Measuring Railway Capacity in Timed CSP for solid state interlockings

Markus Roggenbach

Faron Moller, Hoang Nga Nguyen, Yoshinao Isobe

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SafeCap

Motivation

State of the art:

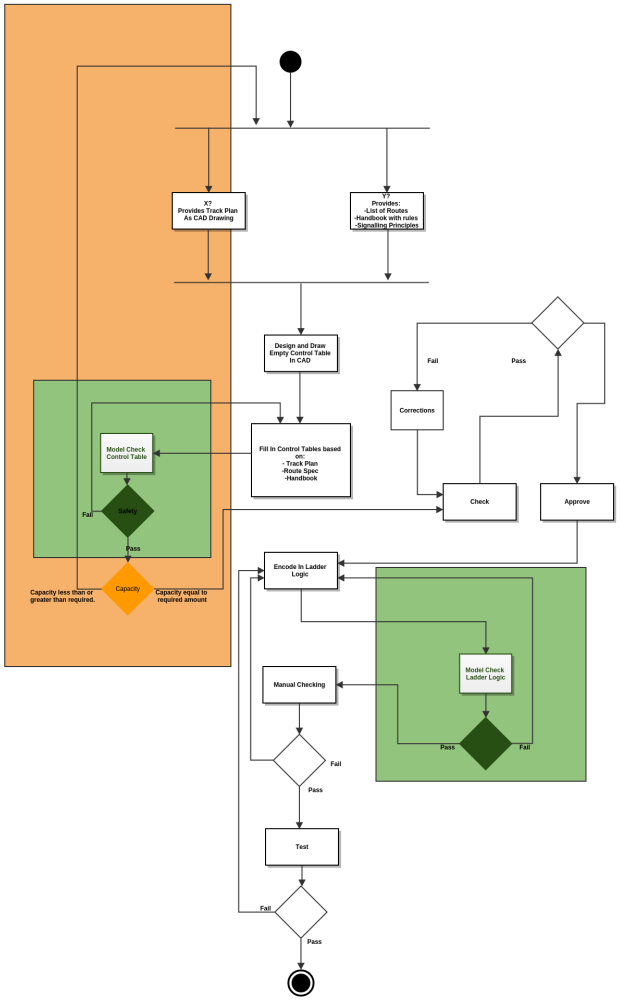
- Experienced engineers "see" the patterns in railway design which lead to high or low capacity.

Open questions:

- Can we give scientific foundations to their experience?
- Can we turn such foundations to an engineering practice?

`From the SafeCap project proposal (2010)`

A pictorial description



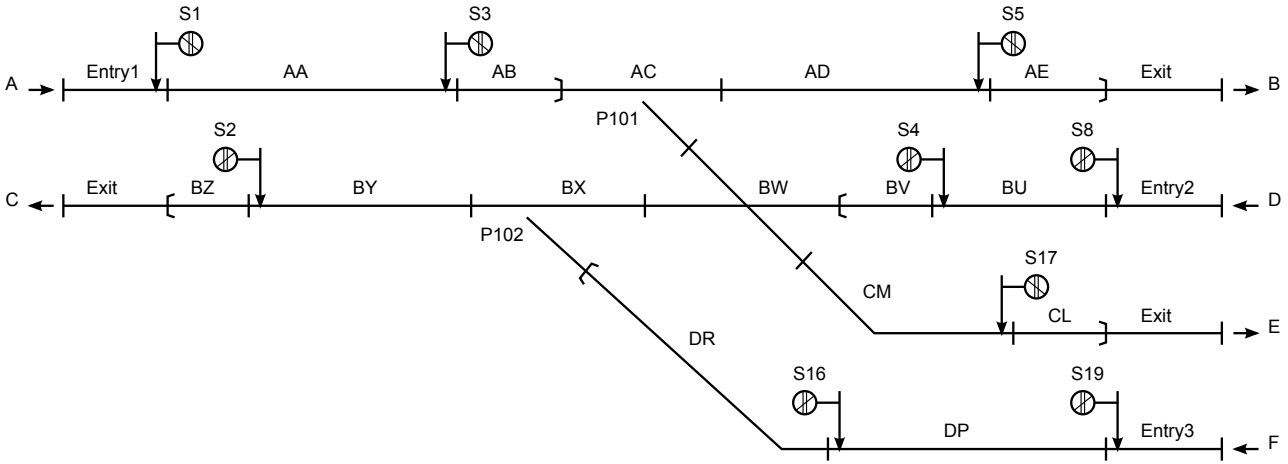
Overview

A simple example
A definition of line capacity
Measuring line capacity in Timed CSP

A simple example

Design 1 – overlaps in the control table

Track plan



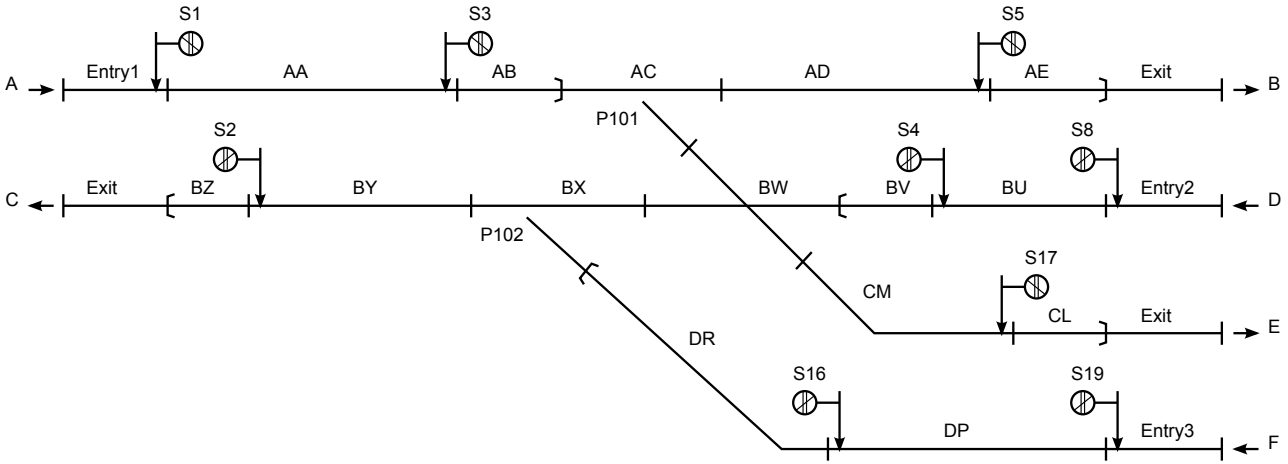
Control table

Route	Normal	Reverse	Clear
3A	P101		AB, AC, AD, AE
3B		P101 P102*	AB, AC, BW, CM, CL
4A	P101* P102		BV, BW, BX, BY, BZ
16A		P102	DR, BX, BY, BZ

* *flank protection*

Design 2 – no overlaps, due to ATP

Track plan



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The example in the world of rail engineers

- Design 1 is what UK legislation requires.
- Design 2 is currently against UK legislation.

Observations:

- Taking overlaps out should increase capacity.
- ATP says: safety should not be compromised.
- Engineers are only "half" comfortable to take overlaps out.
- Safety and capacity are two sides of one coin.

Question:

Does the gain in capacity justify change of regulations?

Scientific questions

Given a scheme-plan (track plan + ctrl tables)

- How to prove safety? $\rightsquigarrow$ e.g. Helen's talk
- How to define a capacity measure to quantify the effect?
- How to actually measure capacity?

A definition of line capacity

Context

Analytic: Model railway infrastructure by means of mathematical formulae and predict theoretical capacity [UIC 405].

Optimisation: Maximise railway capacity by optimising given time tables [UIC 406].

Simulation: Imitate the operation of real world railway systems over time [Barber et al 2007].

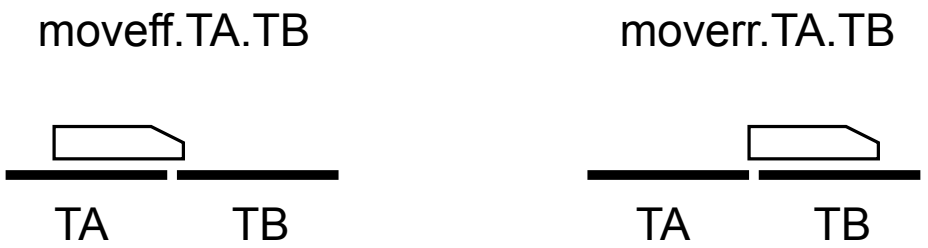
Fantechi: this afternoon.

Our approach

Consider all finite runs of a timed railway model, extending K. Winter's CSP modelling of scheme-plans:

- Open train systems,
- Timed CSP-modelling,
- Train length & speed,
- Track length.

Observations on trains: front and rear movements

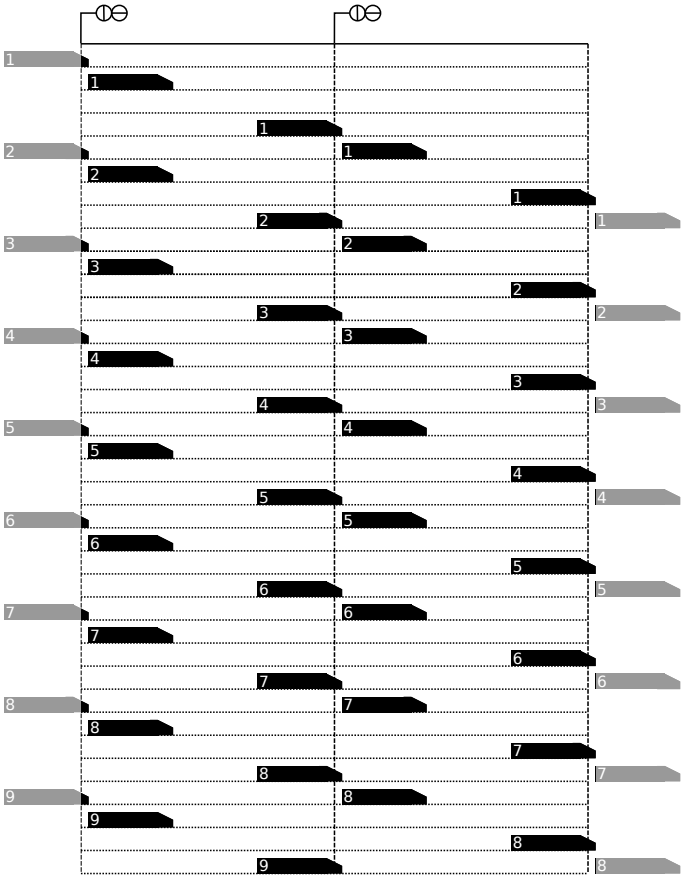


Line capacity - informal

Capacity determines the maximum number of trains that would be able to operate on a given railway infrastructure, during a specific time interval, given the operational conditions. [Abril et al 08]

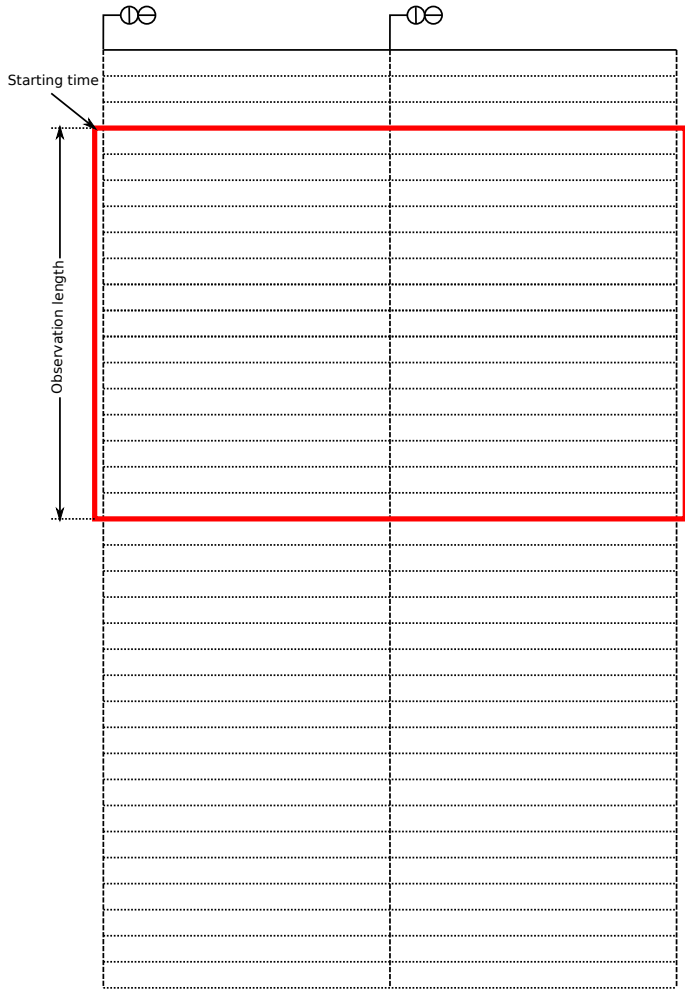
A space-time diagram of a line

Assumption: infinite supply of ready-to-go trains "on the entry"



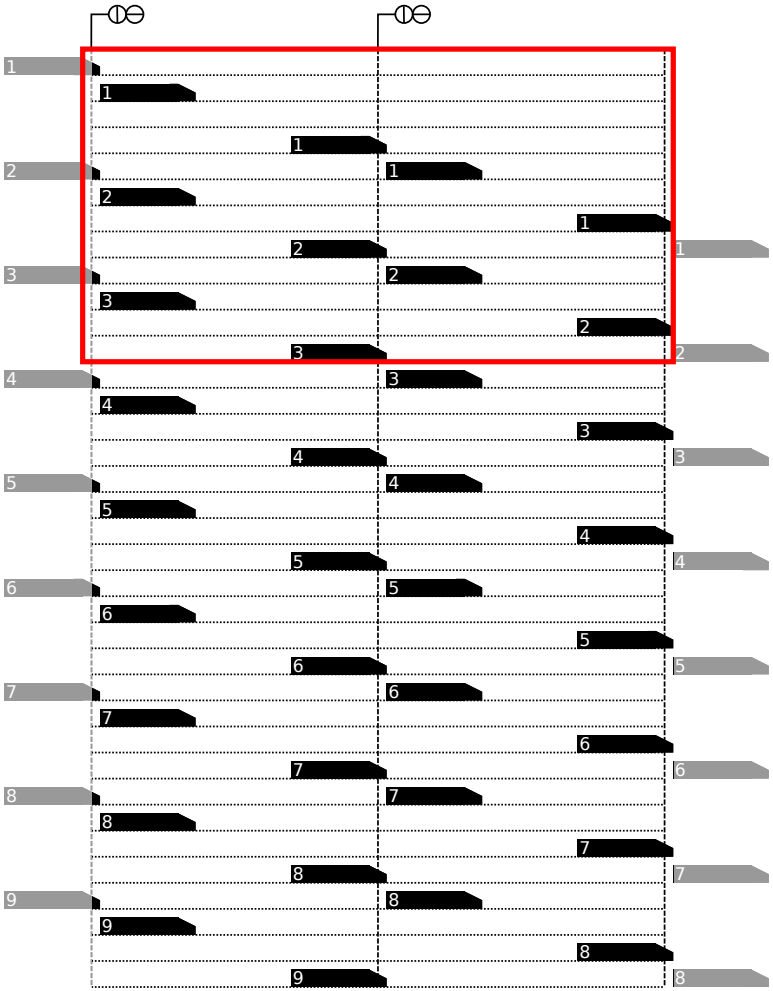
(all trains at the same, constant speed; track-length $\sim$ 3 train-length)

Diagram with observation window



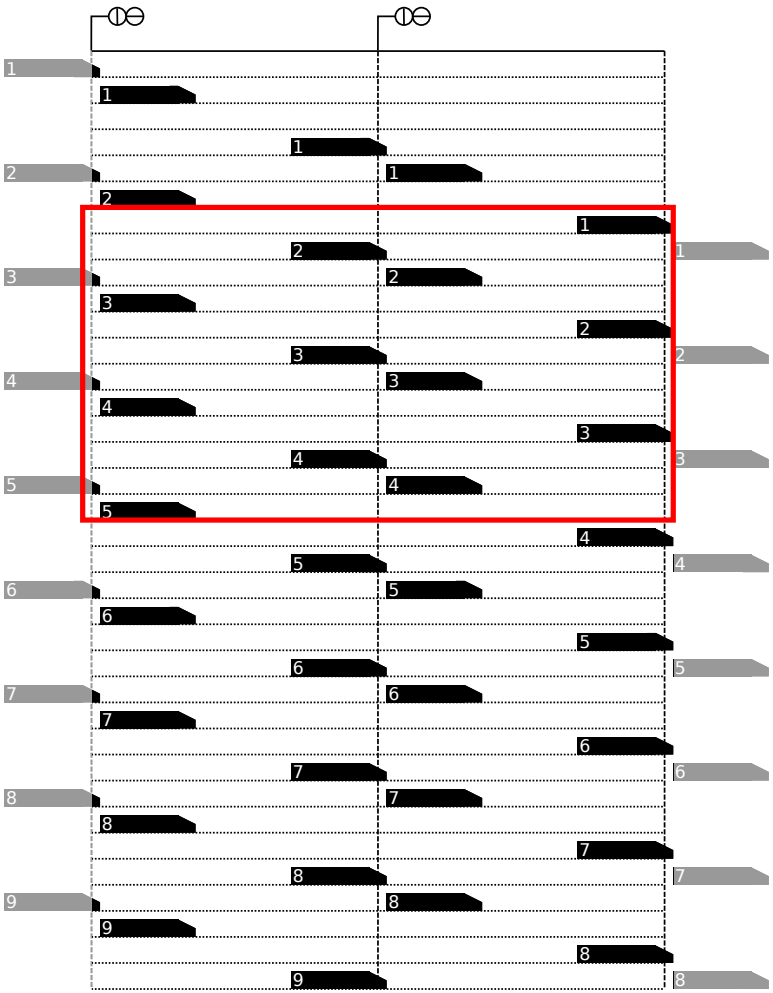
Window-parameters: duration “Delta” & starting time “ST”

Measuring line capacity: Delta = 12, ST = 0



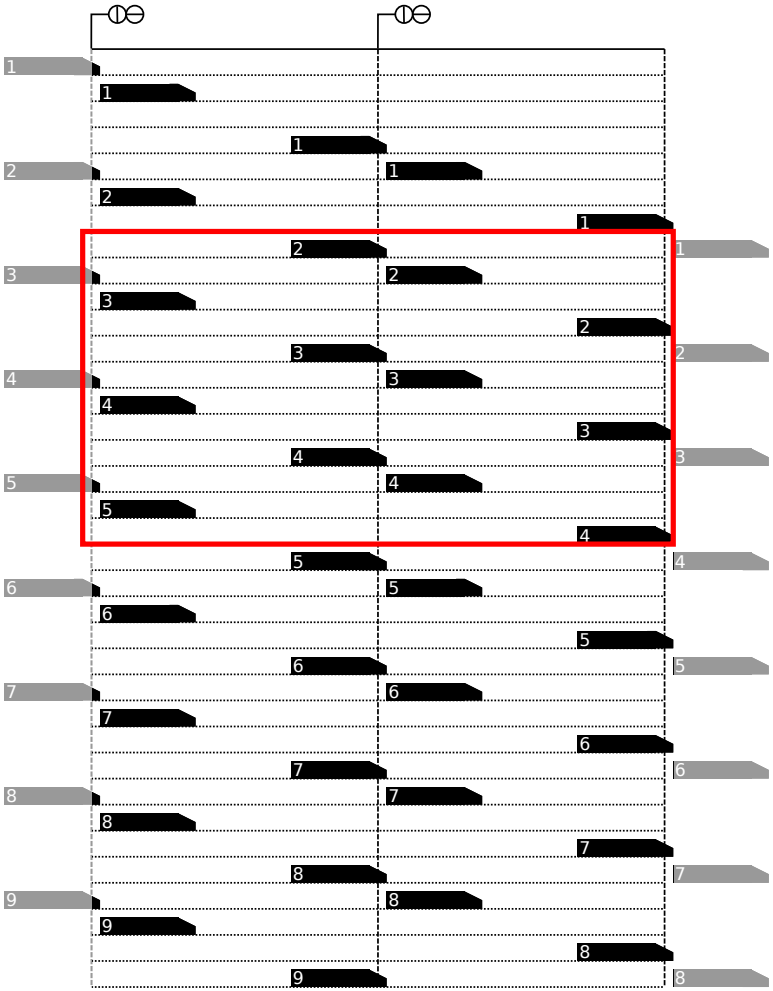
Number of observed trains = 3

Measuring line capacity: Delta = 12, ST = 6



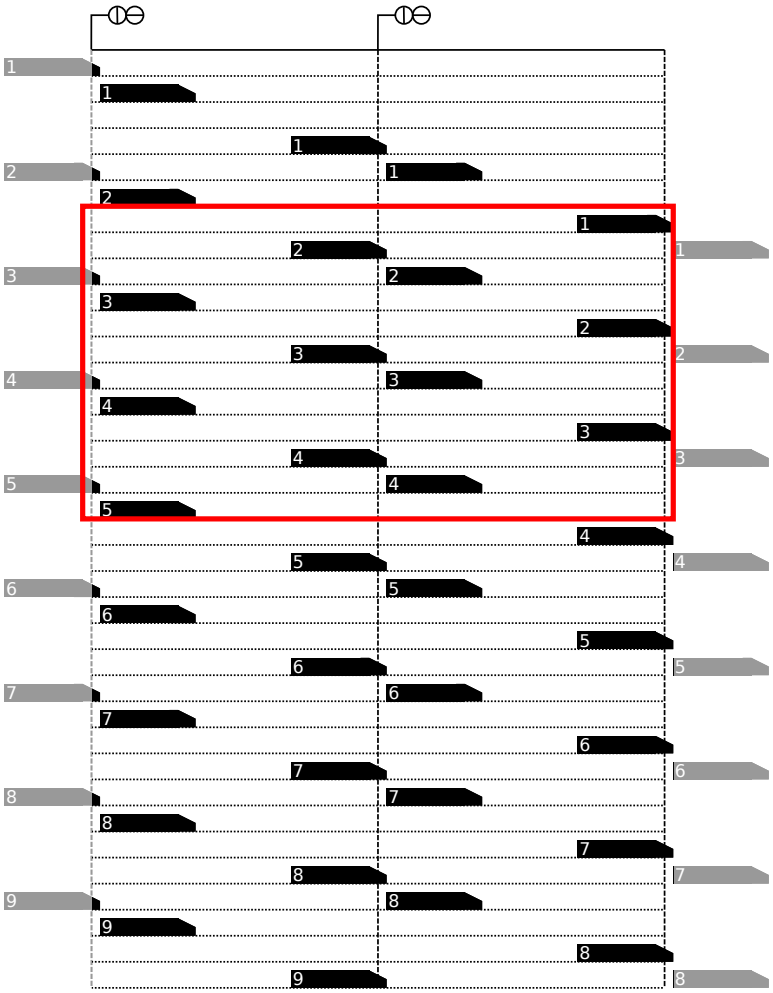
Number of observed trains = 5

Measuring line capacity: Delta = 12, ST = 7



Number of observed trains = 4

For Delta = 12



Maximum of observed trains, over all starting times: 5.

Definition: "line capacity" in Timed-CSP

Given a Timed-CSP process TS modelling a line of a train system and an observation length $\delta > 0$:

$$cap(TS, \delta) = \max\{storage(s_1) + increase(s_2) \mid s_1 \frown s_2 \in \mathcal{T}_{\mathbb{R}_{\geq 0}}[\![TS]\!] \wedge duration(s_2) \leq \delta\}$$

- $storage(s) = s \downarrow entering - s \downarrow leaving$
- $increase(s) = s \downarrow entering$

Given a line with first track F and last track L.

$entering$ – set of timed events of the form moveff.*.F

$leaving$ – set of timed events of the form moverr.L.*

Measuring line capacity in Timed CSP

Characterising line capacity via refinement

Theorem

Let δ be the length of the observation window.

Let n be a natural number.

Let δ be a rational time length. Then it holds:

$$cap(TrainSystem, \delta) = n$$

iff

$$\text{for all } k \geq n\text{: } CapFrom(k, \delta) \sqsubseteq_{TT} TrainSystem' \wedge$$

$$\text{for all } k < n\text{: } CapFrom(k, \delta) \not\sqsubseteq_{TT} TrainSystem'.$$

$$CapFrom(k, \delta) = \sqcap_{n \in \{0..n\}} startObs.\delta \rightarrow infoCap.n \rightarrow Stop$$

Verification process for each line

- FDR: to check safety of both scenarios.
- Timed-CSP Simulator: to estimate a small enough δ to differentiate line capacity of the two designs.
- FDR: to verify the different line capacities.

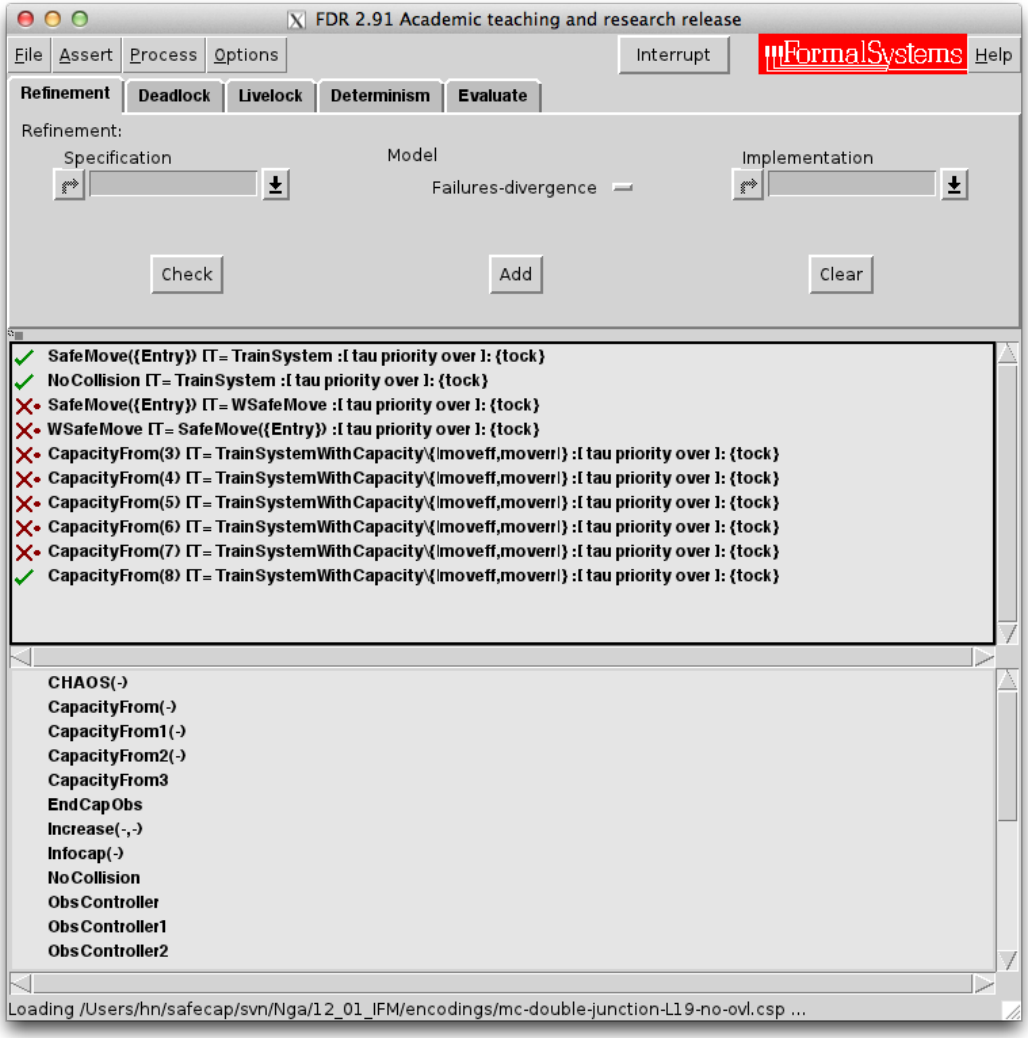
Results for the double junction designs

- Safety: both designs are collision-free (considering each line in isolation)
- Line capacity: "one more train every six minutes"

Path	Window length	Capacity in Design 1	Capacity in Design 2
Line from A to E	397s	7	8
Line from A to B	379s	12	13
Line from D to C	399s	12	13
Line from F to C	328s	7	8

(model-checking takes about 40 seconds for each line)

Snapshot from FDR2



Limitations as of 2012

using FDR2:

- lines of 6–8 tracks could be analysed for safety & capacity
- analysing the double junction as a whole was out of scope

i.e., the approach does not scale.

New insights – Part I: Modelling

Reduction of model complexity is possible

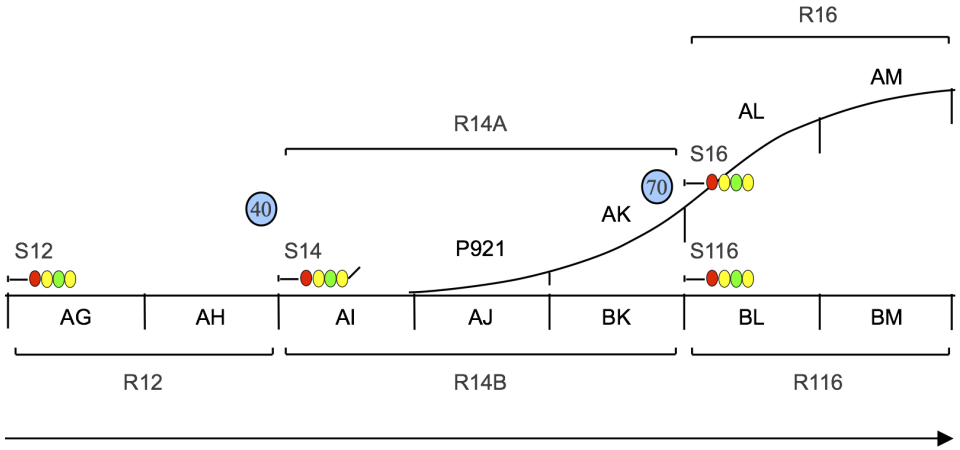
- Clearer model architecture
- No train-length
  (2014 paper in SCP discussing the topic for safety)
- Work with $move$ rather than with $moveff$, $moverr$
  - we have a proof that w.r.t. safety both modelling approaches are equivalent (in CSP)
  - experiments show that model-checking with $move$ is far cheaper

New insights – Part II: Abstraction & Tool

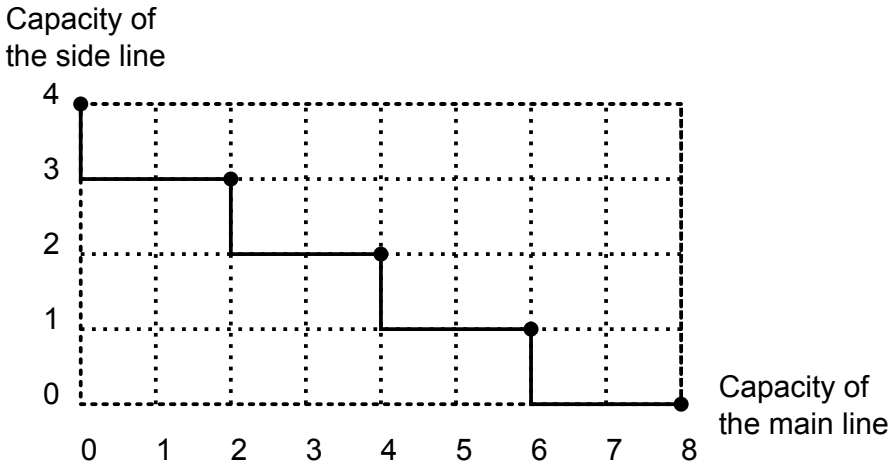
Abstractions for safety
(finitisation and covering were originally discovered
in the context of CSP modelling)

Better tool support: FDR3 is more powerful than FDR2

New insights – Part III: Network Capacity



Observation window of 300 seconds (result via simulation)



Conclusion

Summary

- The problem of theoretical capacity is still open.
- Line Capacity:
  - working definition in Timed CSP
  - tool support needs improvement
- Network Capacity:
  - suggestion for a definition in Timed CSP
  - tool support is open

Future work on capacity @ Swansea

For solid state interlockings:

- Mike Smith will take a fresh look at things
  also using alternative tools & languages such as PRISM.

For ERTMS:

- Ditto project (RA position from March 2015):
  adapt results from solid state interlockings &
  look into alternatives
- Monika's talk provides an alternative view.

Literature

this presentation has been based on our publication

Y. Isobe, F. Moller, H. N. Nguyen, and M. Roggenbach:
Safety and Line Capacity in Railways – An Approach in Timed CSP.
Proceedings of iFM12, LNCS, Springer, 2012.