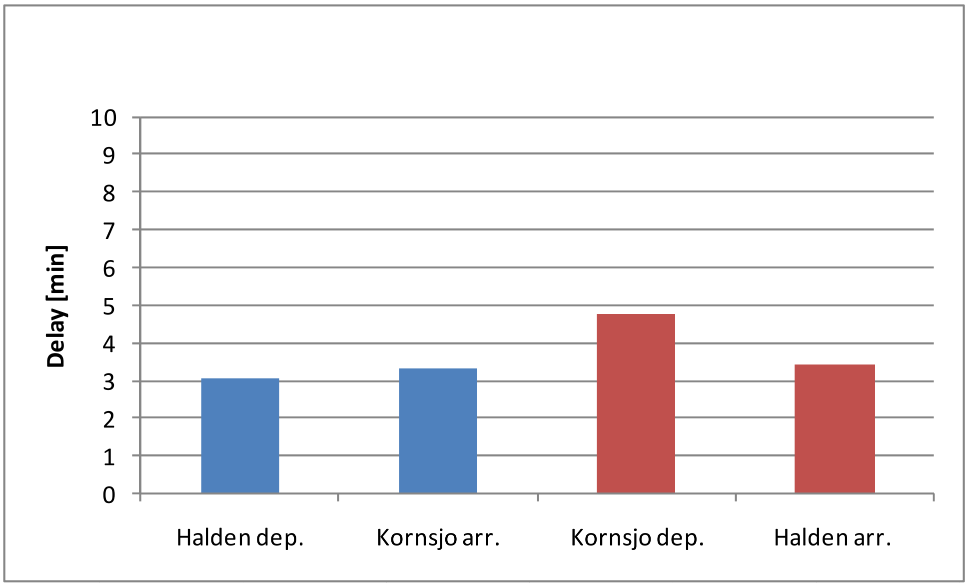

Figure 5 Mean delays for Halden and Kornsjo. All trains operated during 2009 included.

These mean values give the same indication. Trains from Halden to Kornsjø tends to get increase their delay, whereas trains from Kornsjø to Halden recover delay time during their run. The next figure shows the corresponding punctuality values on the five minute level.

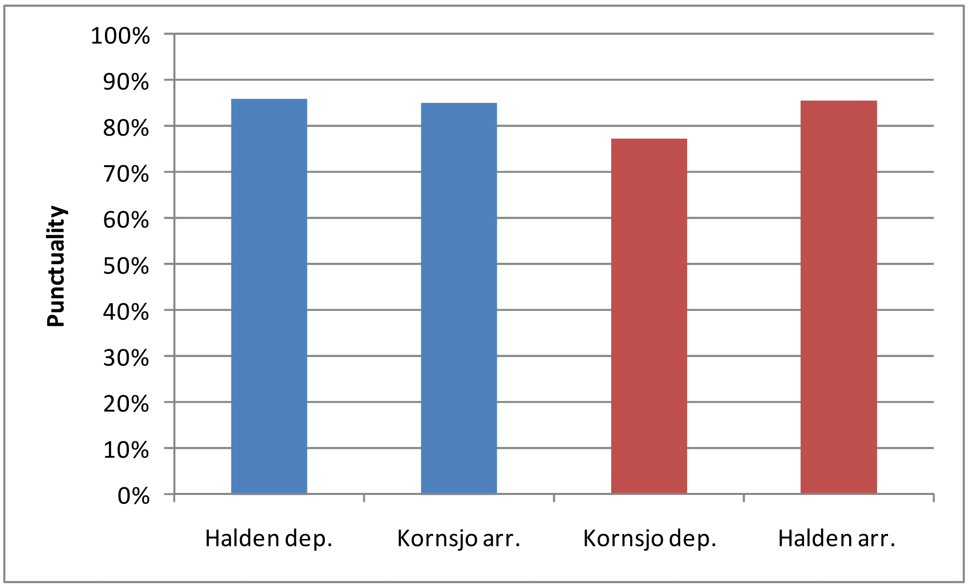

Figure 6 Punctuality (5 minute level) in Halden and Kornsjo. All trains operated during 2009 included.

According to this figure a punctuality level of 85 % is to be expected on existing railway lines in Norway. These values come from a single-track line with mixed traffic, i.e. with operational conditions that differ significantly from dedicated, double-tracked high-speed lines. However, the value 85 % gives a useful indication of a lower limit for the punctuality value to be used in the design work.

Sweden

Swedish railways are already operated by high-speed trains, although these trains have a maximum speed of 200 km/h. All Swedish railway lines are operated with mixed traffic, which means that the high-speed trains are mixed with regional- and freight trains.

However, the Swedish climate is similar to the Norwegian and the high-speed trains are operated on both single- and double-track lines. This makes Sweden an interesting country for comparison of delay statistics.

Two lines have been chosen:

- **The East Coast line** between Gävle and Sundsvall north of Stockholm. This line is single-track and the high-speed traffic suffers from bad punctuality due to an unfavorable traffic mix.
- **The Western Main line** between Stockholm and Gothenburg. This line is double-track and several sections of the line are heavily utilized by both passenger- and freight trains.

For these lines delay statics has been collected and compiled for a period of two months during the autumn of 2008.

The following figure shows the delay distributions for the high-speed trains on the East Coast line. It is clearly seen that the arrival distributions are worse than the departure distributions, which means that the trains suffer from delays that they cannot recover during their run.

Sundsvall is the origin station for most of these high-speed trains and this is seen in very low delays for departing trains. Gävle is an intermediate stop some 150 km north of Stockholm and the trains have gathered great delays before leaving Gävle.

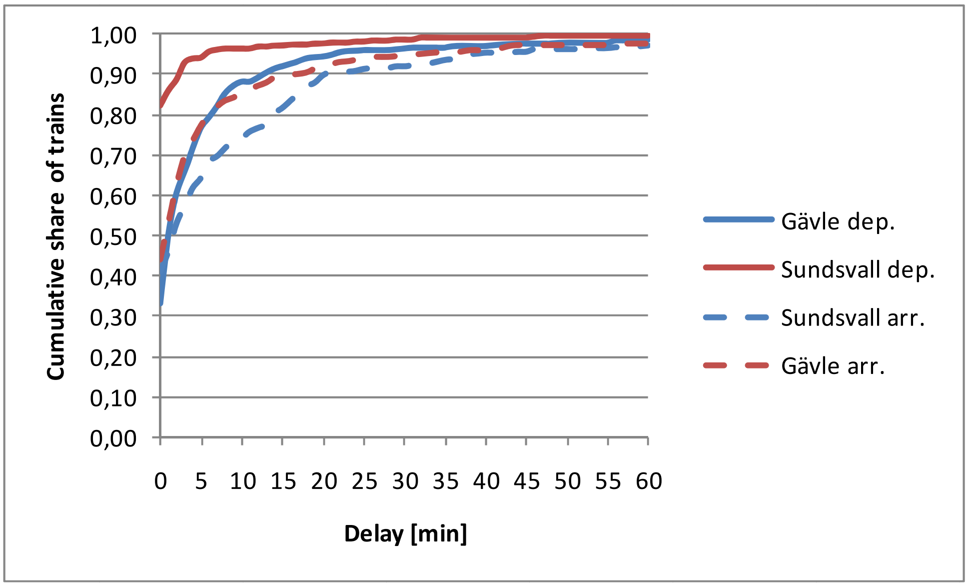

Figure 7 Delay distributions for the Swedish East Coast line.

The following figure shows that the mean delays increase significantly over the studied line sections. Especially south bound traffic suffers from huge increase in delays. A low departure delay is not a guarantee to avoid additional delays.

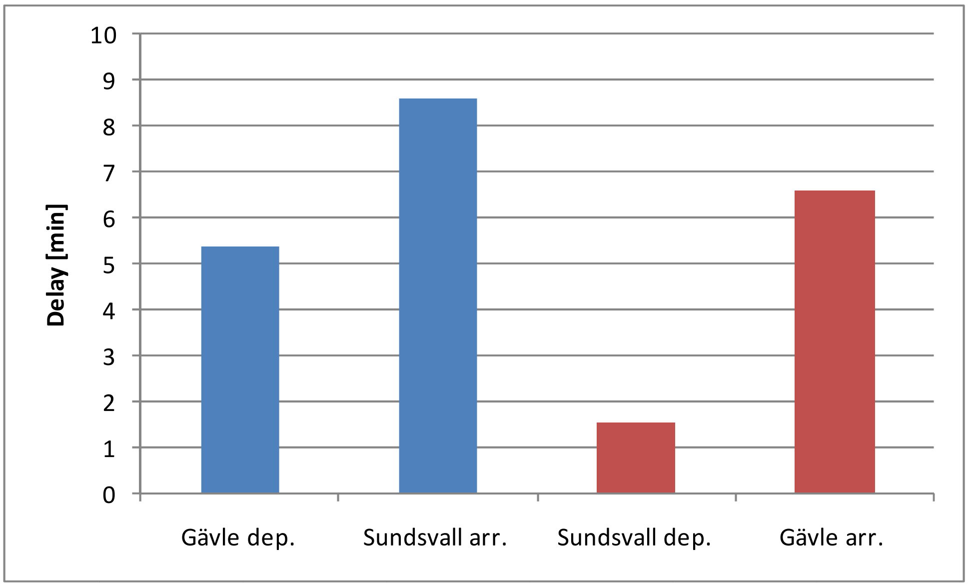

Figure 8 Mean delays for the Swedish East Coast line.

The punctuality values show somewhat different results. The huge increase in mean delay for trains from Sundsvall to Gävle only causes a drop in punctuality by 17 %. This depends on the fact that the punctuality only includes the trains with less than 5 minutes delay, whereas the mean delay includes all trains.

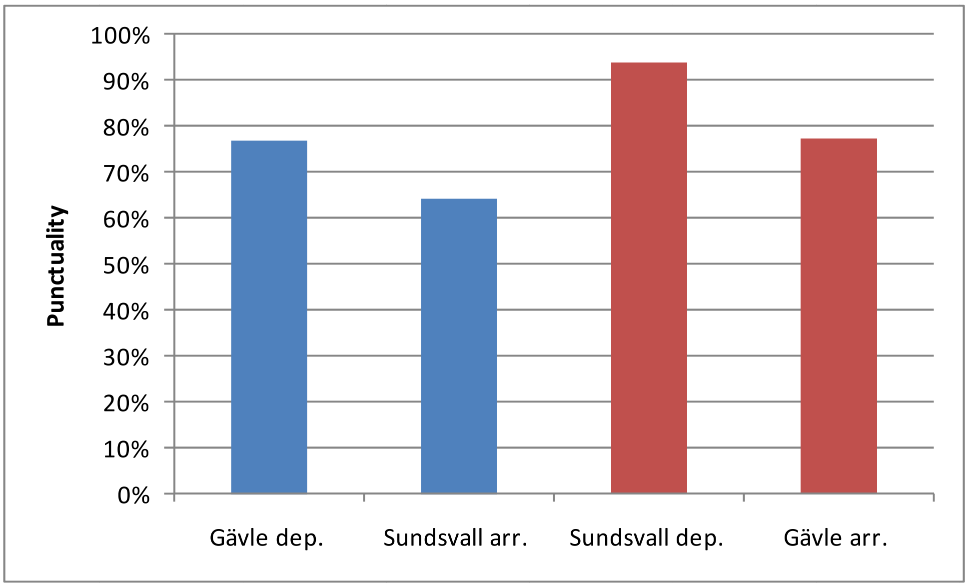

Figure 9 Punctuality for the Swedish East Coast line (5 minute level).

The situation is different on the double-tracked Western Main line. The following figure reveals that these high-speed trains face totally different delay conditions in the two directions.

Trains from Stockholm to Gothenburg start with very low and limit delays, but ends up in Gothenburg heavy delayed. The other direction, from Gothenburg to Stockholm shows a more reasonable situation, where departure and arrival delays follow similar distributions.

One reason for this difference is the commuter traffic close to Gothenburg that causes problems for arriving high speed trains. Moderate delayed high speed trains are often caught behind slower commuter trains and this causes additional delays to the high-speed trains.

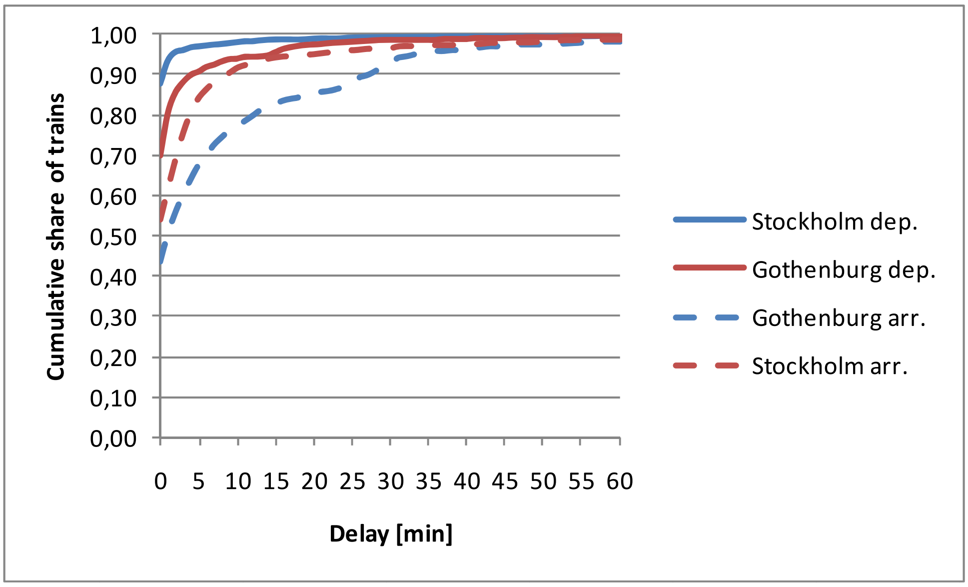

Figure 10 Delay distributions for the Swedish Western Main line.

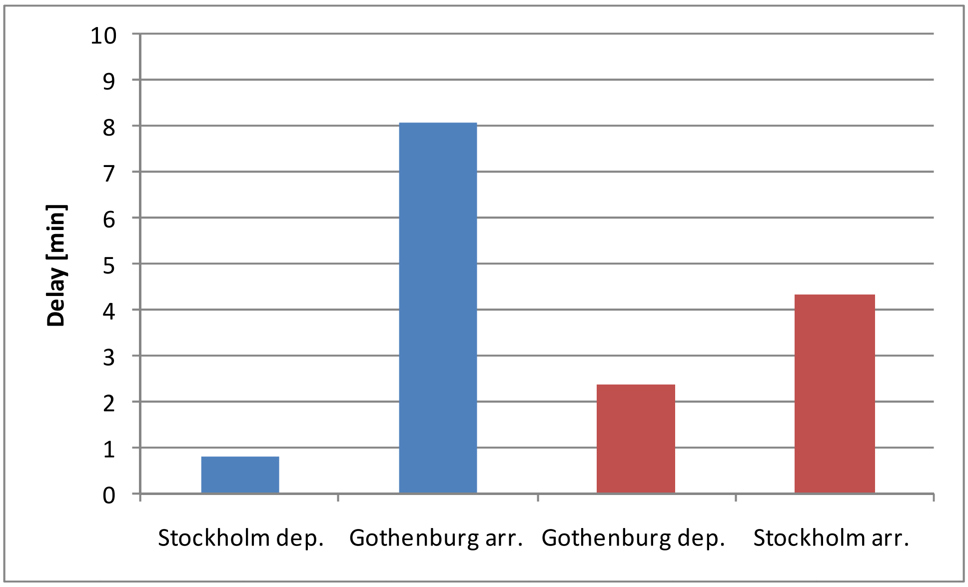

Figure 11 Mean delays for the Swedish Western Main line.

The delay situation is confirmed by the mean delay values. The growth in delay for trains from Stockholm to Gothenburg is unacceptable, whereas the situation is much more reasonable in the opposite direction.

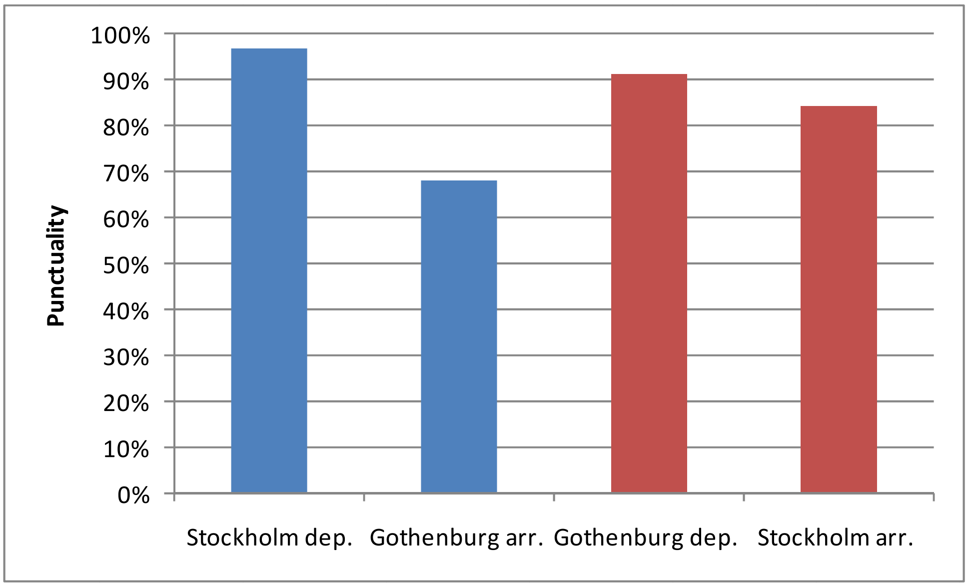

Figure 12 Punctuality for the Swedish Western Main line (5 minute level).

The punctuality values shown above do not reflect the entire delay situation on the Western Main line. Trains delayed more than five minutes are often very heavily delayed and this is not reflected in this simple punctuality measure.

Swedish railway lines have mean delays of 1-2 minutes for departures from origin stations (Stockholm, Gothenburg and Sundsvall) and 4-8 minutes for arrivals at terminal stations. The punctuality is 75-95 % for departures and 65-85 % for arrivals.

Also the Swedish delay and punctuality values have to be considered as lower limits for future, new high-speed lines.

Acceptance criteria for punctuality

The review of delay statistics for existing lines can be summarized in the following table.

Table 2 Delay statistics for existing lines.

	Mean delay [min]		Punctuality at 5 min. level	
	Departure	Arrival	Departure	Arrival
Norway	3-5	3-4	75-85 %	85 %
Sweden	1-2	4-8	75-95 %	65-85 %
Spain (conventional trains)				89-95.9%
Spain (AVE high speed lines)				97.3-98.9%
Proposed acceptance criteria	1-3	1-3	85-95 %	85-95 %

The conclusion and proposal is that the new high speed lines shall be constructed for punctuality on five minute level within the interval 85-95 %. Assuming negative exponential distributed delays these values corresponds to mean delays of 1-3 minutes.

It is important to assume reasonable punctuality levels. If the assumed entry punctuality is higher than the realized one, the infrastructure will be under-dimensioned and cause more knock-on delay and punctuality drop than intended. If the assumed entry punctuality is lower, the infrastructure will be over-dimensioned and the gain in less knock-on delay will not correspond to the higher construction costs.

References

[1] Goverde et. Al.: Delay Distributions in Railway Stations. The 9:th World Conf. on Transport Research, Seoul, Korea, July 22-27, 2001. Paper No. 3605.

[2] Conte C.: Identifying dependencies among delays. PhD thesis, University of Göttingen, 2008.

[3] Luktvasslimo Ö.: Faktabasert styring i jernbanedrift. Institutt for produsjons- og kvalitetsteknikk. NTNU 2005.

[4] Lindfeldt O.: Railway operation analysis – Evaluation of quality and timetable on single and double treack lines with analytical models and simulation.. ISBN 12:978-91-85539-50-5. Doctoral Thesis KTH 2010

[5] Landex A.: Methods to estimate railway capacity and passenger delays. PhD Thesis, DTU Transport 2008.

[6] Railway Timetable & Traffic. Edited by Hansen A and Pachl J:ISBN 978-3-7771-0371-6. Eurailpress 2008.

[7] Statistics on Spanish train punctuality. Control de indices de puntualidad. ADIF. Año 2009

[8] Dr. Alberto Garcia, Fundación de los Ferrocarriles Españoles, FFE. Personal communication october 2010

[9] Mª Pilar Martín Cañizares. Fundación de los Ferrocarriles Españoles FFE. Personal communication, october 2010.

[10] Statistics of Norwegian train delays. Jernbaneverket 2009. Excel sheet.

[11] Leif Aslaksen. Personal communication, october 2010.