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Standards for functions and interfaces as a basis for CBTC on mainline railways in Europe

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Synopsis

A major issue for the migration to CBTC systems on mainline railways is the standardisation of interfaces between CBTC components and conventional signalling components such as interlockings. One basis for such standardisation must be a common approach for the expression of functional requirements. Standard interfaces and standardised expression of functional requirements are main objectives of the Euro-Interlocking project.

The railways of Europe are implementing CBTC in the form of ERTMS/ETCS, whose Level 2 allows elimination of lineside signals and whose Level 3 allows moving blocks. At the same time, the European market for railway interlocking systems – not counting investment in ERTMS/ETCS – exceeds a yearly turnover of €4 billion. With the objective of significantly reducing life-cycle costs for interlocking systems, the Euro-Interlocking project is in the process of introducing standardisation into this area of safety technology for railways.

The European railways launched Euro-Interlocking in 1999 under the auspices of the International Union of Railways (UIC). Since then, the project has developed and approved over 30 standards for the procurement of interlocking systems in Europe. These standards have focused on non-functional requirements – especially reliability, availability, maintainability and safety (RAMS) – for interlocking systems.

The Euro-Interlocking project is now focusing on the development of both European functional requirements and standardised interfaces for interlocking systems. The work on functional requirements is crucial for the procurement of interlocking systems and their validation and verification within the framework of the CENELEC standards EN 50126 to 50129. At the same time,

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the Euro-Interlocking project is pushing forward work to standardise interfaces between interlocking systems and other signalling components, including ERTMS/ETCS.

The list of Euro-Interlocking's benefits is long. Its main focus, however, is to significantly reduce the life-cycle costs of interlocking systems in Europe. One key way the project will cut costs is by clearing a route for the migration to ERTMS/ETCS systems, with their long-term cost and interoperability benefits.

Euro-Interlocking is not just creating standards, but also actively promoting their implementation. To that end, the project is working closely with the French and the Danish railways on their non-functional requirements standards. The Finnish railways will be using the Data File Format Standards for procurement, and the Swiss Federal Railways have used Euro-Interlocking requirements in an extensive tender for interlocking systems. The project team is also supporting the Finnish, the Dutch and the Danish railways in defining and structuring their functional requirements.

1. Introduction

The Euro-Interlocking business case has shown that the European railways spend about €4 billion a year on the procurement and maintenance of interlocking systems (based on data for 1995-99). This excludes outlays for ERTMS/ETCS, AWS, ATP and traffic control systems.

Given both the increasing pressure from train operators to lower the costs of rail infrastructure and the large investments for rail signalling foreseen in the coming years, signalling engineers and managers are under pressure to reduce the overall life-cycle costs of rail signalling systems.

With this in mind, the European railways started the Euro-Interlocking project under the auspices of the UIC in 1999 with the main objective of significantly reducing the life-cycle costs of interlocking systems in Europe.

Starting in 2001, signalling suppliers and supporting companies also joined the project and have been contributing significantly to the development of the Euro-Interlocking standards. Today, 29 railway and signalling companies are members of the Euro-Interlocking project, including all of the major suppliers.

The project is to achieve its objective of life-cycle cost reduction mainly by developing the following sets of standards:

- Standardised requirements for interlocking systems to meet the current and future needs of the European railways, including for the procurement of new interlockings within the framework of ERTMS/ETCS.

- Standardised specifications for interlocking and signalling system interfaces, such as interfaces to adjacent interlocking, traffic control, and ETCS radio block centre systems.

The basis and backbone for all requirements standardisation work in the Euro-Interlocking project is the existing

CENELEC standards, in particular EN 50126 to 50129.

2. Acronyms and terms

As a small contribution to transatlantic understanding, here are some acronyms and special terms appearing in this paper:

ATP	automatic train protection
AWS	automatic warning system
CBTC	communication-based train control
CENELEC	European Committee for Electrotechnical Standardisation
DOORS	Dynamic Object-Oriented Requirements System
EIFFRA	Euro-Interlocking Formalised Functional Requirements Approach
EN	European Standard ("European Norm")
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System (a sub-project within ERTMS)
OCL	Object Constraint Language
radio block centre	In ETCS, landside system governing radio link to train
SELRED	Structured English Language for Requirements Development
UIC	International Union of Railways
UML	Unified Modelling Language

3. The Euro-Interlocking standards

The Euro-Interlocking project is roughly at the midpoint of its work. A body of standards in the non-functional area has been approved, and standards for interfaces and functional requirements are now under development.

3.1 Standards already approved

Between September 2002 and March 2003, in a culmination of efforts since 2000, the Euro-Interlocking project's Steering Group approved 32 standards deliverables. Three more deliverables are slated for approval in May 2003.

These standards open the door for procurement of harmonised interlocking systems in Europe.

The stakeholders in the Euro-Interlocking project have collectively produced and approved requirements standards in the following areas:

- **RAMS requirements** (reliability, availability, maintainability and safety), which form a cornerstone of the CENELEC systems approval process,
- **related non-functional requirements**, including the areas of cross-acceptance, design and architecture, documentation, electromagnetic compatibility (EMC), environmental conditions, verification and validation, installation and commissioning, lifetime, modification, performance, physical construction, and power supply,
- **supporting system requirements** for data preparation, diagnostics, and juridical recording. The approval of data preparation standards will help to significantly shorten time to market for interlocking systems.

3.2 Standards now being developed

The Euro-Interlocking project is now focusing its attention on the following objectives:

- **standardisation of interfaces** from the interlocking system to traffic control systems, to adjacent interlocking systems, to ETCS radio block centres, and to track elements, and
- **functional requirements**, including harmonisation of functionality based on a standardised, object-oriented approach in line with the basic requirements of train operation in Europe. A standard methodology for the expression of functional requirements has been developed and a common core of such requirements for Europe is under development.

4. Overview of non-functional requirements standards

Since September 2002, the project's Steering Group has approved 32 harmonised standards for the procurement of interlocking systems in Europe. This section presents an overview.

4.1 High-level documents

The following high-level standards documents are based on the project's structured approach for requirements development:

- Terms Glossary
- Domain Knowledge / Context Diagram document
- High-Level Requirements
- SELRED Guideline (Structured English Language for Requirements Development)

4.2 CENELEC-related deliverables

The following deliverables and standards are closely related to and based on CENELEC standard EN 50126:

- Generic Safety Plan Template
- Generic Validation and Verification Plan Template
- Generic Preliminary Hazard Analysis Template (generic, standardised list of hazards)
- Guidelines for Hazard Analysis
- Hazard Log Requirements

4.3 Qualitative requirements

The following qualitative RAMS and supporting system requirements build on existing CENELEC standards and promote a harmonised interpretation of these standards when procuring new interlocking systems:

- Availability Requirements
- Cross-Acceptance Requirements
- Design and Architecture Requirements
- Diagnostic System Requirements
- Documentation Requirements
- Electromagnetic Compatibility (EMC) Requirements
- Environmental Condition Requirements
- Installation and Commissioning Requirements
- Juridical Recorder Requirements
- Lifetime Requirements
- Maintainability Requirements
- Modification Requirements

- Performance Requirements
- Physical Construction Requirements
- Power Supply Requirements
- Reliability Requirements
- Safety Requirements

4.4 Data preparation requirements

During the planning and implementation of an interlocking system in a specific application, data preparation systems can significantly reduce planning and design costs and the time needed to implement, test and commission the system.

The following standards support the implementation and use of data preparation systems by railways and suppliers:

- Supplier-Furnished Data Preparation Tool Requirements
- Interlocking Data File Format (IDAFF)
- Location Data File Format

5. ERTMS/ETCS

ERTMS/ETCS is the European project to apply CBTC to mainline railways. The Euro-Interlocking project is the logical continuation of the UIC commitment to system standardisation and cost minimisation in the field of train control and communication. Although the Euro-Interlocking project is separate from the ERTMS/ETCS and GSM-R projects, its common interests and interfaces require close co-ordination with these projects.

The ERTMS/ETCS project has focused primarily on the train side of traffic control. However, at least in ERTMS/ETCS Levels 1 and 2, interlockings still perform the key functions for train safety and control on the infrastructure side. Furthermore, the Euro-Interlocking standards allow the use of interfaces and components with ERTMS/ETCS Level 3 as required for migration and implementation.

6. CENELEC standards

The Euro-Interlocking standards comply fully with the CENELEC standards EN 50126 to 50129 concerning the reliability, availability, maintenance and safety (RAMS) of railway systems.

7. Industry involvement

The participating railways in the Euro-Interlocking project have been dedicated to collaborating closely with signalling and related suppliers in detailed project work. Industry experts are working directly with the project team in carrying out the tasks defined in the Euro-Interlocking work breakdown structure.

Another key role of industry partners will be to draft system specifications based on the Euro-Interlocking requirements and to apply the standards through to implementation and commissioning of projects.

8. Benefits

In addition to the short and long-term financial gains from Euro-Interlocking, the project is also bringing railways the following benefits:

- An open procurement market thanks to the harmonisation of functional and system requirements at a European level.

- Improved reliability and availability resulting from standardisation of interfaces and functionality. This enables interoperability and interchange of components, and thus promotes interlocking system reliability.

- Simplified system verification, validation, and approval arising from:

  - Formalised verification of Euro-Interlocking requirements before implementation.

  - Use of formal methods, languages and tools for verification and validation during development or adaptation of interlocking systems and components.

  - Elimination of costly adaptation of systems and components for individual railway infrastructure owners.

- Cross-acceptance of components and systems throughout Europe.

- More efficient planning, installation and commissioning of individual interlockings through the optimal use of state-of-the-art tools and technologies.

9. Using DOORS for requirements management

Since the start of the project, the Euro-Interlocking core team has used state-of-the-art methods and tools to elicit, capture and develop the Euro-Interlocking requirements standards, and manage change. A key to this work has been the DOORS requirements management tool (Dynamic Object-Oriented Requirements System), which is the basis for all requirements work in the project. This tool allows

- unique identification of all requirements,

- tracking of the development of requirements from their creation onward,

- support for the hierarchy of requirements within the standards,

- linking of the requirements both to one another and to other documents such as the CENELEC standards,

- entry of change proposals through an extranet portal,

- capture, management and tracking of all change proposals and the resulting modifications to the Euro-Interlocking requirements, and

- establishment of successive baselines for all requirements and support for a solid configuration management system.

The Euro-Interlocking project has developed and is actively managing all requirements standards in the DOORS tool.

Since the start of the Euro-Interlocking project, DOORS has established itself as a de facto standard for railways and suppliers in the area of requirements engineering for interlocking systems in Europe.

10. Euro-Interlocking's functional requirements work

10.1 The EIFFRA approach: an introduction

One of Euro-Interlocking's key work packages is the creation of a standardised approach for the development and validation of functional requirements for interlockings.

Since September 2001, a group of experts on signalling, functional requirements, and formal methods have been developing the Euro-Interlocking formalised functional requirements approach (EIFFRA). EIFFRA provides a structured and formal approach for capturing functional requirements that supports the crucial validation and verification process set down by the CENELEC standards EN 50126 to 50129.

In the past, railways have generally expressed their functional requirements in natural-language text supplemented by diagrams. It is clear that functional requirements expressed in this fashion no longer conform to the strict safety and quality standards demanded by the CENELEC standard EN 50126 for system development, validation and approval.

The EIFFRA approach is to be the basis and standard for railways and suppliers to describe the functional requirements for the procurement and development of new interlocking systems. Using the EIFFRA standard to describe the functional requirements of their interlocking systems lets railways save costs and time when procuring new interlocking systems for their network.

The development of the EIFFRA approach is largely completed. Several railways and interlocking suppliers are already using some of the key components of the EIFFRA approach for the description of functional requirements for interlockings, and Euro-Interlocking is now developing the functional requirements of several railways based on this standardised approach.

10.2 Main targets of the EIFFRA approach

The following sections describe the main targets in using formal methods within the Euro-Interlocking project.

10.2.1 Precision of requirements

Using natural language for requirements is almost unavoidable. However, requirements in natural language are often imprecise. Formalised methods can help support natural language in the formulation of precise requirements. One such method is to restrict natural language to a limited subset of words and to define these words in a formal way.

10.2.2 Communicating requirements unambiguously

Requirements should be described and supplemented using several formalised methods. This permits communicating the requirements in several different views and thus promoting a common understanding among the various project stakeholders. The formal approach used for this purpose should consist of different cognitive methods

fitted to the different recipients of the requirements and, if possible, of active links or transformation rules to get from one view of the requirements to another.

10.2.3 Consistency of requirements

Natural language on its own is mainly sequential and unsuited for managing and showing links between requirements. To achieve consistent requirements, a better solution is requirements engineering tools and formal methods, including table-oriented notations and computer-aided requirements management and simulation tools.

10.2.4 Verification and validation

The EIFFRA approach aims to support both verification and validation of functional requirements.

Verification of functional requirements against safety requirements

An important sub-set of functional requirements are safety requirements, which in their role in preventing harm to people have a well-deserved special status. The verification step checks that the functional requirements as a whole fulfil the specified safety requirements. Formal and perhaps automated checking can provide verification. A formal language for the description of safety requirements and a requirements simulation tool can support this process.

Validation of the requirements

After developing a system based on a set of requirements, the fulfilment of all requirements must be shown. EN 50126 calls this process step validation.

To carry out validation, domain experts must first rigorously review and check functional requirements to ensure that the requirements described for an interlocking system are the requirements needed for that system when operating on the railway network. Efficient validation requires the correct and precise capture of requirements and support, for example, by simulation and test cases.

10.3 Solutions adopted for the EIFFRA approach

The EIFFRA approach addresses the needs described in section 10.2 and foresees the use of a combination of different formalised methods for the description of functional requirements.

10.3.1 Notations and tools: an overview

The strength of the EIFFRA approach lies in the use of a combination of several functional requirements engineering methods, tools and techniques. This section is an overview of the elements of the EIFFRA approach standard.

The EIFFRA approach uses five notations or tools for the description of functional requirements (Figure 1). The resulting requirements can be classified as textual or as model-based.

<table>
<tr><th>Class of specification</th><th colspan="2">Notations and tools</th></tr>
<tr><td rowspan="2">Textual requirements</td><td colspan="2">DOORS</td></tr>
<tr><td colspan="2">SELRED Guideline</td></tr>
<tr><td rowspan="2">Model-based requirements</td><td>UML</td><td>Statecharts / Statemate</td></tr>
<tr><td colspan="2">OCL</td></tr>
</table>

Figure 1: Classification of the notations and tools in the EIFFRA approach

10.3.2 Textual requirements

DOORS

As section 9 describes, the Euro-Interlocking project uses the DOORS requirements engineering and management tool for all textual requirements.

In the area of functional requirements, the DOORS tool captures textual requirements, domain knowledge, operating rules and hazard lists. DOORS also supports change requests and configuration management.

SELRED Guideline

The SELRED Guideline (Structured English Language for Requirements Development) provides structure and formalisation for requirements written in natural language. Developed within the Euro-Interlocking project, SELRED rigorously defines a subset of natural English language that offers unambiguous interpretation. The SELRED Guideline places the following constraints on engineers developing textual requirements:

- High-level requirements as basis for the derivation of all other requirements.
- Clear, non-circular definition of terms.
- Clear distinction between requirements, targets, domain knowledge and comments.
- Guidelines for logical constructions, sentence structure, and verb use.

10.3.3 Model-based requirements

In addition to text-based expression of requirements, the EIFFRA approach foresees model-based expression. This provides a diversity of views of the functional requirements for interlockings. This diversity is particularly useful for verification and validation.

For formalised modelling of requirements, the EIFFRA approach identifies two main options:

- Option 1: The UML standard (Unified Modelling Language) for object-oriented requirements modelling.
- Option 2: Requirements modelling based on statecharts and supported by the Statemate tool.

Powerful tools for the simulation of proposed functional requirements accompany both of these modelling techniques. Such simulation is a key for the validation and safety approval of products based on stated requirements.

UML

Bases for modelling textual requirements with UML are the following notations: collaboration diagrams, use cases, sequence diagrams, object class diagrams and state/event diagrams.

The Euro-Interlocking project models requirements in the Real-Time Studio tool from Artisan UML. Specifically designed for requirements modelling, this tool is known for its intuitive user interface. A bi-directional interface to DOORS allows the establishment of links between textual requirements and the corresponding parts of the UML model.

Statecharts / Statemate

The Statemate tool from I-logix supports a statechart notation. The EIFFRA approach recommends such statecharts as a second option next to UML. Statecharts and Statemate are particularly appropriate when functional requirements defined in relay diagrams are to be transformed into a semi-formal notation. An interface is also available from Statemate to DOORS.

Object constraint language (OCL)

In the EIFFRA approach, safety functional requirements (for example, “a point shall not move under a train”) are described using the Object Constraint Language (OCL), which is part of the UML world standard. The requirements described in OCL support the formal verification of the functional requirements.

10.3.4 Simulation of requirements

Requirements simulation provides powerful support for both verification and validation.

Once functional requirements have been modelled in UML or Statemate, an online simulation of the requirements can be carried out to support their validation and verification. This is particularly advantageous in the European context, since simulation of the requirements is language-neutral and thus does not depend on knowledge of the English language. It also presents ergonomic advantages.

The Euro-Interlocking project is using the Cassandra simulation tool, developed by KnowGravity in Zurich, in association with the Artisan Real-Time Studio tool.

For the statechart approach, the Statemate tool has a powerful built-in simulation tool associated with a user-friendly graphical editor.

10.3.5 Formal verification of requirements

For requirements based on a UML model, the general approach is to verify the UML functional requirements against the safety requirements described in OCL. The Euro-Interlocking project is now working together with the University of Karlsruhe to develop an automatic verification tool based on the university’s KeY project.

For modelling in Statemate, a verification tool has been developed by OSC/OFFIS in Oldenburg, Germany.

10.4 Applications of the EIFFRA approach

The following deliverables are being developed within the context of the Euro-Interlocking project's EIFFRA approach.

10.4.1 Country-specific functional requirements based on the EIFFRA approach

The Euro-Interlocking project is helping European railways and signalling suppliers develop country-specific functional requirements based on the EIFFRA approach. The following work has been completed to date:

- Completion by BS (Denmark) and RHK (Finland) of a set of textual functional requirements written in DOORS and based on SELRED.
- Development of a UML "mini-interlocking" model of an interlocking with minimal functionality based on the functional requirements from SNCF (France) and ProRail (Netherlands).
- Creation by SNCF of a complete model of functional requirements for their interlocking systems using the Statemate tool.

10.4.2 Common vocabulary

A common glossary of terms for the functionality of European interlocking systems is under development. This is an add-on to the existing Terms Glossary developed for the non-functional requirements standards. This glossary serves as a basis for a common understanding of interlocking functionality among both railways and suppliers.

10.4.3 Commands and statuses catalogue and cross-reference guide

A catalogue of commands and statuses for the interlocking systems of 18 European railways is under development. This catalogue shall

- be a reference guide available to all project participants concerning the commands and statuses of European railways in a common vocabulary,
- serve to identify commonalities of commands and statuses of the European railways, and
- serve as a cross-reference guide to enable the comparison and translation of commands and statuses among participating stakeholders.

10.4.4 Common core of European functional requirements

Increasingly, the signalling business is demanding generic interlocking systems that can be easily adapted to the needs of particular railway networks and to the functional needs of ERTMS/ETCS.

The development of country-specific functional requirements using the common EIFFRA approach is providing the basis for defining the complete, generic scope of interlocking functional requirements on all railways in Europe. This is a basic pre-condition for the development of generic interlocking products.

This common core can serve as a powerful basis to promote and facilitate the harmonisation of interlocking systems in Europe. See Figure 2 below.

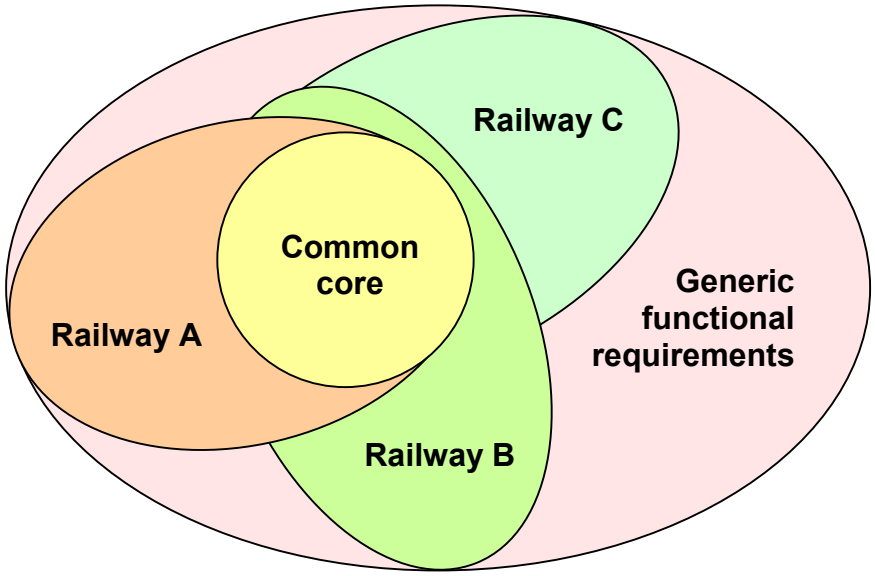

Figure 2: European interlocking functional requirements based on EIFFRA

10.5 Prognosis for EIFFRA

It will take more experience in developing functional requirements based on the EIFFRA approach to judge whether the approach can truly fulfil its promise. However, based on the best knowledge of experts in the area of requirements engineering and railway signalling from around Europe, and experience with the development of the "mini-interlocking", the EIFFRA approach is very promising.

11. Development of interface standards for signalling systems

One of the key work packages in the Euro-Interlocking project is the creation of standardised interfaces for interlockings and other signalling systems. To date, no such interface standards exist in Europe.

For railways and signalling suppliers, the lack of interface standards is a great obstacle to the integration of new interlockings and other signalling systems within the rail network. It not only makes system integration unnecessarily long and costly, but also inhibits the introduction of new technologies having the potential to enhance the performance and reliability of railway infrastructure and to cut life-cycle costs.

Together with European railways and all of the large signalling suppliers in Europe, the European Union is supporting the Euro-Interlocking project

in development of open standards for interfaces.

As with interface standards in other industries, these standards have the potential to greatly ease the introduction of and migration to new technologies and products, and to cut the cost of new signalling systems.

The Euro-Interlocking project is now developing standards for the following interfaces for signalling systems (see also Figure 3).

- interlocking system – ETCS radio block centre
- interlocking system – traffic control system
- traffic control system – ETCS radio block centre
- interlocking system – adjacent interlocking system
- interlocking system – track elements (points, signals, track circuits)

Since all of these interfaces can share a common non-functional specification for data transport, project stakeholders decided to put first priority on the standardisation of a common non-functional interface specification.

At its 15 May 2003 meeting, the Euro-Interlocking Steering Group is expected to approve a standard set of non-functional interface requirements. This will serve as the basis for the technical specification a non-functional interface standard.

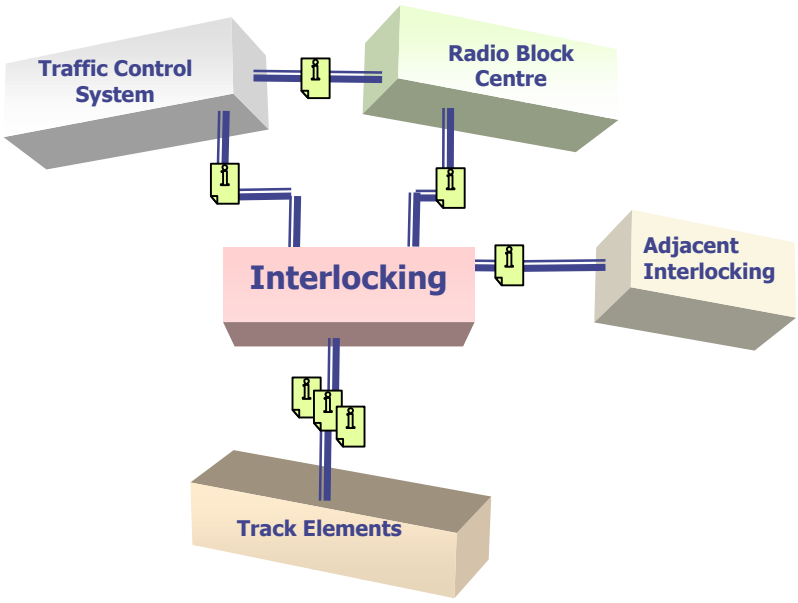

Figure 3: European interface standards for signalling systems

The development of the functional interface specifications (FIS) for the interfaces in Figure 3 will go hand-in-hand with the development of European functional requirements for interlocking systems based on the EIFFRA approach described in Section 10.

12. Railway experience with the Euro-Interlocking requirements standards

12.1 RFF/SNCF (France)

Signalling experts of both infrastructure owner RFF and the railway SNCF made a significant contribution to the development of the Euro-Interlocking standards. In parallel, SNCF, under contract with RFF, have been developing a formalised definition of their functional requirements for interlocking systems in an approach based on statecharts and transition diagrams and supported by the Statemate tool.

These functional requirements, together with the Euro-Interlocking non-functional requirements standards, are to be the bases for international procurement of new interlocking systems for RFF in 2003.

12.2 SBB (Switzerland)

Swiss Federal Railways (SBB) sent out an international call for tenders in 2002 for a framework contract covering some 120 new interlocking systems over the next seven years. This is an implementation rate about three times higher than in the previous five years.

A preliminary version of the Euro-Interlocking requirements standards was the basis for some of the key requirements in the call for tenders. SBB is now evaluating the tenders submitted by the suppliers. SBB has also already used Euro-Interlocking's Interlocking Data Exchange (IDAFF) standard for procurement.

12.3 RHK (Finland)

Finnish Railway Infrastructure (RHK) will be using the Euro-Interlocking requirements standards for a major procurement of interlocking systems in the summer of 2003 for their new Kerava-Lahti direct line.

The Euro-Interlocking project team is supporting RHK in defining and structuring their functional requirements.

In 2001, RHK also used the Euro-Interlocking Data File Format Standards for the procurement of new infrastructure databank and data preparation systems

12.4 BS (Denmark)

Danish Rail Infrastructure (BS) will be using the Euro-Interlocking requirements standards as a basis for the non-functional requirements in the procurement of two large interlocking systems in 2003. The Euro-Interlocking project team is also supporting BS in defining and structuring their functional requirements.

12.5 NS/ProRail (Netherlands)

Dutch Rail Infrastructure (ProRail) intends to use the Euro-Interlocking requirements standards as a basis for long-term framework contracts for new interlocking systems on their network. As at RHK and BS, the Euro-Interlocking project team is supporting ProRail in

defining and structuring their functional requirements.

13. Conclusion and outlook

The Euro-Interlocking project has succeeded in developing and approving over 30 European standards for interlocking systems within three years. The project has also brought together the major European stakeholders in the railway signalling business and promoted closer co-operation and improved communication among railways and suppliers.

Based on this success, the project will continue pressing forward to encourage the development of both European functional requirements for interlocking systems and European interface standards for signalling systems, thus clearing routes for lower whole-life costs in signalling and for the migration to ERTMS/ETCS.

