A simulation environment to reduce the development cost of an automatic train operation system

Hélène Papini¹, Olivier Martinot¹ & Mihai Lungu²
¹Alcatel, France
²Alcatel, Canada

Abstract

Increasing product quality and performance while lowering costs have become priorities in Railways today. To achieve these goals, product development time has to be minimised.

When developing an automatic pilot, one of the longest and most difficult phases is the tuning of the automatic pilot parameters. This tuning permits the train to travel smoothly along the guideway, offering the passengers a smooth ride at the highest possible speeds.

Currently, this tuning is performed in the laboratory through simulations, and then during the field tests when the pilot is integrated into the train.

This last phase is very expensive and often takes a long time. To reduce integration phase, it has become necessary to define a more realistic lab-simulation environment.

To meet this need, Alcatel developed a Simulation and Testing Environment (STE) using MatLab© and SIMULINK© software packages. The STE’s underlying simulator is partly based on a previous model simulator that was developed by Alcatel in the VISSIM© software package. This complete tool allows the control designer to prepare the automatic pilot for the final field tests, taking into account various perturbations coming from external conditions, signalling, measurement, and train itself.

To that end, the STE provides a model of the train and tools to create realistic scenarios, run simulations, analyse their results and perform statistical analyses. The STE provides two more sophisticated tools, one to perform automatic identification of train model parameters, second to automatically adjust the pilot parameters (for one specific automatic pilot) regarding train performance specifications.
1 Introduction

As an introduction of the paper it is welcome to present the requirements that the STE has to fulfil. The STE aims at simulating the environment of an automatic pilot in order to test it. Analysis tools complement the test.

For the simulation the STE has to provide to the automatic pilot inputs that are as far as possible realistic. This means that both the ideal environment of the automatic pilot and the realistic disturbances must be provided. When dealing with disturbances, it is necessary to express their level, and the purpose of these disturbances. As the reality is very complex, a lot of disturbances can be introduced in the model. Some may have big impact, some may have low impact. They also can be simplified, and combined. Therefore the best way to define where the modelling of the disturbances has to stop is to define exactly what has to be tested on the automatic pilot. This can be done through a functional approach, or a performance, or robustness approach.

The automatic pilot should provide the fastest permitted travel, within the constraints of passenger comfort, under normal train traffic conditions. From this, the demand is speed, constrained in magnitude and with additional constraints on acceleration and jerk.

The ATP (Automatic Train Protection) controls the non-respect of these constraints. The ATP system is an independent system that is part of the safety critical systems. It has to check that the velocity and acceleration constraints are respected. If not then the ATP is in charge to apply the emergency brake system, not using the automatic pilot way. These requirements have to be fulfilled as far as possible in most of the realistic conditions that can encounter the train during travel.

The requirements for the automatic pilot regarding robustness are:
- no overspeed,
- no undershoot for speed restriction,
- limitation of the jerk,
- stopping precision maintained,
- avoid harmful oscillations on the propulsion/braking system.

2 The generic interface for the automatic pilot

To ensure that the STE will be usable for several automatic pilot generic interfaces have been defined. To connect one specific automatic pilot the user can define an interface conversion module. Therefore the common interface is given by

For the input:
- maximal velocity command,
- target distance,
- nominal deceleration rate,
- current grade,
The simulations are constrained by a set of parameters that define the scenario. Different kind of parameters are distinguished:
- topology parameters,
- signalling parameters,
- train parameters,
- disturbances parameters.
Parameters for the automatic pilot are also defined to tune it.
The following parts present the different sub-systems that define the STE simulation model. In the presentation the different parameters that affect the model and are associated to the different categories are defined.

4 General underlying model implemented on the STE

The model implemented on the STE allows to provide as inputs of the automatic pilot input that are as far as possible realistic. This induces that not only an ideal system is simulated but also the implemented model allows taking into account realistic disturbances, that will allow to check the robustness of the automatic pilot. The implemented model is split into different sub-systems (each sub-system will be more precisely explained in the following paragraphs):
- the train model,
- the dynamic model,
- the odometry model,
- the signalling model.
The interface of the sub-systems that interact directly with the automatic pilot are defined in such a way that it is a generic one, such that it is possible to use this simulation model not only for one dedicated automatic pilot. According to
4.1 The signalling model

The signalling model considers the constraints associated to the velocity limitation, the acceleration limitation, the target point. This is the information provided by the Vehicle Control Centre (VCC). The VCC is responsible to dynamically update the train's driving profile used by the automatic pilot to compute the motor/brake system orders.

4.2 The VOBC (Vehicle On-Board Computer) model

Note that between the signalling system that is a centralised and not on-board system, and the VOBC that is an on-board system, there is a communication channel, that is source of disturbances. The disturbances that are considered in the STE are mainly delay. In fact a parameter can be configured to define more or less delay. This delay has a real incidence on the behaviour of the ASC. Note that according to the real delay the ASC will have to be tuned such that it behaves in a predictive way.

4.3 The vehicle simulation model

The train model takes as input the force demand from the automatic pilot. According to this demand the model computes the provided force. This model considers delay, and response time from the motor/brake system. Different brake systems are combined on this model. The automatic pilot can command separately the different brake systems, or the force demand can be applied to the different brake systems, according to a brake blending algorithm that is part of the train model.

The general model architecture of the vehicle is given by the figure 2.
4.4 The dynamic model

The dynamic model is provided by the $F = m \cdot a$ formula. Where $F$ is the force provided by the model minus the friction force, adhesion forces. The adhesion forces computation includes a slip-slide model (that is a more elaborated adhesion model); this adhesion force is a real-phenomenon and therefore is part of the disturbances that modify the train's behaviour.
4.5 The odometry model

The odometry model is a simple model that takes the “real” data produced by the train dynamic model, to compute the estimated data as they would in output of the on board odometry system of the train.

This model allows the computation of slip/slide detection, and rollback detection

4.6 The track test replay

This module is used to shunt the ASC. The purpose of this module is to analyse and debug in laboratory the results provided by a real ASC in Field tests.

This module only manages stored data during field test. Those data are the input data from the VOBC provided during the field tests and the output that are the resulting command from the ASC considering the input. These output commands are applied to the motor/brake system. The STE provides capabilities to replay the real field test scenario. This induces that the environment data are also integrated when replaying the field tests.

4.7 Conclusion

The simulation model supported by the STE is split into simulation components that can be easily adapted case by case according to what will really exist. However this is a capability of the STE, but the main purpose of the modelling has been to define as far as possible a generic model of the system.

5 STE FUNCTIONALITIES

5.1 STE configuration

The STE permits to configure on one hand, the train parameters, on the other hand, the automatic pilot parameters. Moreover, it permits to create a complete scenario (see figure 3) that is to say:

- an interstation description: length, grade, curve, line voltage.
- a signalling description: velocity profile, deceleration level, relocalisation errors.
- a travel description: target points, train load, simulation of slip/slide, coasting level.

All those configurations are done via spreadsheet editor or dialog boxes and can be visualised graphically.

Among all those parameters, some are considered to be disturbances. They are the following:

- train load variation,
- grade,
5.2 STE simulation

The STE permits to run a single simulation after modification of parameters or scenarios. User can tune the automatic pilot, see how it reacts on several interstations, modify some parameters to verify the robustness of the tuning.

When the tuning seems good enough, we enter the validation stage. Commonly on this stage, to validate the automatic pilot, a predefined set of simulations should be run to verify that all requirements made on the automatic pilot are followed. The STE permits to run in batch such a set of scenarios and to analyse them afterwards globally or one by one.

5.3 STE analysis

For a single simulation, the STE provides the display of the main simulation data that are necessary for an efficient and relevant analysis of the automatic pilot behaviour: mainly position, velocity, acceleration, with profile values, requested values, real values, measurements values (see figure 4).

The STE provides time referenced displays as location referenced displays (figure 5). A dialog box displays the most important results of the simulation: stopping precision, velocity deviation or undershoot, rollback and slip-slide occurrence, jerk level...
Figure 4: Simulation Configuration

Figure 5: Motion Curves Display
For a set of simulation, only statistics on the previously defined most important results are displayed (figure 6). But user can afterwards display one by one the results of each scenario. A CSV (Comma Separated Values) file is also provided which contains all the most important results for each scenarios.

It is also possible to download the results of two different simulations to make graphical comparison on their results.

The STE provides screen copy facilities, and report generation. These reports are more precisely provided in CSV format, such that they can be exploited via spreadsheet editor.

5.4 STE tune-up tool

The aim of the tune-up tool is not to tune all the parameters of the automatic pilot because some of them are directly related to the rolling stock and others do not need a priori to be tuned as they are defined by the project characteristics.

This tool permits to reach a consistent value for the most important parameters (those related to the start-up phase, the jerk, the propulsion and the stopping). Then, the operator can refine by hand, the values that do not satisfy him. Therefore it cannot be considered as an expert system but as help for the operator.

5.5 STE identification tool

The purpose of the STE identification tools is to determine the characteristics of a real train (propulsion, braking curves, weight,...) in order to simulate it inside the STE environment. This determination is made using field tests measurements, and concerns only characteristics that are said to be "observable", that is measurable in a way or another. For the most recent trains, the
constructors give the train characteristics but for older ones, those characteristics references are lost or never existed. Identification is then necessary to simulate those trains, or verify characteristics.

The process of the identification is first to run several specific field tests (constant speed run, follow of a specific velocity profile,...) in open loop (no automatic pilot, a driver should perform the requested commands). Each of those specific field tests aims to identify one or several particular parameters. After those field tests are run, the STE identification tool takes the field tests results in a particular order to compute each train characteristic with the best precision. Each characteristic has an "a priori" value. The more field tests are exploited, the more characteristics become identified ones (no longer "a priori" values).

At the end of the identification process, every train characteristics are instantiated with estimated values and simulation results can be compared to the field tests to verify the precision of the identification.

6 General conclusion

6.1 STE time performances

The STE has been designed such that it will be possible to “open” the simulation loop, and add the real ASC that will be the adding of the real VOBC that supports the ASC. For this purpose the STE performances are such that it can be possible to stimulate a real time system. Therefore the current result of the STE is that it simulates at a 40% level of real time (on an up-to-date PC). That means that 1 real time second takes in fact 0.4 second to be simulated.

6.2 STE used for a real project

The STE is currently used for the test and the performances analysis of an automatic pilot. It has been used in a first step in the development phase of the automatic pilot, in a second step, in elementary analysis to adjust development and tuning of the pilot, and in the last step, in final validation before field tests.

6.3 Further steps

However to finalise this simulation environment with regard to field tests, next steps will be the following ones:

- validate the environment regarding real data that will be collected during field tests,
- validated the identification algorithm.

Till now the performances analysis provided by the environment for validation are considered sufficient to this purpose.

Moreover the design of the STE has been done to be able to work inside a real time. This would be the next step of the project.
7 References