Energy-efficient timetabling at NS

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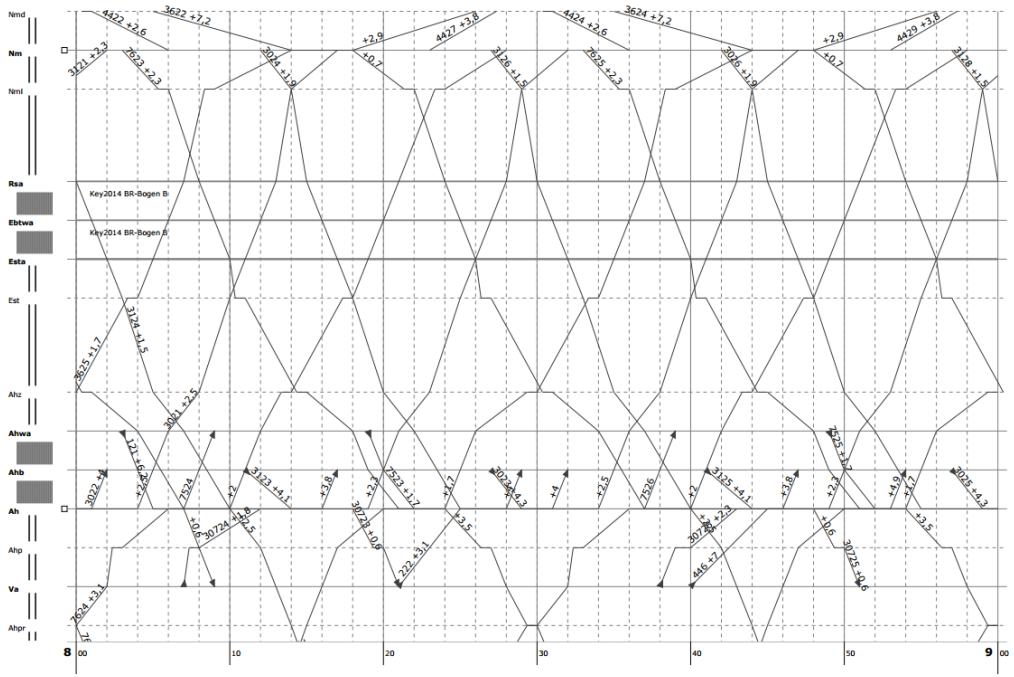


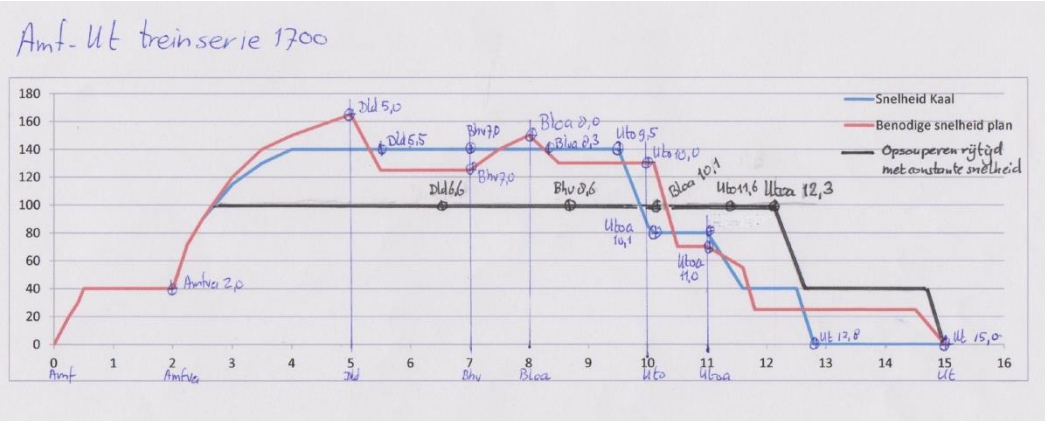
Introduction

- Current timetable is not always conflict-free and realizable for train driver
- There is a need to improve our current way of timetable design:
  - Improve on-time running
  - Increase capacity
  - Decrease energy consumption
- Different projects to improve our timetable design methodology:
  - Project DINT
  - Project running times
  - RailwayLAB research
  - PhD research on EETC & EETT

Project DINT (1/5)

- Current timetable is developed and delivered in full minutes
- For improving on-time running, timetable fractions for train drivers (arrival) and train conductors (departure) should be separated and on smaller intervals
- Develop timetable in 1/10 min (6 s) accuracy
- Better for executing the timetable by train drivers and train conductors & provides more realistic slack time distribution

TP	Act	Com	Sched	Sup
Amf	V	10.0	10	
Amfva	D	12.2	12	0.0
Dld	D	15.8	15	-0.5
Bhv	D	17.3	17	0.5
Bloa	D	18.6	18	-0.3
Uto	D	19.9	20	0.8
Utoa	D	20.6	21	0.4
Ut	A	23.4	25	1.3



Project DINT (2/5)

- By-pass in timetable design process (only 2-monthly amendments) since 2016 (Viriato/DONS)
- Pilot with Smart Watch for train conductor to departure exactly on time, counter starts at 35 s and disappears at 15 s
- Current research: project PINT (planning in Donna in 1/10 min)
- Energy savings only DINT: 2% in 2016
- More energy savings achieved combined with DAS RolTijd App at least 4% extra (up to 6%)

Project DINT (3/5)

Example

Current timetable in full minutes

```
HC   UT      610     di 13-jan-2015
17:45     01:45            8:00
Soort        Trein      Van      Tot
*                       Ut       Ut
              6069      Ut       Tl
              6070      Tl       Ut
RBCRes                  Ut       Ut
```

Difference with current timetable

1. Planned times in s
2. Short stops divided into arrival and departure
3. Some arrivals are earlier
4. Extra information (dwell time, running time, supplements, speed advice, etc.)

```
*
Ut          18:20
Ut          18:55
---------------
            6069
Ut        V18:55
Utl       +18:59
Htn       +19:04
Htnc      A19:07
Htnc      V19:09
Cl        +19:15
Gdm       A19:21
Gdm       V19:23
Tpsw      +19:31
Tl        A19:35
---------------
            6070
Tl        V19:51
Tpsw      +19:54
Gdm       A20:03
Gdm       V20:07
Cl        +20:13
Htnc      +20:19
Htn       +20:22
Ut        A20:30
---------------
RBCRes
Ut          21:00
Ut
```

Improved timetable with 1/10 minutes

1

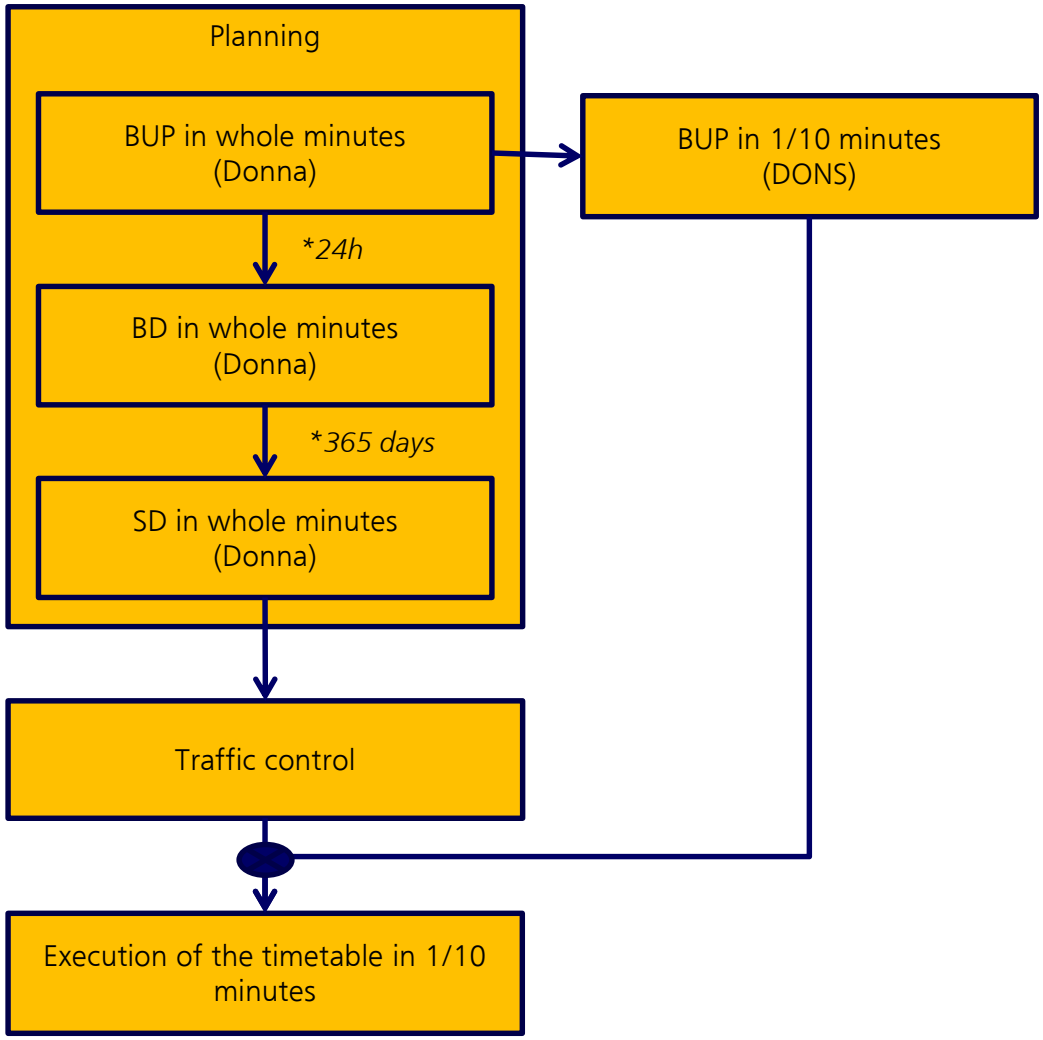
4. 6000 oneven

patroon tweede halfuur

	SLT		km	Dienstregeling		Rijtijd/ Halteertijd	Buffer	Opmerkingen	Rijadvies
	Ut	V		x 55					
	Utva	D	36.5	x 57		1 36	24	Doorkomst na 3500 ri Hrl	1x 80
	Utl	A		x 59	12	2 00	12		
2.	Utl	V		x 59	54	42			1x 85
3.	Htn	A		x 03	24	3 18	12		
2.	Htn	V		x 04	06	42			1x 70
3.	Htnc	A		x 06	36	2 18	12		
	Htnc	V		x 09		42	1 42	Wachten op vertrektijd; vertrek na patroonmatige goederentrein	
3.	Cl	A		x 15	06	5 06	1	Overmatige buffer ivm patroonmatige goederentrein	
2.	Cl	V		x 16		54			
	Gdma	D	24.6	x 19	42	3 42		Geen buffer, doorkomst kort voor 800 ri Mt	
	Gdm	A		x 21		1 24	-06	Te krappe rijtijd; aankomst kort voor 800 ri Mt	
	Gdm	V		x 23		42	1 18	Wachten op vertrektijd ivm kruisen Wnn	1x 100
	Wnn	D	37.3	x 29		5 36	24		
3.	Tpsw	A		x 30	30	1 24	06		
2.	Tpsw	V		x 31	24	54		Stop/doorschakeling	1x 80
3.	Tl	A		x 34	54	2 48	42		

Project DINT (4/5)

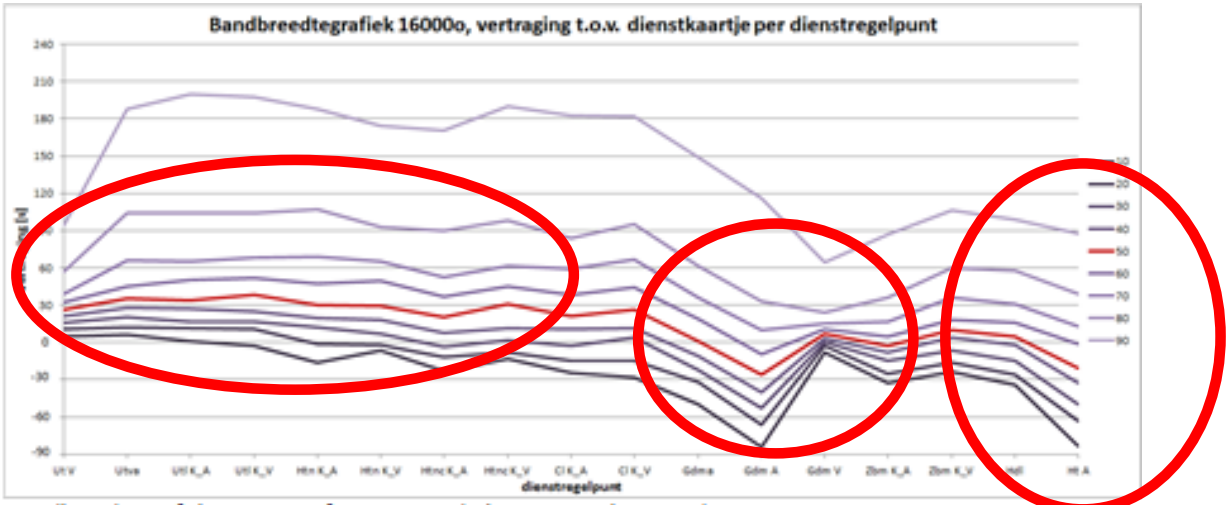
Process with “by-pass” to generate 1/10 min timetable



Project DINT (5/5)

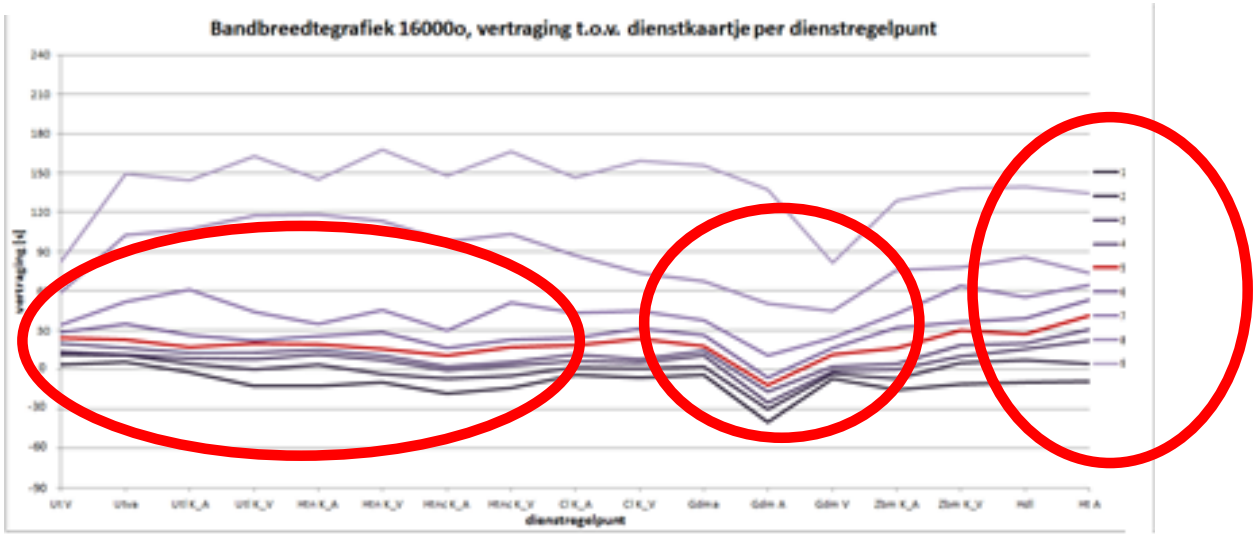
Results

Full minutes



Bandbreedtegrafiek 16000o, referentieperiode (1 -7 september 2014).

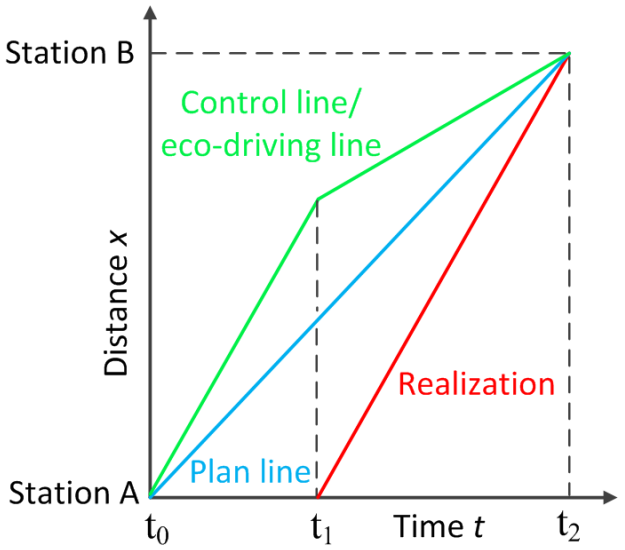
1/10 minutes



Bandbreedtegrafiek 16000o, treinen die deelgenomen hebben aan de proef.

Project running times

- Investigate how to compute running times and slack time
- Computation of running times:
  - Minimal
  - Total with slack time
- Computation of slack time:
  - Amount
  - Distribution
- Current results:
  - Use smaller time fractions for timetable (1/10 min)
  - Minimal running times: MA, CR (speed limit), MB (0.5 m/s^2)
  - Apply 8% slack time without rounding to full minutes
  - Distribute slack time equally over trajectory

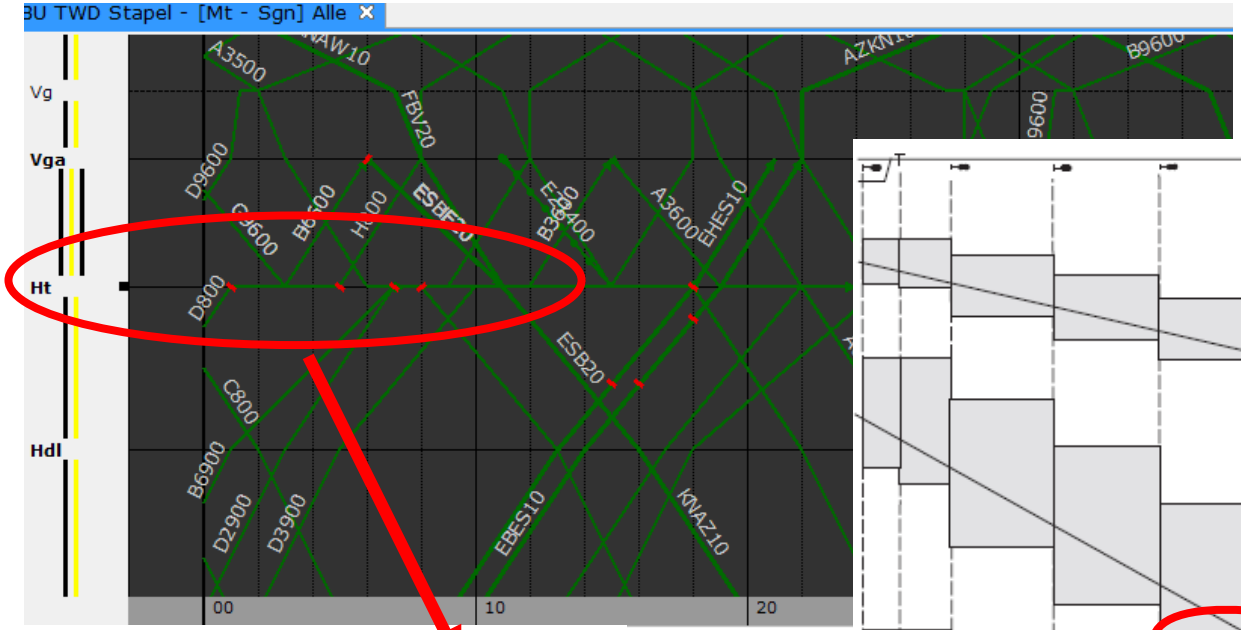


RailwayLAB (1/2)

- RailwayLAB: ProRail + NS innovation departments
- Focus: serious gaming, simulation and planning
- Planning in seconds instead of full minutes
- Timetable performance indicators (start with feasibility)
- Checking both scientific research + market consultation + European infrastructure managers & train operating companies
- Result: focus on microscopic timetable design & simulation
- Pilot with RailSys:
  - Aim: gain insight into microscopic timetable design and simulation and compare this with current timetable design process
  - Active participation of timetable planners NS on case Oude Lijn
  - Comparing conflict detection based on norms vs. block overlap
  - Analysing effect conflicts with deterministic simulation

Intermezzo: conflict detection (macro vs. micro)

Macroscopic: detection at timetable points based on norms (headway times) by Donna



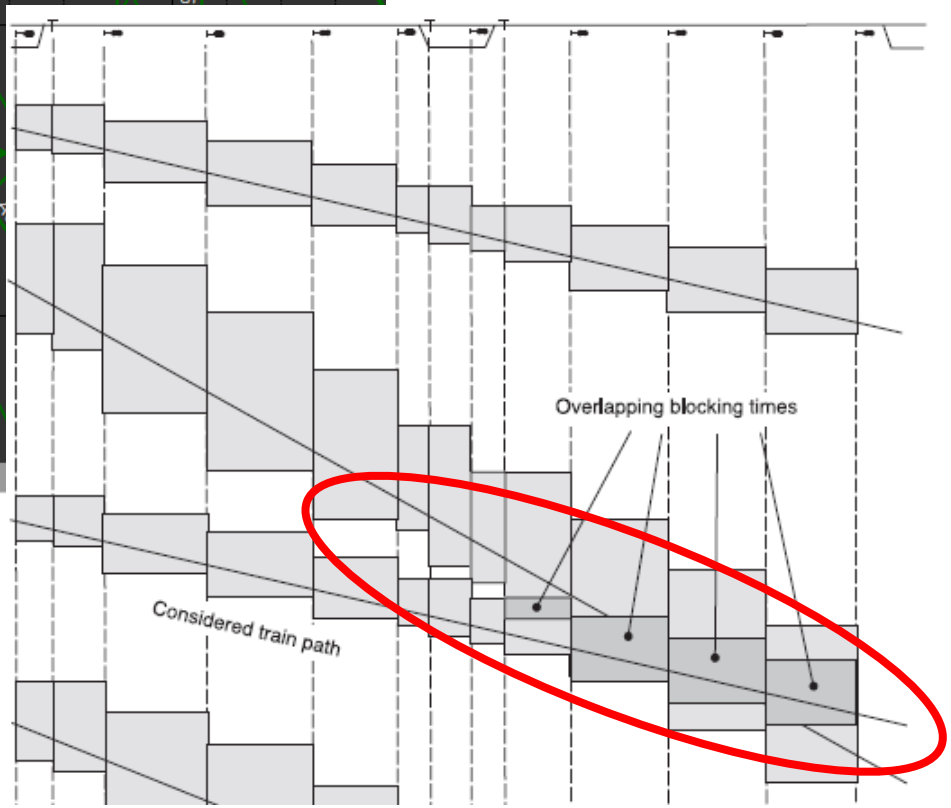
Tabel 1 Opvolgtijd in minuten

Tabel 2 Overkruistijd in dezelfde richting in minuten

Tabel 3 Overkruistijd in tegengestelde richting in minuten

Activiteit 1e trein		Activiteit 2e trein			
		A	D	K	V
	aankomst (A)	3	2	1	1
	doorkomst (D)	4	3	4	1
	korte stop (K)	6	5	6	1
	vertrek (V)	6	5	6	2

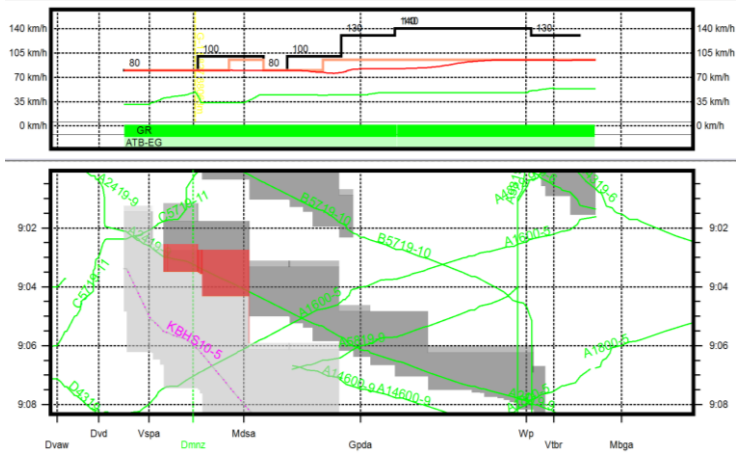
*



Microscopic: detection based on block occupation

RailwayLAB (2/2)

- Direct feedback with RailSys whether timetable is feasible by checking conflicts and speed profile
- Insight in effect distribution running time supplements for train driver
- Possibility for planners to apply deterministic simulation to see effect of possible conflict
- Potential: compute energy consumption of developed timetable
- Improvement DONS: including block occupation + conflict detection



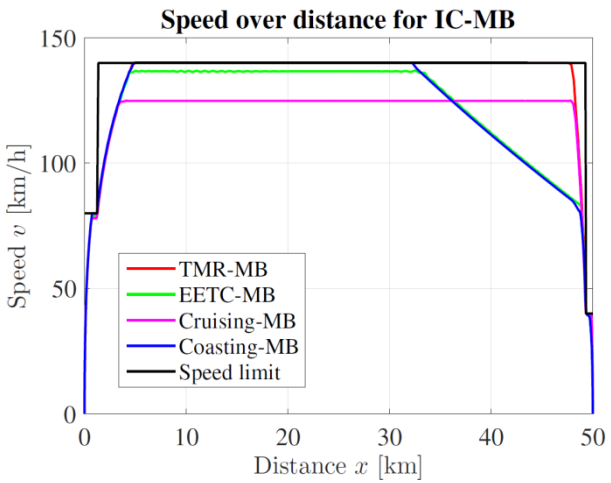
PhD research on EETC and EETT

- PhD research about energy-efficient train control (EETC) and energy-efficient train timetabling (EETT)
- PhD research commissioned by NS & conducted with TU Delft
- Aim thesis: develop design principles for energy-efficient timetables by considering total running time + robustness timetable
- Current research results mainly for EETC:
  - Literature review and optimal control theory
  - Comparing different (eco-)driving strategies
- Research on EETT still in progress

Invited Review

Review of energy-efficient train control and timetabling

Gerben M. Scheepmaker[a,b,*], Rob M. P. Goverde[a], Leo G. Kroon[c,d]

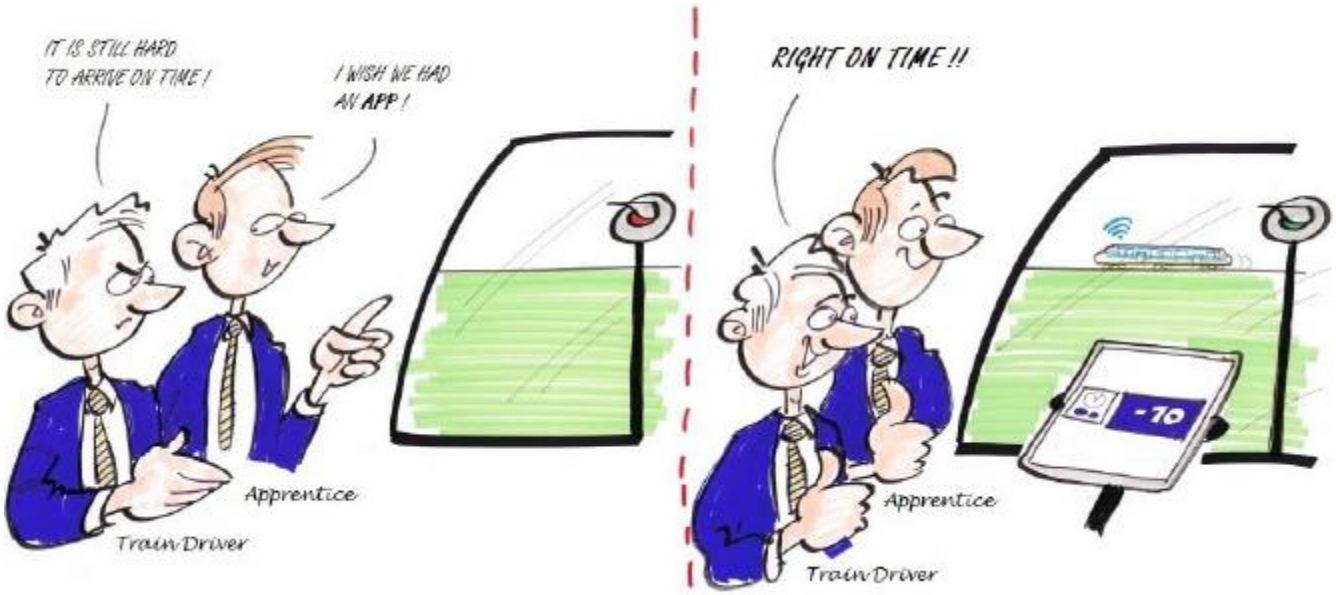


Conclusions

- Project DINT:
  - Improving timetable by smaller time fractions
  - Currently by-pass, in future in timetable model
- Project running times:
  - Focus: computation of running times for timetable design
  - Smaller time fractions
  - 8% slack time and equal distribution
- RailwayLAB:
  - Collaboration between NS and ProRail Innovation
  - Research microscopic timetable design and simulation
- PhD research:
  - Developing design principles for energy-efficient timetabling

Questions?

Thank you for your attention!



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