

## RobustRails Mini Conference August 27, 2015

# Robustness in Railway Transport

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DTU Transport

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# Two perspectives

1) Train and system performance

2) Passenger experience

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## Nye forsinkelser for tog på Vestfyn

Fejlen ved et sporskifte i Tommerup er rettet, men det har skabt forsinkelser.



Det kører ikke for DSB og Banedanmark i disse uger. (Foto: DSB - pressefoto © DSB)

Samfund 7. maj 2015 - kl. 11:44 Opdateret 7. maj 2015 - kl. 12:10

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## DSB til forsinkede passagerer: Nyd udsigten

Fortsat problemer med togdriften over Fyn

Af: Claus Jessen @cjessen1



Nyd udsigten til denne betonmur, opfordrer DSB. Foto: Claus Jessen

# Robustness in railway transport

How robust the system is in order to avoid

- Delays
- Cancelled trains

## Fejl på fejl på fejl

IC4-togene har fra start været en farce, der af eksperter er udnævnt til en af Europas største togskandaler. Ekstra Bladet har her listet alle de fejl, man indtil videre har konstateret på de 50 tog, DSB indtil videre har modtaget fra den italienske producent.

**Kabine:**  
**Sæder:** Passagerer har klaget over, at siddekomforten er langt dårligere end i eksempelvis IC3.  
**Loftpaneler:** Panele over passagererne sidder løst og kan falde ned i hovedet på passagerne.  
**Støj:** En Ekstra Blads-læser har målt larm på op mod 100 decibel ved et sæde på første klasse.  
**Varmeanlæg:** I vinteren 2010 virkede mange af varmeanlæggene ikke. Det førte til iskolde kabiner. Da man endelig fik ordnet problemet, førte det til overophedede kabiner.  
**Mobildækning:** Mobildækningen er elendig, bl.a. fordi mobilsignalerne har svært ved at nå ind og ud af IC4-tog, da de er spækkede med elektronik til at styre døre, lys etc.

**Ingen frostsikring:** Vandforsyningen til toiletter og håndvaske er ikke sikret mod frost.

**Døre:**  
**Dørtlukning:** Døre lukker ikke ordentligt, og dørene lukker langsommere end i de fleste andre danske tog.  
**Dørkamera:** På de første togsæt virkede dørkameraerne ikke, så lokoføreren kunne ikke se dørene på displayet i toget.  
**Dørtin:** De mikroswitches, der skal registrere, hvorvidt dørtinnet er trukket korrekt ind og dørene korrekt lukkede, har vist sig at blive påvirket af skidt, slag og sne.

**Kørecomputer:** Kørecomputeren er ikke indstillet til den rigtige hjulstørrelse. Softwaren til kørecomputeren er i det hele taget så dårlig, at der skal udvikles helt ny software, hvis det skal virke.

**Motorfejl:** Hvert togsæt har fire motorer, og man mister tit styringen over én eller flere. Ofte med affysning til følge, idet toget ikke må passere Storebælt, hvis det ikke har en trækraft på mindst 50 pct. af den maksimale ydelse.

**Bremseventiler:** Falske fejlmeldinger fra togsættens bremseventiler får togcomputeren til at registrere togets parkeringsbremse som indkoblet. Det blokerer for videre kørsel.

**Flere fejl**  
**Infoskærmene virker vilkårligt:** IC4's interne informationsskærme viser ofte ingen informationer.  
**Underdimensioneret ledningsnet:** Dét er årsagen til, at de forskellige togsæt ikke kan kobles. Der er simpelthen så stort et spændingsfald i ledningerne, at informationerne mellem togsættene ikke når frem. Der skal altså skiftes hundredvis af kilometer ledning i alle togsæt.  
**Reservevedle:** Der er op til 280 dages ventetid på reservevedle fra AnsaldoBreda.  
**Sjusk:** De leverede IC4-tog er fyldt med håndværksmæssig sjusk. Det gælder bl.a. simple ting som el og montage.  
**Upålideligt:** IC4-togene skal på værksted for hver 2000 kilometer, de har kørt. Andre tog kører normalt 20.000 kilometer interval mellem værkstedsbesøg.  
**Løse skruer:** Rør og ledninger sidder løst i mange togsæt og skal strammes efter modtagelsen.  
**CO<sub>2</sub>-udledning:** IC4 udleder mere CO<sub>2</sub> end antaget. Det anslår den norske forsker Morten Simonsen fra Vestlandsforskning med udgangspunkt i et nyt notat, som Transportministeriet har udarbejdet.  
**Daglige nedbrud:** De få IC4-tog, der er i drift, rammes af daglige nedbrud på grund af tekniske problemer og pludselige nedbrud, så afgange må aflyses eller bliver forsinket.

**Ingen salgsvogn:** Salgsvognene kan ikke køre gennem toget, fordi de er designet med høje trapper mellem nogle af kupeerne.

**Isolation i førerkabine:** De første IC4-tog havde ingen isolering i førerkabine, så lokoførerne måtte styre toget i iskolde kabiner.

*Grafik: ML / Kilde: Ingeniøren*

# The overall performance of the railway system and its components



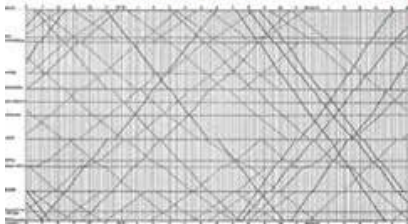
Rolling Stock

## Railway System



Signalling Equipments and Computer-based systems

Timetable



Infrastructure



# Matrix of explanations

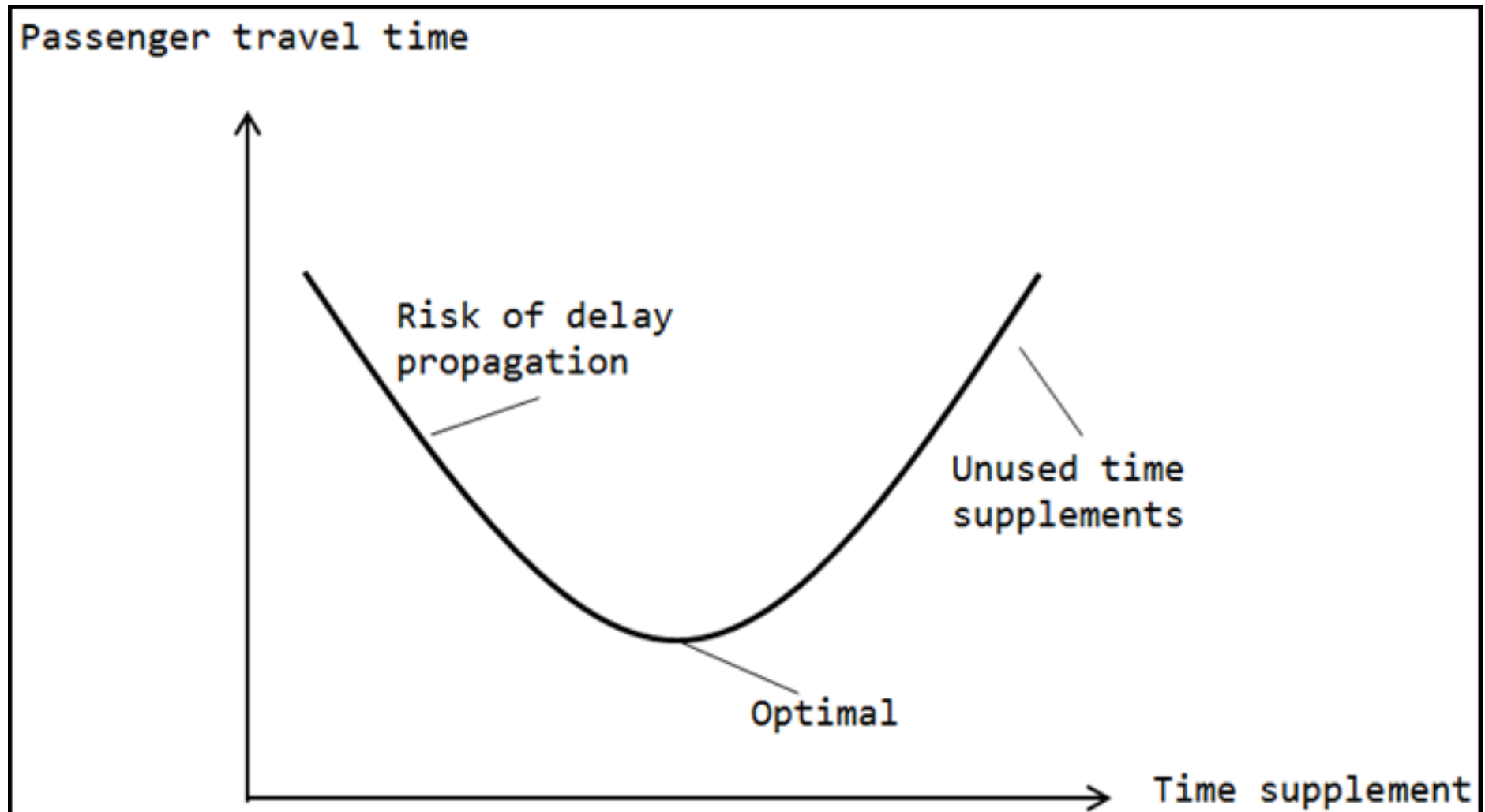
- Probability distribution for events

	<i>Infrastructure</i>	<i>Traffic Control</i>	<i>Rolling stock</i>	<i>Operations</i>	<i>Passager flows</i>	<i>Other factors</i>
Links						
Nodes						
Stations/platforms						

# Railway Robustness definition?

- A common definition of robustness is the ability of a timetable to absorb smaller delays with or without light dispatching measures, given the state of the railway components
- Can be achieved with:
  - Running and dwell time supplements
  - Buffer times
- Efficiency – the balance between supplements and short travel times
  - Minimize the average travel time of the passengers

# Timetable supplements



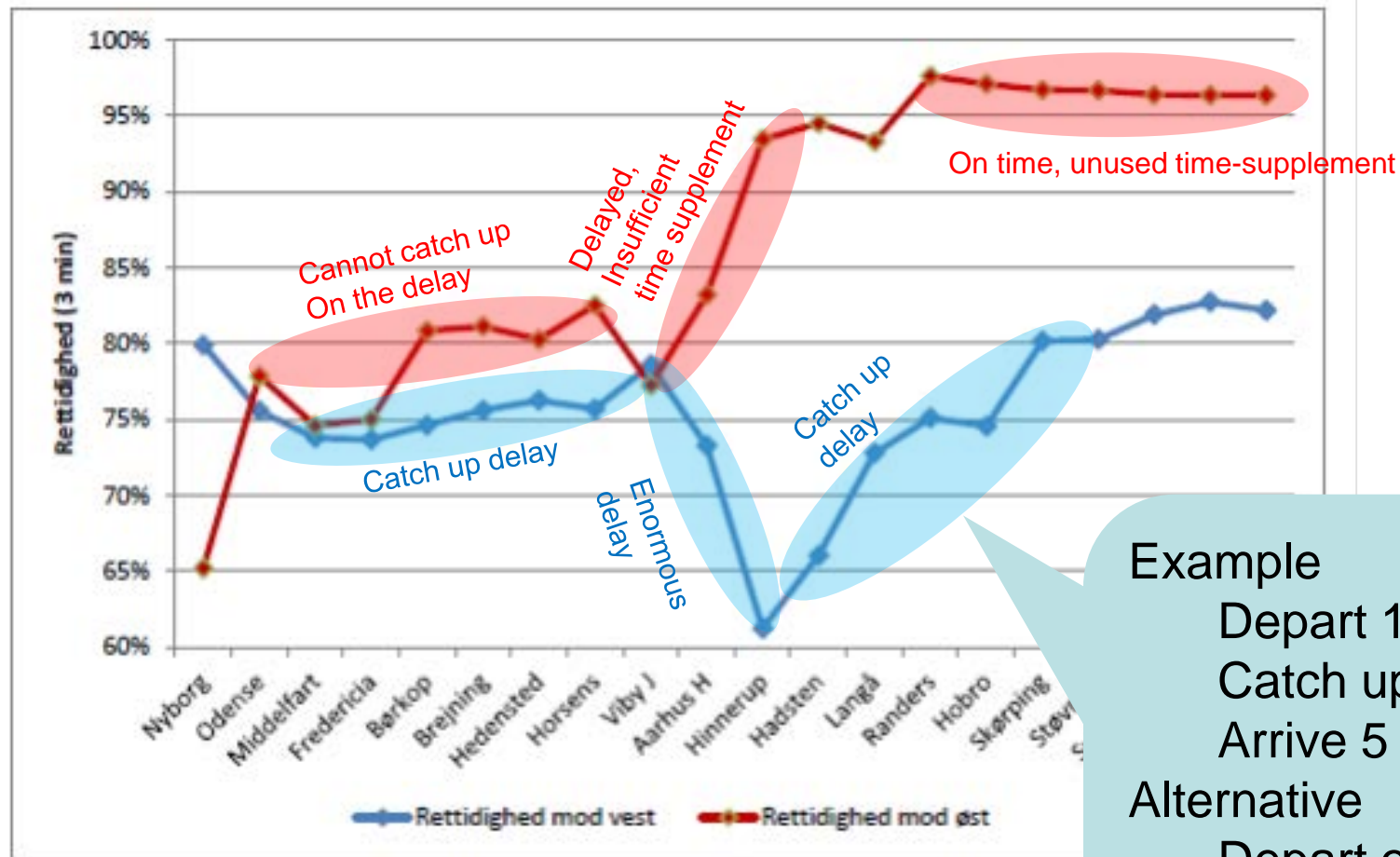
# Optimal allocation of time supplement in schedules

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

Tabel 2: Køreplanstillæg brugt af Banedanmark og UIC forslag



# Example of simulation of robustness



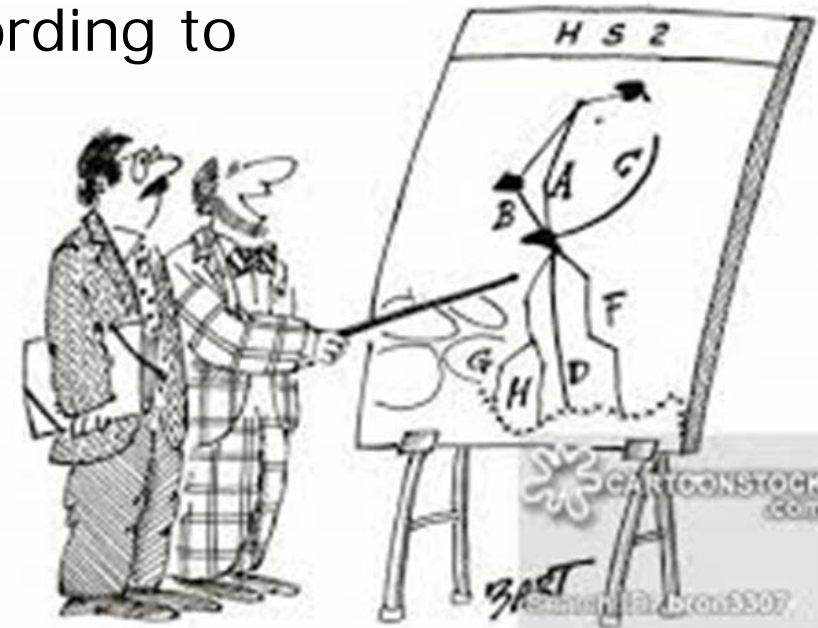
Figur 14. Rettidighed for linje 11 fordelt på retninger i basissituationen

Example  
 Depart 10 min too late  
 Catch up 5 min  
 Arrive 5 min too late

Alternative  
 Depart on time  
 5 min. faster time-table  
 Arrive on time

# Railway Robustness indicators (WP3.1)

- Can robustness indicators be used in early planning phases and mathematical models instead of simulation which is time consuming to set up?
  - Semantics of robustness indicators:  
when is a timetable robust according to an indicator?



*"Let's build all possible variants and see which one turns out to be the cheapest to run!"*

# How do we measure railway robustness?

- Microscopic simulation of the operation
  - Requires a detailed infrastructure model
- (Potential) robustness indicators
  - Capacity consumption (UIC 406)
    - Measure capacity consumption on railway lines by compressing train paths
    - Expression of the available buffer time between consecutive trains
  - Heterogeneity indices
    - Measure the distribution of trains on line sections and at stations
    - Indirectly indicate the robustness of a timetable by measuring the spread of buffer times
  - Complexity indices
    - Evaluate the complexity of infrastructure and the timetable in increasing detail (depending on indicator)
    - Increasing complexity = increasing risk of delays

# How do we measure robustness?

- Robustness indicators (continued)
  - Train path fix points and risk profiles
    - Fix points are points in the timetable where a train path is dependent on another train path
      - E.g. scheduled crossings and overtakings, level junctions and transition, terminal and transfer stations
    - Risk profile can be created for a train or a group of trains as the amount of time supplements between fix points
    - Indicator of the timetable's ability to absorb delays on the different sections
- Others

# Robustness Indicators

Indicator	Initial delays		Time supp.		Buffer times		PTT	Applicable	Input
	Size	Dist(s)	Size	Dist(s)	Size	Dist(t)			
UIC 406					(●)			L	TT
Heterogeneity						●		L & S	TT
Infra. complexity					(●)			S	I (P)
TT complexity	●	●			●	●		L & S	TT D
Fix points			●	●				L & S	P
WTTE	●	●	●	●	●	●	●	A	TT D
Simulation	●	●	●	●	●	●	(●)	A	TT D
Max-Plus	●	●	●	●	●	●		A	TT D

*Size*: size of, *Dist*: distribution of, *s*: distance, *t*: time

*L*: lines, *S*: stations, *A*: lines and stations aggregated

*TT*: timetable, *I*: infrastructure, *P*: plan of operation, *D*: delay,

*PTT*: passenger travel times, *WTTE*: weighted travel time extension

# Some references

- Jensen, L.W.  
**Robustness indicators and capacity models for railway networks.**  
Comming PhD Thesis. 2015
- Jensen L.W., Landex, A. & Nielsen, O.A.  
**Evaluation of robustness indicators using railway operation simulation.**  
COMPRAIL. 2014
- Landex, A. & Jensen L.W.  
**Measures for track complexity and robustness of operation at stations.**  
Journal of Rail Transport Planning & Management. 2013
- Jensen L.W. & Landex, A. **Measuring Robustness of Timetables at Stations using a Probability Distribution.**  
RailCopenhagen. 2013

# Estimation of passenger preferences

## - What matters?

- Travel time
  - Punctuality and travel time variability
  - Use of the travel time
- Many other factors
  - Frequency, information, cost, terminal





For Transportministeriet

**Togets konkurrenceevne**  
- "En jernbane i vækst"

Kundeparametre og udvalgte instrumenter

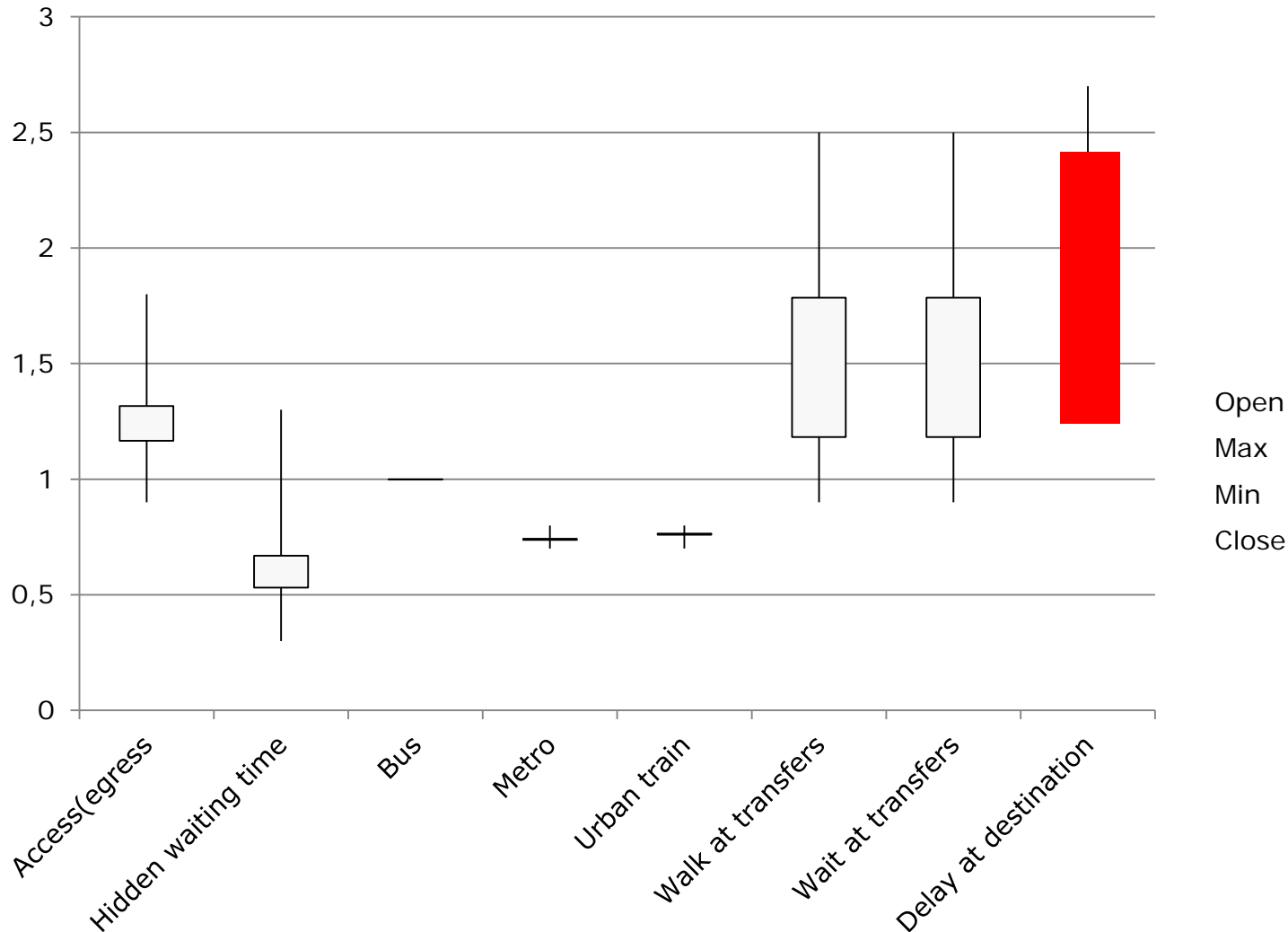


**Før biltrafikken står stille**  
Hvad kan den kollektive transport bidrage med?  
Juni 2009

Udarbejdet for:  




# Danish Value of Time studies (extract of 12 surveys compared to bus)





# Passenger delays equal train delays?

- Trains tend to be more delayed during peak hour (larger capacity utilization)
- Peak hour delays normally affects more passengers per train
- Delays tends to accumulate during a train run, i.e. more and more delayed e.g. when approaching Copenhagen in the morning peak
- Passenger are hit by the delay when they exit the train. Whether the train is on-time during the run matters less, if it is delayed at the destination
- If a connection is missed, then the passenger delay is much larger than the train delay



Are delays of this train affecting more passengers?



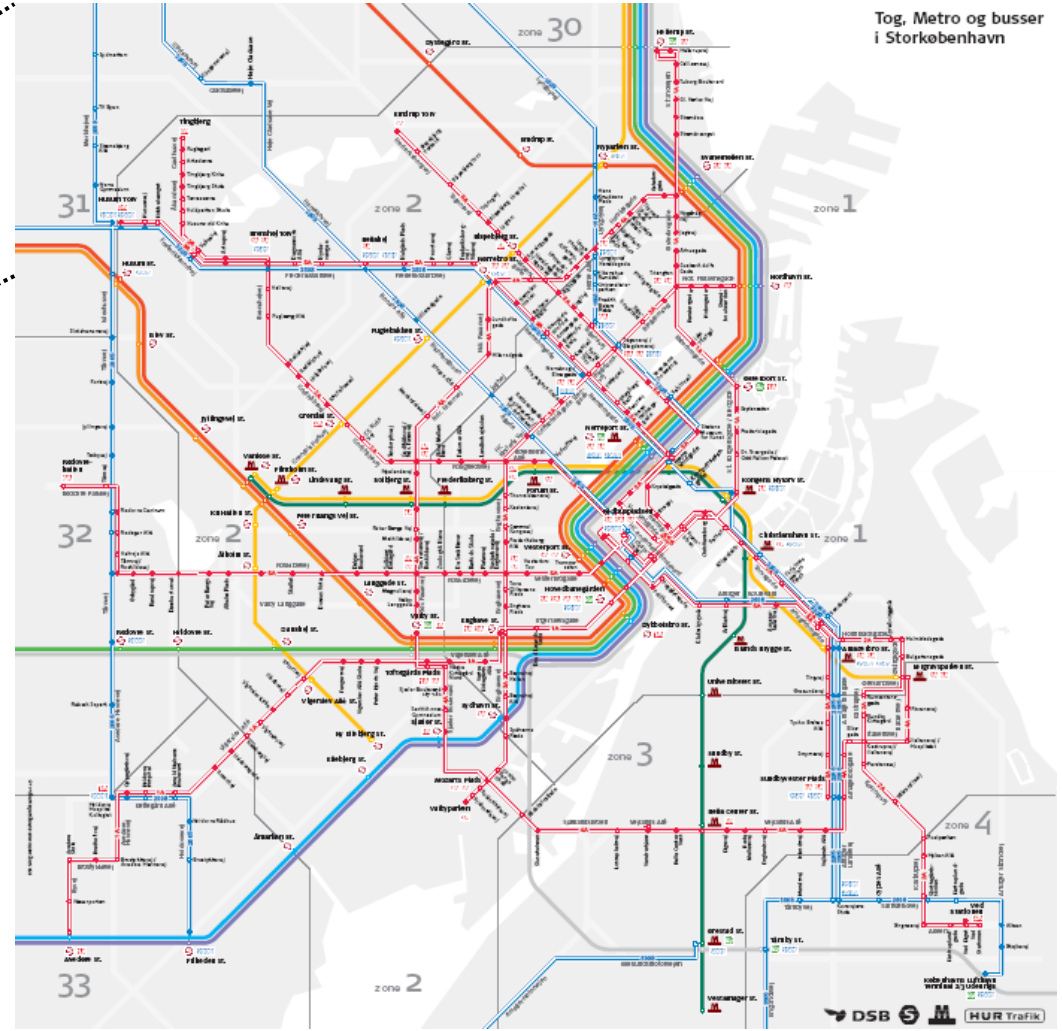
Are passengers delayed if this train is not on time?

# Full scale calculations on the Copenhagen Urban Rail network



- 104 "zones", 80 trains
- 1.8 million inhabitants in Copenhagen,
- 330,000 trips made each day by the urban rail
- 42 main time intervals with 1-5 min. Launches
- 60,000 OD-elements (sparse matrix)
- 1,200 train runs per day
- Diachronic graph with 200,000 links and 120,000 nodes
- A calculation of an entire day takes between 10 and 20 minutes with 5 min. launches

# Alternative route options?



# Comparing train and passenger delays

Thres- hold (sec)	Train regularity and punctuality	Morning		Day hours		Afternoon		Other hours		Total	
		99,6	<b>95,4</b>	94,5	<b>90,6</b>	99,3	<b>95,4</b>	98,6	<b>91,4</b>	97,6	<b>92,7</b>
	Base OD launches (min)	10	5	20	10	10	5	20	10	10/20	5/10
50	Regularity	100,0	100,0	100,0	100,0	100,0	100,0	98,1	98,1	99,7	99,7
	<b>Punctuality (no delays)</b>	<b>84,0</b>	<b>84,3</b>	<b>80,5</b>	<b>80,6</b>	<b>90,3</b>	<b>89,1</b>	<b>86,8</b>	<b>83,0</b>	<b>85,0</b>	<b>84,3</b>
	of this before time	15,7	14,1	17,3	15,3	22,5	19,3	25,5	22,6	19,6	17,3
	Average delay (min)	8,2	7,9	9,0	7,7	7,9	6,7	7,5	7,5	8,4	7,5
150	Regularity	100,0	100,0	100,0	100,0	100,0	100,0	98,1	98,1	99,7	99,7
	<b>Punctuality (no delays)</b>	<b>82,7</b>	<b>83,4</b>	<b>79,8</b>	<b>79,2</b>	<b>88,9</b>	<b>87,9</b>	<b>86,6</b>	<b>82,7</b>	<b>84,1</b>	<b>83,2</b>
	of this before time	15,3	13,9	16,8	14,9	22,4	19,1	24,8	22,6	19,2	17,0
	Average delay (min)	8,4	7,9	9,1	8,0	8,2	7,0	7,8	7,7	8,6	7,7
248	Regularity	100,0	100,0	100,0	100,0	100,0	100,0	98,1	98,1	99,7	99,7
	<b>Punctuality (no delays)</b>	<b>81,3</b>	<b>82,4</b>	<b>79,2</b>	<b>78,1</b>	<b>87,9</b>	<b>86,3</b>	<b>86,1</b>	<b>80,7</b>	<b>83,2</b>	<b>81,9</b>
	of this before time	14,9	13,7	16,5	14,7	22,1	18,9	24,7	22,5	18,9	16,8
	Average delay (min)	8,9	8,1	9,4	8,1	8,8	7,3	8,3	7,5	9,0	7,8
400	Regularity	100,0	100,0	100,0	100,0	100,0	100,0	98,1	98,1	99,7	99,7
	<b>Punctuality (no delays)</b>	<b>80,1</b>	<b>80,7</b>	<b>78,8</b>	<b>76,6</b>	<b>87,0</b>	<b>84,7</b>	<b>85,4</b>	<b>80,1</b>	<b>82,4</b>	<b>80,4</b>
	of this before time	14,6	13,4	16,2	14,5	22,0	18,5	24,2	22,2	18,6	16,5
	Average delay (min)	9,4	8,6	10,1	8,6	10,0	7,8	8,6	7,8		

Trains

Passengers  
With fast  
information

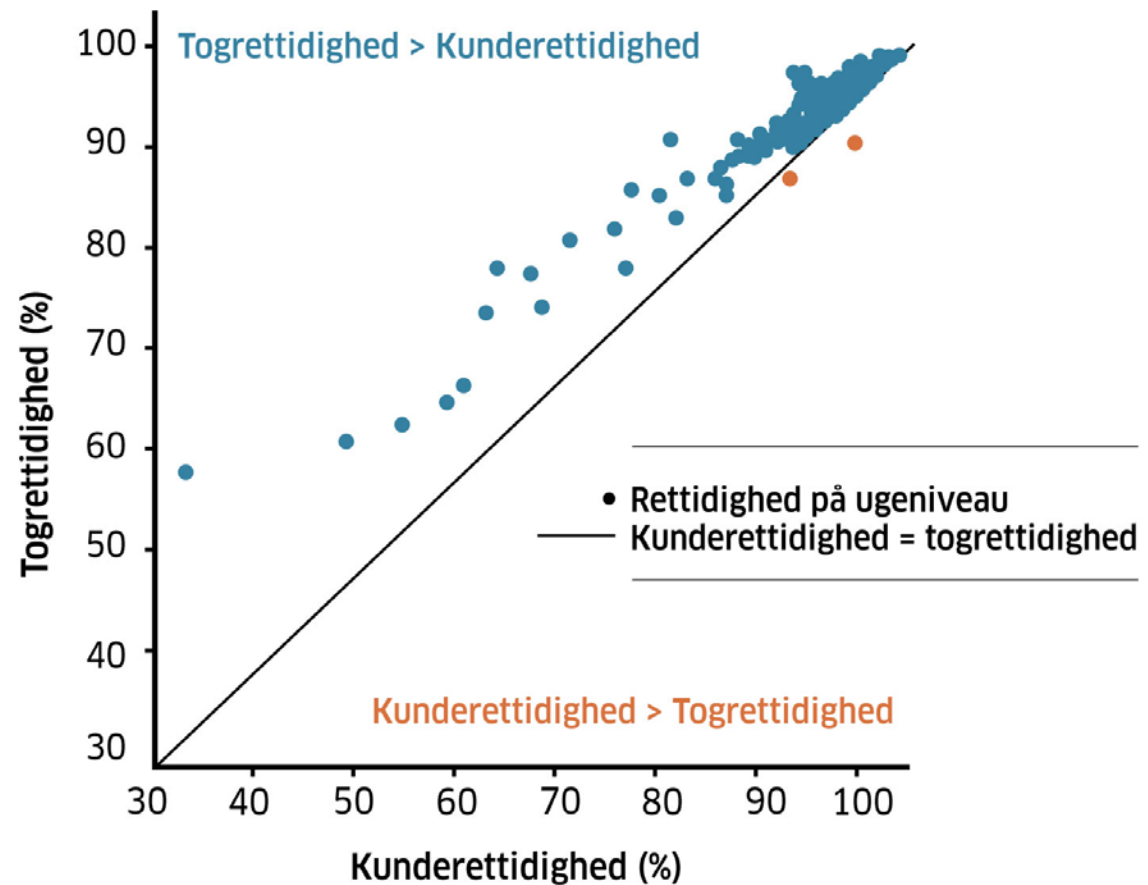
Passengers



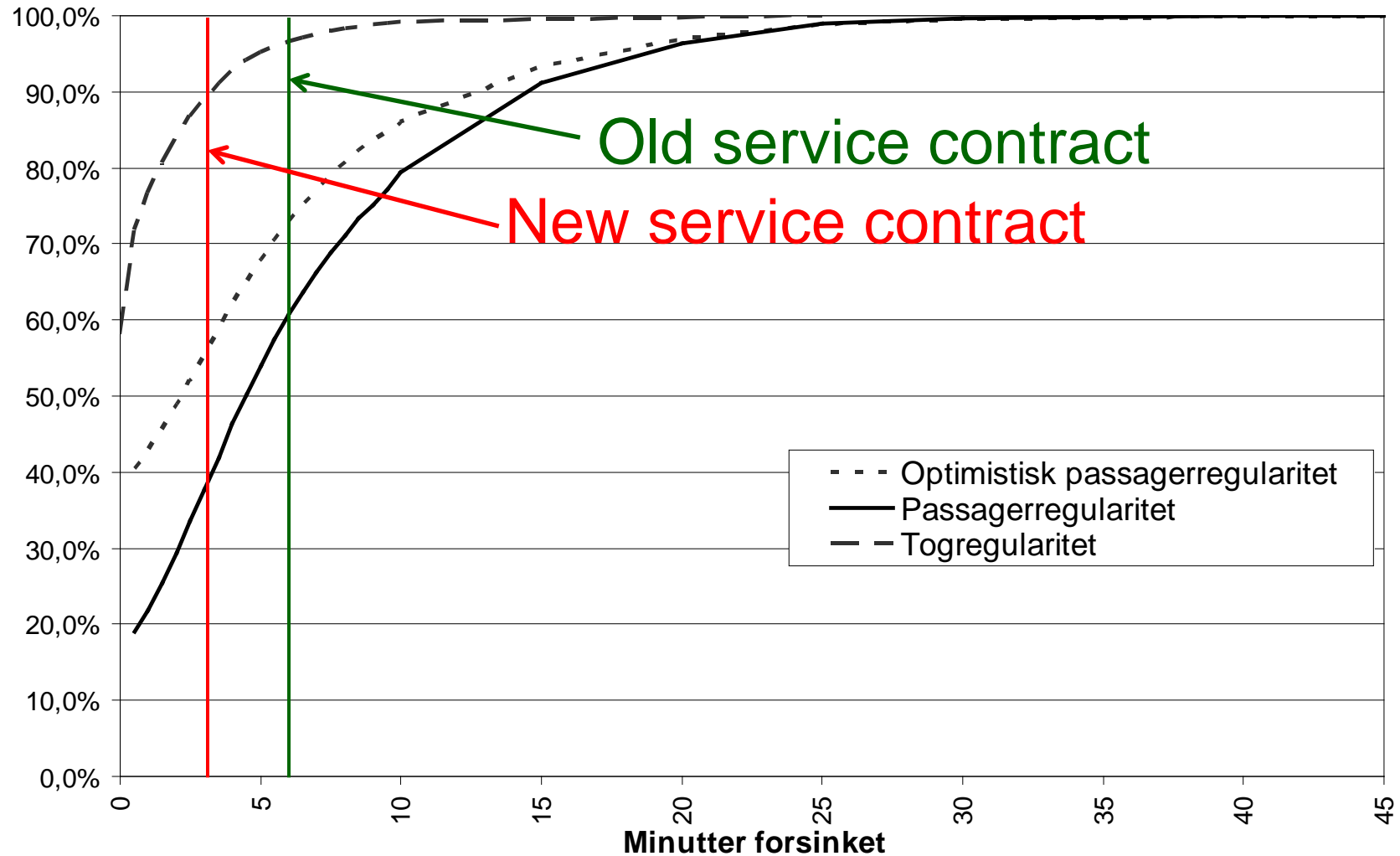
# Punctuality and delays

## KUNDERNE ER MERE FORSINKEDE END TOGENE

Hvert datapunkt angiver på ugeniveau hhv. kunde- og togrettidigheden for S-tog (2010-14)

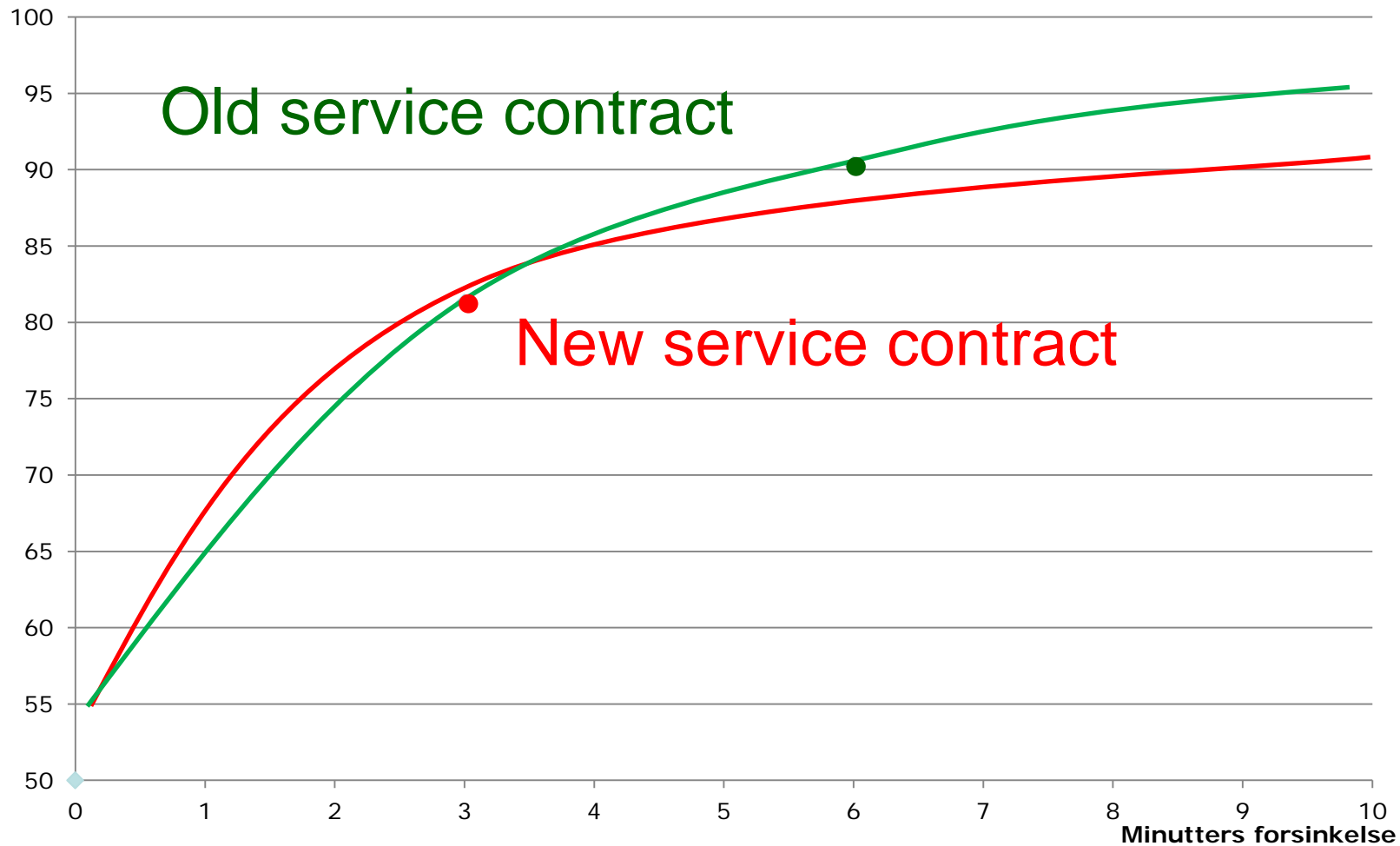


# Delays, examples of measurements



# Measurements (KPI's) and service contract – Focus on sub-components in the journey

% delayed more than x minuttet



# Questions?





# Some key references,...

- Andersson, E., Peterson, A., Törnquist Krasemann, J. (2011). Robustness in Swedish railway traffic timetables. *Railrome 2011: Book of Abstracts 4th International Seminar on Railway Operations Modelling and Analysis*.
- Bates, J., Polak, J., Jones, P., Cook, A. (2001). The valuation of reliability for personal travel. *Transportation Research Part E: Logistics and Transportation Review*, 37(2), 191-229.
- Carrasco, N. (2012). Quantifying Reliability of Transit Service in Zurich, Switzerland. *Transportation Research Record: Journal of the Transportation Research Board*, 2274(1), 114-125.
- Transfer attributes in route choice models for public transport passengers. Dyrberg, Mette Berner; Christensen, Charlotte B.; Anderson, Marie Karen; Nielsen, Otto Anker and Prato, Carlo G. Paper accepted for 4th symposium arranged by European Association for Research in Transportation (hEART), Copenhagen
- Fischetti, M., Monaci, M. (2009). Light robustness. *Robust and online large-scale optimization* (pp. 61-84). Springer Berlin Heidelberg.
- Kroon, L. G., Dekker, R., Vromans, M. J. (2007). Cyclic Railway Timetabling: A Stochastic Optimization Approach. *Algorithmic Methods for Railway Optimization*, 41.
- Jensen, L.W. Robustness indicators and capacity models for railway networks. Comming PhD Thesis. 2015
- Jensen L.W. & Landex, A. Measuring Robustness of Timetables at Stations using a Probability Distribution. RailCopenhagen. 2013
- Jensen L.W., Landex, A. & Nielsen, O.A. Evaluation of robustness indicators using railway operation simulation. COMPRAIL. 2014
- Landex, A. & Jensen L.W. Measures for track complexity and robustness of operation at stations. *Journal of Rail Transport Planning & Management*. 2013
- Liebchen, C., Schachtebeck, M., Schöbel, A., Stiller, S., Prigge, A. (2010). Computing delay resistant railway timetables. *Computers & Operations Research*, 37(5), 857-868.
- Medeossi, G., Marchionna, A. Longo, G. (2009). Capacity and Reliability on Railway Networks: A Simulative Approach.
- Nielsen, O. A. (2000). A stochastic transit assignment model considering differences in passengers utility functions. *Transportation Research Part B: Methodological*, 34(5), 377-402.
- Nielsen, Otto Anker; Landex, Alex & Frederiksen, Rasmus Dyrh (2008). Passengers route choices in delayed rail networks. *Schedule-based Modelling of Transportation Networks: Theory and Applications*. Series: Operations Research/Computer Science Interfaces. Vol 46. (Eds) Wilson, Nigel H.M. & Nuzzolo, Agostino. Springer, ISBN: 978-0-387-84811-2
- Oort, N.v. (2011). Service Reliability Improvement by enhanced Network and Timetable Planning. *Conference on Advanced Systems for Public Transport July 2012, Santiago, Chile*.
- Parbo, J. Nielsen, O.A. Prato, C.G. (2014). "User perspectives in Public Transport Timetable Optimisation", *Transportation Research Part C*, 48, 269-284.
- Parbo, J., Nielsen, O. A., Prato, C. G. (2015). Adapting Stopping Patterns in Complex Railway Networks to Reduce Passengers' Travel Time.
- Quaglietta, E., 2011. A Microscopic Simulation Model for Supporting the Design of Railway Systems: Development and Applications. PhD Thesis, University of Naples Federico II, Naples
- Salido, M. A., Barber, F., Ingolotti, L. (2012). Robustness for a single railway line: Analytical and simulation methods. *Expert Systems with Applications*, 39(18), 13305-13327.
- Schöbel, A. Kratz, A. (2009). A Bi-criteria Approach for Robust Timetabling. *Robust and Online Large-Scale Optimization. Lecture Notes in Computer Science* Vol. 5868 pp. 119-144.
- Takeuchi, Y., Tomii, N., Hirai, C. (2007). Evaluation method of robustness for train schedules. *Railway Technical Research Institute, Quarterly Reports*, 48(4).
- Vansteenwegen, P., Van Oudheusden, D. (2007). Decreasing the passenger waiting time for an intercity rail network. *Transportation Research Part B: Methodological*, 41(4), 478-492.
- Wardman, M., Chintakayala, V. P. K., Jong, G. d. (2014). Review and Meta-Analysis of European Values of Travel Time.