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IC3 and IC4 Trains Under Risk of Blocking their Wheels

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Publication date:
2015

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IC3 and IC4 Trains Under Risk of Blocking their Wheels

A case study on challenges when working with data from multiple databases

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Big Data, Data Warehousing, and Data Analytics

DTU, August 26, 2015

$$f(x+\Delta x)=\sum_{i=0}^{\infty}\frac{(\Delta x)^{i}}{i!}f^{(i)}(x)$$

Department of Applied Mathematics and Computer Science
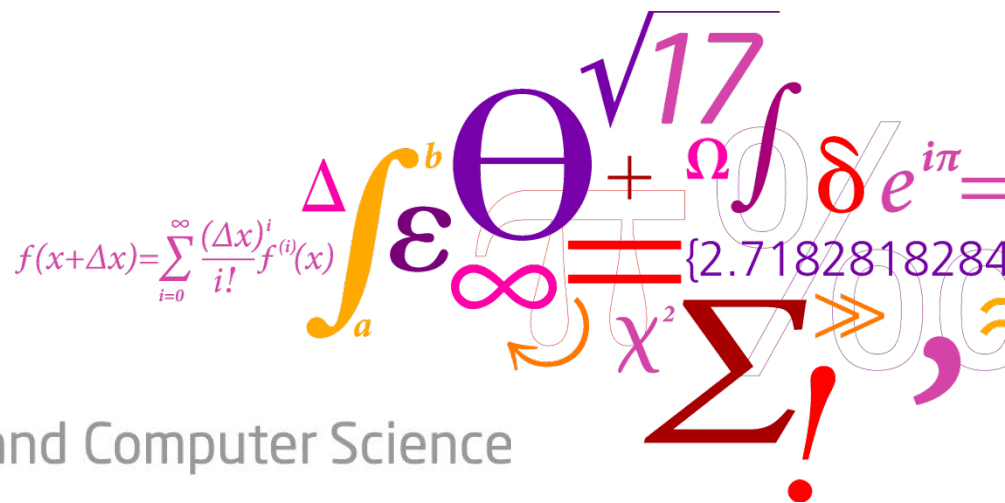
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- Camilla Thyregod

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26/08/2015

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The Marslev Incident

On November 7th, 2011, an IC4 train passed an active stop sign at the Fuenen town Marslev.

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The Marslev Incident

- On November 7th, 2011, an IC4 train passed an active stop sign at the Fuenen town Marslev.

- The train attempted to break, but the wheels blocked.

- From an initial speed of 180 km/h, it took the train 2.800 meters to come to a halt; it passed the stop sign with 651 meters, and stopped just **371 meters** from an anterior freight train.

- Shortly after the Marslev Incident, the Accident Investigation Board was notified of an **additional 3 incidents**, where the train driver experienced problems with an IC4 train.

The Marslev Incident – Consequences

- After the Marslev Incident, the maximum train speed for IC4 trains was lowered to 140 km/h, in contrast to the 180 km/h for the older IC3 trains.

- An investigation was commenced, focusing on the mechanics and the electronics in the IC4 train, in order to clarify whether the braking system was working as it should.

- DTU, including the Section for Statistics and Data Analysis, was involved in this work.

- In August 2013, a report aquitted the braking system of the IC4 trains – it was functioning as it should.

What was then the cause
of the Marslev Incident?

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The Marslev Incident – Consequences

- In the autumn 2012, 30 test rides were performed on the route Copenhagen-Århus.

- Data from the test rides were handed over to DTU Statistics and Data Analysis, with the commision to:

  - Find the cause of the wheel blockings;
  - Investigate if the IC3 and IC4 trains differed wrt. wheel blockings.

- The suspicion gathered around **leaf juice**; leaf juice makes the tracks slippery.

- Method: Analysing the Adhesion Coefficient; a measure for the level of contact between wheels and track.

- However, it turned out the the Adhesion Coefficient could not be calculated from the available data.

Analysis Plan

- The only response that indicated anything about the functionality of the brakes was the so-called blocking flag; the train computer indicating that the wheels are blocking.

- Therefore, the response of the analysis was a given quantity.

Necessary data for this to actually give som reasonable results were identified

Data Base; Train logs:

- Data from train logs for the test rides contained:

- Speed; Time Stamp; Braking Power; Blocking Flag Status.

Speedplot for train 3
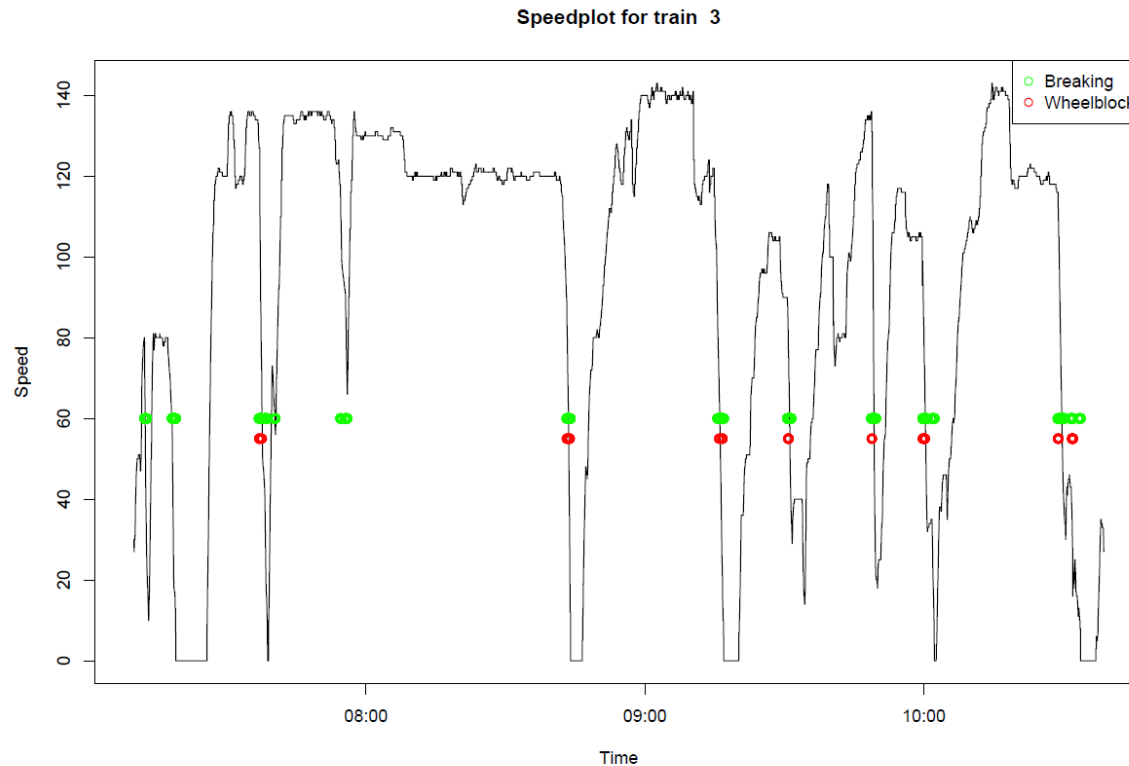
Data Base for Statistical Analysis

Indexed by time

- Train logs;
- GPS logs (position);

- Records of vegetation along the rail track;
  - **forest**, **bushes** and **solitary trees**.
- The Curve register;
  - **curvature**.

Indexed by distance to Copenhagen H.

- The route register (coordination of time and position);
  - Distance to Copenhagen Central Station.
- Extracts from the track register – to assess which track on the route that the train was running on.
- Register data for **elevations/recesses**

- Meteorological data fra DMI (environmental conditions);
  - **temperature**, **dew point**, **wind speed**, wind direction, **turbulence**, **precipitation** og **solar radiation**.
  - Within the last hour, and accumulated over 3, 4, 5, 6, 7, 8 and 24 hours.

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Train Ride Data

Date 2012:	29/10	31/10	2/11	6/11	7/11	13/11	19/11	20/11	23/11	28/11	29/11	All	Used
Number of IC3 train rides:	2	2*	2	1*	2*	2*	2	1	1	2	2	19	15
Number of IC4 train rides:	1	1	1	1	1	1	1	1	1	1	1	11	11
Total number of train rides:	3	3*	3	2*	3*	3*	3	2	2	3	3	30	26

* : One of these train rides were not used in the analysis.

Train Data:

Train type	Log files	Minimum	Mean	Maximum	Time spent	Data per second:
IC3	19	1378	2466	3601	4.72h	1/7
IC4	11	31318	39721	45225	3.53h	3.1

GPS Data:

Train type	Log files	Minimum	Mean	Maximum	Time spent	Seconds between data:
IC3	19	250	369	428	4.72h	46
IC4	11	188	269	380	3.53h	47

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Messy Data I

Data for train-log:
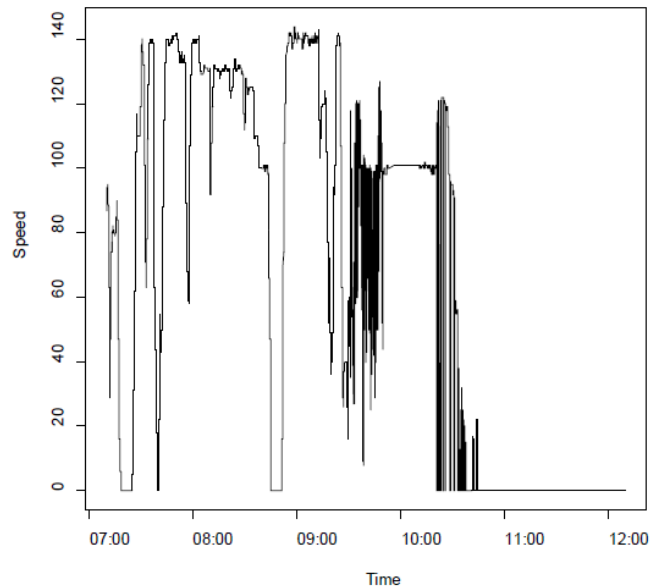
Here plotted sequentially from the dataset:

Time shifts
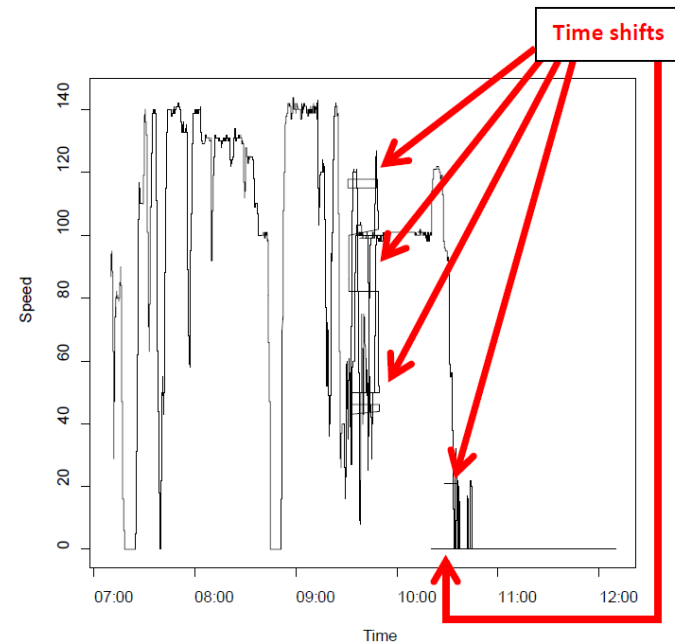
Comment from the date provider:

"Anders har ret. Tiden går baglæns. Jeg har ikke nogen forklaring på det"
("Anders is right. Time goes backwards. I have no explanation of it")

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Cleansing the Speed Profiles

Differenced Time Stamps, Train 12

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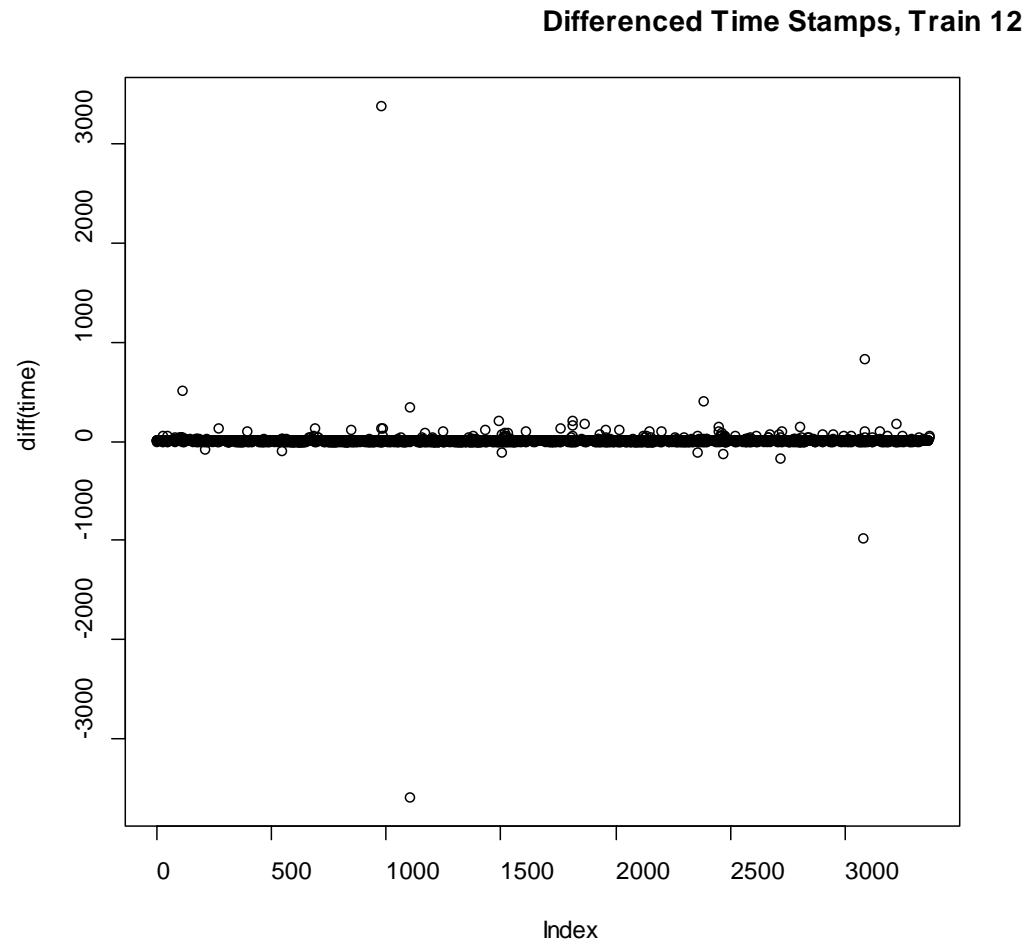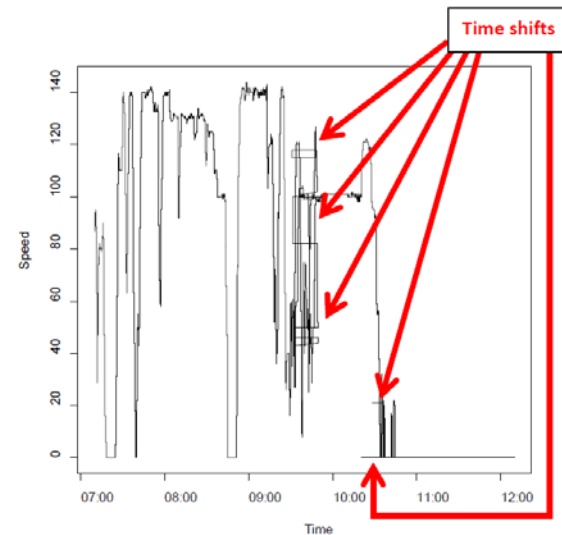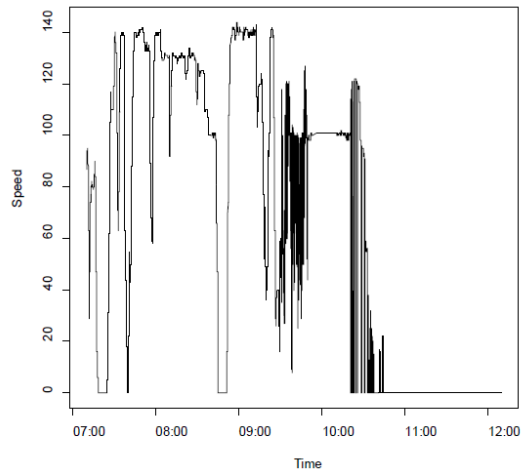
Messy Data I

Cleansed Speed profile:

113 corrections for time
shifts unaccounted for.

Messy Data II

The position, and thus the traveled distance, from the DLU log is unreliable, in particular because of uncertainty about the time variable, and also in the case of braking/slipping.
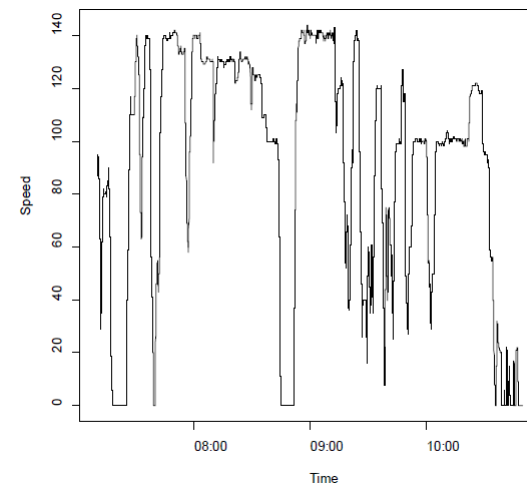
Position should be derived from GPS data –

But – typically there is only a few hundred GPS points from Copenhagen to Århus – and 328 km.

Impossible to re-create position from interpolation between GPS points – already at Glostrup, a shortfall of 500 meters is seen.

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Messy Data II

Time	TrainNumber	Litra	Type	lon	lat	Delay	Speed	OprTogNr	totTime
2012-11-02 06:59:56	121	5006	København H	12.56605	55.67148	0	0	121	2012-11-02 06:59:56
2012-11-02 07:00:57	121	5006	København H	12.56605	55.67150	-57	0	121	2012-11-02 07:00:57
2012-11-02 07:01:48	121	5006	GPS_Afgang: København H	12.56615	55.67140	-108	10	121	2012-11-02 07:01:48
2012-11-02 07:02:49	121	5006		12.56344	55.66677	-153	40	121	2012-11-02 07:02:49
2012-11-02 07:03:49	121	5006		12.54796	55.66324	-159	78	121	2012-11-02 07:03:49
2012-11-02 07:04:50	121	5006		12.52604	55.66356	-150	96	121	2012-11-02 07:04:50
2012-11-02 07:05:10	121	5006	Station: Valby	12.51664	55.66363	-130	114	121	2012-11-02 07:05:10
2012-11-02 07:06:10	121	5006		12.48085	55.66430	-119	149	121	2012-11-02 07:06:10
2012-11-02 07:06:37	121	5006	Station: Hvidovre Fjern	12.46241	55.66462	-97	159	121	2012-11-02 07:06:37
2012-11-02 07:07:37	121	5006		12.42151	55.66512	-82	136	121	2012-11-02 07:07:37
2012-11-02 07:08:13	121	5006	Station: Glostrup	12.40213	55.66340	-73	119	121	2012-11-02 07:08:13
2012-11-02 07:09:14	121	5006		12.37029	55.65982	-81	128	121	2012-11-02 07:09:14

For positioning, we use that we know WHEN you are at a station – 40 reference points on the Copenhagen-Århus, which exists in the route register. Using these, we can fix the time points of the remaining GPS points, relative to the train logs, and calculate positions using great circle distances.

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Track Lanes

- Necessary information to decide the curvature.
- Always use the right track we were told; but

Figure 1: Track lanes around Toftegårds Alle near Valby Station. Source: Krak®/Eniro Danmark A/S.

- After presenting this picture, a new dataset with 'most probable track' was constructed, for curvature measurements.

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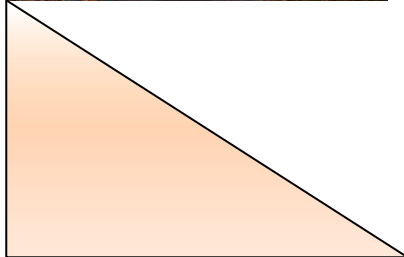# What explains variations in Blocking Flags?

-**Slippery tracks**;

- **Vegetation**;
- **Weather**;

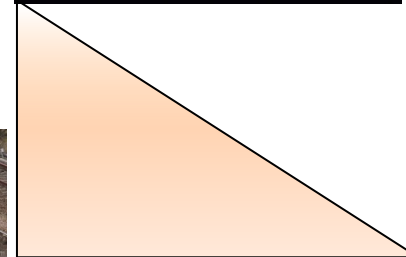-**Track and Train characteristics**;
INTERACTIONS between these.

Construction of the local Leaf Fall Index:
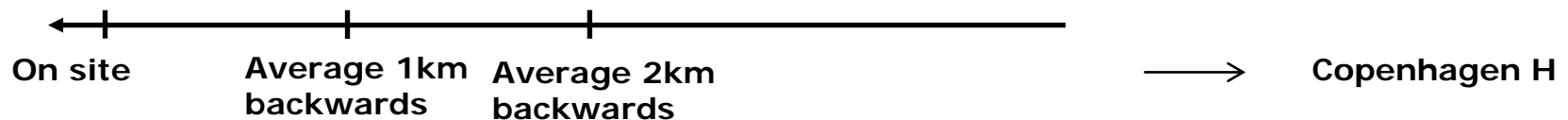# The Thickness Index T

Forest

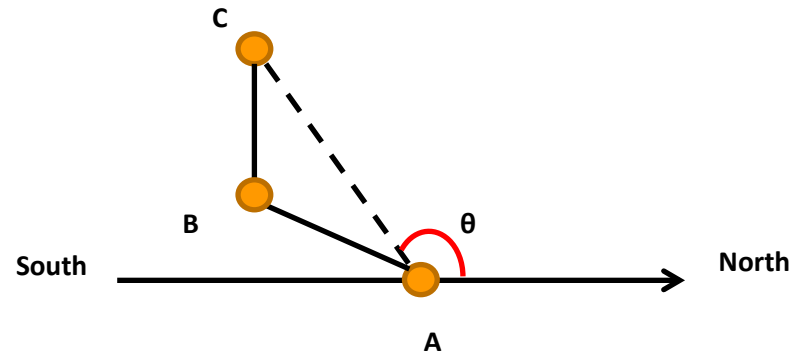**Bushes**

30m

10m

Forest:

30 meters thickness: T=1.   15 meters: T= 3/4. 10 meters: T= 4/9.

On site

Average 1km backwards

Average 2km backwards

$\longrightarrow$ **Copenhagen H**

Construction of the local Leaf Fall Index

- Track angle θ_T i punktet B:

- Let θ_W denote the angle between the immediate wind direction and the north-south axis, and and let T_R, T_L be the Thickness Index to the left and the right of the track, respectively.

- **The Leaf Fall Index** *I* is then constructed as

$$I_F = |\sin(\theta_W - \theta_T)| \big(T_R 1_{\{\sin(\theta_W - \theta_T) < 0\}} + T_L 1_{\{\sin(\theta_W - \theta_T) > 0\}} \big)$$

- Full effect if the wind is perpendicular to the rail track, no effect if it is parallel.

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Local Leaf Fall Index

Vegetation	Direct position		500 meters back		1 km back		2 km back	
	%positive	Mean	%positive	Mean	%positive	Mean	%positive	Mean
Forest	11%	0.23	22%	0.13	31%	0.09	46%	0.07
Bushes	4%	0.27	11%	0.14	12%	0.08	14%	0.05
Trees	0.1%	0.70	4%	0.04	4%	0.02	4%	0.01

	% positive	Minimum	Mean	Maximum
Elevation	32%	0.001	4.00	18.33
Recess	21%	0.007	4.40	30.12

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Local Leaf Fall Index

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Forest	11%	0.23	22%	0.13	31%	0.09	46%	0.07
Bushes	4%	0.27	11%	0.14	12%	0.08	14%	0.05
Trees	0.1%	0.70	4%	0.04	4%	0.02	4%	0.01

	% positive	Minimum	Mean	Maximum
Elevation	32%	0.001	4.00	18.33
Recess	21%	0.007	4.40	30.12

Should be combined with a continuous leaf fall index that measures the rate that leaves fall off the trees as a function of calendar time.

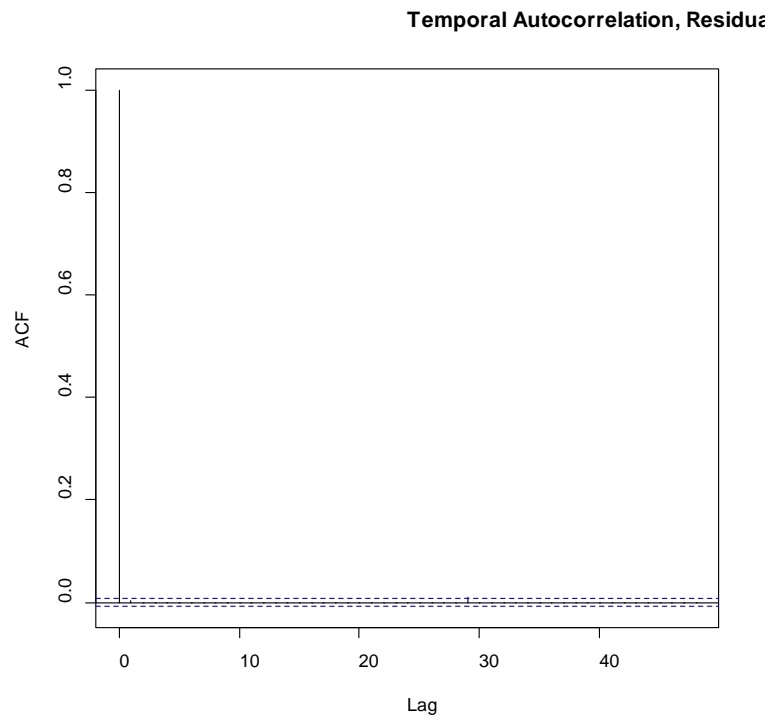But such knowledge do not exist (Forest & Landscape, University of Copenhagen 2013, personal communication).

To rectify this, we used polynomial regression on calendar time.

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Blocking Sequence

- If first a wheel blocks, the system reacts slowly to changing circumstances.

- The problem is handled by introducing a blocking sequence indicator, which indicates that the train had issued a blocking Flag at the previous recorded position.

- Of course, this is incompatible with the principle of independence between observations. However, it does comform with the notion of conditional independece given the past, which will do for the mehtods that we apply.

- This introduction is necessary, since the IC4 trains records far more data points the the IC3 trains, and therefore also far more blocking flags, sincs a blocking flag will be followed be a blocking sequence.
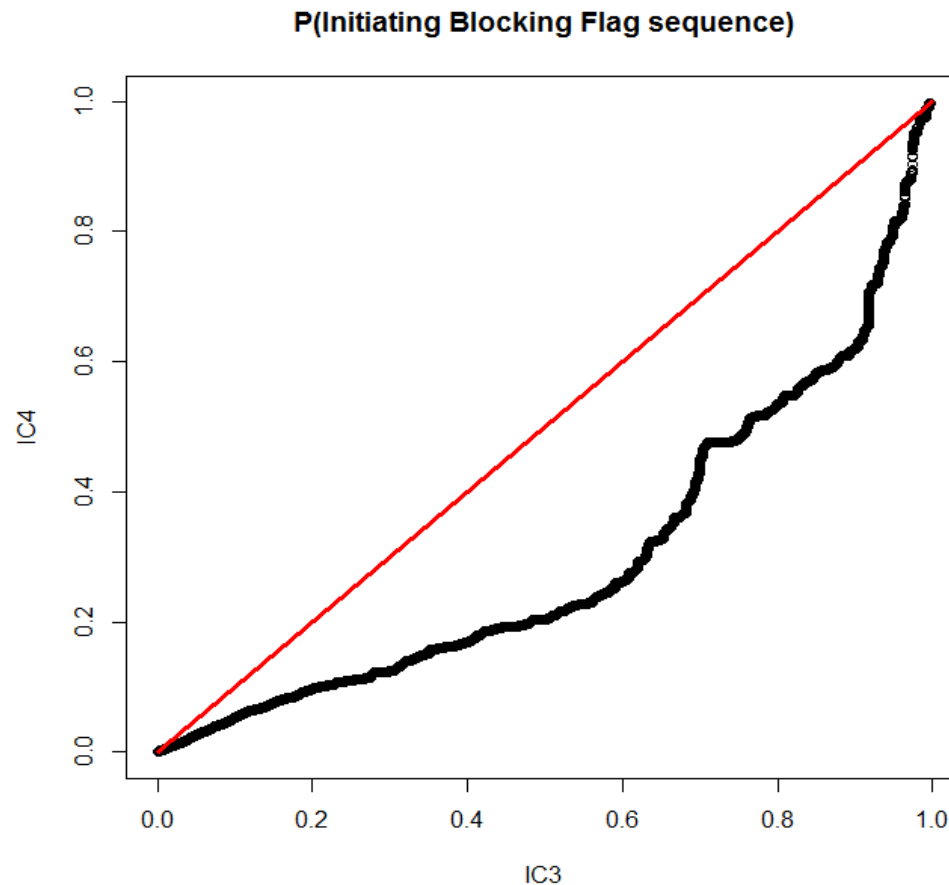
Analysis

$$\text{logit}(p(\text{initiating blocking Sequence})) \sim \beta^T X$$

Temporal Autocorrelation, Residual

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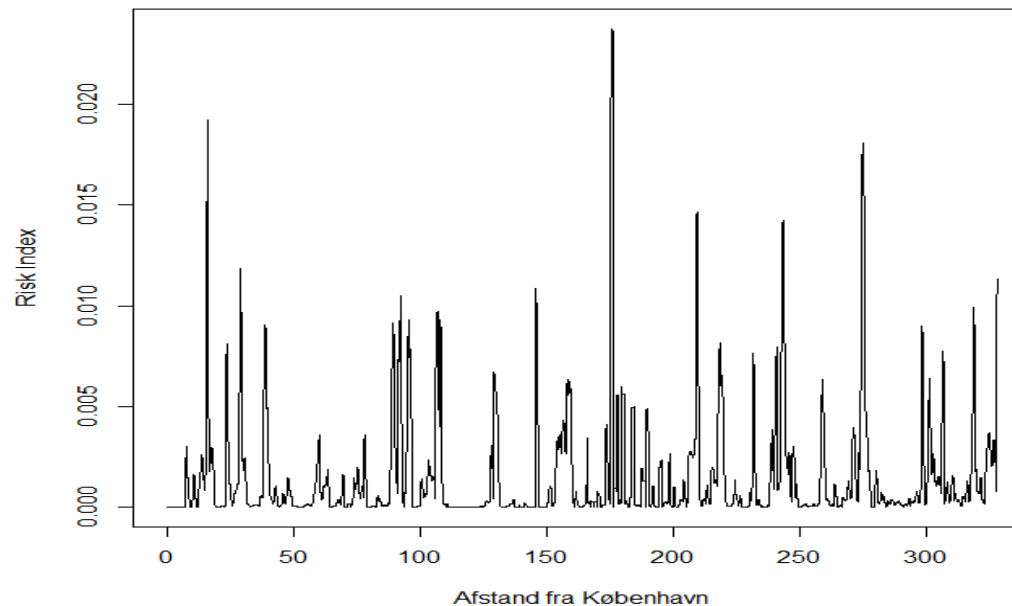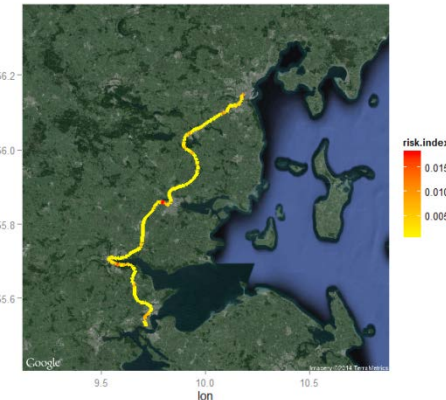Colloquium in Mathematics and Computer Science, DTU

IC4 vs. IC3 trains
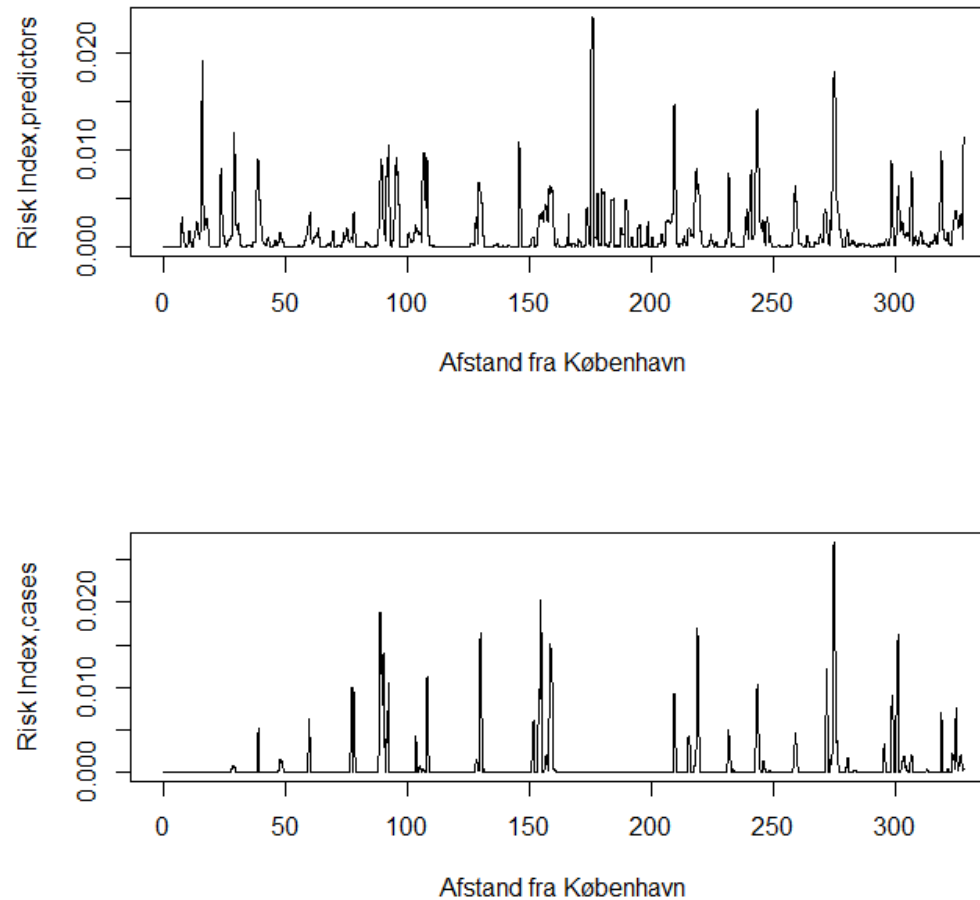
- Predict probabilities for all test rides, assuming a constant speed of 140 km/h, and IC3/IC4 status. Inversed linear predictors:
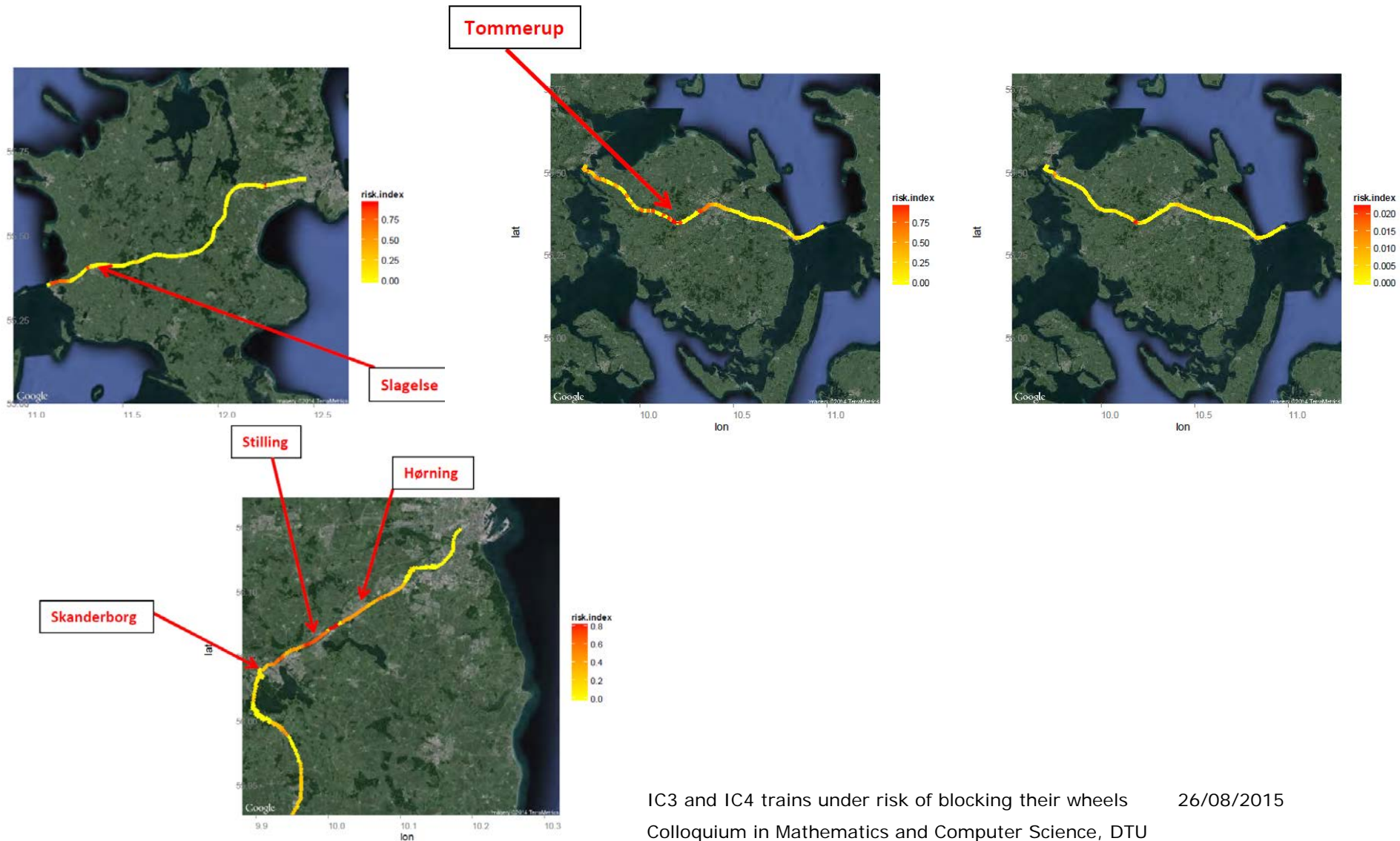
P(Initiating Blocking Flag sequence)

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Smoothed Risks

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Risks vs. Cases

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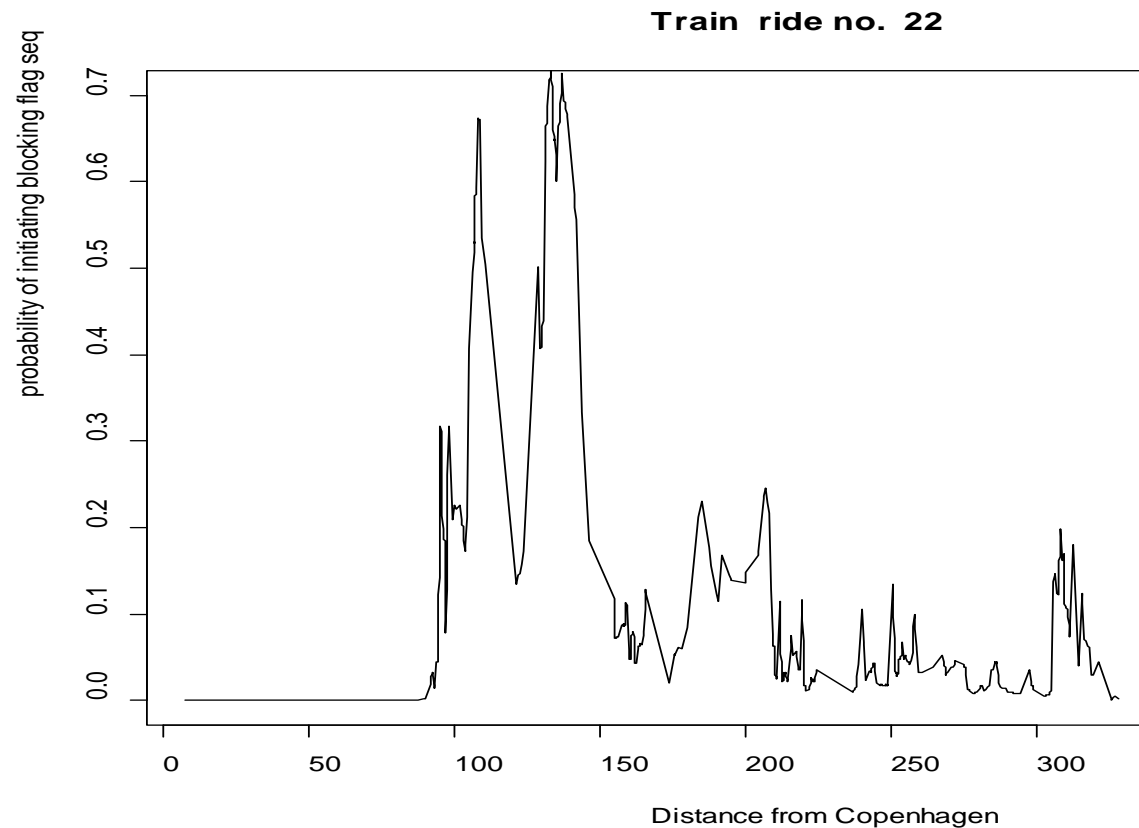
Constant Speed 180 km/h, Braking Power 2.6

Constant Speed 180 km/h,
Train Ride 22

Train ride no. 22

Distance from Copenhagen

probability of initiating blocking flag seq
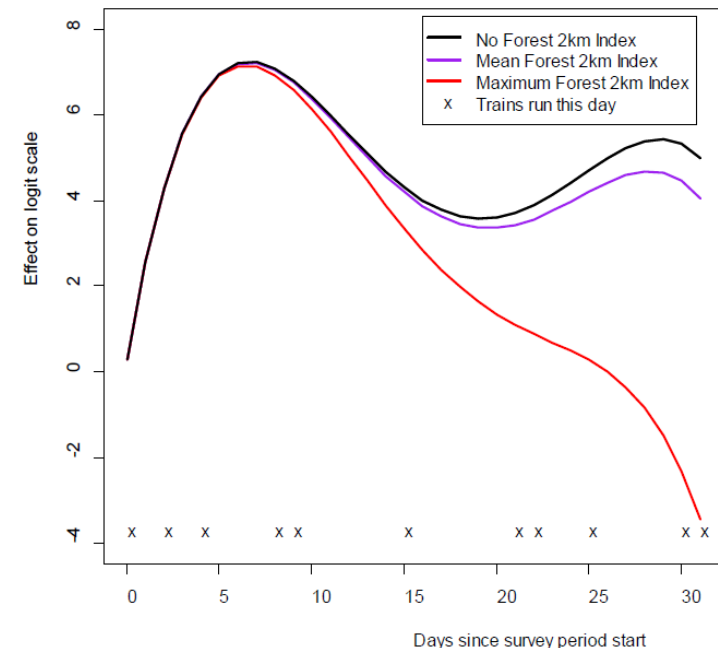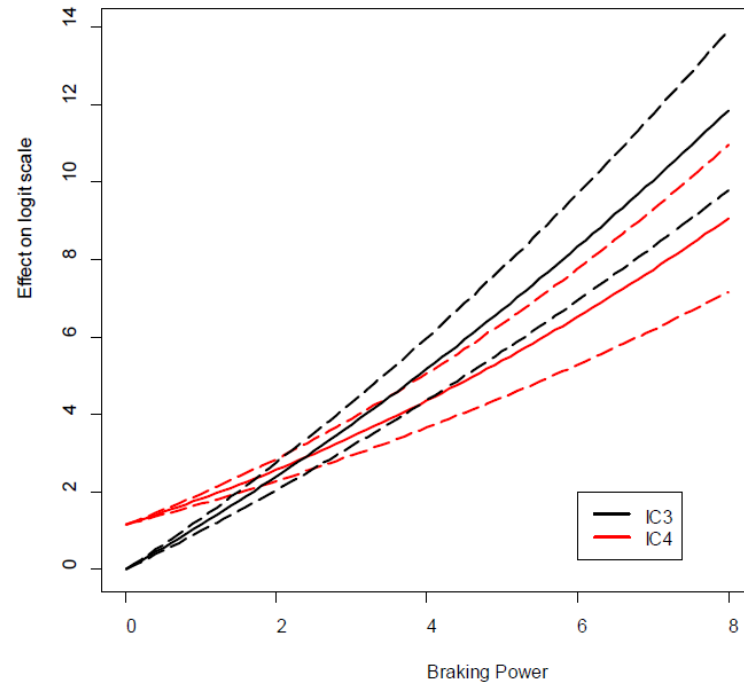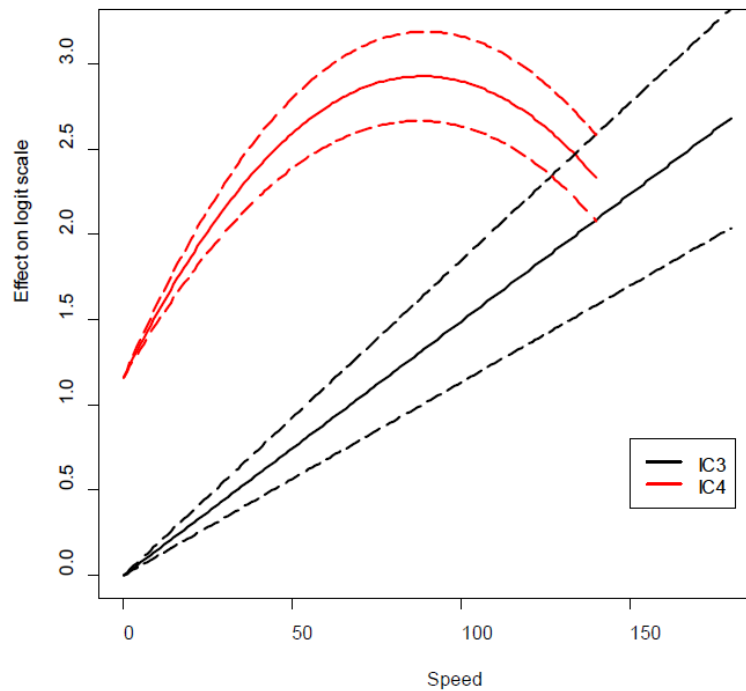
Effect of Leaf Juice

- Both Leaf Fall Index for forest and bushes are statistically significant; on site, 1km back and 2km back.

- Solitary trees are not signifikant.

- The effect declines with calendar time; the amount of leaves becomes less.

- Leaf Fall Index interacts with
- meteorological covariates at large.

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Effects of Speed and Braking Power

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How about the Marslev Incident?

- We managed to obtain information on the Marslev Incident.

- However, the environmental circumstances were so extreme compared to our test rides, that the probability of a initiating a Blocking Flag Sequence was just 1, 1, 1 and always 1.

- Thus, we cannot claim to have modeled the event, but it is clear that the conditions were indicating extremely slippery tracks.

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Conclusion
1.

A. The low number of GPS positions relative to the number of data points constitutes a problem. Since position is based on GPS data, position, and thus track characteristics, vegetation and meteorological data are subject to uncvertainty. This lowers the validity of the study results.

B. The Speed Profiles are faulty. While we do not believe that this play a role, we cannot say for sure. A large amount of missing data also adds to the picture of a deficient data base.

C. Data are collected on a limitied number of days. In fact, the applied data are from only 11 different days, and this limits the possibility for generalising the results. Additionally,we cannot generalize the result to outside the leaf fall period.

D. The combination of many different databases present challenges in data handling and interpretation.

Conclusion
2.

A. The probability of initiating a Blocking Flag Sequence is affected by slippery tracks.

B. One of the factors that contributes to tracks slipperiness in the trial period is leaf juice.

C. Data are based on too many approximations to deliver results with sufficient evidential weight.

D. For the same reason we cannot conclude that the IC3 and IC4 trains are different, even though there is evidence that they have different probabilities of initiating Blocking Flag sequences.

E. Should the problems with data resolve themselves, it is our opinion that the method may be generalized beyond the leaf fall period.

F. For further development, one of the perspectives is an early warning system in the train traffic.

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