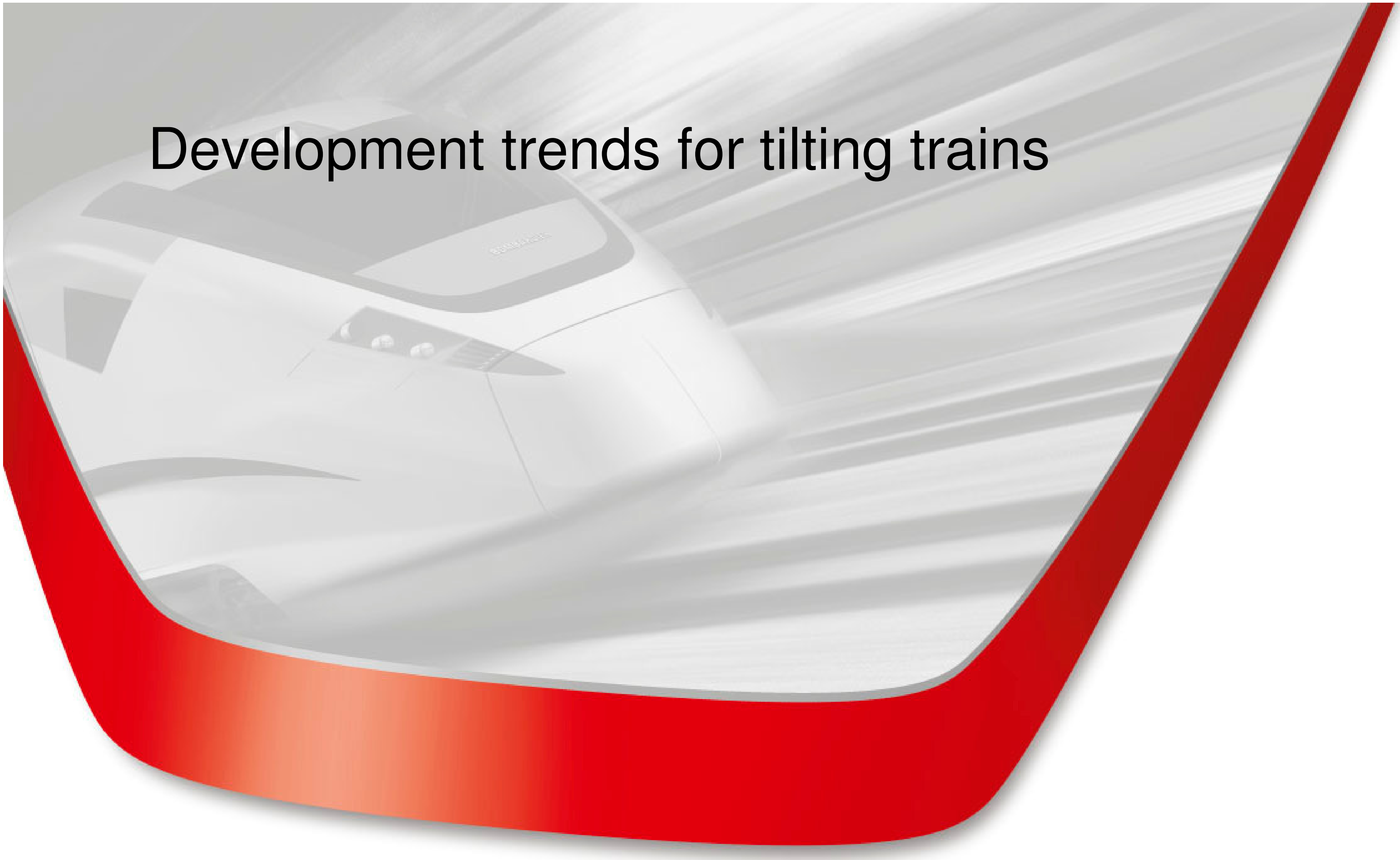
Development trends for tilting trains



NSJT 2012

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On the agenda

- Operator view on selecting tilt or not
- Tilting mechanisms
- Tilting control
- Acceptance for less tilt
- Summary

Operator view on selecting tilt or not

Property	Answer
Running time	Reduced running time attract more passengers and they are willing to pay more. Reduced running time also decrease train and crew cost per km
Ride comfort (quasi-static lateral acceleration perceived by the passenger)	The quasi-static lateral acceleration is a threshold
Motion sickness	Motion sickness give negative publicity
Service failures	Service failures give negative publicity
Maintenance cost	The maintenance cost increase with tilt
Acquisition cost	Tilt makes the train more expensive

The benefit of shorter running times

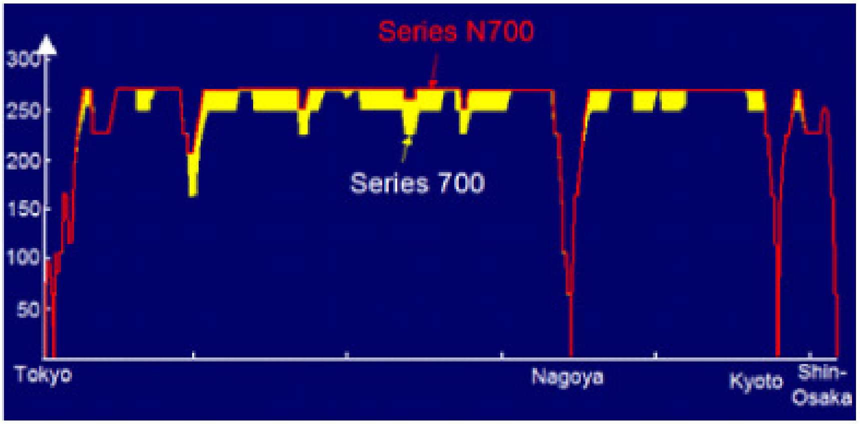
Service	Operator view	Trend for tilt
Regional	Competition from cars, which will be faster door to door independently of tilt	Decreasing 
Long distance	Competition from air or other train operator. Tilt could be important to offer the fastest door to door service	Decreasing 
High speed	Competition from air or other train operator. Tilt could be important to offer the fastest door to door service	Increasing 
Particular cases	Tilt is necessary to reach a certain goal.	Increasing 

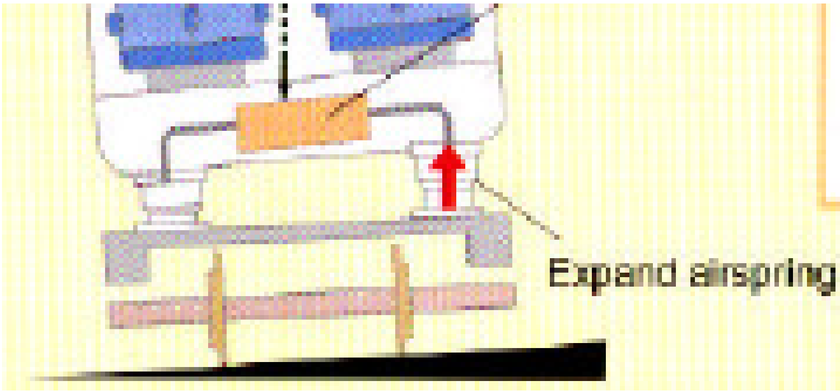
The high speed tilting train

- Requirements on crosswind stability limit the gain for tilt.
  Simpler solutions as pneumatic tilt is sufficient.

Gain: 5 minutes on a 155 minutes ride

Shinkansen N700 with air suspension tilt





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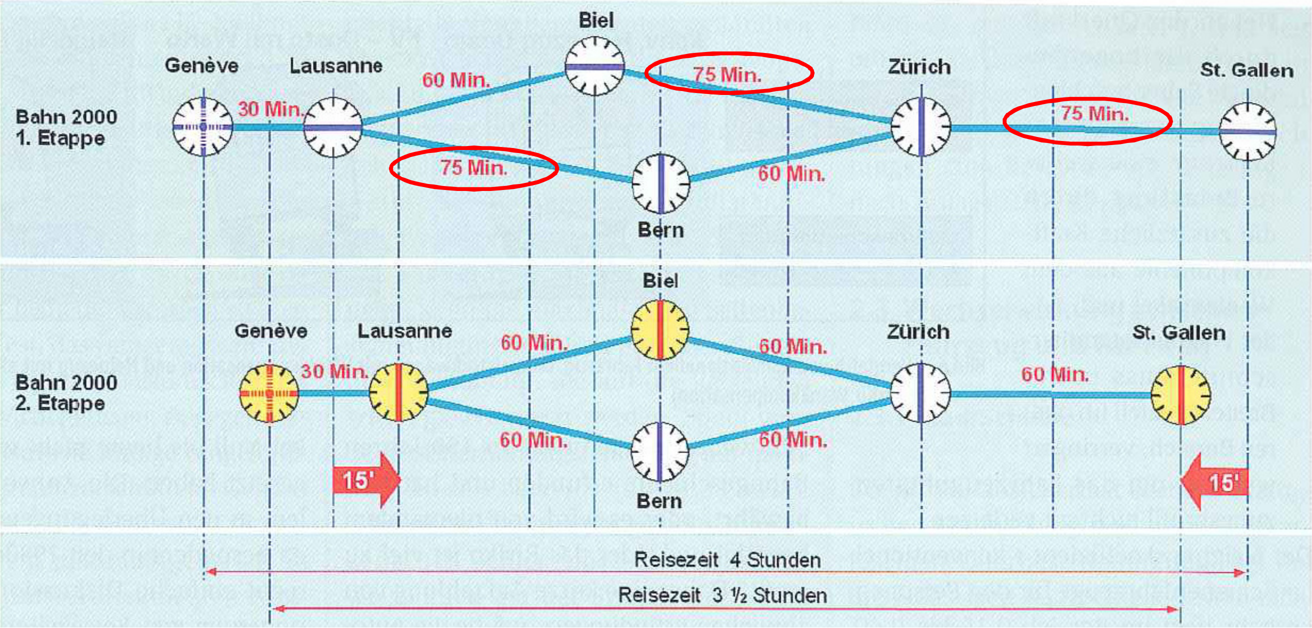
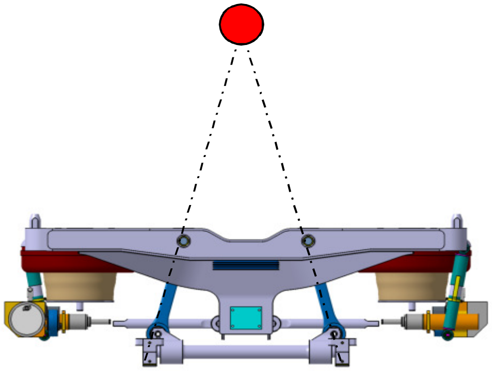
Particular cases motivating tilt

Requirements from running schedules

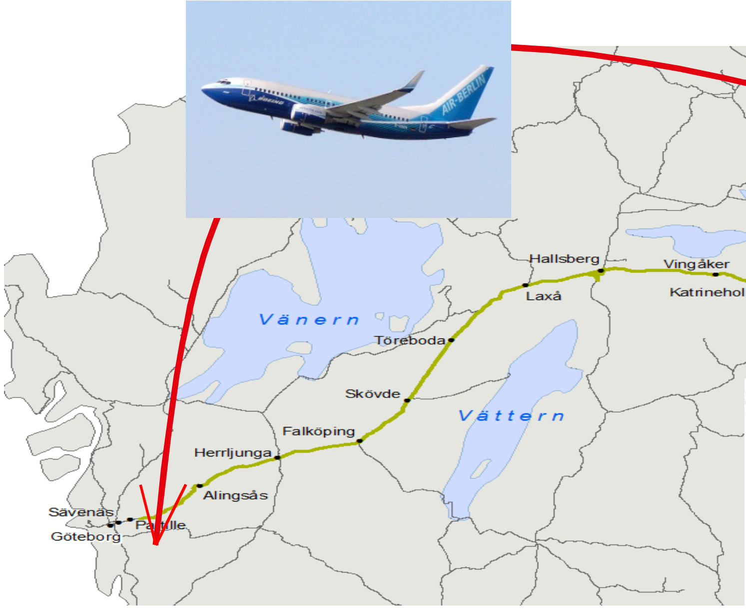



SBB TWX with WAKO

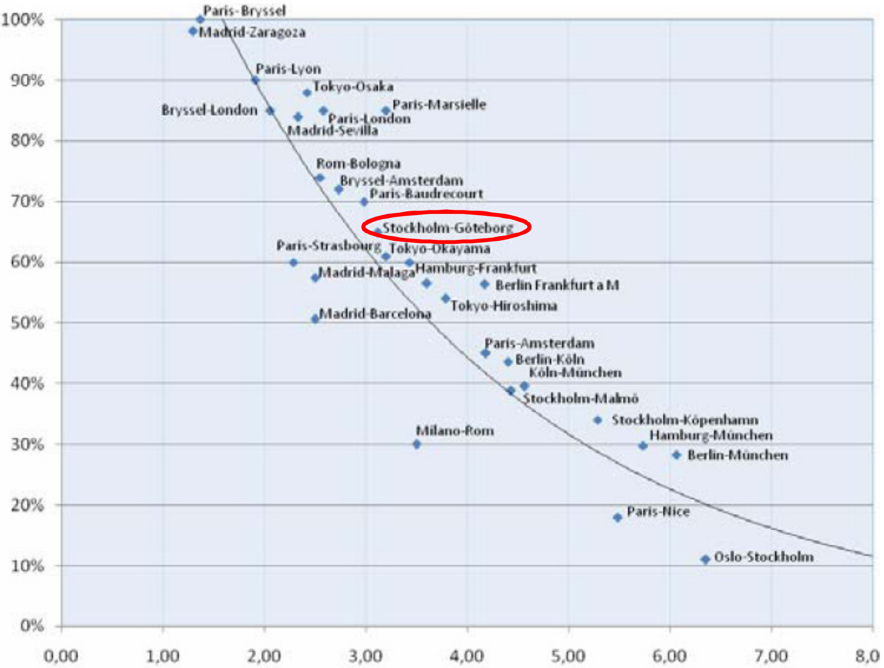


Particular cases motivating tilt

Competition from air



Market share vs travel time for train



Tilt control trends

Controller	Comment
Nulling carbody lateral acceleration	The control loop became slow and gave motion sickness
Bogie lateral acceleration formed the tilt command	The control loop became faster, but delay in leading cars was still a problem
Bogie yaw velocity formed the tilt command	Reduced the delay in leading cars, but track irregularities was still influencing the tilt
Track data base form the tilt command	No influence from track irregularities and perfect timing in alla cars
Compensation variable over distance	Less risk for motion sickness

Track data base form the tilt command

Track data stored on board

Speed

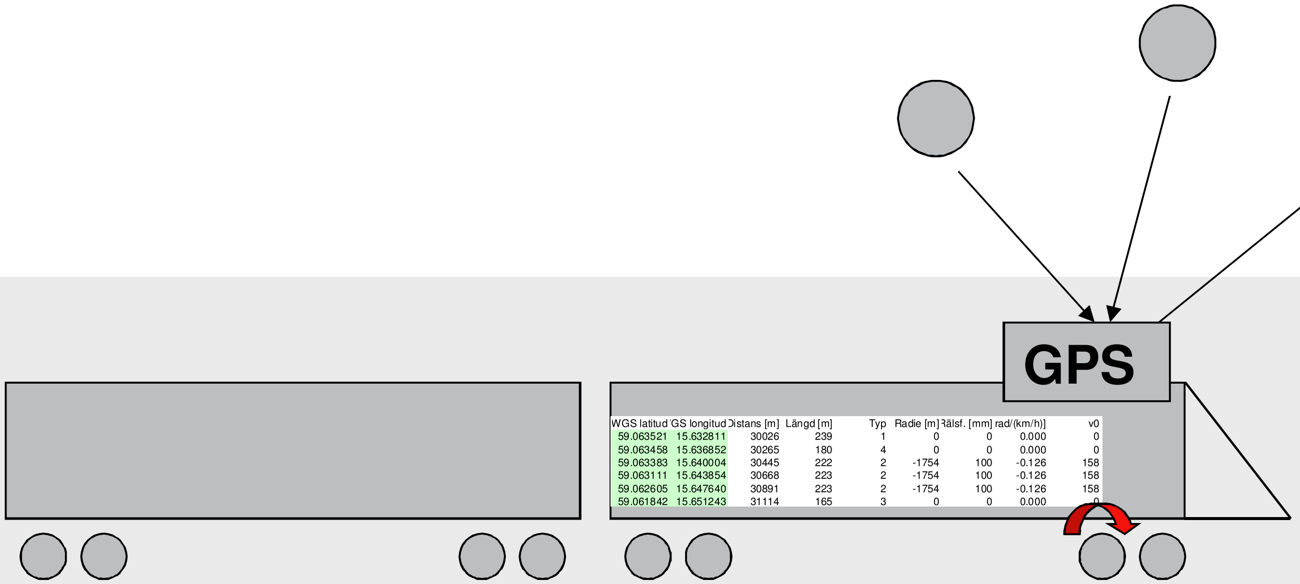
GPS

Satellites

Tilt angle

Position

Position from integrated speed if no GPS



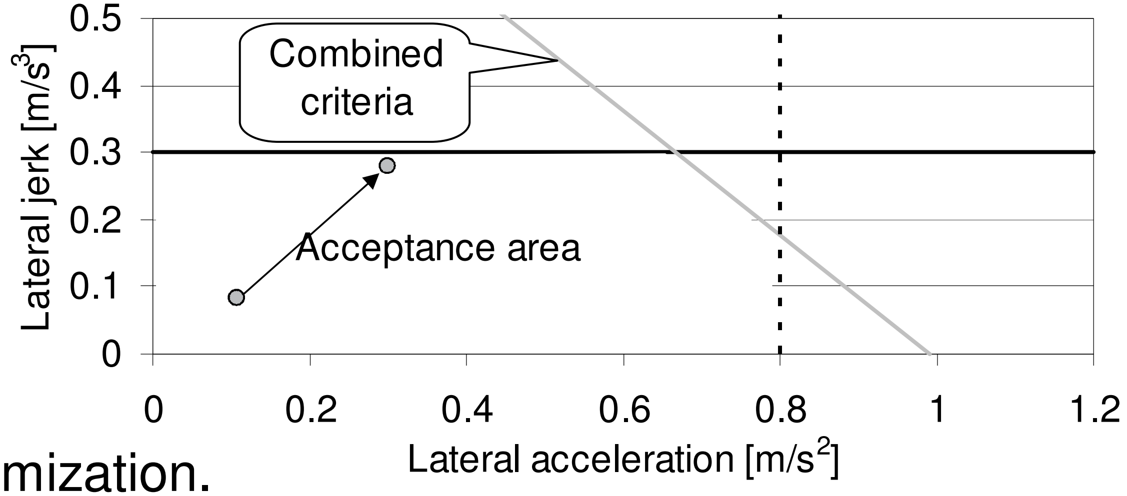
WGS latitud	GS longitud	istans [m]	Längd [m]	Typ	Radie [m]	älsf. [mm]	rad/(km/h)]	v0
59.063521	15.632811	30026	239	1	0	0	0.000	0
59.063458	15.636852	30265	180	4	0	0	0.000	0
59.063383	15.640004	30445	222	2	-1754	100	-0.126	158
59.063111	15.643854	30668	223	2	-1754	100	-0.126	158
59.062605	15.647640	30891	223	2	-1754	100	-0.126	158
59.061842	15.651243	31114	165	3	0	0	0.000	0

Compensation variable over distance

Tilting trains have larger risk to cause motion sickness in sensitive passenger than non-tilting ones -> Let us make the tilting trains more non-tilting like!

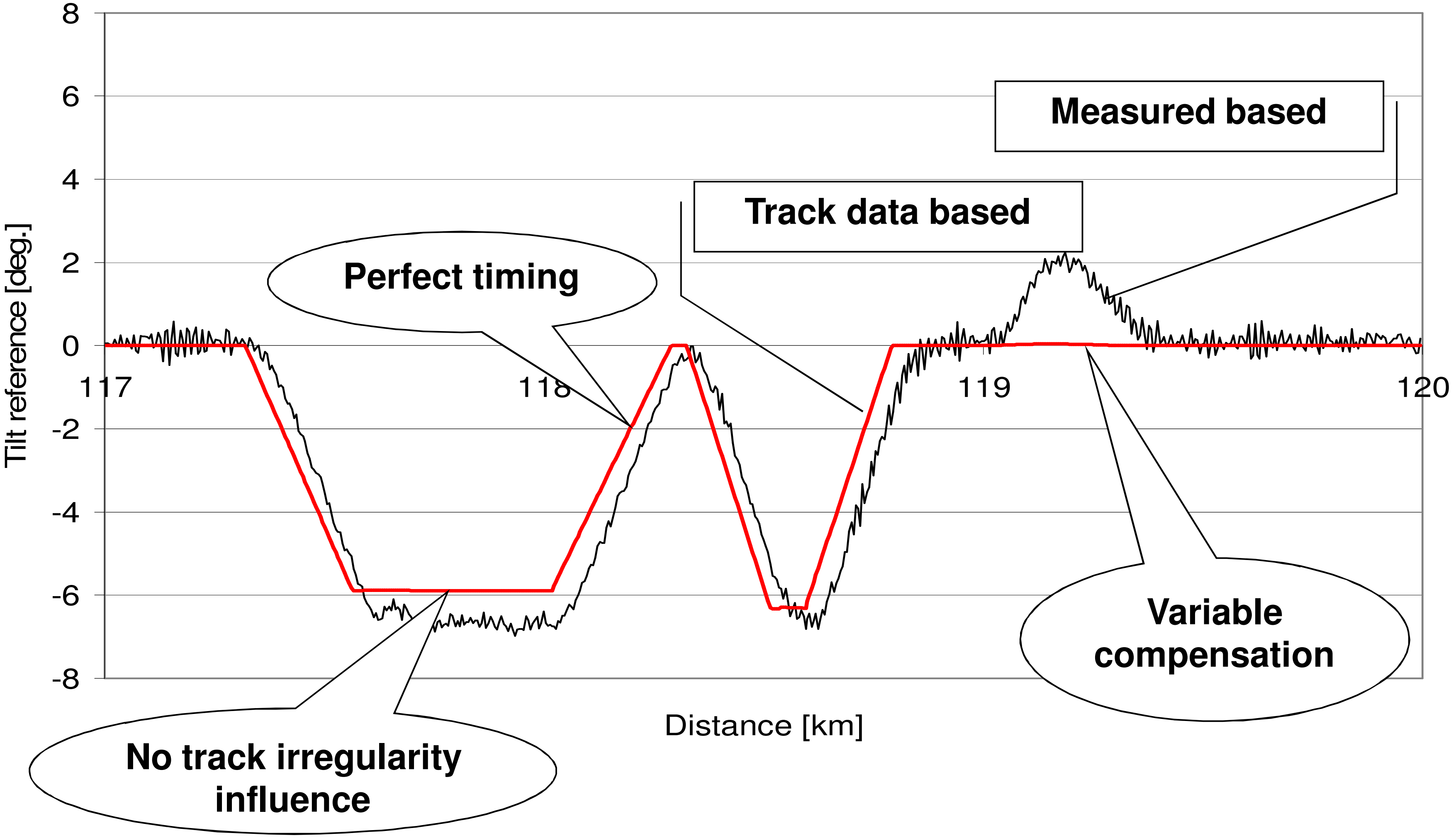
Examples from Stockholm – Gothenburg, all at 180 km/h

Track data			Original control			Optimized control		
Element	Radii [m]	Cant [mm]	$\ddot{y}$ [m/s^2]	$\ddot{z}$ [m/s^2]	$\dot{\varphi}$ [deg/s]	$\ddot{y}$ [m/s^2]	$\ddot{z}$ [m/s^2]	$\dot{\varphi}$ [deg/s]
Transition					2.0			1.0
Circular	5440	25	0.11	0.010		0.30	0.006	
Transition					2.0			1.0



Large potential for further optimization.

On-track test, where track data base form the tilt command and compensation is a function of distance



On-track test results

Tilt command based on track data with compensation variable over distance was tested on-track 2010 with following results compared to the reference case:

- Reduced risk of motion sickness (4 – 19%)
- Improved objective ride comfort (10% on weighted acceleration)
- Subjective ride comfort unchanged

Lateral acceleration perceived by the passenger

1. Most infrastructure managers today allows track plane accelerations for non-tilting trains in the range of 1 m/s^2, which with a 20% suspension flexibility addition gives 1.2 m/s^2 perceived by the passenger.
2. Most tilting trains offer a much lower lateral acceleration perceived by the passenger (SJ2000 has 0.6 m/s^2) and this has been questioned. The on-track tests in 2010 showed that an increase of 0.2 m/s^2 gives 0.2 decrease of the subjective ride comfort on a seven graded scale.
3. Shinkansen N700 and SBB TWX are aiming for the same lateral acceleration for the passengers as corresponding non-tilting trains.

Development trends for tilting trains

Property	Trend
Top speed	⬆
Cant deficiency	↘
Mechanical complexity	⬇
Control complexity	⬆
Lateral acceleration felt by the passenger	⬆
Motion sickness	↘