Advance Industry Day

WP1 : Railway Case Study

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SEVENTH FRAMEWORK PROGRAMME

23/10/2014

Advance

Overview

1. Goals and Motivations
2. Interlocking Dynamic Controller
3. Achievements
4. Conclusions

1 – Goals & Motivations

- Prove formally that an interlocking system (IXL) complies with system-level safety requirements
  - *Satisfy transport operators (e.g. Paris, New York) request*
- Develop a proof technique independent of the complexity and implementation technology of IXL
  - *Overcome model checking technology drawbacks*
- Develop an industrial system development process involving Advance methods and tools
  - *Satisfy European railway standards (CENELEC)*
- Apply and improve Advance methods and tools
  - *Increase quality & productivity*

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2 - Interlocking Dynamic Controller (IXL-DC)

- IXL is designed to set and lock the routes of trains in order to avoid:
  - Derailments,
  - Hurting of maintenance staff,
  - Head-on collisions,
  - Side-on collisions, and often but not systematically,
  - Rear-end collisions

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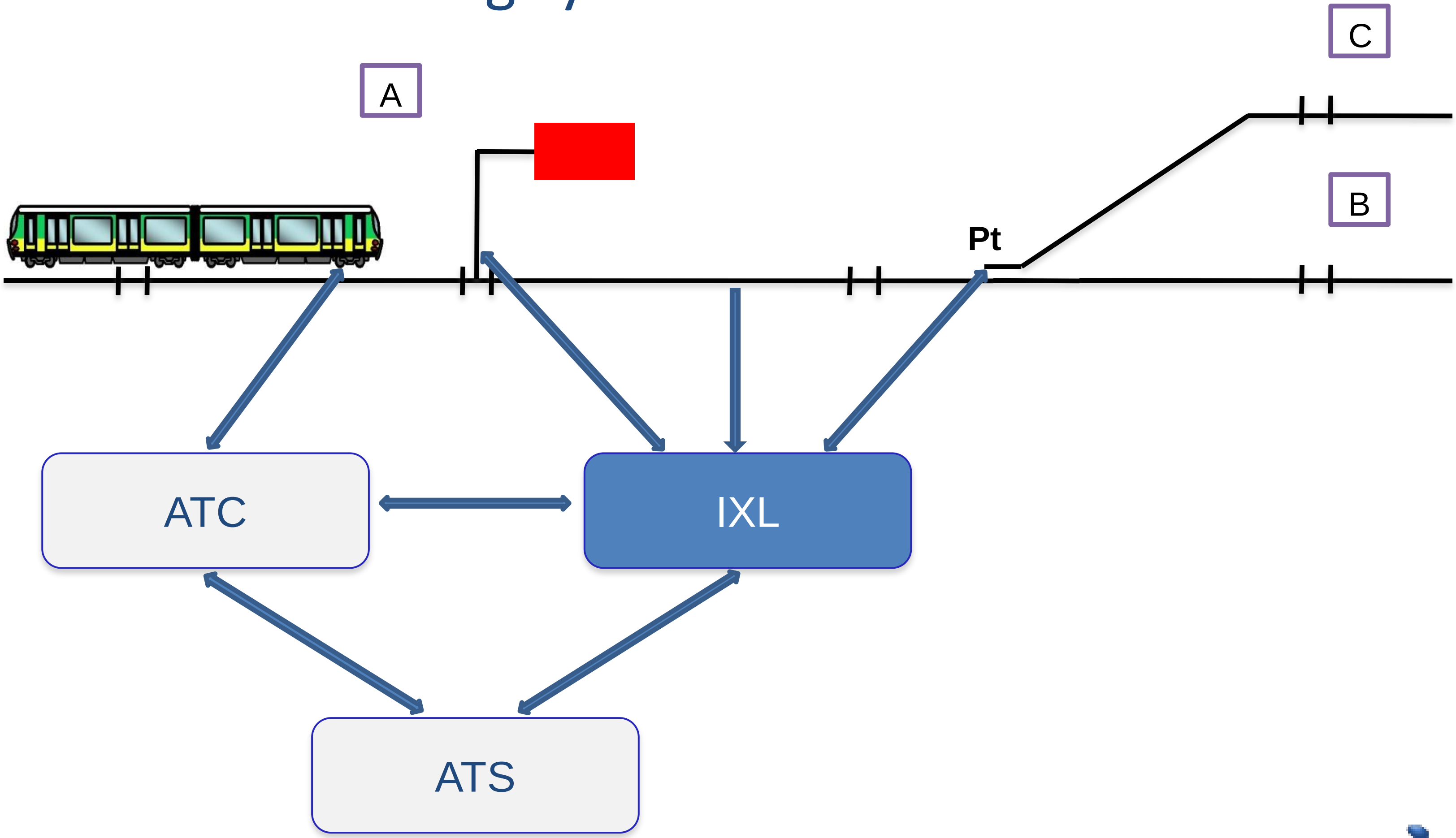
2 - Interlocking Dynamic Controller (IXL-DC)

Interlocking system in its environment



2 - Interlocking Dynamic Controller (IXL-DC)

- IXL-DC is designed to check at runtime that safety requirements on IXL are met:
  - No uncontrolled points in routes,
  - No incompatible routes are set at the same time,
  - No unsafe permissive signals,
  - No incompatible permissive signals at the same time,
  - …

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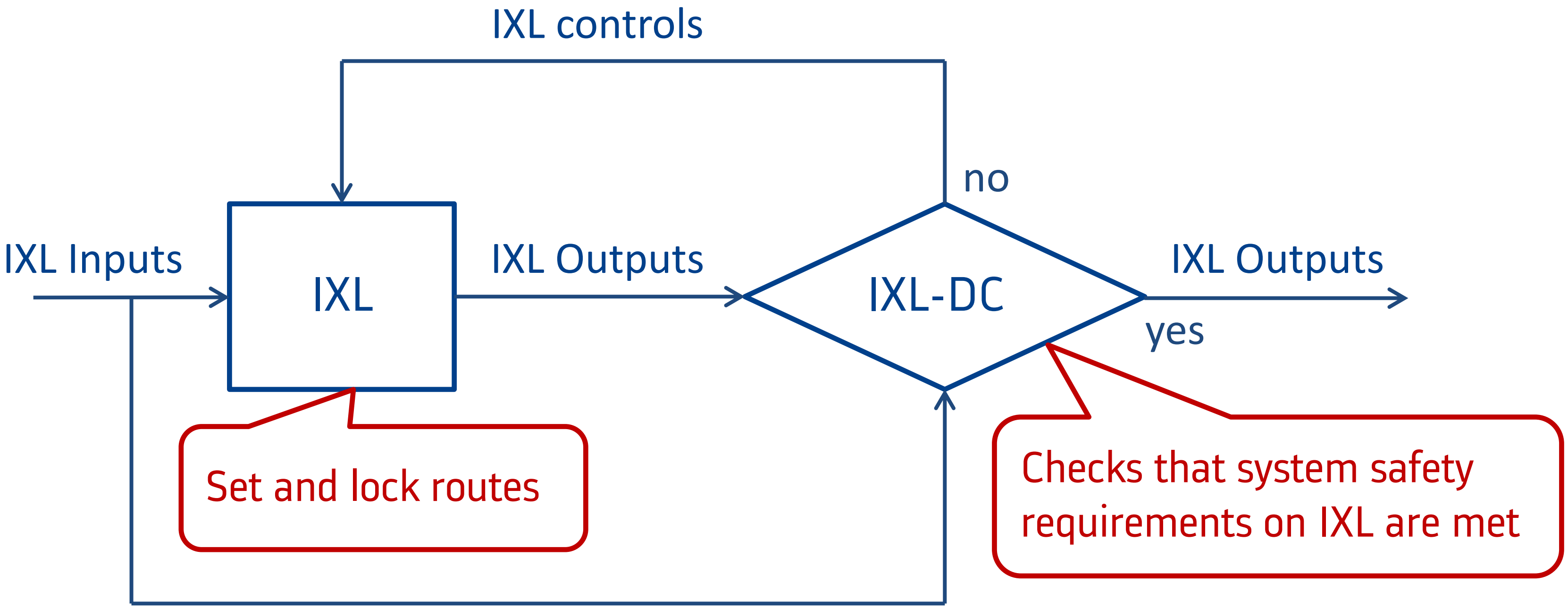
2 - Interlocking Dynamic Controller (IXL-DC)

Interlocking and Interlocking Dynamic Controller



2 - Interlocking Dynamic Controller (IXL-DC)

Case study formalisms, methods and tools

- Safety analysis
  - Formalism: System Theory
  - Method : STAMP/STPA
  - Tool : ProR (for requirements management)
- Model creation
  - Formalism: Event-B
  - Method: Model refinement and decomposition
  - Tool: Rodin

2 - Interlocking Dynamic Controller (IXL-DC)

Case study formalisms, methods and tools

- Model verification
  - – Formalism: Event-B
  - – Method: Proof
  - – Tool: Rodin
- Model validation
  - – Formalism: B
  - – Method: Animation
  - – Tool: ProB

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3 - Achievements

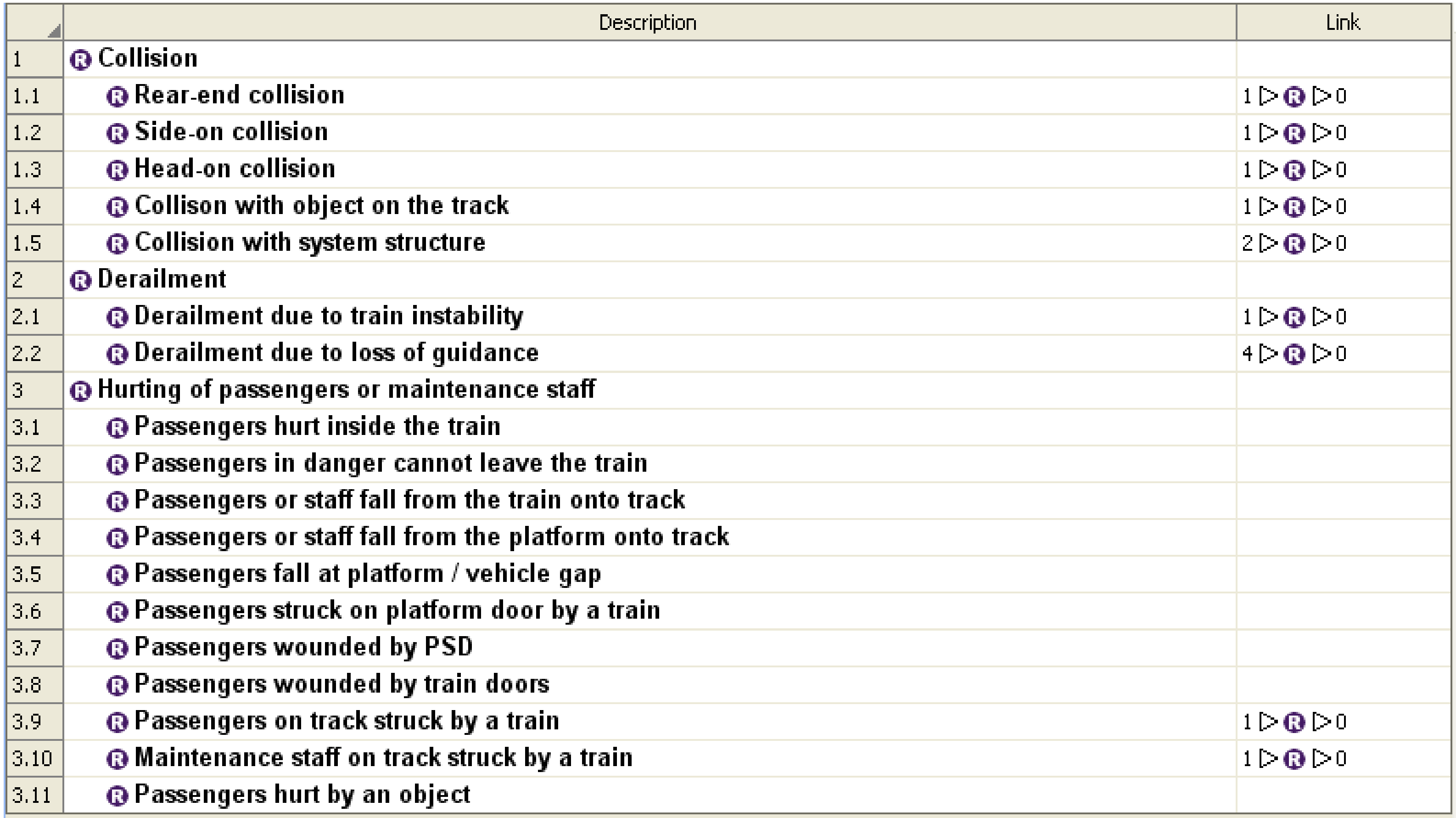
Hazard analysis with STAMP/STPA

- Identification of the potential accidents
- Identification of the system-level hazards
- Identification of the system-level requirements
- Creation of the control structure of the system
- Hazardous controls analysis
- Casual factor analysis
- Requirements management

3 - Achievements

Hazard Analysis with STAMP/STPA

- Identification of accidents



	Description	Link
1	Ⓡ Collision	
1.1	Ⓡ Rear-end collision	1 ▷ Ⓡ ▷ 0
1.2	Ⓡ Side-on collision	1 ▷ Ⓡ ▷ 0
1.3	Ⓡ Head-on collision	1 ▷ Ⓡ ▷ 0
1.4	Ⓡ Collison with object on the track	1 ▷ Ⓡ ▷ 0
1.5	Ⓡ Collision with system structure	2 ▷ Ⓡ ▷ 0
2	Ⓡ Derailment	
2.1	Ⓡ Derailment due to train instability	1 ▷ Ⓡ ▷ 0
2.2	Ⓡ Derailment due to loss of guidance	4 ▷ Ⓡ ▷ 0
3	Ⓡ Hurting of passengers or maintenance staff	
3.1	Ⓡ Passengers hurt inside the train	
3.2	Ⓡ Passengers in danger cannot leave the train	
3.3	Ⓡ Passengers or staff fall from the train onto track	
3.4	Ⓡ Passengers or staff fall from the platform onto track	
3.5	Ⓡ Passengers fall at platform / vehicle gap	
3.6	Ⓡ Passengers struck on platform door by a train	
3.7	Ⓡ Passengers wounded by PSD	
3.8	Ⓡ Passengers wounded by train doors	
3.9	Ⓡ Passengers on track struck by a train	1 ▷ Ⓡ ▷ 0
3.10	Ⓡ Maintenance staff on track struck by a train	1 ▷ Ⓡ ▷ 0
3.11	Ⓡ Passengers hurt by an object	

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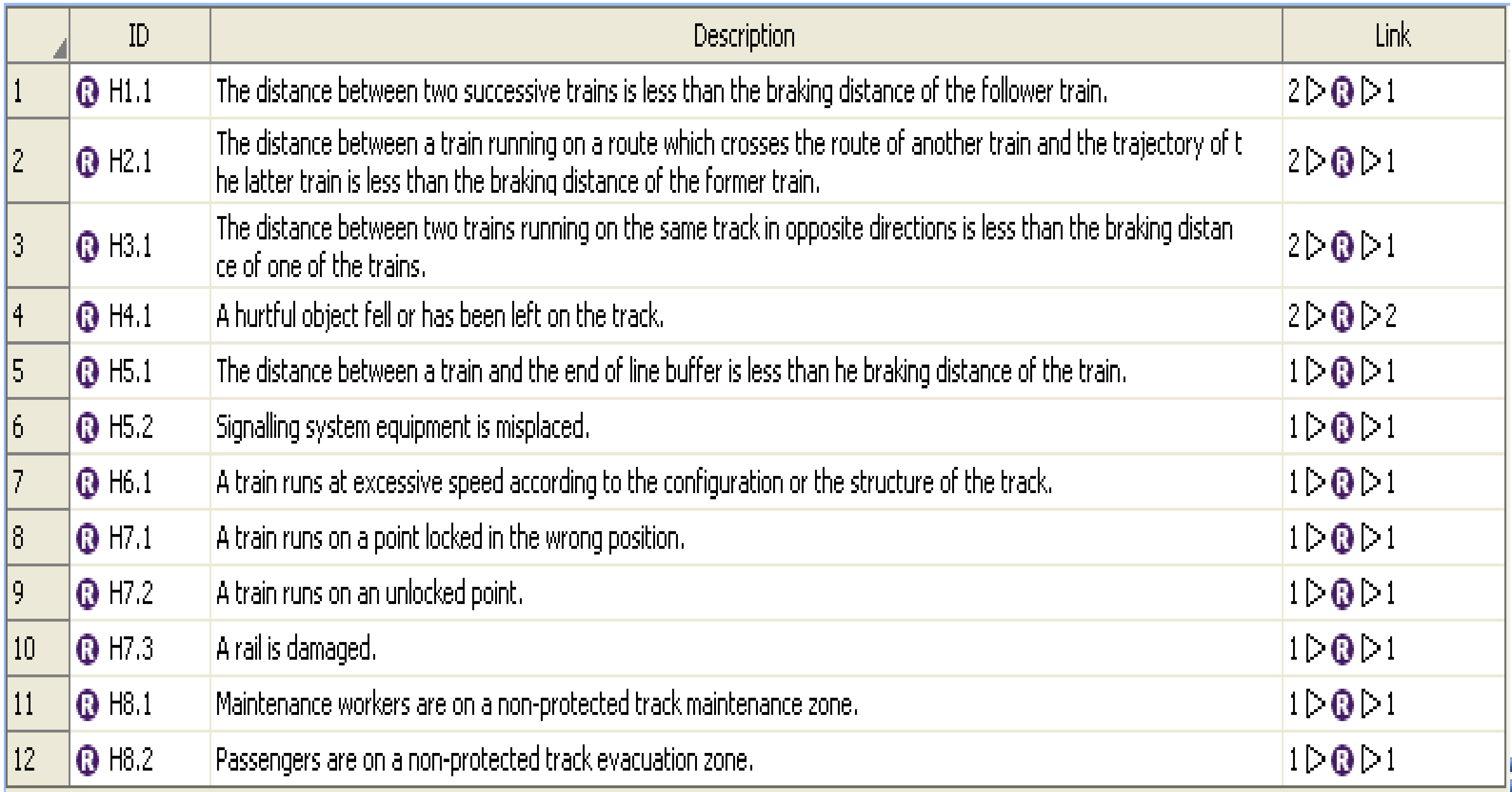
3 - Achievements

Hazard Analysis with STAMP/STPA

- Identification of hazards

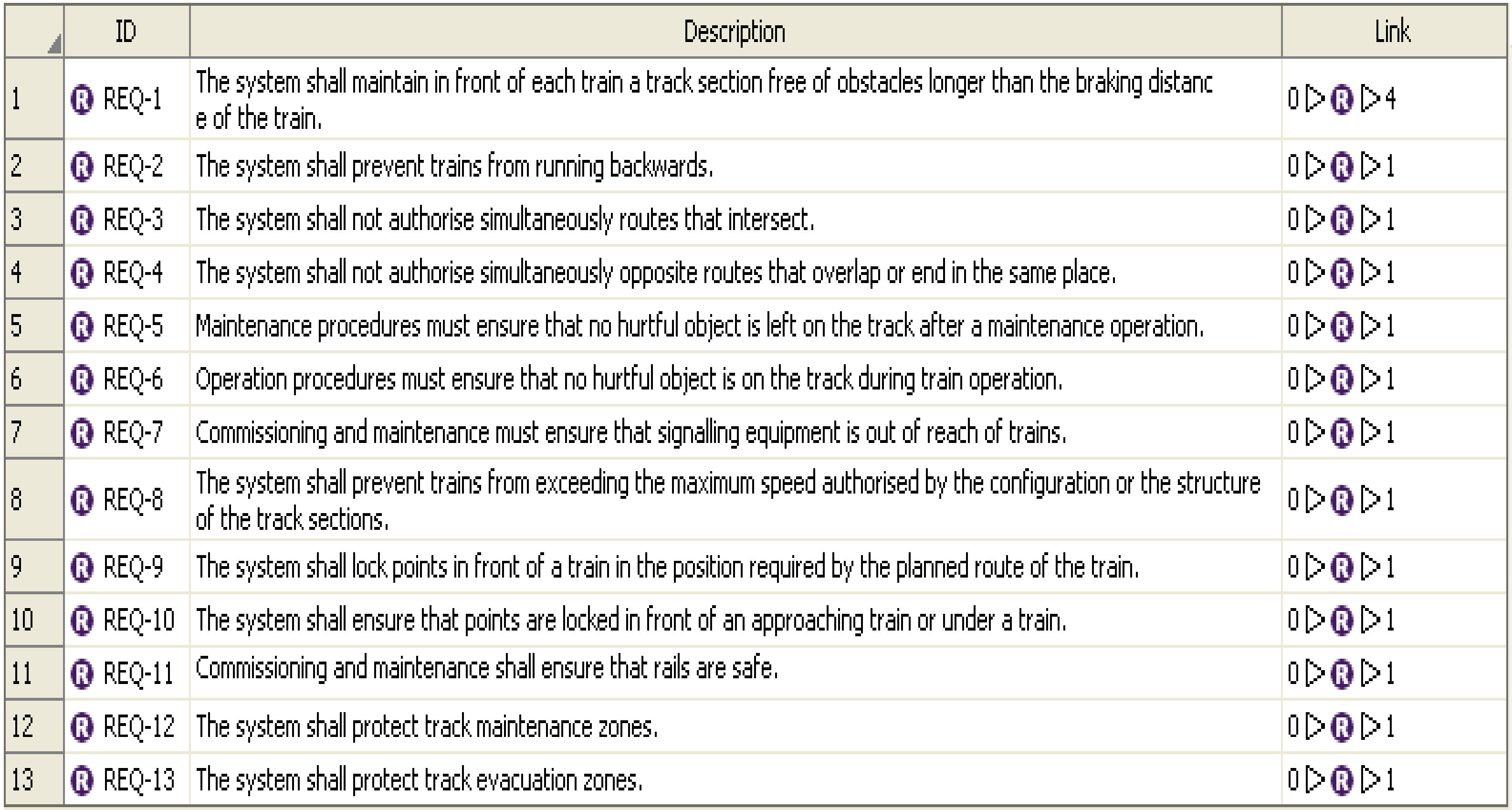


	ID	Description	Link
1	Ⓡ H1.1	The distance between two successive trains is less than the braking distance of the follower train.	2 ▷ Ⓡ ▷ 1
2	Ⓡ H2.1	The distance between a train running on a route which crosses the route of another train and the trajectory of the latter train is less than the braking distance of the former train.	2 ▷ Ⓡ ▷ 1
3	Ⓡ H3.1	The distance between two trains running on the same track in opposite directions is less than the braking distance of one of the trains.	2 ▷ Ⓡ ▷ 1
4	Ⓡ H4.1	A hurtful object fell or has been left on the track.	2 ▷ Ⓡ ▷ 2
5	Ⓡ H5.1	The distance between a train and the end of line buffer is less than he braking distance of the train.	1 ▷ Ⓡ ▷ 1
6	Ⓡ H5.2	Signalling system equipment is misplaced.	1 ▷ Ⓡ ▷ 1
7	Ⓡ H6.1	A train runs at excessive speed according to the configuration or the structure of the track.	1 ▷ Ⓡ ▷ 1
8	Ⓡ H7.1	A train runs on a point locked in the wrong position.	1 ▷ Ⓡ ▷ 1
9	Ⓡ H7.2	A train runs on an unlocked point.	1 ▷ Ⓡ ▷ 1
10	Ⓡ H7.3	A rail is damaged.	1 ▷ Ⓡ ▷ 1
11	Ⓡ H8.1	Maintenance workers are on a non-protected track maintenance zone.	1 ▷ Ⓡ ▷ 1
12	Ⓡ H8.2	Passengers are on a non-protected track evacuation zone.	1 ▷ Ⓡ ▷ 1

3 - Achievements

Hazard Analysis with STAMP/STPA

- Identification of requirements

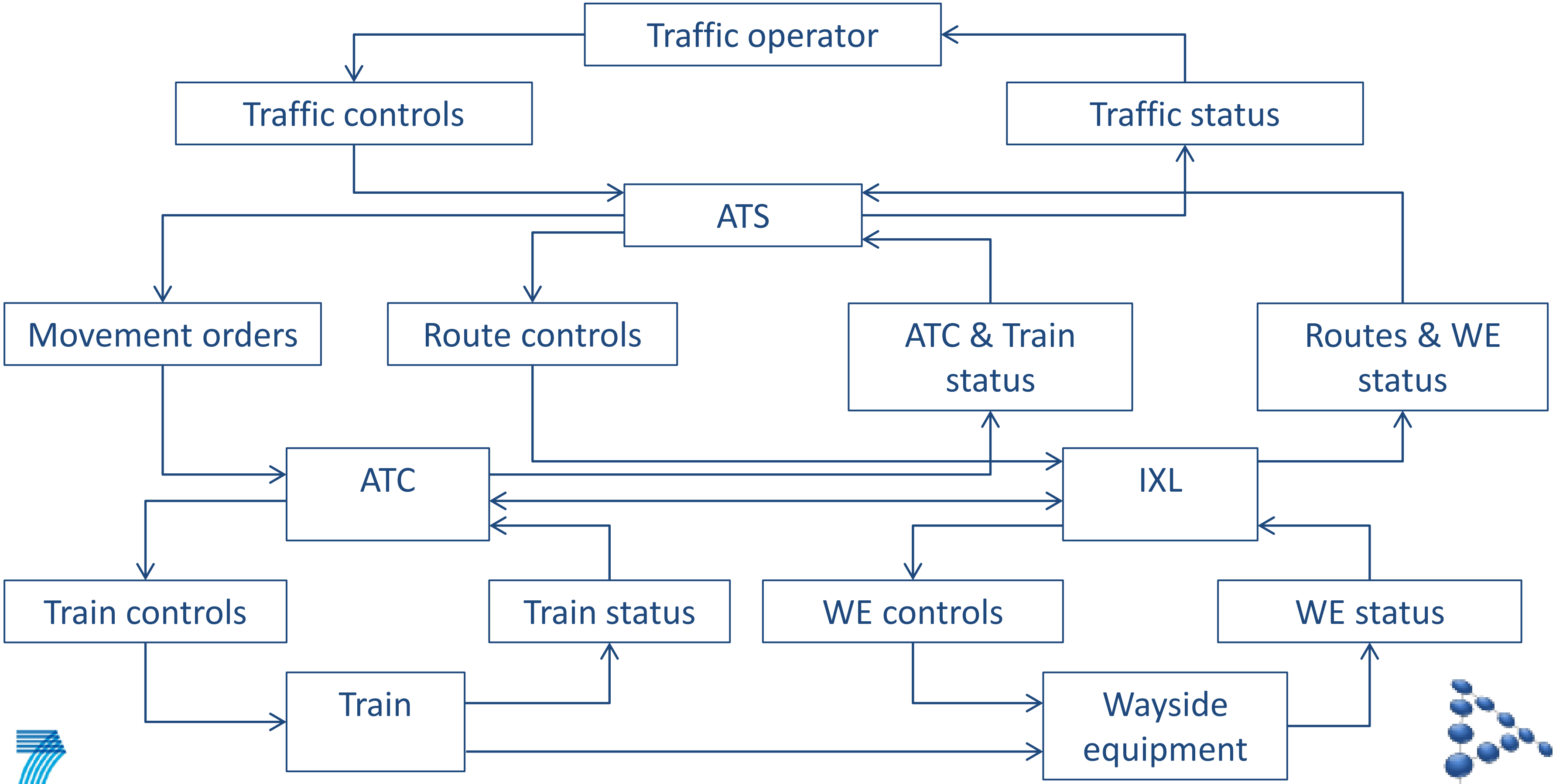


	ID	Description	Link
1	Ⓡ REQ-1	The system shall maintain in front of each train a track section free of obstacles longer than the braking distance of the train.	0 ▷ Ⓡ ▷ 4
2	Ⓡ REQ-2	The system shall prevent trains from running backwards.	0 ▷ Ⓡ ▷ 1
3	Ⓡ REQ-3	The system shall not authorise simultaneously routes that intersect.	0 ▷ Ⓡ ▷ 1
4	Ⓡ REQ-4	The system shall not authorise simultaneously opposite routes that overlap or end in the same place.	0 ▷ Ⓡ ▷ 1
5	Ⓡ REQ-5	Maintenance procedures must ensure that no hurtful object is left on the track after a maintenance operation.	0 ▷ Ⓡ ▷ 1
6	Ⓡ REQ-6	Operation procedures must ensure that no hurtful object is on the track during train operation.	0 ▷ Ⓡ ▷ 1
7	Ⓡ REQ-7	Commissioning and maintenance must ensure that signalling equipment is out of reach of trains.	0 ▷ Ⓡ ▷ 1
8	Ⓡ REQ-8	The system shall prevent trains from exceeding the maximum speed authorised by the configuration or the structure of the track sections.	0 ▷ Ⓡ ▷ 1
9	Ⓡ REQ-9	The system shall lock points in front of a train in the position required by the planned route of the train.	0 ▷ Ⓡ ▷ 1
10	Ⓡ REQ-10	The system shall ensure that points are locked in front of an approaching train or under a train.	0 ▷ Ⓡ ▷ 1
11	Ⓡ REQ-11	Commissioning and maintenance shall ensure that rails are safe.	0 ▷ Ⓡ ▷ 1
12	Ⓡ REQ-12	The system shall protect track maintenance zones.	0 ▷ Ⓡ ▷ 1
13	Ⓡ REQ-13	The system shall protect track evacuation zones.	0 ▷ Ⓡ ▷ 1

3 - Achievements

Hazard analysis with STAMP/STPA

- Control structure



3 - Achievements

Hazard analysis with STAMP/STPA

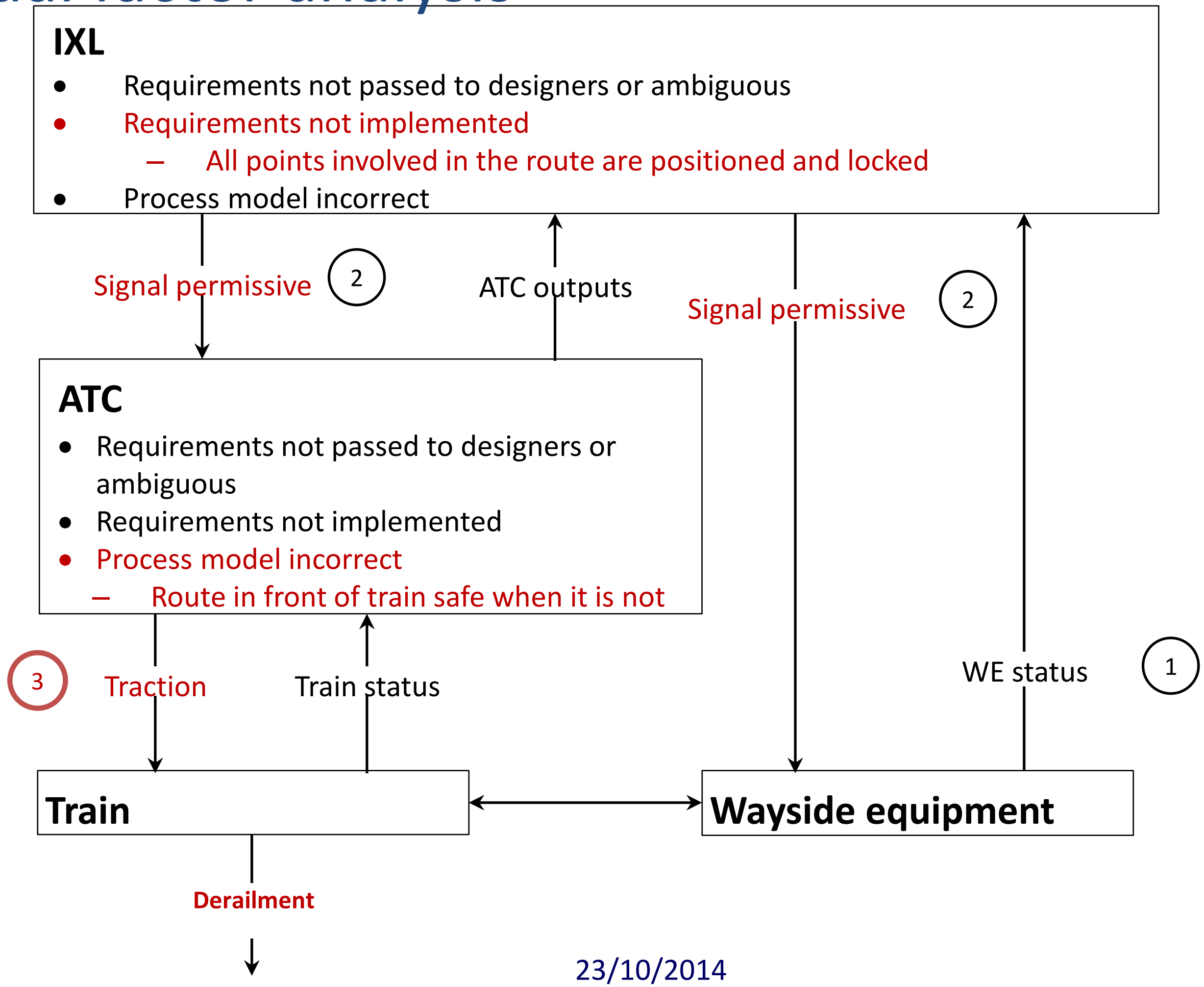
- Hazardous controls analysis

Control	Not providing causes hazard	Providing causes hazard	Wrong timing/order causes hazard	Stopped too soon/applied too long causes hazard
Signal Permissive	Not hazardous	Braking distance too short; unlocked or wrongly positioned point; excessive speed	Too early : cf. 2nd column	Too soon : not hazardous
			Too late : not hazardous	Too long : cf. 2nd column
Signal restrictive	Braking distance too short; unlocked or wrongly positioned point; excessive speed	Not hazardous	Too early : not hazardous	Too soon : cf. 2nd column
			Too late : cf. 2nd column	Too long : not hazardous
			Wrong order :	
Control point	Wrongly positioned point	Unlocked or wrongly positioned point; excessive speed	Too early : Unlocked point	Too soon : Unlocked point
			Too late : Unlocked point	Too long : not hazardous

3 - Achievements

Hazard analysis with STAMP/STPA

- Casual factor analysis



IXL

- Requirements not passed to designers or ambiguous
- Requirements not implemented
  - All points involved in the route are positioned and locked
- Process model incorrect

ATC

- Requirements not passed to designers or ambiguous
- Requirements not implemented
- Process model incorrect
  - Route in front of train safe when it is not

Train

Wayside equipment

3 - Achievements

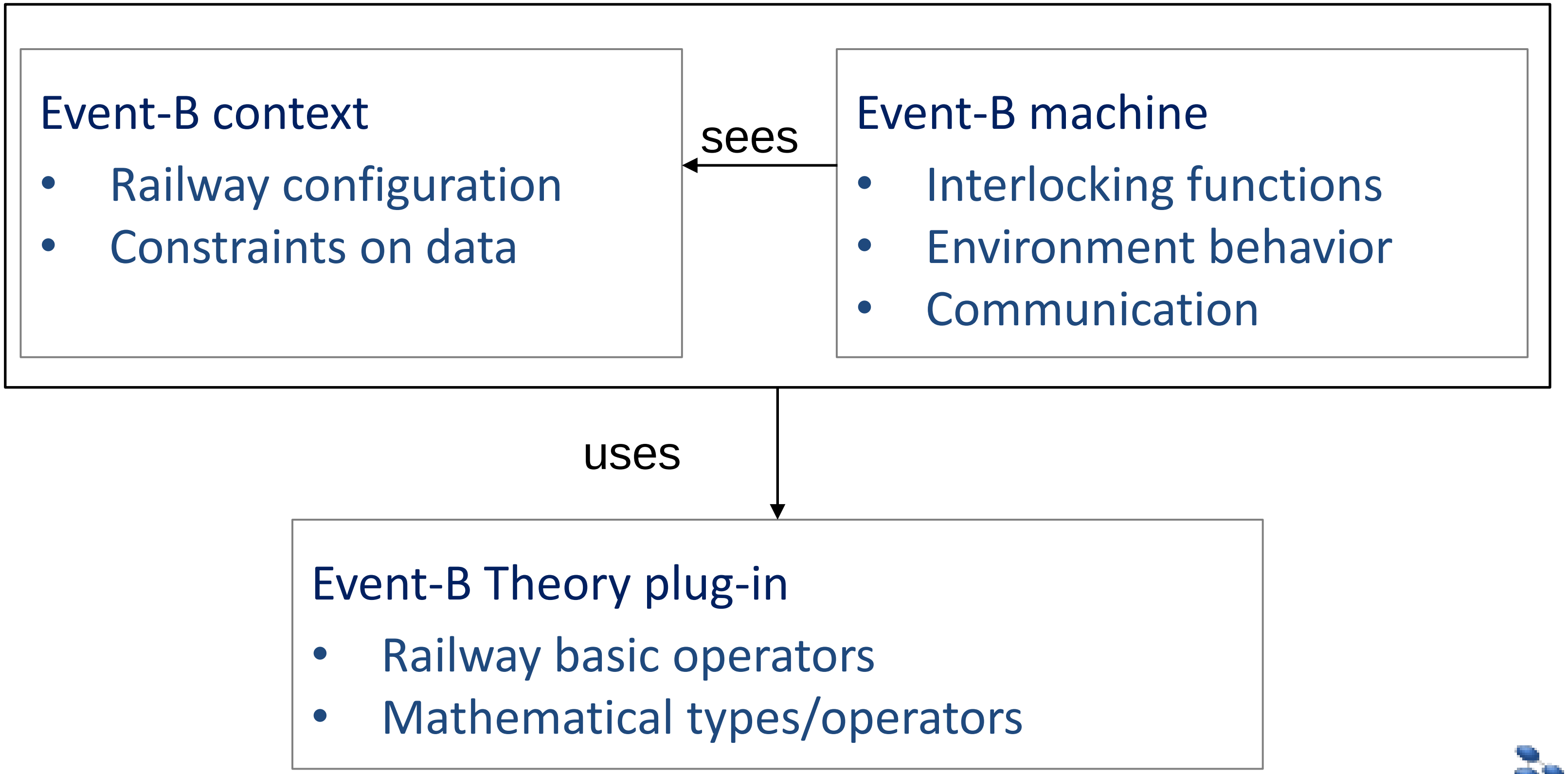
Modelling and proof with Rodin

- Using refinement
  - From system overview to railway devices
- Using Event-B Theory plug-in
  - Defining mathematical and railway operators
- Using Composition/Decomposition plug-in
  - Separating environment, controller and communication
- Proving
  - Defining theorems and proof rules
  - Defining tactics for automatic PO discharge

3 - Achievements

Modelling and proof with Rodin

- Model structure



Event-B context

- Railway configuration
- Constraints on data

Event-B machine

- Interlocking functions
- Environment behavior
- Communication

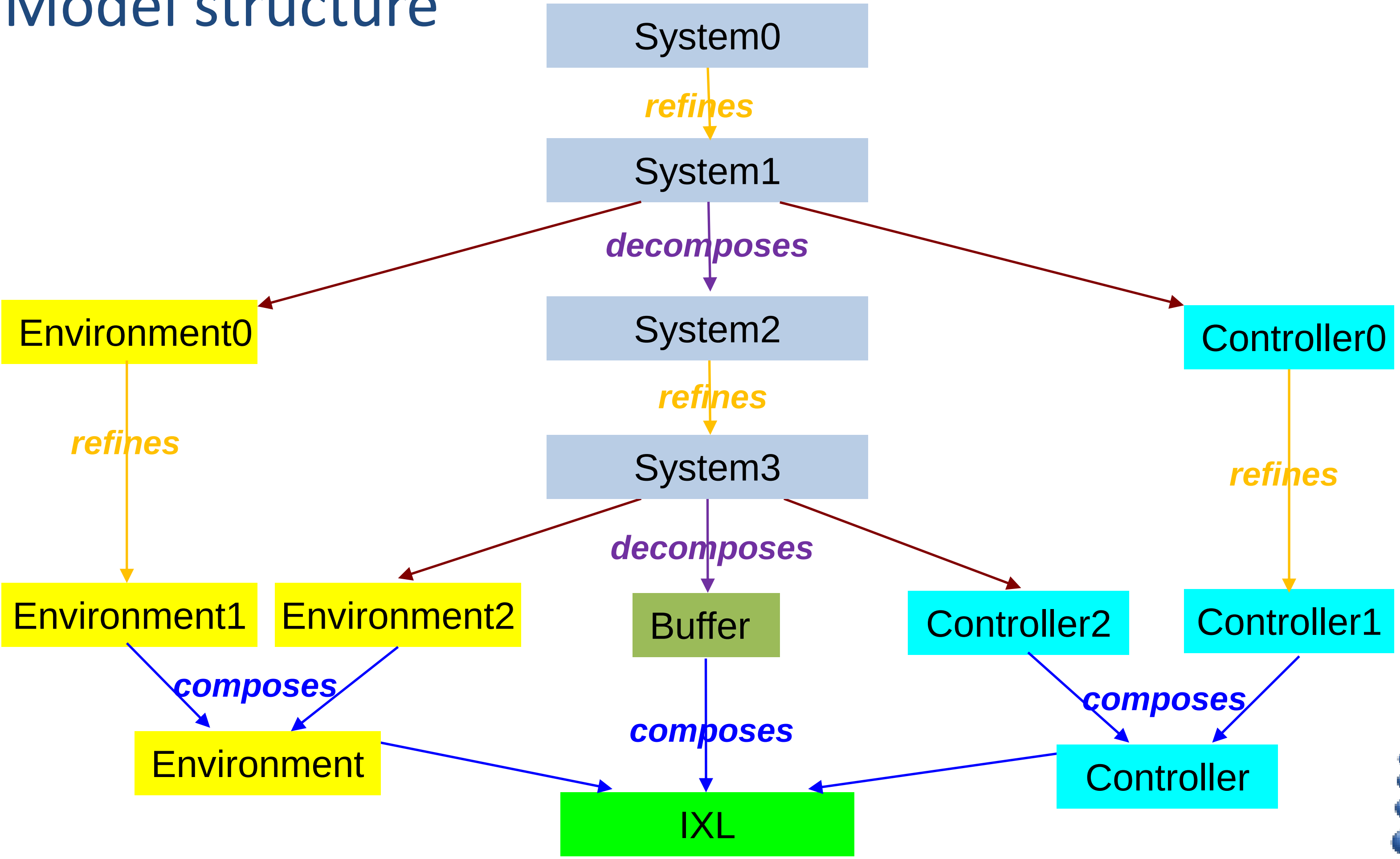
Event-B Theory plug-in

- Railway basic operators
- Mathematical types/operators

3 - Achievements

Modelling and proof with Rodin

- Model structure



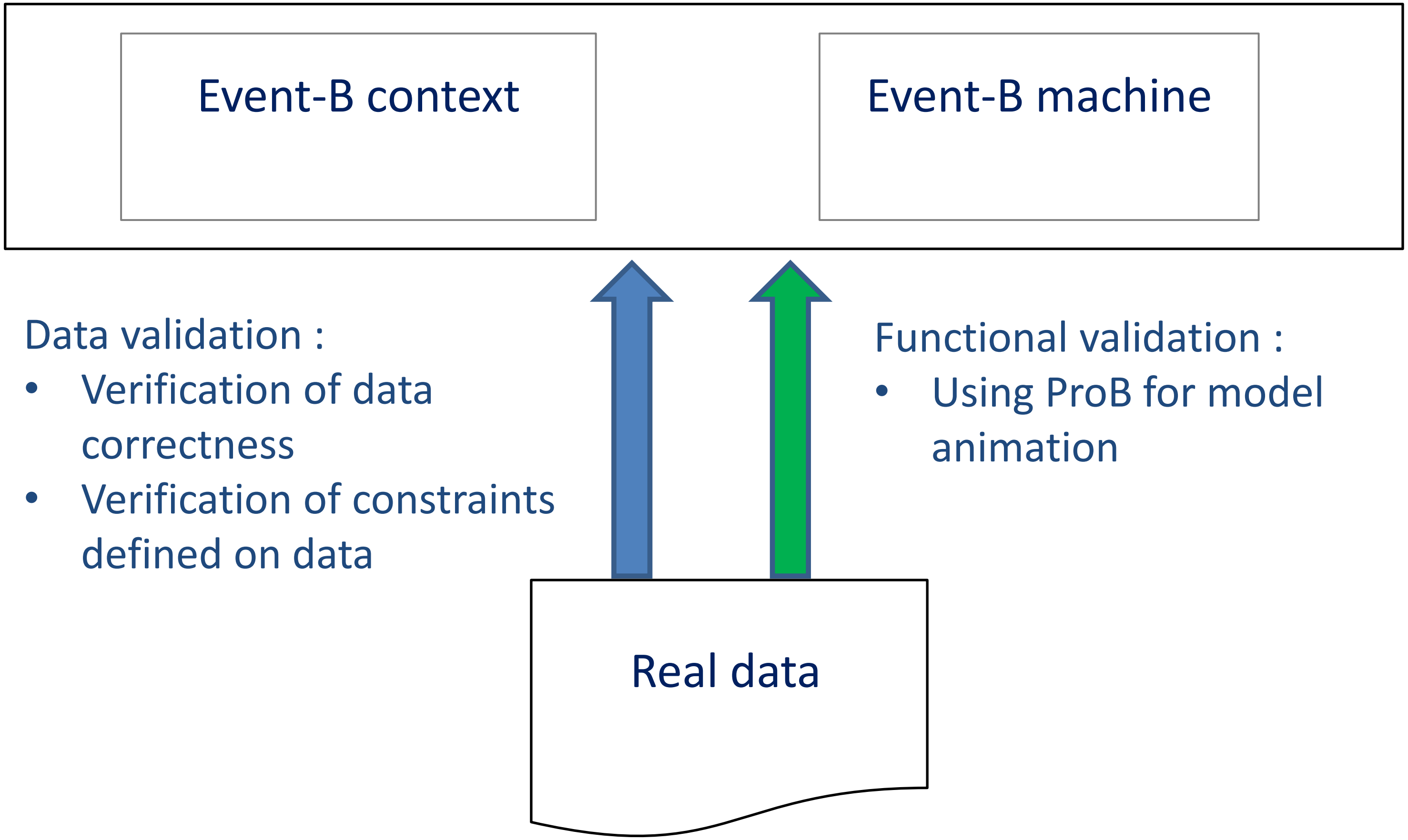
3 - Achievements

Modelling and proof with Rodin

- Proof
  - Automatic proof :
    - Using proof engines integrated in Rodin platform (SMT, AtelierB, etc.)
    - Defining proof tactics
  - Manual proof :
    - Proof of theorems and rules defined in Event-B Theory plug-in components
    - Proof of Event-B components :
      - Using theorems defined in Event-B Theory plug-in components
      - Using manual proof rules defined in Event-B Theory plug-in components

3 - Achievements

Model animation with ProB



Data validation :

- Verification of data correctness
- Verification of constraints defined on data

Functional validation :

- Using ProB for model animation

3 - Achievements

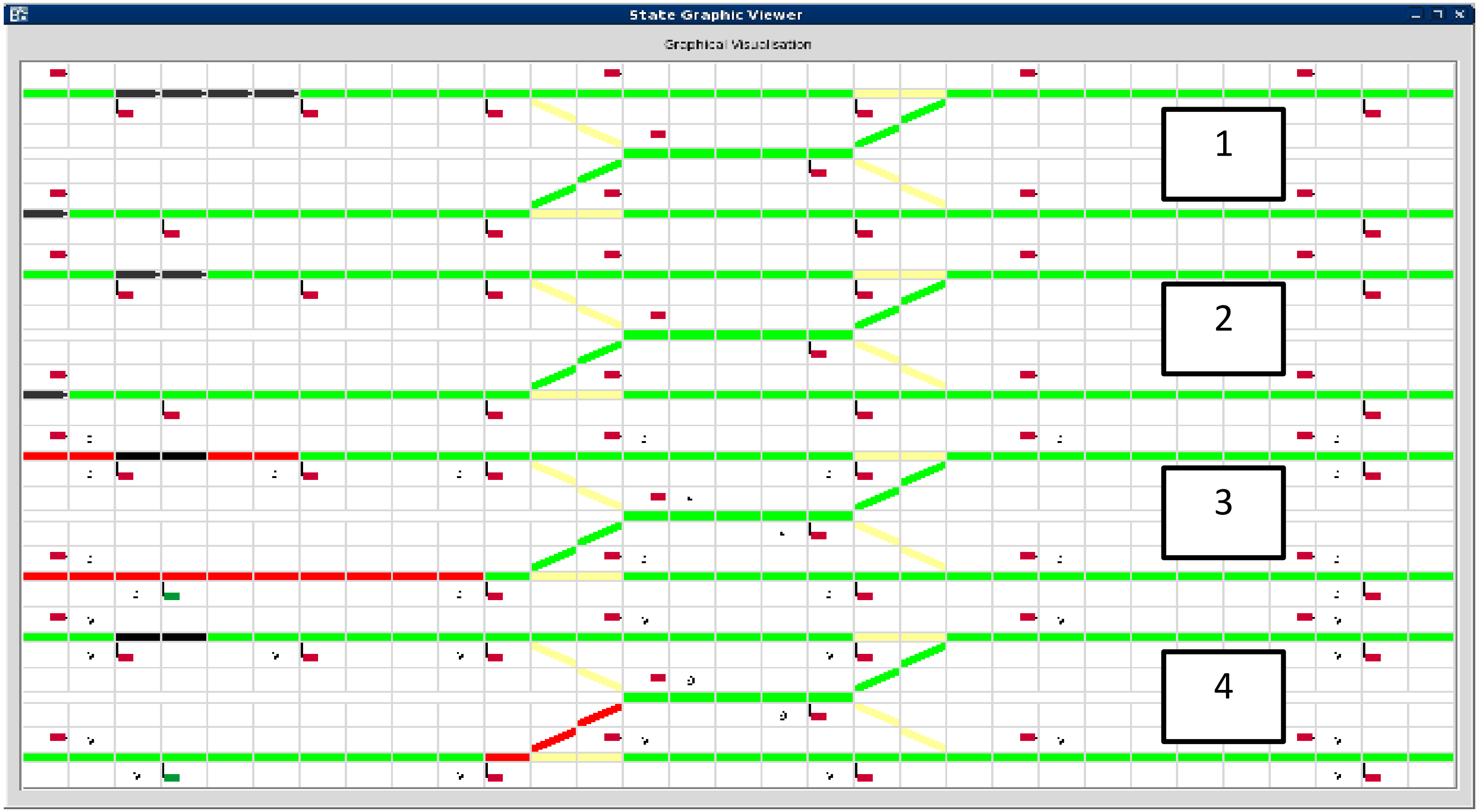
Model animation with ProB

- Manual animation
  - Analysis of degraded modes
    - Track circuits, points and train shunting defaults
  - Analysis of asynchronies due to communication delays
  - Analysis of unsafe scenarios

3 - Achievements

Model animation with ProB

- Manual animation display



3 - Achievements

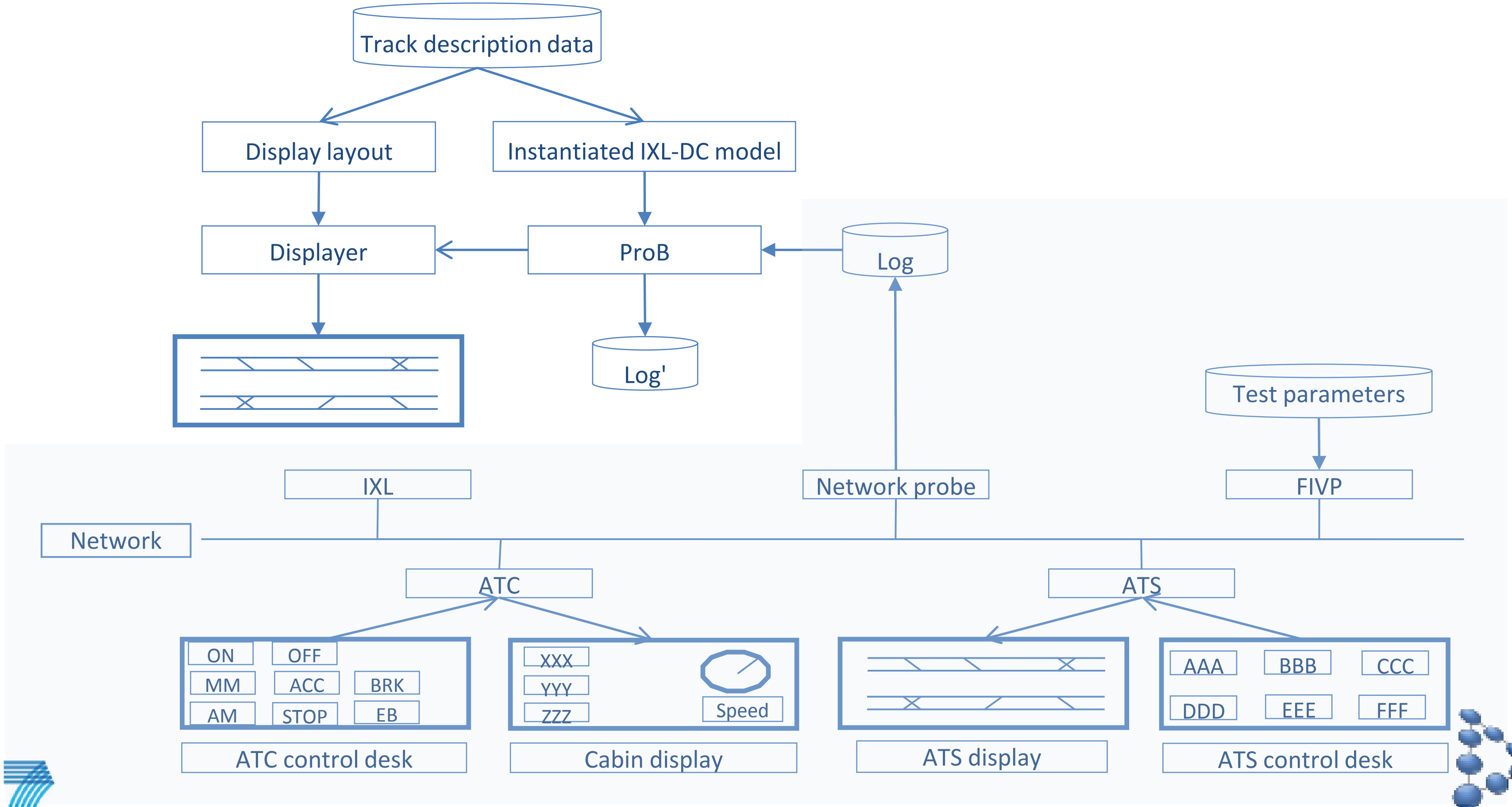
Model animation with ProB

- Automatic animation
  - Test IXL-DC model in realistic conditions
    - Revenue service line
    - Integrated with ATS, ATC and IXL systems
  - Test IXL-DC model with more comprehensive and diverse scenarios
  - Test IXL-DC model is not too restrictive

3 - Achievements

Model animation with ProB

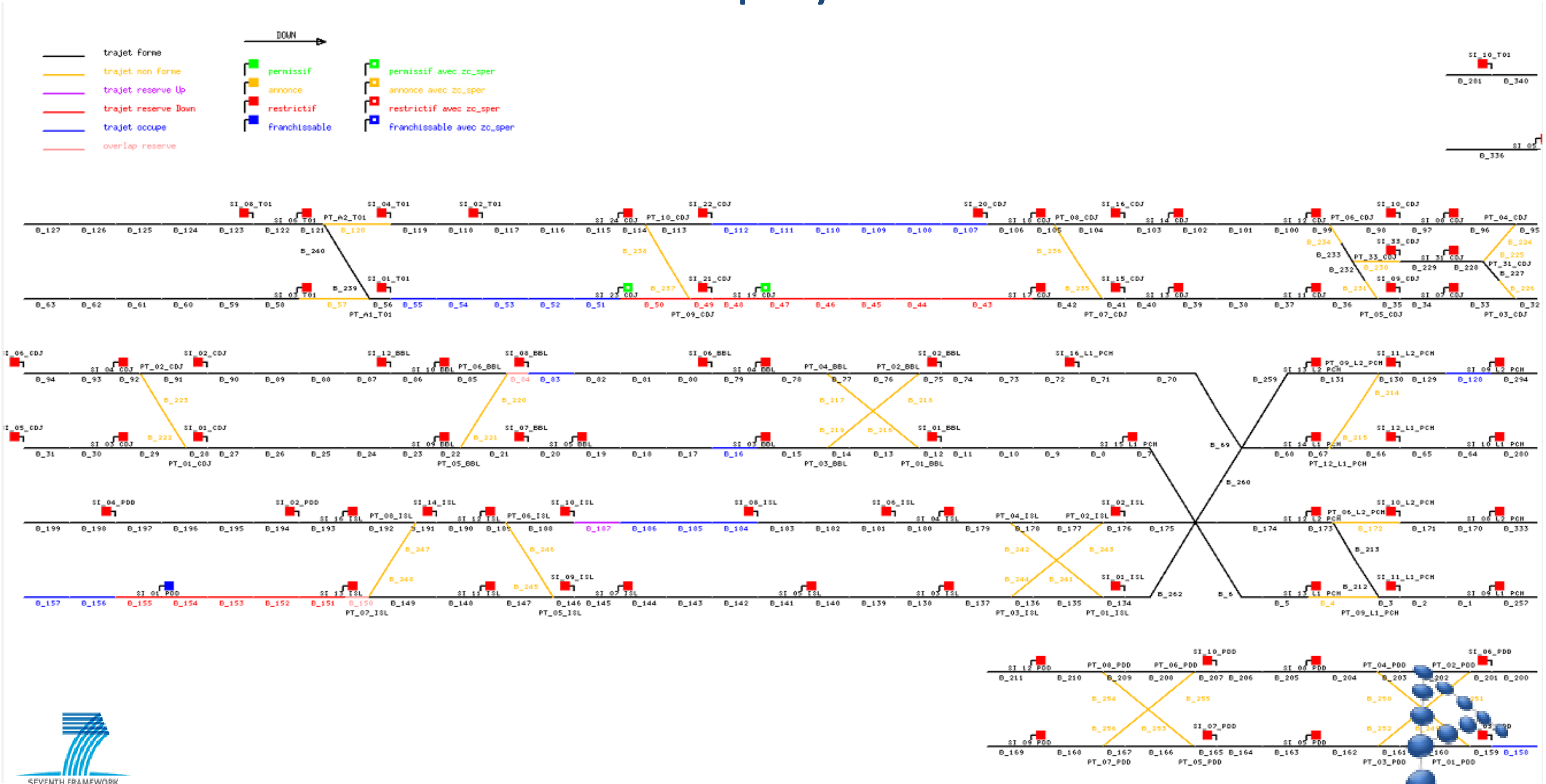
- Automatic animation architecture



3 - Achievements

Model animation with ProB

- Automatic animation display



3 - Achievements

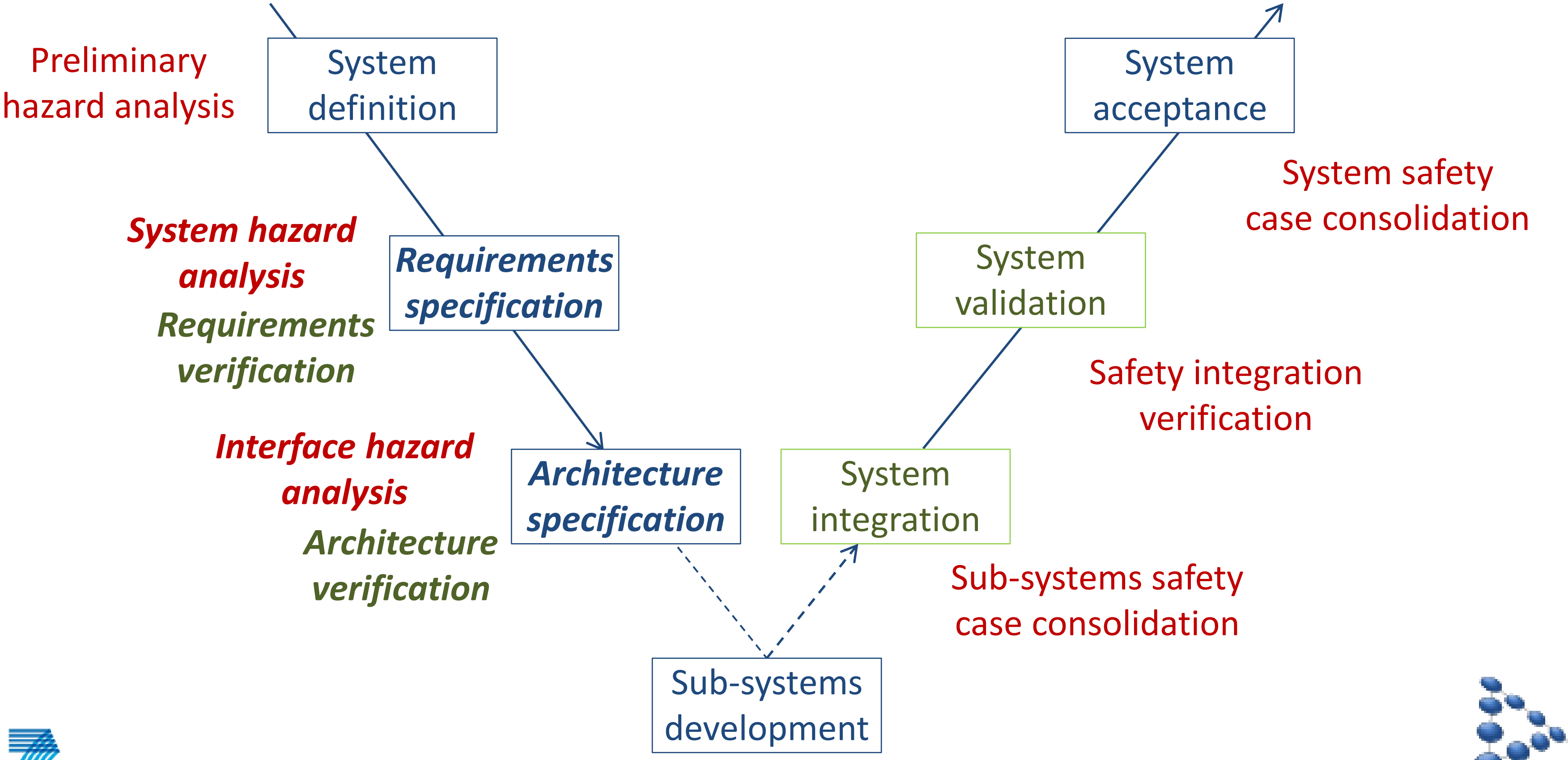
System Development Process

- Goal:
  - Introduce formal model development with Advance methods and tools in a system process compliant with CENELEC standards
- Motivations:
  - Improve quality of system definition
  - Improve V&V effectiveness
  - Reduce V&V costs & non conformity costs
  - Improve traceability with sub-system development and software development

3 - Achievements

System Development Process

- Flow of activities compliant with CENELEC standards



Preliminary hazard analysis

System definition

System hazard analysis

Requirements specification

Requirements verification

Interface hazard analysis

Architecture specification

Architecture verification

Sub-systems development

System integration

Sub-systems safety case consolidation

System validation

Safety integration verification

System acceptance

System safety case consolidation

23/10/2014

3 - Achievements

System Development Process

- System definition
  - No particular application of Advance M&T
- Preliminary hazard analysis
  - No particular application of Advance M&T
- Requirements specification
  - Event-B modelling (Rodin)
  - Tests definition by animation (ProB) and co-simulation (ProB – FMI)
  - Proof (Rodin)

3 - Achievements

System Development Process

- System hazard analysis
  - STAMP & STPA
- Requirements verification
  - Event-B model verification
  - Tests scenarios verification
  - Proof report verification
- Architecture specification
  - Sub-system modelling by refinement and decomposition (Rodin)
  - Proof (Rodin)

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3 - Achievements

System Development Process

- Interface hazard analysis
  - STAMP & STPA
- Architecture verification
  - Sub-system models verification
  - Proof verification
- Sub-systems safety case consolidation
  - Reuse of safety cases of sub-systems
- System integration
  - Reuse of proofs to reduce testing

3 - Achievements

System Development Process

- Safety integration verification
  - Reuse of safety analysis and verifications
- System validation
  - Reuse of tests scenarios
- System safety case consolidation
  - Reuse of safety analysis and verifications

4 - Conclusions

- IXL-DC model has been proved
  - ✓ *Proof that IXL + IXL-DC comply with system safety requirements*
- IXL-DC model is made of a generic part proved once for all and a specific part verified formally for each project
  - ✓ *Proof technique is independent of the complexity and the implementation technology of IXL*
- IXL-DC model specified, created and validated following an integrated system development process
  - ✓ *Integration of Advance M&T in an industrial system development process*

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4 - Conclusions

- Creation and proof of IXL-DC model improved the model construction and proof techniques of Event-B and Rodin
  - ✓ *Refinement and model decomposition methods applied*
  - ✓ *Composition/decomposition and “Theory” plugins of Rodin improved*
- Animation of the IXL-DC model improved and extended the capabilities of ProB
  - ✓ *Link with other development processes via scripting and I/O library*
  - ✓ *Performance of ProB’s kernel improved*
  - ✓ *New visualisation capabilities of ProBMotion tested and improved*
  - ✓ *Tests of ProB 2’s scripting architecture*

4 - Conclusions

- Advance methods and tools for formal system development are powerful and complementary :

  ✓ *Hazard analysis + Formal modelling + Model animation + Proof*

  => System specification suited & safe by construction

  => Significant costs reduction & quality improvement

- But to be fully compliant with industrial needs :

  – A reliable and sustainable model of development, training and support of Advance methods and tools must be implemented

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