Application of advanced systems engineering for train control systems

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Abstract

Methods of advanced systems engineering are discussed. The specification work for the European Train Control System (ETCS) and Radio Based Railway Operation (RBRO), as examples of very complex systems, needs the application of methods of advanced systems engineering. In this paper the control systems will be shortly presented in order to evaluate the advantages and disadvantages which occurred in the project. Furthermore we will discuss the future work concerning these systems.

1 Motivation

Technical design becomes more difficult as the systems get more and more complex and the degree of automation is always increasing [13]. With the development of a future train control system we have to deal with a very complex distributed system. The project was established in a german and french context called DEUFRAKO, in which the SNCF, the DB and french and german industrialists (GEC-Alsthom, CS-Transport, SEL-Alcatel, Siemens) participated. During the project we had to consider the fact, that we must ensure the completeness and correctness of the specification. To work efficiently together designers usually use tools for representation of their knowledge in the design process and for implementation of new products such as computer programs or mechanical constructions. This encouraged us to support the work with the use of different methods of systems engineering.

In chapter 2 we will give a short overview over the theory of the design process

itself. Then in chapter 3 the basics of the European Train Control System (ETCS) and its national variant for low cost tracks called Radio Based Railway Operation (RBRO) will be introduced, including the state of progress in both projects. Finally in chapter 4 the results and evaluation of the method application are presented.

2   Design Process

The design process is characterised with transformation and transmission of information starting from ideas stored in the human brain till the implementation of the final product [8]. After writing down the ideas, in the next step abstract models use the information from the written or spoken text, which must be transformed into a formal and structured description. This is usually the part of *systems analysts* who must have experience and knowledge of certain methods. Usually it is the first time to integrate automated support tools in the design process.

During the project we had to handle exactly this case. The basic requirements to fulfil for an European Train Control System were briefly defined in [5]. It is a description of the operators' needs towards ETCS, made by a team of European operators called the A200 / FRS team. The structure of this document was given by a list of requirements written in natural language with its incompleteness, incorrectness, ambiguousness and contradictions.

To describe an entire system with all elements and all links between them in a comprehensive way, all aspects like a combination of objects, attributes, states, activities and dynamics, logical conditions must be considered as shown in [9]. A technical specification for the two train control systems taking into account all the mentioned aspects should be included in a unique description. CASE-Tools offer different methods to describe more or less of the mentioned aspects (e.g. SA/RT Yourdon [18], Hatley/Pirbhai [7]), StateCharts (e.g. Harel et al. [6]), Petri Nets (e.g. Jensen [10], Petri [11], English [4]) or Object Oriented Design (e.g. Rumbaugh et al. [12], Shlaer/Mellor [17]). In the project a mixture of many different types of specification languages was used. This resulted in some advantages, but also disadvantages occurred as mentioned in chapter 4.

Used in the specification group have been the following methods:

- SA/RT with the combination of *data flow diagrams, state transition diagrams* and *decision tables,*
- State charts,
- Process specifications in natural language,
- Graph theory.

3 The ETCS and low cost variant for regional railways

The ETCS project declaration was issued by the UIC (Union Internationale des Chemins de Fer) in January 1992. This system is mainly intended to guarantee the safe running of trains on railways, to ensure trains interoperability, i.e. to allow an international train passing from one country to another without changing neither the master unit nor the driver, to increase the performance of the railways in terms of train flow and speed, and to decrease the cost of operation of lines equipped with this system. All new international lines should be equipped with ETCS. The EEC will motivate financially also the use of ETCS for new lines, especially for the high speed ones.

The ETCS is divided in a trackside part and an on-board one. The trackside part is mainly dedicated to the elaboration of orders and advices to be sent to the on-board one. It can be implemented as an overlay system, i.e. in superposition to the existing system, or as an integrated system. The on-board part of ETCS is mainly dedicated to ensure the respectation of the orders and the taking into account of the advices, either for automatic train operation, or simply for the comfort of the driver. The environment of the Radio Block Center is shown in figure 1.

The ETCS system declines in several levels of equipment, the level 3 being the most sophisticated. To each of these levels correspond a different cost, especially due to
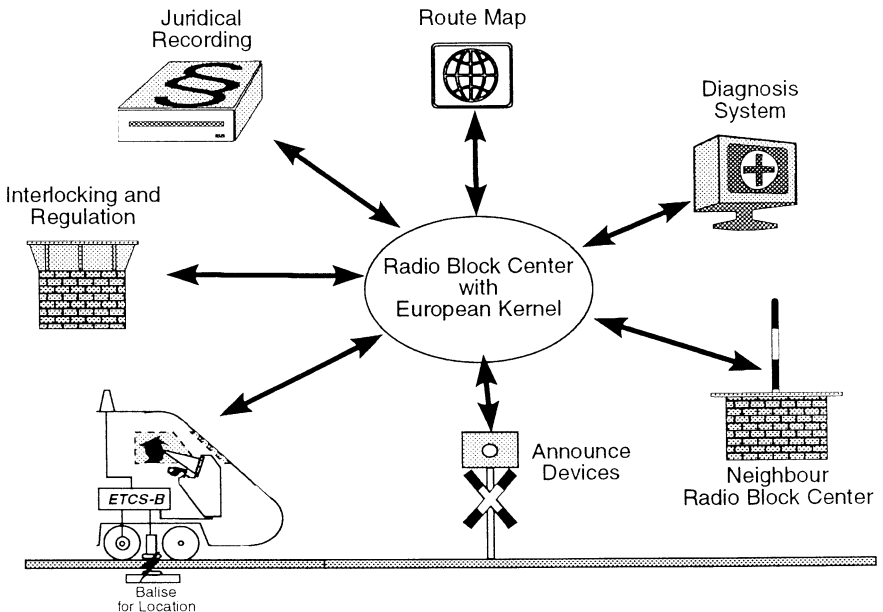

Figure 1: System Environment of Radio Block Center (RBC).

the fact that some levels allow the presence of trains on the tracks, which do not have an ETCS equipment inside.

The lowest level of ETCS is called the level 1. This overlay system only implies spot transmission devices to give quite simple information to the trains, and it is mainly used to increase the safety of running. All trains allowed on the area are not necessarily fitted with ETCS at this level.

The intermediate level of ETCS is the level 2. This overlay or integrated system implies spot transmission devices, and a radio link between the trackside part (called the Radio Block Center or *RBC*) and the on-board one to exchange information related or not to safety. It brings safety and can also be used to increase the trains' speed. All trains allowed on the area are not necessarily fitted with ETCS at this level.

The highest level of ETCS is the level 3. This system can be overlay or integrated, but its best performance is reached in the case of integrated implementation. It implies spot transmission devices, and a radio link between the trackside part (*RBC*) and the on-board one to exchange information related or not to safety. It brings safety and can be used to increase the trains' speed and flow. All trains allowed on the area are necessarily fitted with ETCS level 3 at this level.

The levels are linked by a relation of downward compatibility, i.e. a train equipped at ETCS level n can run as ETCS train on a line equipped with ETCS level n-1. The opposite is not true.

From the first specification [5], a functional modelization has been made with the Structured Analysis method, in which some aspects as levels' application, safe or non safe, on-board and trackside location have also been described. This work was done in the DEUFRAKO group.

The specification is being enriched with a system specification done with the SA/RT (real time) method, in which the engineering view with some architectural aspects of implementation has been added. This work is also done in the DEUFRAKO context. The trackside part of the system (*RBC*), has already been described. The description of the trainborne part is under way.

For the future of ETCS an European Economical Interests Group (EEIG) has been established in Brussels. It has to choose which documents will be retained for the call of tender of ETCS, and is responsible to ensure the interoperability. A first call for tender will be issued for three test bases in Italy, France and Germany in October 1996.

The advantages of using the ETCS are not restricted to high speed applications. This fact will be shown by means of the Radio Based Railway Operation System (RBRO) of German Rail. The goal of the RBRO is to automate the train operation on regional or low traffic railways based on private radio communication networks, integrating parts of functionality of the ETCS application level 3.

As the result of former operation systems, the reduction of infrastructure costs as well as the railway staff are the main reasons for the innovation of the RBRO. A third aspect is the possibility to install the new control system on any existing track without the need of an extensive and expensive infrastructure equipment.

Such as ETCS, the RBRO is doing its operational work without trackside signals, axle counters, or train control systems using loops for data transmissions, which in the past have increased the infrastructure costs. It needs an all-time exact localization of the train as well as intelligent on-board systems which ensure the train integrity or calculate the dynamic speed profiles.

The main difference between these two control systems is because the RBRO communicates immediately with the trackside devices, i.e. the approaching train sends the order to activate a level crossing directly to it, not the interlocking/ regulation system (see figures 2 and 3). In other words: a given movement authority (MA) in ETCS stands for a path completely blocked/set from the beginning to the end of the MA. In the RBRO, a MA only allows the train to run on the reserved track sections. That's why each device has to be called on time.

To ensure a safe train running the speed profile or rather the braking curve ends before the next danger point, e.g. level crossings, switches, or train stops. It will be taken back only in the case that the track device called by the train returns
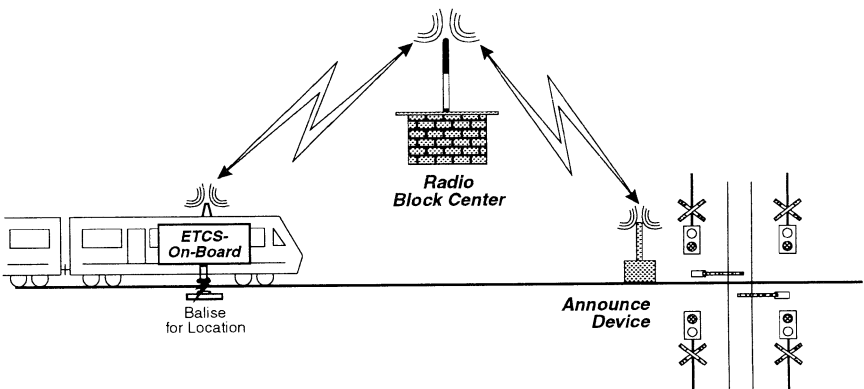

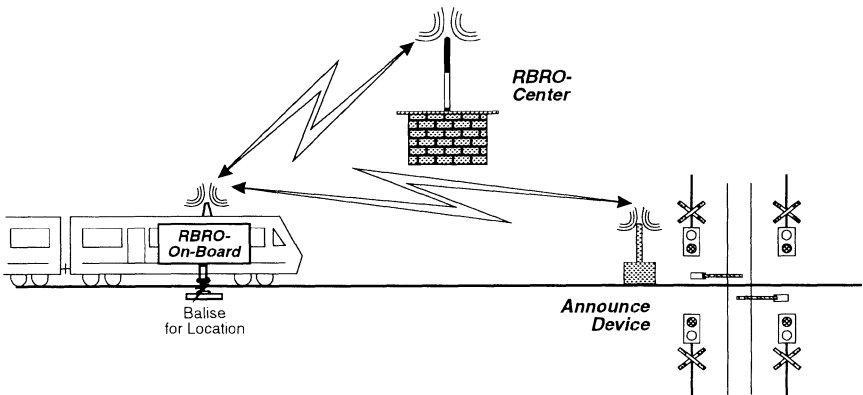Figure 2: Communication relations in the ETCS.

Figure 3: Communication relations in the RBRO.

the correct and expected status; otherwise the train is going to stop.

In a first step two small lines in Rheinland Pfalz will be equipped with the RBRO by the end of 1996. A functional modelization has likewise been made with the SA/RT method. Based on this model, two additional requirement specifications describing

- the demands of the local railway departments, and

- the technical requirements like the radio communication structure or the trackside and trainborne interfaces

are completing the specification work. During a competition in March 1996, the railway industry was called up to propose their ideas for an appropriate system structure for the RBRO which installation will have begun in the middle of 1996.

4   Conclusions

The advantages of SA/RT lay in its graphical description and its ability to apply a partial consistency check. The graphical descriptions improve the understandability of the specification, because human beings understand easier images than text. This is deriving from the fact that graphical representation is already closer to human knowledge representation. Also additional information can be shown as for example the actual decomposition of functions, architectural information like separation between the trackside and the on-board part, the safe and the non safe part, etc. Furthermore, it gives the possibility to find generic functions, i.e. functions which are used for a lot of functionalities and can be supplied with standard inputs and produce standard outputs in a lot of situations.

The consistency check allows to verify that each output of a function or external system is actually used as an input of another function or external system.

Nevertheless, it is only a partial consistency check because, for instance, the inner behaviour of each elementary function, which is described by natural language, cannot be checked.

The dynamic behaviour with respect to causal bahaviour of the system can be shown also only partially with the use of the RT part (called Real Time extension) of SA/RT. This RT part can show for example the sequential activation of a set of functions involved in a global process. The causal can be described with finite state machines or with combinatory tables. Nevertheless, as the elementary functions still involve dynamic processes in the context of time behaviour, the description level of the dynamics is limited to the level of decomposition in logical elementary functions. Furthermore, as the elementary functions are described by natural language, it is not possible to simulate automatically their behaviour, and their validation needs a lot of manual operation. So we can resume that the Real Time Extension of SA/RT can only give additional logical conditions or information, but is not able to specify time behaviour of the system.

The most comfortable way of specification, from the validation point of view, would be the use of pseudocode in the description of the elementary functions.

Even when using the RT part of SA/RT, it is still possible to hide the dynamics of the system functions. To avoid too many interpretations of the system description, it has been chosen to apply additional conventions to the functional description, which were not covered by the pure theory of the method. These conventions are aimed at improving the readability of the models, especially from the point of view of the sequential activation of functions. Thanks to these conventions, it is easier to understand the way the functions trigger each other, and the way each function reacts when triggerred.

Abbreviations

DEUFRAKO	German-French Cooperation
EEC	European Economic Community
EEIG	European Economical Interests Group
ETCS	European Train Control System
FRS	Functional Requirement Specification
MA	Movement Authority
RBC	Radio Block Center
RBRO	Radio Based Railway Operation System
SA/RT	Structured Analysis with Real Time extension
UIC	Union Internationale des Chemins de Fer

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