Safety & Capacity of ERTMS - modelled and analyzed in Real-Time Maude

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1st Meeting of the European Technical Working Group on Formal Methods in Railway Control, 28 January 2015

Overview: Safety & Capacity of ERTMS

To investigate
how Real-Time Maude can be used to
verify and simulate the European Rail Traffic Management System

Overview:

- Part I: ERTMS – what it is
- Part II: ERTMS – how it works
- Part II: Generic Modelling: ERTMS as a hybrid automaton
- Part I: Encoding in Real-Time Maude
- Part V: Verification & simulation results

European Rail Traffic Management System (ERTMS) I

What it is:

- European standard of signalling, control and train protection
- to replace the many incompatible safety systems currently used by European railways
- offers possibility for traffic management

What it shall achieve:

- interoperability
- ease of maintenance (less track equipment)
- high capacity

European Rail Traffic Management System (ERTMS) II

Formal methods and ERTMS:

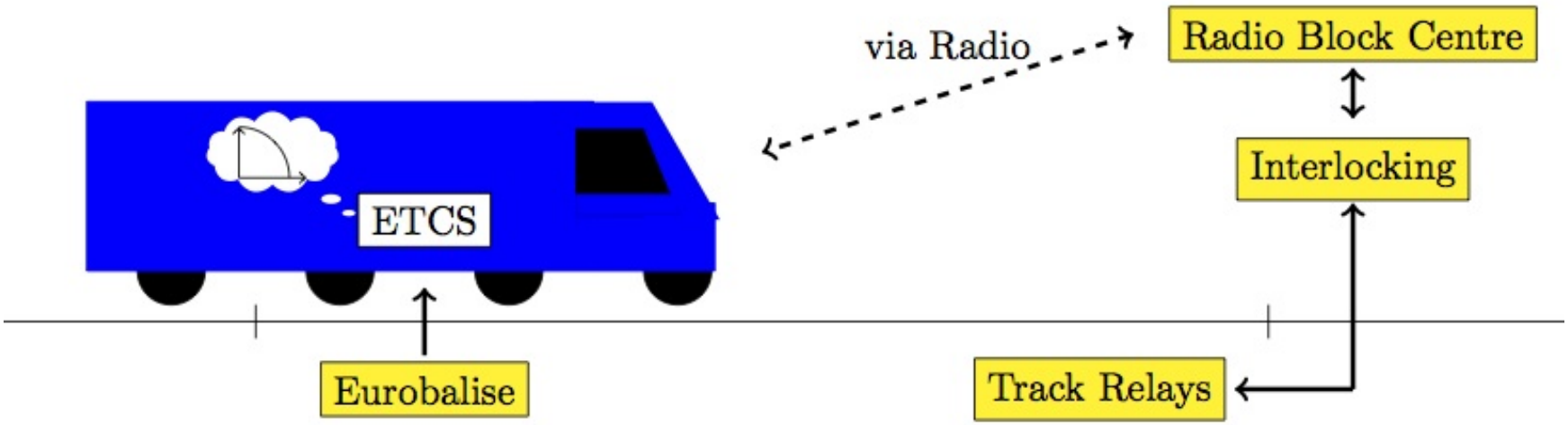
- EuRailCheck (2009): suggested methodology and tools for formalization and validation of the standard.
- Open ETCS Project (ongoing): works towards an integrated framework for modelling, development, implementation and testing of the standard.

Open research questions include:

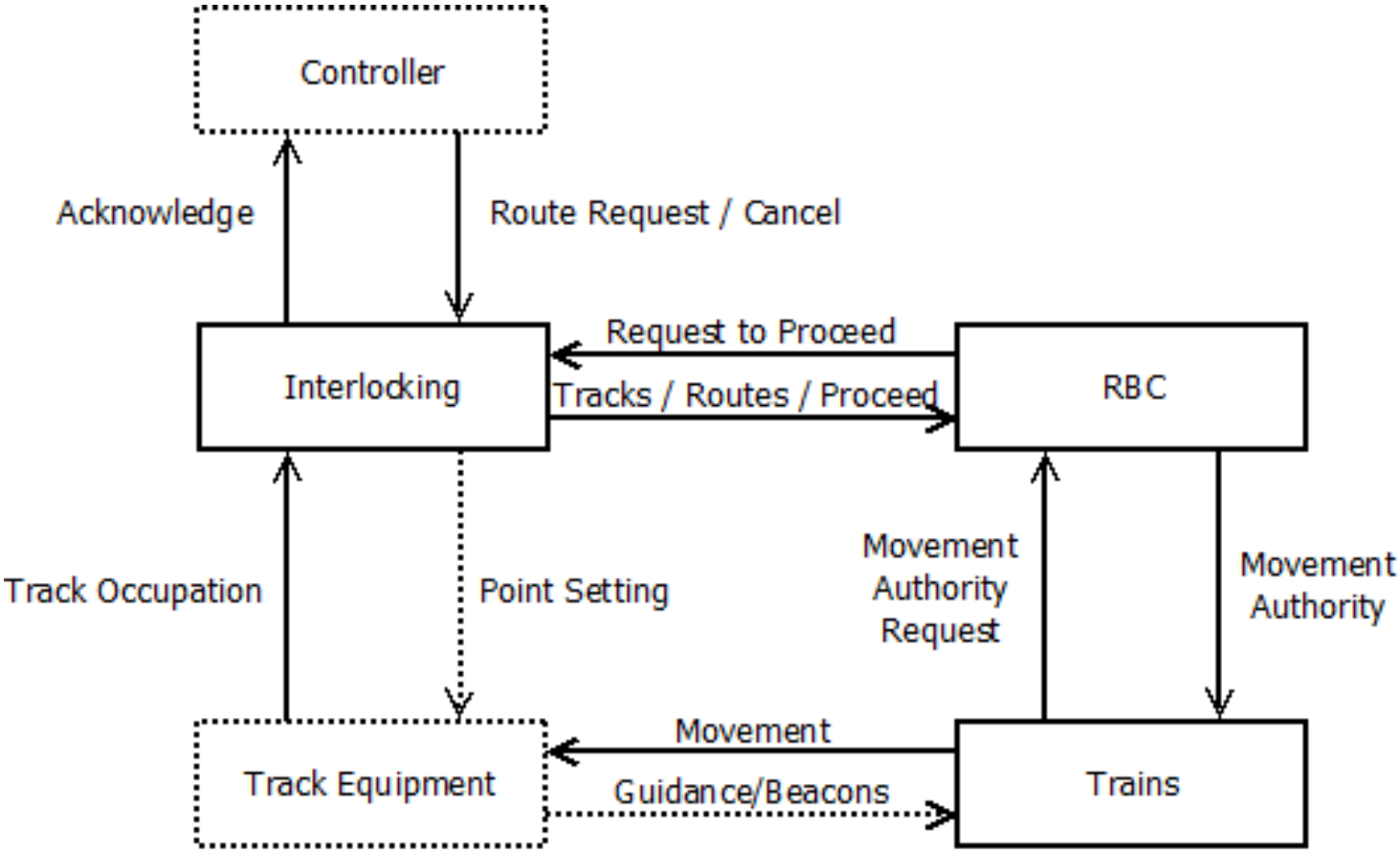
1. How can safety be verified?
2. How can capacity be measured and improved?
3. How can reliability be measured and estimated?

Here: 1 and, partially, 2.

System components of ERTMS, level 2



Information flow in ERTMS, level 2



Data in the ERTMS, level 2

The radio block processor (RBC) deals with continuous data such as the speed and position of the train and grants a movement authority (MA).

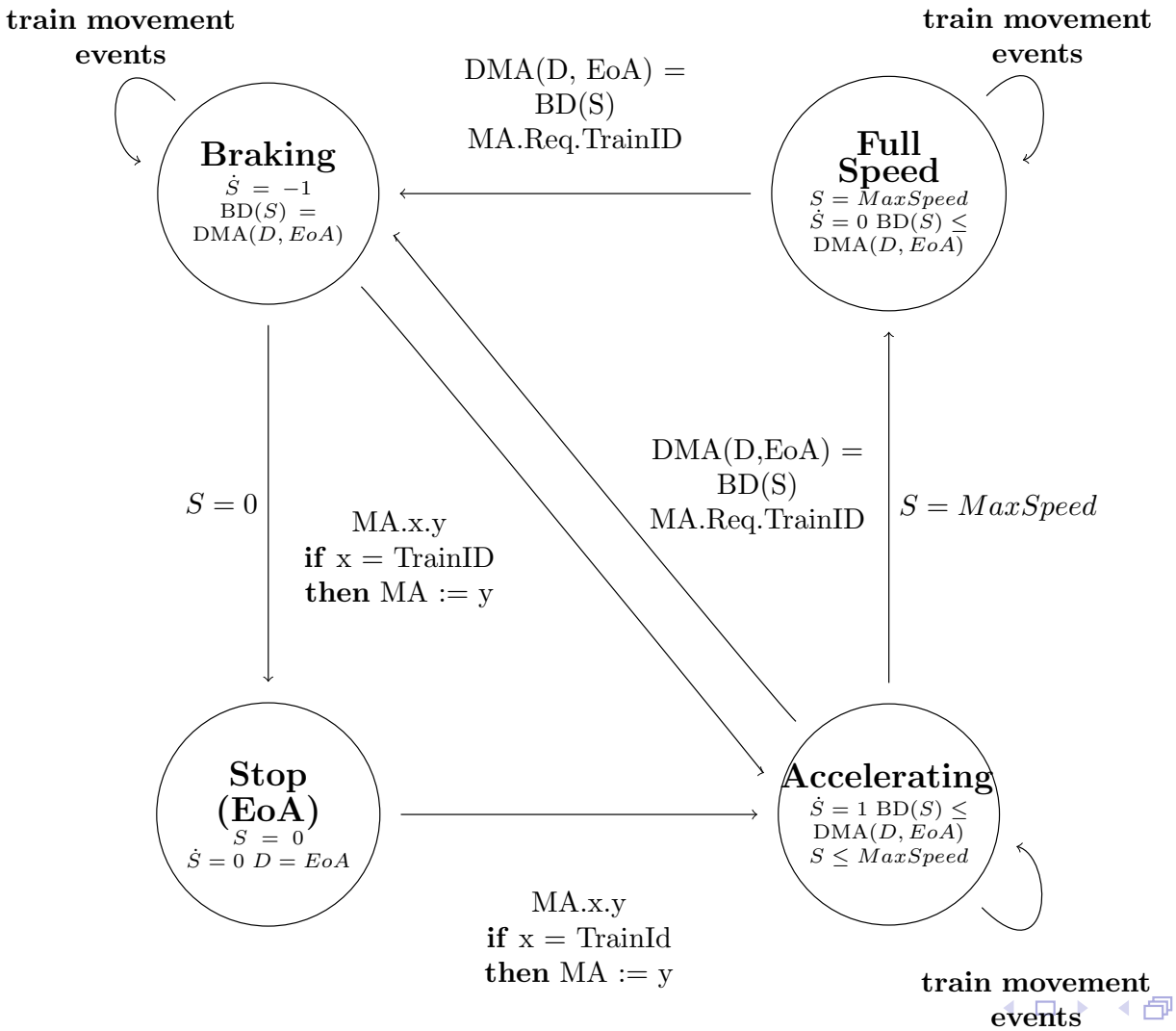
The MA consists of a position on the track past which the train cannot proceed called the end of authority (EoA) and a static speed profile.

Trains move on the track according to the physical laws of movement, their breaking is controlled against a differential equation, their acceleration follows a differential equation.

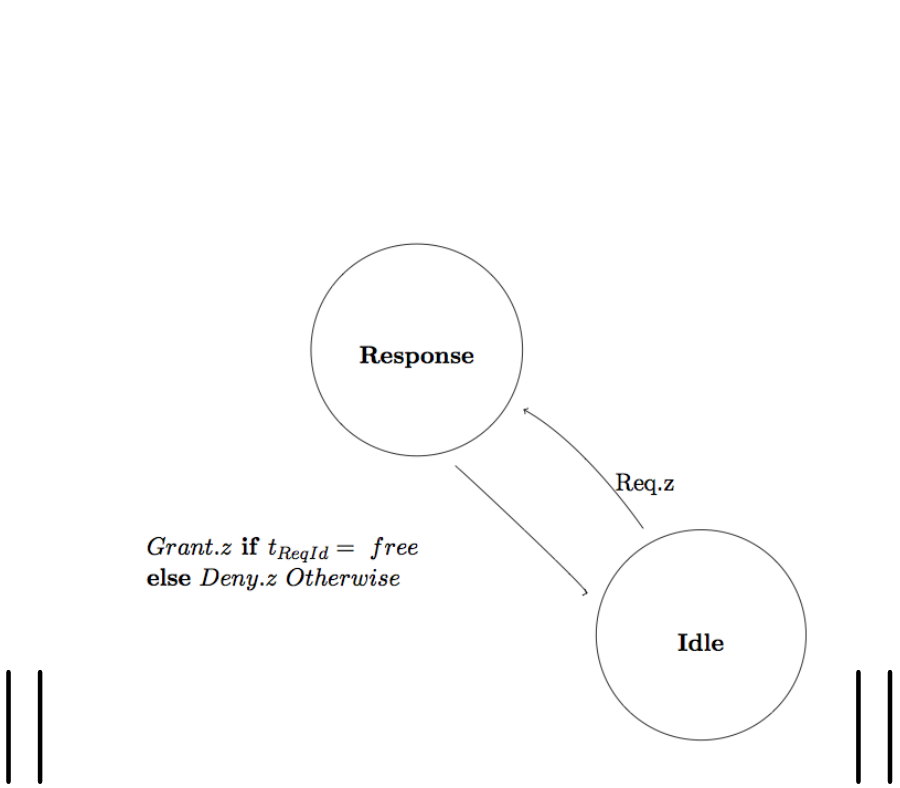
Together the RBC, trains and the interlocking form a hybrid system.

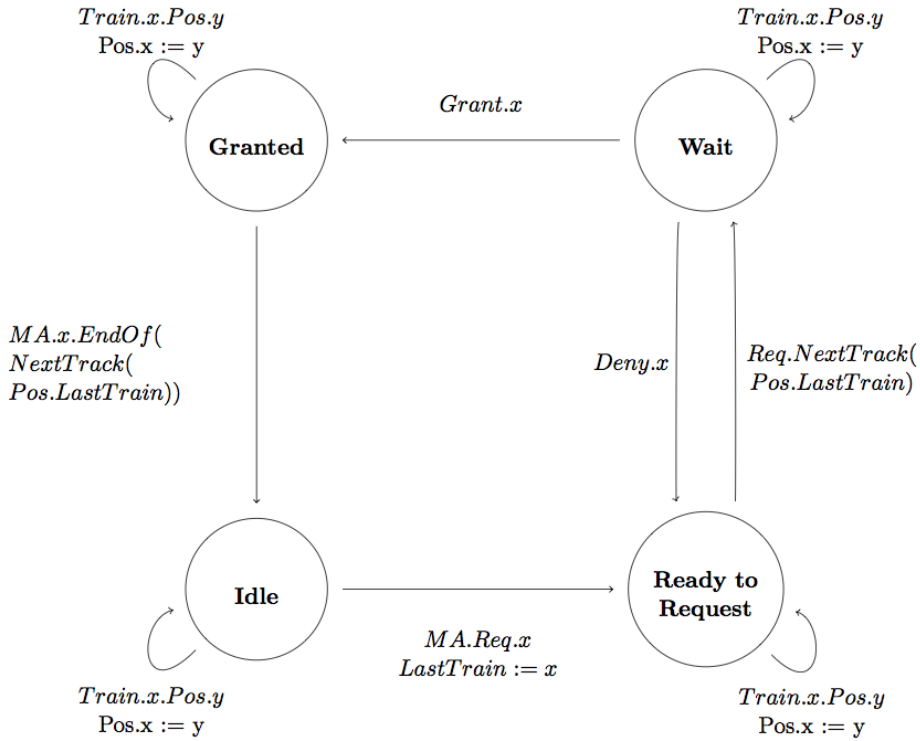
Generic modelling: ERTMS as a hybrid automaton

A model of a train with ERTMS equipment

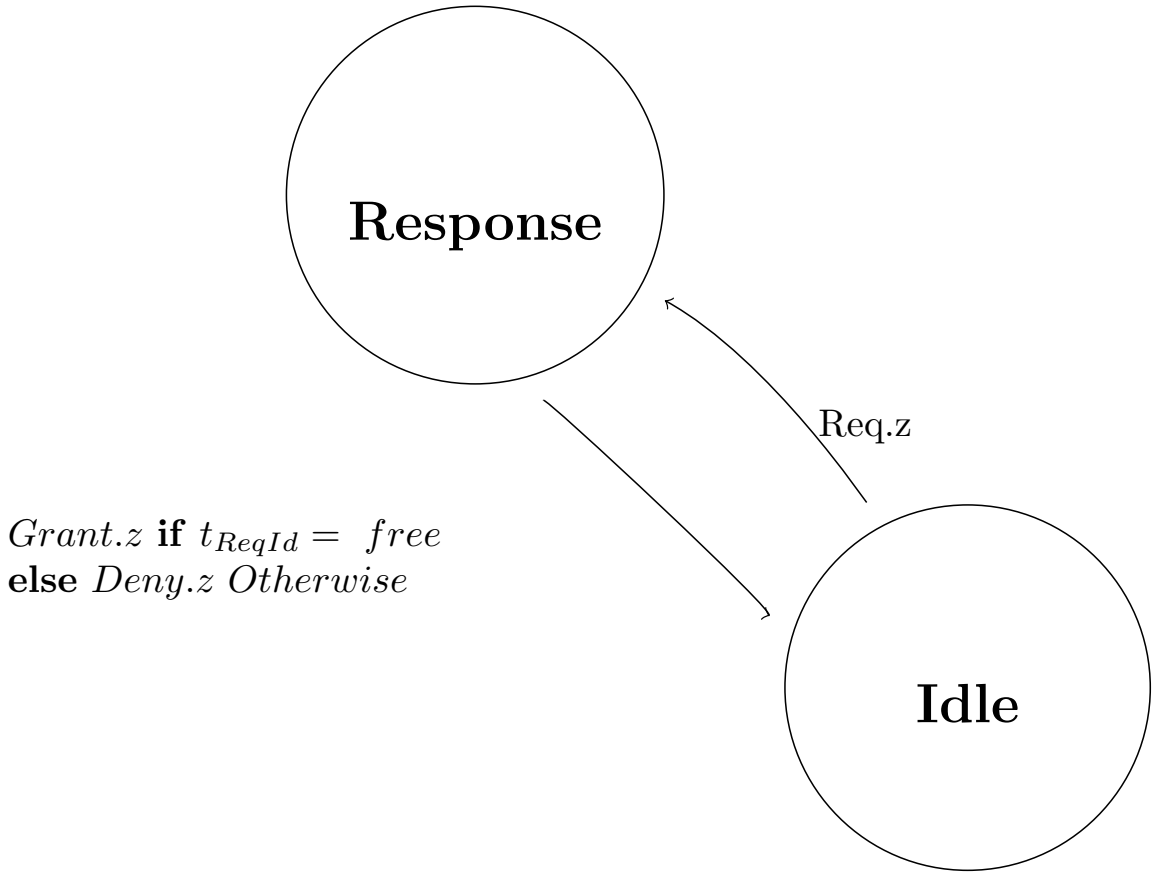


ERTMS as a hybrid automaton

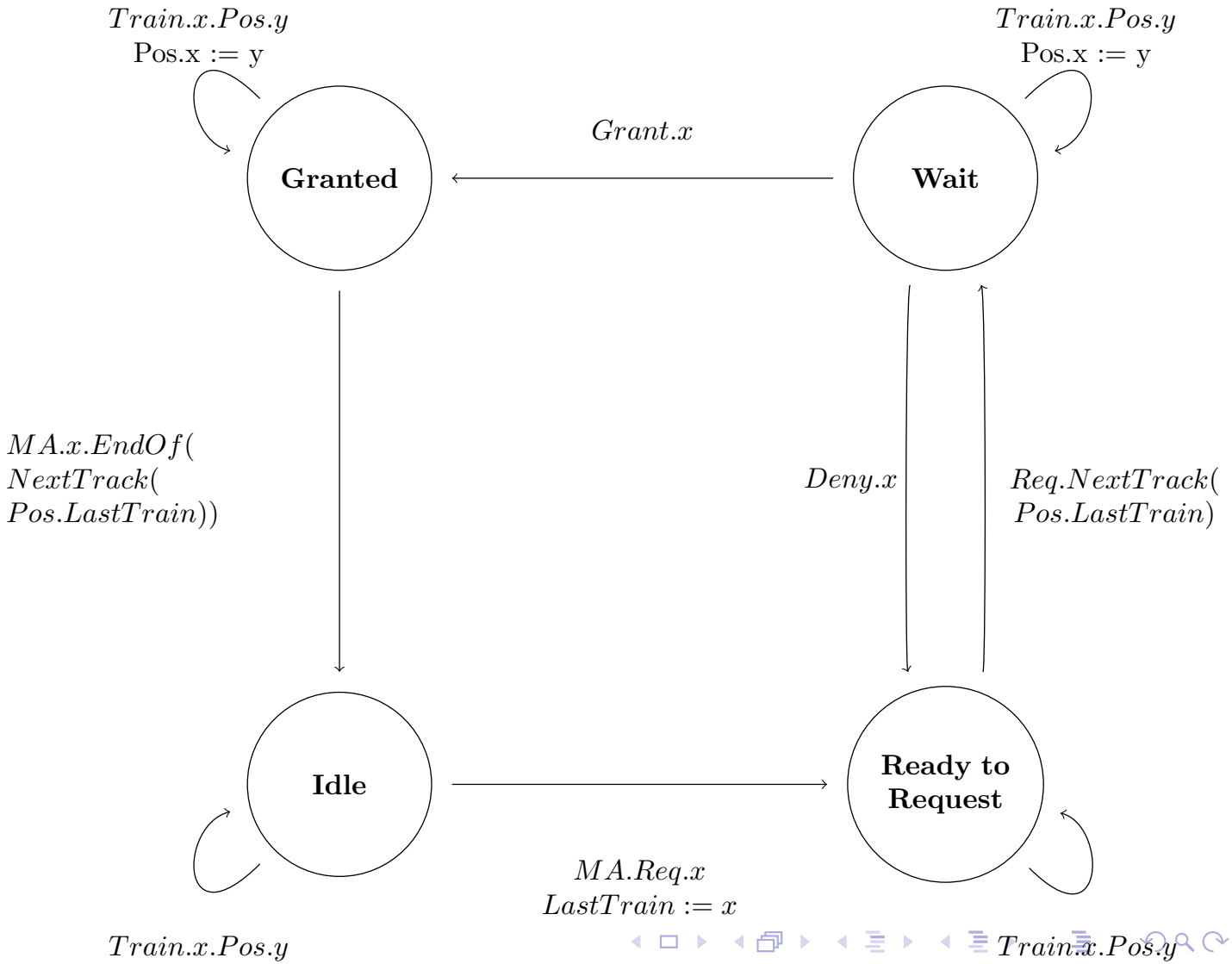




Modelling the Interlocking



Modelling the RBC



Well-formedness of the hybrid automaton

Modelling based on Henzinger, 2000.

Theorem This hybrid automaton is non-Zeno,
i.e. every finite initialised trajectory in the labelled transition system defined by the automaton has an infinite trajectory of which it is a prefix in set of divergent initialized trajectories in the automaton.

Encoding in Real-Time Maude

Real-Time Maude (Peter C. Ölveczky and José Meseguer 2002) is a language and tool extending Maude, that allows for simulation and formal analysis of real-time and hybrid systems.

We make use of especially of its

- OO features
- Discrete time rewriting rules:

```
rl [label] :  {Sys} => {Sys} in time t .
crl [label] :  {Sys} => {Sys} in time t if C .
```

Object Oriented Modelling

```
mod CONFIGURATION is
    *** basic object system sorts
    sorts Object Msg Configuration .

    *** construction of configurations
    subsort Object Msg < Configuration .
    op none : -> Configuration [ctor] .
    op __ : Configuration Configuration -> Configuration
         [ctor config assoc comm id: none] .
```

Timed Progress of a train in state "accelerating"

```
crl [incspeed] :
  {delta(< O : Train | state : acc, dist : DT, speed : S,
                       ac : A, ma : MA, maxspeed : MAX >
         )
   REST
  }
=>
  {pos(O,DT)
   < O : Train |  dist : (DT + S), speed : S + A >
   REST
  }
if S + A < MAX and ... .
```

Message consumption for the RBC in state "wait"

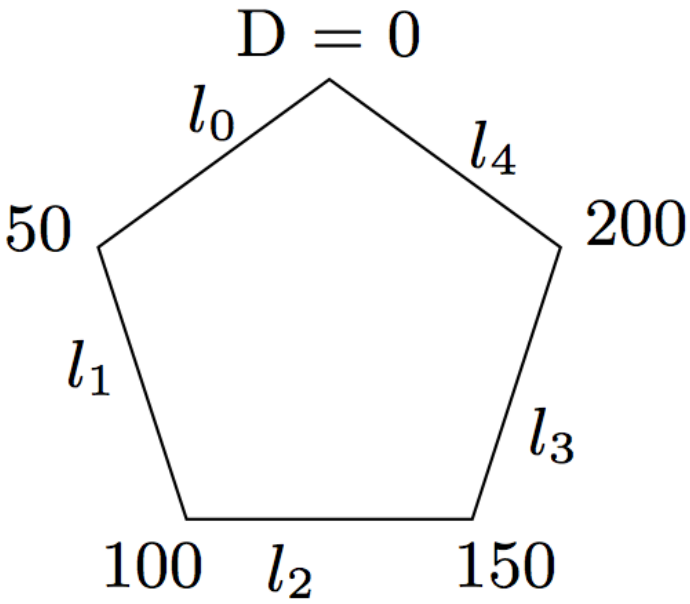
```
rl [rbcgrant]:
  { grant(N)
    <O : RBC | state : wait, lasttrain : T1, ma : MAP1 >
    REST
  }

=>

  { <O : RBC | state : rbcidle,
               ma : insert(T1,endoftrack(N),MAP1) >
    grantma(T1, endoftrack(N))
    REST
  } .
```

δ operator – by Ölveczky and Thorvaldsen, 2007

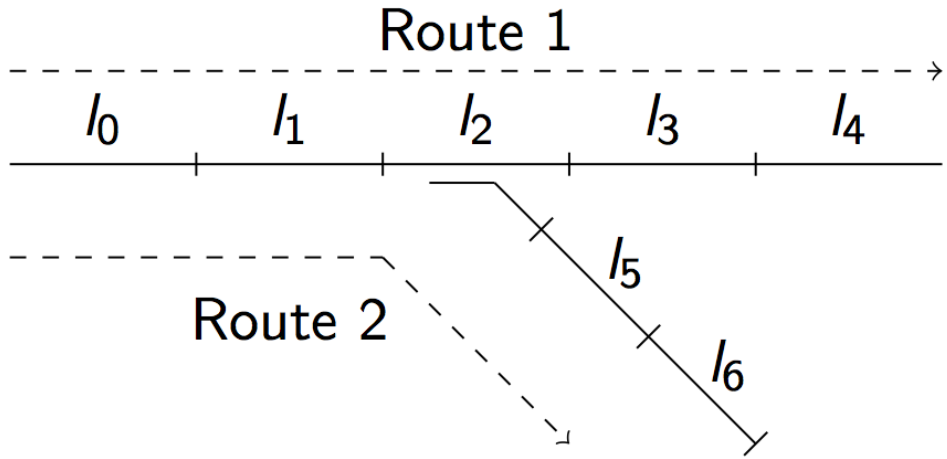
```
op delta : Configuration -> Configuration .
vars CON CON1 CON2 : Configuration .
var OCREST : ObjectConfiguration .


rl [timetrans] : {OCREST} => {delta(OCREST)} in time 1 .
rl [delta] : delta(CON1 CON2) => delta(CON1) delta(CON2) .

--- mte = maximal time elapse
rl [mte] : {CON} => {delta(CON)} in time 1 if mte (CON) >= 1 .

eq mte(none) = INF
eq mte(CON1 CON2) = min(mte(CON1), mte(CON2)).
eg mte (MSG) = 0
eg mte (<    >) = ....
```

Verification & simulation results

First examples with 2 trains in each scenario

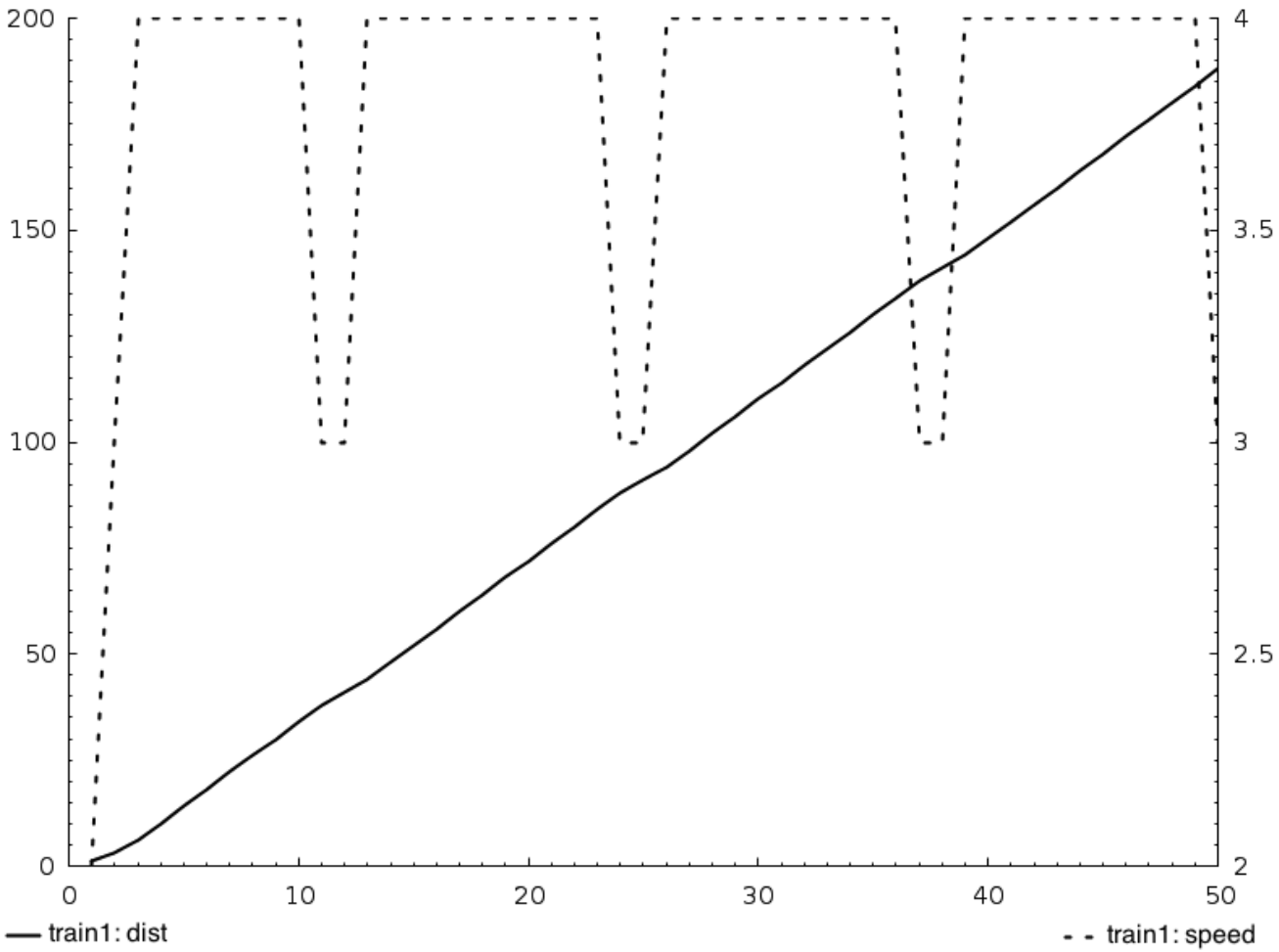


Pentagon-Example

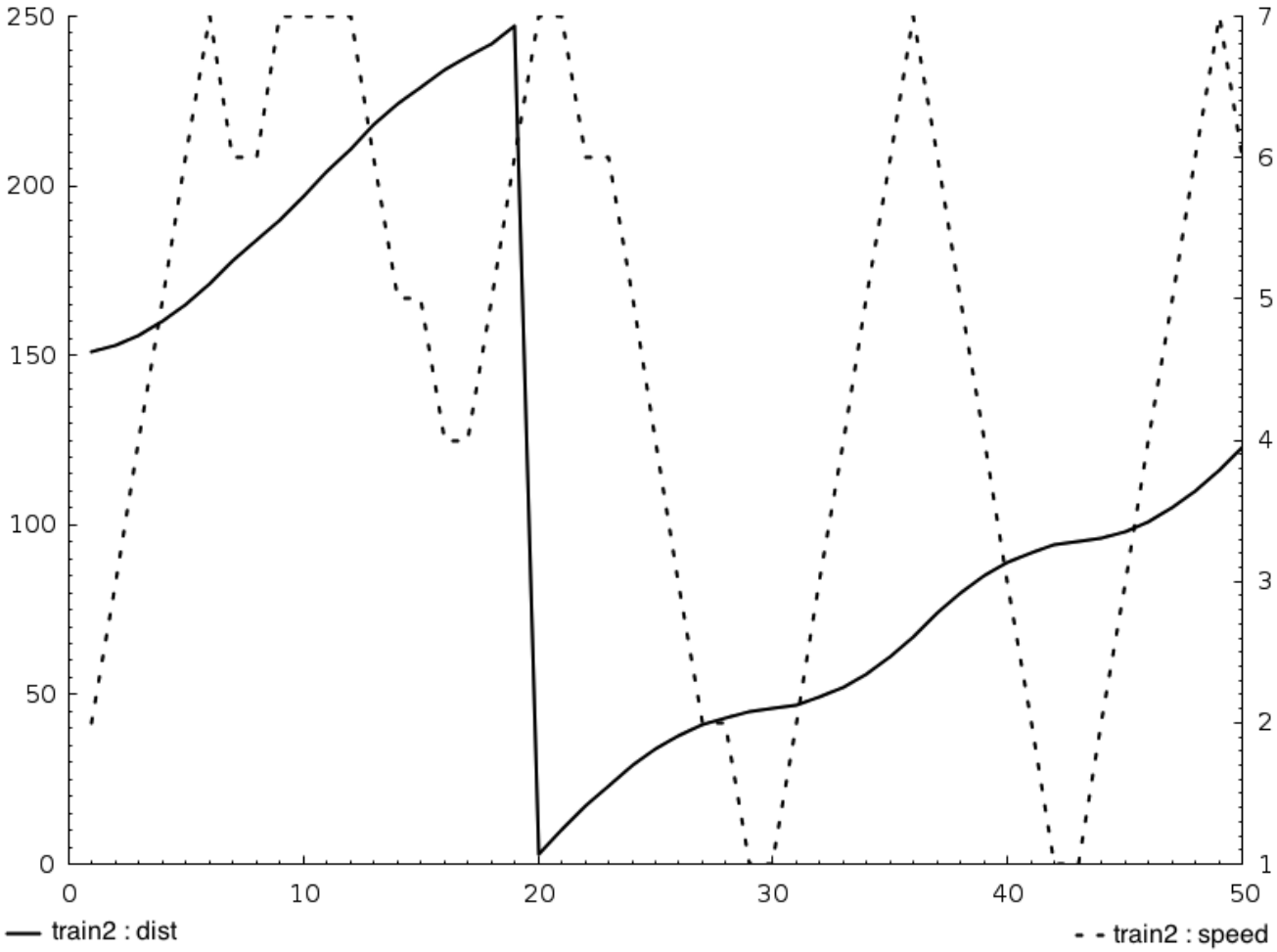


Junction

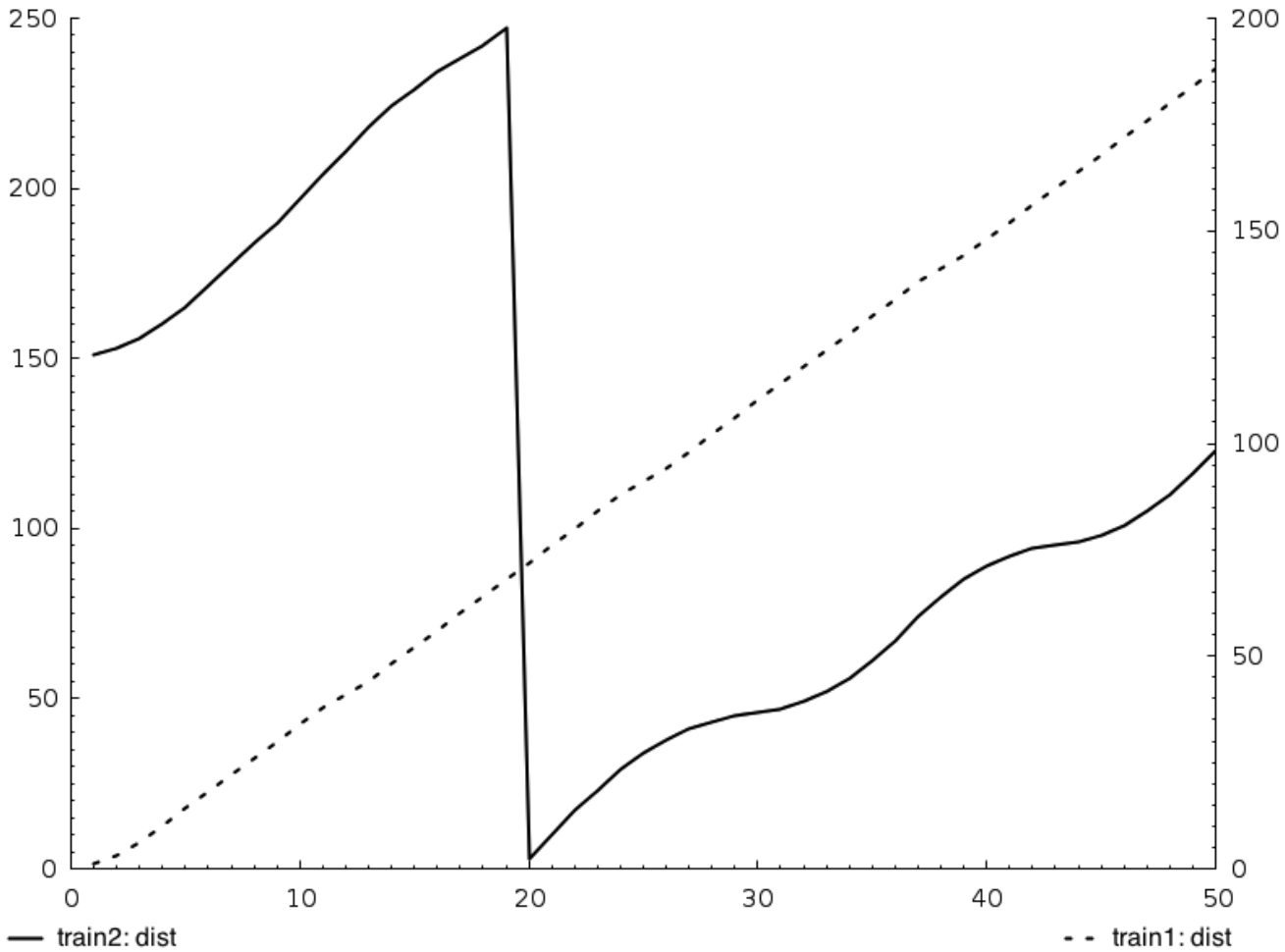
Train speed / distance over time – Pentagon example



Train speed / distance over time – Pentagon, 2nd train



Comparison of both trains



Safety-Verification by applying Real-Time Maude Model-checking for Linear Temporal Logic

Pentagon Example - 2 trains:

- no overlapping MA in the first 100 time units – takes 91 secs

Junction - 2 trains:

- no overlapping MA – takes 7 secs
- no derailment – takes 6 secs

Safety-Verification by applying Real-Time Maude Model-checking for Linear Temporal Logic

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We also compared with realistic tracklengths of 5000 - speed 120/70

Pentagon Example - 2 trains:

- no overlapping MA in the first 70 time units – takes 79 secs

Ongoing work

- Modelling of the controller:
  currently acts as a scheduler in the second example:
  Knows of trains routes, max speed of each train, initializes trains.
  $\rightarrow$ Route setting, interaction with interlocking.
  $\rightarrow$ Cancellation of routes.

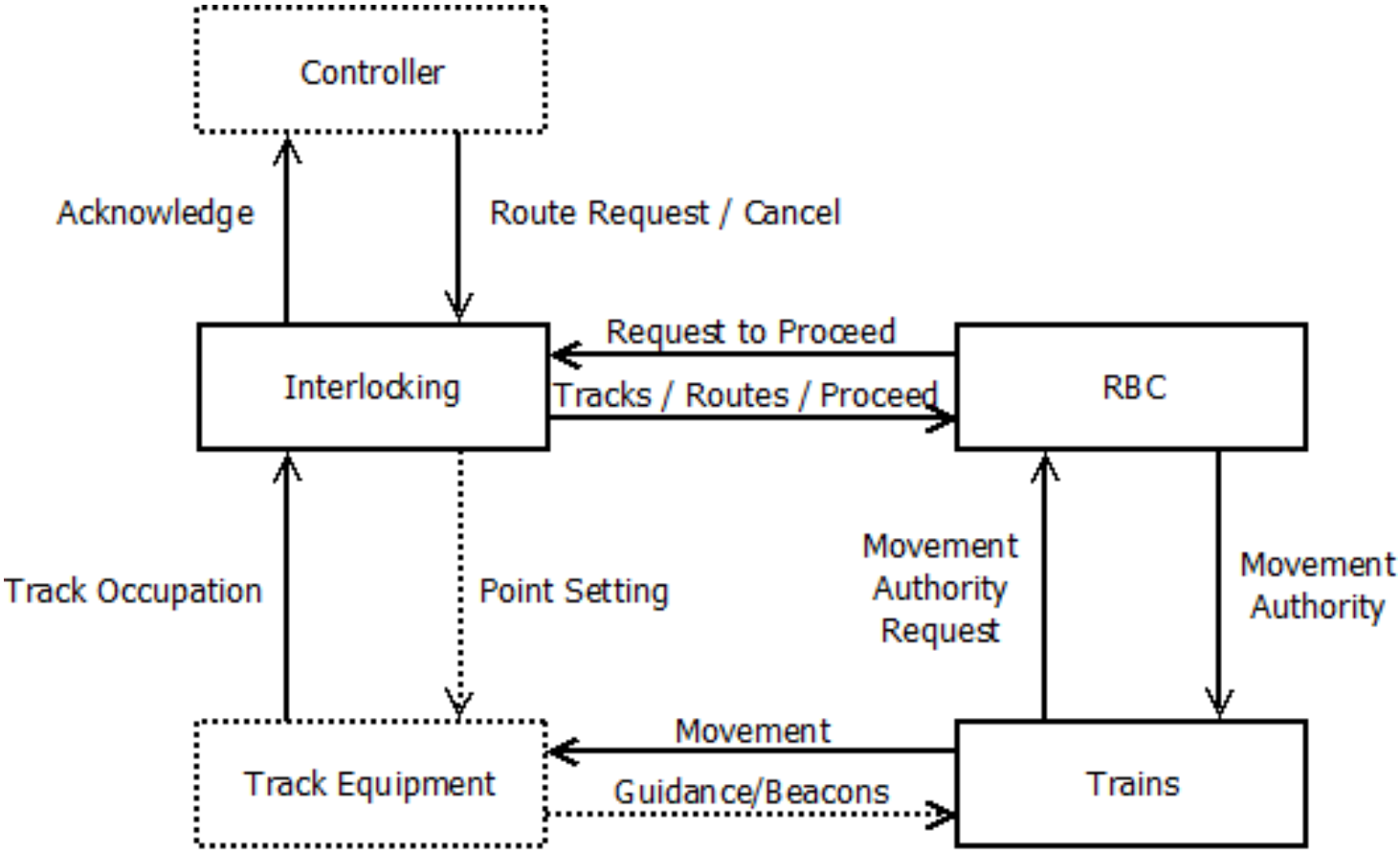
- Sequential release.

- Review of information flow.

- Generic track plans.

- Review of assumptions.

Information flow in ERTMS as implemented by Siemens



Conclusion & Future Work

- Our modelling approach works and is rich enough it to analyze ERTMS for important safety and capacity properties.
- Real-Time Maude offers a competitive framework for modelling & analysing ERTMS.

Future Work:

- Enrich the modelling to capture more aspects of ERTMS.
- Develop the timed simulations towards capacity measures.

- Aside: Final year student - Automatic translation of Ladderlogic into Real-Time Maude