SUMMARY

In the past 20 years electronic components have been introduced in almost all signalling systems. As a consequence of decisions taken in the past, infrastructure managers are nowadays forced to deal with the obsolescence of electronic components. Furthermore infrastructure managers have to face the problem of a large variety of different systems and even more different interfaces.

The diversity of signalling systems is in fact not purely a technical problem but has a large impact on the life cycle costs of the entire production system. In order to manage those threats, the standardisation of complex technical systems like signalling systems is vital for all strategic considerations.

What can we do? As in other industries that have to deal with complex safety related systems, we will have to apply sophisticated methods to first of all cover and in a second step manage the complexity of signalling systems. Systems engineering is one of those methods that has been successfully applied in other industries to manage the complexity of systems and to develop platform concepts to deal with the complexity in a proper way.

The paper will provide an inside view into the on-going work at DB Netz. Using semi-formal methods like SysML, the technology department of DB is specifying functional and technical requirements of all subsystems of the signalling system more precisely than it has been done before. For example, using state charts and sequence diagrams enables us to specify not only the static but also the dynamic behaviour of the subsystems in interaction. Modern tools offer testing and simulation functionalities that help us to improve the quality of our specifications.

Having followed the systems engineering approach for more than three years now, the presentation will show concrete results, e.g. the semi-formal specification of the interlocking – RBC interface. Furthermore the “lessons learnt” give useful advice for all interested infrastructure managers who want to describe their signalling systems in a similar way.

The systems engineering project at DB Netz is still in progress and has currently resulted in so called “reference implementations”. Reference implementation means that together with suppliers the specifications will be implemented and tested not just in a lab but in our network including the approval processes. Doing this we have installed a feedback loop to ensure, that mistakes or missing parts in the specification can be detected and improved.

Finally we develop test cases on the basis of the semi-formal specification in order to not just standardise the specification itself but also to standardise the test specifications.
1 Introduction

Motivation

The German rail network is operated today by more than 4,000 signal boxes with still a large number of mechanical, electro mechanical and relay based interlockings. Experience shows that the lifetime of each of these “generations” decreases, e.g. electronic interlockings cannot be operated for as long times as relay based ones without massive re-investment. During the next years strategies are needed to either replace the systems or extend the lifetime. DB believes that only a combination of both approaches can realistically be achieved within the given financial framework.

Computer based interlocking as the state of the art technology in railway signalling has been in use in the German network since the early 1990s (with some first applications in the 1980s) with today more than 1,100 systems in operation. While these systems deliver a high degree of automation compared to e.g. mechanical interlocking these systems are not standardised thus requiring the management of a large quantity of different interfaces. This does not only hamper market entry for new companies but also raises costs for operation of the network.

Studies – both internal and external – show that initial investment costs (CAPEX) are an important factor during the life cycle of a system but at least 50 % of life cycle costs occur during the operation of the system (OPEX). Figure 1 shows the outcome of a Life Cycle Cost analysis of signalling systems in Europe derived from real projects in six European countries (INESS, 2012).

![Figure 1: LCC view of a signalling system (25 years)](image)

While this analysis was done under the assumption of an asset lifetime of 25 years real systems are expected to be in use for even longer times. This will once again change the apportionment of costs and increase the OPEX share.

Therefore activities need to be defined which support cost efficient operation. We believe that much higher automation is necessary and achievable. On the other hand maintenance practices need to be changed to condition based maintenance. This will require a reliable and standardised diagnosis system which will not only detect the failure of a system or component but is also capable to detect degradation of elements.

Finally the system architecture must support cost efficient replacement of components without the need of new approval processes. Therefore the design must be made in a way that software can be reused even on new hardware platforms and obsolete hardware can be replaced modular by state of the art technology.

In this paper will describe the way DB has chosen for the specification of its future signalling systems in general and the approach of standardising interfaces in particular. This is an enabler for even further improvements over
the Life Cycle of a signalling system and a precondition for automation and tool support in planning, development, testing, commissioning and operation.

2 Systems engineering approach in railway signalling

Striving for open markets and efficient railway organisations, in the 1990s many European railway companies have been privatised and new cooperation models between railway companies and industry have been implemented. As a consequence of these new roles in Germany the engineering of new systems was solely done by industry with neither complete technical specifications nor close technical steering during the development phase. Going that way, many railways have missed the chance of setting standards and have lost relevant know-how about their technical systems.

Without a complete set of technical and functional specifications it is obvious that there is still room left for interpretation. As we can learn from similar situations within other industries (e.g. telecommunication), having these preconditions within the signalling sector we cannot expect technical interoperable solutions from different suppliers. Diversity is inevitable.

Missing standardisation and interoperability is not only a problem for railways. Standardisation is a key success factor to reduce risks, to accelerate innovation and the basis for effective and efficient processes within the entire sector.

To protect the status quo – meaning to continue using specifications based on natural language – is a real threat for the entire sector since innovation is hindered and innovation speed is one of the most critical factors to keep a leading edge in a global competition.

Systems engineering

Systems engineering is a structured approach to support the design and creation of complex systems. The approach consists of identification and quantification of system goals, creation of alternative system design concepts, selection and implementation of the best design, verification that the design is properly built and integrated.

In order to specify and standardise complex systems like interlocking systems, the approach provides a proven framework to structure and organise the engineering work.

Specification

Signalling system requirements are the outcome of more than one century of experience gained on national markets. Unfortunately the way in which these requirements are described have – in most railways – not yet adopted modern specification techniques.

Even today most of DB’s requirements are described using natural language. Apart from the fact that these requirements cover thousands of pages they seem to be easily readable and understandable by everyone, even without special knowledge about system modelling. But actually these specifications are not precise enough to avoid different interpretations. In the past this lead to the situation that requirements have been implemented in different ways by different implementers (see Figure 2) (Hon, 2008).

**Natural language description:**

"The signal can show aspects: Ks1 or Ks2 and additionally Zs3 aspect."

**Can be interpreted in different ways:**

"The signal can show aspects: Ks1 or Ks2 and additionally Zs3 aspect."  or  "The signal can show aspects: Ks1 or Ks2 and additionally Zs3 aspect."

*Figure 2: Natural language requirement description and different interpretations*
To avoid such interpretations specifications need to be made using (semi)formal methods like SysML by the railways. To achieve this, DB started the transfer of their specifications by transferring the documents into the IBM requirements tracking tool DOORS. This step was necessary to structure all requirements coming from different documents in one database. Furthermore this step helped to split complex requirements into smaller bits which – in the next step – can be formalised. A formal description of the above mentioned example can be seen in Figure 3.

\[
K_s_1 \lor (K_s_2 \land Z_s_3) = (K_s_1 \land Z_s_3) \lor (K_s_2 \land Z_s_3)
\]

Figure 3: Formal interpretations of specifications

A result of natural language description can already be seen from this simple example. If the interpretation is left to the implementer of a system the outcome might differ. In this example the result would be different understandings of a valid signal aspect (see Figure 4).

Figure 4: Signal aspects derived from the interpretation

Using the established cooperation processes each supplier would start the development of its systems on the basis of these interpretations. Much later in the process – normally during the implementation of the first project in a real railway network – unintended situations would be revealed. This would result in time consuming and expensive changes in the product and lead to a later commissioning of the project.

Therefore DB will provide specifications in a formal language in the future. In a first step this will force railways to build up the systems engineering processes and to train people in following these processes. The clear advantage is that this step has to be done only once in the future and not by every supplier. Furthermore software developers on supplier side can much more easily implement the functionalities in their systems even without complete railway (requirements) knowledge. A state machine representation of the above shown example can be seen in Figure 5.
**System Modelling Language (SysML)**

SysML is a general purpose modelling language for systems engineering applications. It supports the specification, analysis, design, verification and validation of a broad range of systems and systems-of-systems. These systems may include hardware, software, information, and others. SysML is an open source specification.

SysML is a dialect of the Unified Modelling Language, the industry standard for modelling software-intensive systems. The advantages of SysML over UML for systems engineering become obvious using a concrete example. With SysML you can use requirement diagrams to efficiently capture functional, performance and interface requirements, whereas with UML you are subject to the limitations of Use Case Diagrams to define high-level functional requirements. Likewise, with SysML you can use Parametric Diagrams to precisely define performance and quantitative constraints such as e.g. maximum response times. UML provides no straightforward mechanism to capture this sort of essential performance and quantitative information.

Even if SysML provides a powerful set of models to describe complex systems, SysML is still a semi-formal method. In case you want to simulate the behaviour of the model we have made the experience that we still have to put effort into the models in order to make them executable. Therefore we have just started to use SCADE, a formal description language that probably support us to generate executable models more easily for simulation purposes.
Example: Standard Communication Interface Interlocking-RBC (SCI-RBC)

In cooperation with industry DB has specified the system design and system behaviour of the interface between the interlocking and the RBC. Based on defined use cases the interaction between the two subsystems as well as their complete status have been described using state charts (Figure 6) and sequence diagrams (Figure 7).

Figure 6: State chart excerpt of the interface between interlocking and RBC (SCI-RBC)

Figure 7: Sequence diagram of the SCI-RBC interface

A modern tool-chain provides the opportunity to continually verify the consistency of the model. In addition to that, our target is to simulate the behaviour of the systems in order to identify mistakes or missing parts of the specifications as early as possible. Even if the initial effort to specify a complex system is high we believe that this investment will pay off since future changes or new developments will certainly profit from this initial work. Even more we believe that making these results open to every interested party – especially railway infrastructure managers – a clear benefit through economies of scale will be possible.


Reference Implementation

From other standardisation initiatives like ETCS we have learned that it is fairly difficult to develop a system specification that needs to be complete, correct and consistent by just using a paper-based approach. Without practical experiences we believe that it is nearly impossible to model a complex system in order to guarantee a high quality specification which enables different companies to implement the system in exactly the same way.

In this context DB develops the idea of “reference implementations”. A reference implementation means that we will implement e.g. an interface together with our partners before finalising the specification. Our objective is to make sure that the specification is correct, complete, and consistent and covers all system functionalities that we require. DB has started the first reference implementation projects as a pre-competitive initiative with all suppliers. With the help of the reference implementation we want to achieve a high specification quality and in addition to that gain the necessary test cases to validate the interfaces. The organisation of these projects can be seen in Figure 8.

![Reference implementation of interfaces – Organisation](image)

The formal specification is the basis for the implementation in a real project. During the implementation this specification is validated and in case of identified gaps appropriate solutions are developed and added to the specification. This will at the end provide a complete and validated interface specification.

Additionally during the implementation a test specification for the interface is developed which will allow independent product conformity tests. DB intends to use these tests to ensure that new products, either from new or established suppliers, as well as new components can much more easily be integrated into the existing network. Tests will to a much higher degree be done off-site in a test lab. The focus of these tests is not the product itself but the behaviour at its interface to ensure that it will work in the surrounding environment.

The development contract includes all suppliers with an interest in a specific interface, e.g. interlocking / RBC. The Consortium Manager is the contractual partner of DB and OEM of one of the subsystems involved - (i.e. the interlocking). He is responsible for the management of all activities and works together with the Interface Partner (i.e. the OEM of the RBC). All suppliers of signalling technology not directly involved with their own equipment in the chosen asset act as Interface User. They have full access to all specifications and need to be consulted for any change to the specification. This ensures that the final interface specification can be implemented by each party.

DB as the user and operator of the systems reserves the right to make any architectural decision in a Change Advisory Board on the basis of proposals submitted by the Consortium Manager on behalf of the joint development team.

This cooperation model is a significant innovation as now railways specify the systems to a much higher degree and directly pay for the development of the systems. On supplier side efforts for development are not only reduced but also directly funded by the customer.
As railways take more risk during the specification and invest more for the product development this might not seem to be a positive business for the railway but the reduction of proprietary interfaces in the network and the publication of the interface specification to any interested party ensures modular systems as well as flexible obsolescence strategies.

**Testing**

Testing is a vital issue within the systems engineering approach. Within each step of the development process it is necessary to verify if the requirements set in the previous step have been taken into account in a proper way. Furthermore the system has to be validated if all requirements are covered and realised correctly.

Since testing consumes a large proportion of the development resources it is necessary to make testing smarter than it has been done up to now. To reach that goal one of the major issues is to go for standards not just for the interface specification but also for the test specifications and processes. Therefore testing should be model based to gain a higher degree of automation.

The presentation describes the approach taken at DB to standardise the testing regime. The approach covers aspects as e. g. testing environment, testing formats, test cases etc. The initiative includes the idea of setting up a test centre in cooperation with partner from industry and research institutes to establish a neutral organisation fulfilling the role of a designated body providing conformity tests according to national and international standards.

3  **Conclusion**

Railway infrastructure managers are facing a situation of limited investment budgets, diverse legacy systems that they have to keep in operation for a longer period of time and striving customers’ expectations for highly reliable, interoperable and performing signalling systems. Most importantly the life cycle costs of new signalling systems must be reduced dramatically to have the opportunity to renew old systems in order to sustainably assure the high quality of the infrastructure. The approach taken by DB is an open initiative involving the entire sector since we believe we can only overcome the threads if we manage to set standards and foster technical and process innovation within each part of the life cycle.

**Lessons Learnt**

After four years of intensive experience we are convinced that system engineering provides an excellent framework to support the development process of complex systems. Together with our partners from industry we have learned how to develop a Form Fit Function Interface Specification (FFFIS) specification using (semi-)formal methods. But we have also learned that it takes time to set up internal structures and to gain the necessary know-how. In our case it has taken more than three years and a lot of external support and we are still within the learning curve.

Specifying signalling systems in a formal way as well as the standardisation of testing processes provides new opportunities for innovation and cost reduction. Starting reference implementation projects at DB Netz in December 2011 we will have to learn if the specifications are correct and complete and ready to start the rollout. We expect to have a complete set of standardised interfaces by 2015.

Standardisation is highly relevant for the entire sector to accelerate innovation cycles and keep the leading edge. DB Netz has taken an open approach that means all results are available for third parties. Having implemented the new standards as mandatory for new signalling systems in our frame contract with industry, we have already defined the rollout of the new standard into the German rail network.

4  **Reference**
