EXAMINATION OF LEVEL CROSSINGS ON ETCS EQUIPPED LINES WITH COMPLEX SIMULATION

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Summary Because of the lack of former experiences with the new ETCS system, several experiments and tests have to be carried out with various technologies before any installation. For such a new system, it is also very important to have well documented test results of the existing installations for further designing or demonstrational purposes. This paper briefly describes a complex simulation tool, which has been developed in order fulfill these demands, and a study concerning with a particular ETCS application [1].

1. INTRODUCTION

1.1. Context of the study

The first installation of the ETCS system took place on the border crossing between Austria and Hungary, as a part of a pilot project in 1999. It aimed to demonstrate the powerful features of the ERTMS/ETCS system, focusing on the interoperability and interfacing with the existing train protection systems. Based on the experiences of the successful trials, ETCS level 1 train control system was deployed on the new line between Slovenia and Hungary (Hodos-Zalalövő) in 2001. Currently ETCS level 1 and 2 systems are under installation on the Boba-Zalalövő(-Hodos), Budapest-Vienna and Budapest- Szolnok-Lőkösháza lines. (Fig.1.)

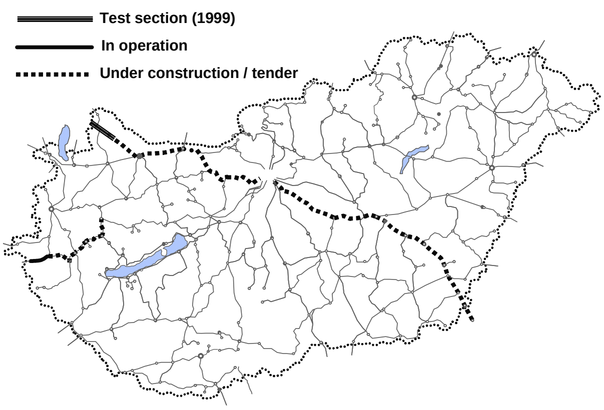

Fig.1. Overview of the ETCS projects in Hungary, 2004

The study described in this paper focused on the new Zalalövő-Hodos section, where the ETCS system is now fully operational. Currently the maximum speed is 100 km/h. After the electrification, this can be raised up to 160 km/h. This will require some (partially already prepared) changes in the level crossing (LX) protection equipment.

The aim of the study was to examine both the existing and the projected level crossing constructions from the point of view of safety in critical situations, and to produce various diagrams for demonstration and comparison purposes.

1.2. Methodology

Since the testing and the analyzing process of a complex system in the real life would be a very lengthy, costly and sometimes hazardous process, there was no question of using other method than risk analysis in simulated environment.

Regarding the aims of the study and the complexity of the critical situations which had to be analyzed, the FMEA (Failure Method and Effect Analysis) risk analysis method was chosen, which is widely used in engineering to identify and counter weak points of products and processes [2].

2. THE MODELLING ENVIRONMENT

2.1. Requirements

In order to achieve the most accurate results, a custom simulation tool was developed, considering the following requirements:

a.) real-time operation
b.) all objects related to the level crossing and the ETCS system must be simulated (train borne equipment, trackside equipment, train dynamics, barriers, signals etc.)
c.) fully modular simulation, where the simulation objects can be easily changed or replaced, even with real hardware (Hardware-In-The-Loop, HIL)
d.) simulation objects can be made in any programming language
e.) open architecture
f.) use of common engineering softwares (e.g. AUTOCAD) for building test environments.

2.2. System architecture

According to the requirements, a special, object-oriented simulation architecture was built up for the examination (Fig 2.). In this architecture, simulation objects are stored in dynamic link libraries, with standardized interface. This allows not just great flexibilty during the development, but also makes HIL testing possible. Initialization, release and communication of the objects are managed by the simulation kernel, which serves as a „root object“ for all other objects.

Each **object** can have a handler program, a three-dimensional graphical model, name, type, priority, position, orientation and other object specific data. For flexibility, none of the object properties is obligatory to be set. For example, an object without graphical model is not displayed on the screen or an object without name can not be addressed by the kernel, but otherwise it can work in the simulation.

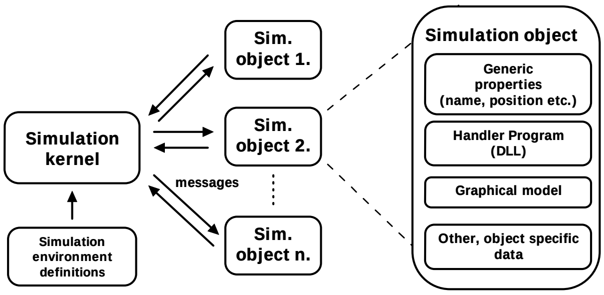

Fig.2.Simulation architecture

Communication between the objects and the kernel is done via asynchronous messages, using a common message interface. It is possible to send messages to a certain object, or a group of objects based on name, type or distance. This approach makes the non-contious, balise based ETCS system easy to simulate. There is a special message which is sent by the kernel to every object in the beginning of a time slot, sequenced by object priority.

The simulation **environment,** including objects, their properties, locations, track layout etc. can designed with various CAD/3D editing tools like 3D Studio MAX. The program’s unique feature is its ability to use commonly used railway engineering softwares’ output for building the simulated railway track. Curves, points, crossings etc. are automatically detected from the series of spatial points aligned on the track centerline. Track sections are also treated as basic objects, thus they are able to send messages to their related objects (this is useful for processing track occupancy).

It is possible to build a realistic **terrain** surrounding the track for improved visualization.

2.3. Running the simulation

Once the simulation objects and the scene have been set up, the test run can be started. Whilst the whole simulation runs in real-time, the time step depends on the speed of computer and the complexity of simulation scene (typically 10 ms).

Some of the objects work automatically; some may require manual interaction (e.g. locomotive controls). For visualization and manual interaction, any object can have dialog window with displays and controls (Fig.3).

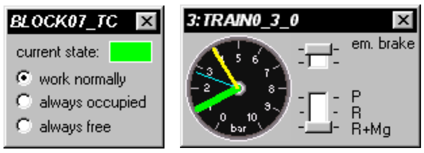

Fig.3.Dialogs of a track circuit and a passenger car

During the run, each object can log various properties (simulation time, state codes, speed, position, occupancy) for documenting.

The tracks, the position and the status of the objects can be continuously monitored in both 2D (top view map, Fig.4.) and 3D displays, even simultaneously.

Summing up: the **simulation kernel** periodically sends messages to the objects, receives and processes their answers, calculates vehicle dynamics, moves the vehicles in the simulation space, manages the system log, and provides visualization for the user.

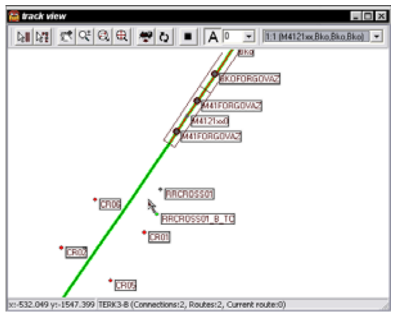

Fig.4. Map, showing a track section and some objects

2.4. Processing the results

Since logged results are stored in conventional text files, they can be directly loaded into commonly used spreadsheet or database softwares, for various filtering, graphing etc. operations.

3. THE EXAMINATIONS

3.1. Simulated objects

The correct risk analysis of a level crossing on an ETCS equipped line requires proper simulation of

a.) level crossing protection devices (detection devices, barriers, signals, control)
b.) both passive and active ETCS balises
c.) ETCS onboard equipment, with DMI (Driver Machine Interface or Man-Machine Interface)
d.) train dynamics, brake system

Based on the relay circuit diagrams, four **level crossing control objects** have been developed for the tests, with the same state graph (Fig.5), but with different state transition conditions.

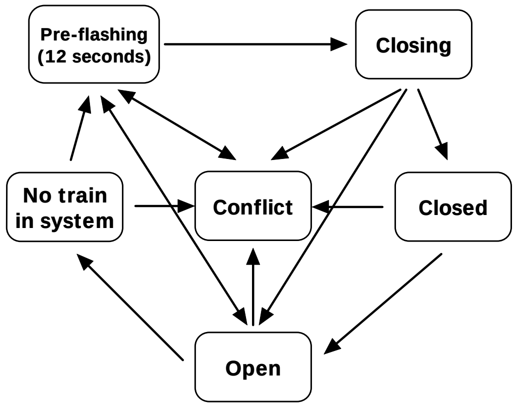

Fig.5.Graph of the level crossing's control object

The first variant simulated the original, existing level crossing design; the others were for higher (160 km/h) speed.

Balise objects are aligned on the track centerline. They send their programmed telegram by the means of distance based messages to the ETCS on-board equipment objects on receiving a request.

The **ETCS on-board equipment object** is the most complex object of the simulation. It communicates with the driver through the DMI display, calculates braking curves, receives and processes telegrams from the balises, and controls interventions by sending messages to the locomotive object.

Vehicle objects, like the locomotive object calculate their motion parameters and forces in every simulation step, then transmit them to the simulation kernel. The kernel keeps track of the changes, sums the forces and calculates movement within the time slot.

For the examination, two consists of existing diesel (M41) and electric (V63) locomotives with five passenger cars were used. For this reason, dynamic, block, disk, and electro-magnetic rail brakes had to be simulated.

3.2. The test track

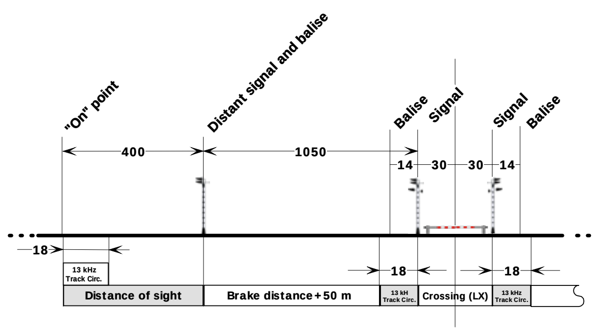

Fig.6. Plan of the existing crossing. Distances are in meters.

The used test track was based on the real scenery, including four signals, four barriers, four track circuits or axle counters, five or seven balises, depending on the level crossing variant (Fig.6.).

3.3. Test runs

The concrete purpose of the test runs was to produce accurate distance-speed, time-speed, distance-state, time-state etc. diagrams for demonstrations and comparisons, and to find the answer to the following questions:

- Is the ETCS system able to stop or slow down the train when the crossing is not working properly, without manual intervention?
- Since the current ETCS implementation transmits signalling information only at certain points, there is a major safety "hole" in the system: What happens if the crossing falls into error or conflicting state while a train is approaching?
- Which design variant has the optimal closing time?

Several test runs were done for each variant, producing about 100 megabytes of logged information. In the framework of this paper we can't go through the details of every test run, just present some of the most interesting results.

a.) Original level crossing variant

The layout of the original design is show on Fig.6. Here, four test runs were carried out:

1.) Everything works properly
2.) Everything works properly, but the crossing is closed manually (80 km/h speed restriction)
3.) The crossing is in "conflict" state, road signals are dark (15 km/h speed restriction)
4.) The crossing falls into "conflict" after the train passed the distant signal.

As we expected, in the first three cases everything went smoothly during the runs. Although the "driver" did not respond to the warning signals, the ETCS onboard system could efficiently slow down the train with service brake intervention before the crossing (Fig.7.).

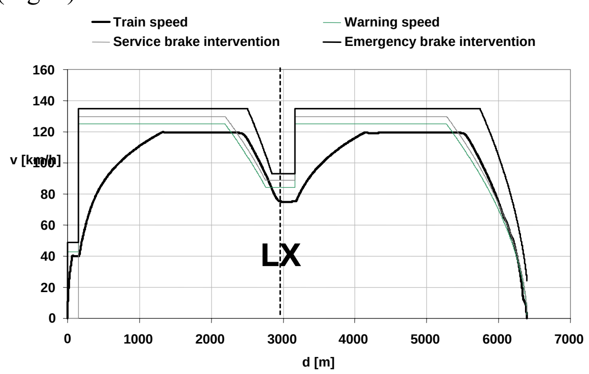

Fig.7. Distance-speed diagram of a case 2. test run on the original variant.

In the fourth case, the crossing had fallen into conflict state when the head of train was just about 450 meters away, so the train simply could not slow down to 15 km/h. However, it did not lead to a truly hazardous situation, because two of the barriers had reached the horizontal position, and all road signals were turned off.

b.) First 160 km/h variant

This variant was practically the same as the original, just the brake distances were lengthened to allow higher speed, and a new failure mode was introduced with 120 km/h speed restriction.

According to the expectations, the similar design resulted in similar test results, with slightly increased closing times (about 20%).

Interestingly, trains moving above 120 km/h and braking with electro-magnetic rail brake had stopped about halfway of the provided brake distance. This accurately meets the measured values from the real tests, and suggests that the brake distances may be a bit oversized for a typical passenger train.

c.) Second 160 km/h variant

Increasing track speed causes longer closing times for slower trains, which can be unfavorable for the road traffic. By deploying additional train detecting devices, closing time can be optimalized for slower trains.

This variant has two pairs of axle counters for detecting the speed of the incoming train in two steps (below/above 120km/h). Because of these axle counter pairs detects only “high” speed trains, conventional track circuits were used for the “normal” speed trains. Since two additional balises are required for signalling the normal trains, not just the closing time but safety has been improved.

A very special situation was tested, when one of the road signals unexpectedly began to show free aspect, while a high speed train was between the normal and the high speed detecting devices. In this case, interestingly, due to the additional balises and the designed long brake distances, the test train could easily stop with emergency braking before the crossing (Fig.8.)

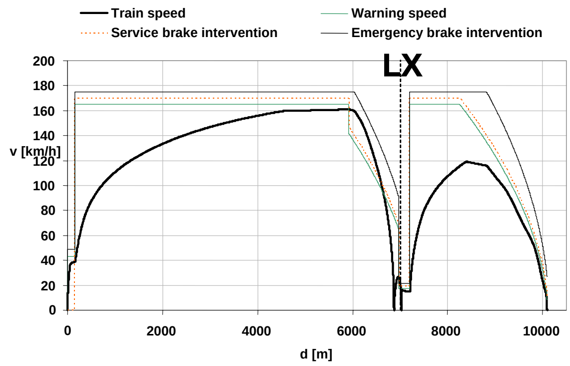

Fig.8. Distance-speed diagram of a test run on the variant “c”.

d.) Third 160 km/h variant

Generally the same as the previous variant, but the railway signals are permissive, which makes the control subsystem much simpler. Another advantage is that when the level crossing is in conflicting state, it is not necessary for the whole train to pass the crossing at reduced speed. As soon as the locomotive had left the crossing, the train could immediately accelerate.

4. CONCLUSION

However the described study could not utilize every powerful feature of the applied complex simulation system, it proved its efficiency and usefulness in the design process.

Generally, all level crossing variants were working safe in the critical situations. It also had been proven that the suspected “safety hole” due to the non-continuous train control is not as serious as it looks for the first glance.

Important to note that the optimized variants with additional speed-sensitive train detecting devices are able to reduce the closing time up to 15 seconds for trains traveling at the high/normal switching speed (120 km/h). This means about 20% decrease in the waiting time for the road traffic, but with significant increase of costs.

5. REFERENCES

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[2] F. Vuille, D. Vernez, N. Macabrey, Risk Analysis of an ETCS level 2 operated line, In: Tarnai G., E. Schnieder: *Formal Methods for Railway Operation and Control Systems.* FORMS 2003 conference proceedings, Budapest, pp 243-255. (2003)