GPS-based train positioning in Belgian railway operations

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Abstract

GPS based train positioning is opening more and more new means for rail transport improvement. Based on GPS, the train positioning system OPTIVIA developed by Bombardier Transportation combines multi-sensor data and provides an integrated positioning solution which can be used in many rail applications without a cost intensive infrastructure.

This paper at first presents the principle systems architecture of the OPTIVIA System. This system consists of a scalable hardware and modular software. Thus it can easily be adapted to customer needs. The system is delivered yet to industrial railways, rail transport operators and main railways.

For its ATLAS - Advanced Train Location and Administration System project SNCF/NMBS has awarded a contract to Bombardier Transportation to deliver the OPTIVIA System. The idea of ATLAS is presented in this paper. To improve the fleet and locomotive management at the control center, the OPTIVIA Mobile train positioning platforms are installed on about 450 locomotives and report their positions periodically via public radio communication (GSM-SMS) to the OPTIVIA Center at Brussels. This application enables SNCF/NMBS to combine and calculate all data which are depending on the locomotive position from their existing data bases. The paper will also describe various railway operational functions as far as they are part of the ATLAS project.
1 Introduction

A key technology for increasing the attractiveness of rail transport is the application of world-wide, continuously available, absolute positioning information supplied by navigation satellite systems for location and where required, traffic control of rail vehicles, without the need for any track-side equipment. Additionally, depending on vehicle system requirements, it is necessary to combine intelligently the advantages of various sensor principles. If positional information is not only utilized on the vehicle itself, effective communications management via a control center is essential due to cost considerations.

Since around 1995, as a result of the above developments, Bombardier Transportation, Rail Control Solutions, has been developing a GPS-supported positioning platform for railway vehicles, with the product name OPTIVIA [1]. The pre-competitive ground work on GNSS 1, using a GPS/Glonass-receiver with varying augmentation segments (differential correction, EGNOS) was kindly supported by the EC Direction DG XIII “Telematics” with the project MAGNET. The results of field studies with the SNCF were submitted in 1998. The main work involves using the available space technology in terms of the satellite-supported positioning of locomotives in a typical railway environment and functionality and is sponsored by the SALON project, through the project’s supporting organization, the German Aerospace Center (DLR) on behalf of the Federal Ministry for Education and Research (BMBF).

The special structure of OPTIVIA fulfils the rail-specific requirements, which sometimes vary considerably from those of other modes of transport, including non-vital requirements. Compared to the usual numbers required by the electronics sector, the rail industry typically orders much smaller quantities of similar equipment. The OPTIVIA system architecture takes this into account, with hardware which is scaleable according to requirements and modular functionality using software packages. The value added of the OPTIVIA system results on the one hand from the real-time generation and linking of vehicle-oriented database information, on the other hand from off-line evaluation of the data history.

2 SNCF/NMBS ATLAS project

For approximately the last two years, various European rail operators have been testing its feasibility for non-vital applications such as locomotive tracking and tracing. Since last year, there has been serious activity among the large European railway companies, NSB, FS, NS, SNCF, SNCB and DB aimed at procuring satellite-supported positioning platforms for non-vital applications.
The Belgian main-line railway SNCB’s department Traction installs at the time being the ATLAS (Advanced Train Location and Administration System) on about 450 locomotives and a central in Brussels.

ATLAS builds on existing methods of determining locomotive positions. These take the following forms for the vehicles listed:

- **Shunting locomotives:**
  - Localization when entering the repair workshop
  - Number of kilometers travelled are mainly determined at a flat rate

- **Diesel line locomotives and diesel railcars:**
  - Localization when entering the repair workshop
  - Calculating the number of kilometers travelled depends upon the entries in the vehicle driver’s report and coding in the bonus office

- **Electric locomotives:**
  - Localization and follow-up of the “first departures” of the day by station staff, but no adjustment or alteration during the day
  - Calculating the number of kilometers travelled depends upon the entries in the vehicle driver’s report and coding in the bonus office

- **Electric rail cars:**
  - Monitored in the same way as electric locomotives but more precisely (difference between passenger transport <-> freight transport)

Due to the methods currently in operation, the controller of the rolling stock works with little real-time information. These procedures also conflict with the following operational changes:

- **Division of the SNCB into administration of the infrastructure and railway operations**
- **A new generation of locomotives increasingly used in international traffic, which pull trains outside the SNCB network (making tracking more difficult)**
- **The desire to improve the maintenance programs of the railcars through knowledge of the actual number of kilometers travelled**
- **Reliable communication with the train (driver) is of increasing importance**

In order to take this development into account, SNCB has specified the ATLAS project.

For such non-vital applications, Bombardier Transportation offers the OPTIVIA Monitoring Package as a rail operation level solution. The vehicle equipment and the relevant software of the OPTIVIA Mobile allow determination of the current position and speed of rail vehicles and this information can be transferred to central databases and other vehicle equipment.
The system architecture is shown here

At the control center, the vehicle positions recorded in the database are displayed on a screen. The OPTIVIA Client is particularly suitable for this purpose. The data transfer medium for SNCB is GSM service provided by Belgacom Mobile (Proximus). This ensures that the data are correct, even in poor reception conditions, and prevents any loss of information. GSM data transfer can optionally be either link-oriented or via SMS. To shorten the query times of individual positions, the server of Proximus is used. Several applications at SNCB are connected via ISDN to this server. Position transfer via SMS is faster and cheaper, but not as reliable as a link-oriented communication. Using GSM and SMS transfer, other useful data, as well as the position, can also be exchanged between the control center and the vehicle. There is no limit to the number of vehicles which can be served by GSM. In future, General Packet Radio Service (GPRS) can also be used without any problem and the rail-specific data transfer GSM-R(ail) can be utilized.

3 OPTIVIA vehicle positioning system

The OPTIVIA vehicle positioning system of Bombardier Transportation consists of
- the space segment,
- the augmentation segment which due to low required accuracy is not effective here,
- the ground segment consisting of
  - about 450 vehicle equipment,
3.1 Space Segment

The freely available satellite-navigation system, GPS, is operated by the U.S. Ministry of Defense and is under military control. At least 24 satellites are available, which are orbiting the earth at a height of between 19000 – 20000 km and guarantee world-wide continuous positional availability. In 95% of cases, the positional accuracy, when only GPS signals are used, is currently estimated at less than 6 m in the horizontal axis, although the specified accuracy is only 20 m. In the vertical axis, the positional accuracy is generally twice this.

The advantages of position determination using GPS lie mainly in the long-term stability of the calculated absolute position. The applied measurement technique is not subject to drift or any decrease in the measurement accuracy during the life of a GPS receiver. Regular calibration is thus not necessary and the sensor is ideal for initializing the position determination.

One disadvantage, however, is the sensitivity of the GPS receiver to signal shadowing. Position determination with this sensor is, therefore, not possible within buildings or between very tall buildings.

3.2 Ground segment

3.2.1 Vehicle Equipment

The OPTIVIA Vehicle Equipment set consists of a OPTIVIA Mobile, OPTIVIA Driver Terminal two HF-cables for GPS and GSM, a combined GPS/GSM antenna, a pre-amplifier for the GPS signal, and installation material. The workshops of SNCB are additional equipped with OPTIVIA Tools as OPTIVIA Breakout Box to check the correct function of the cabling and a OPTIVIA Recovery Laptop to save data from a technically by fault isolated OPTIVIA Mobile. The maintenance concept foresees the immediate exchange of a faulty OPTIVIA Mobile. Within the active phase of the test set lasting from May 2000 to January 2002 only one fault occurs. That was identified as a vibration problem of the SIM-card holder. Consequently this component was changed for the running serial production.

The OPTIVIA Vehicle Equipment is European certified to following standards:

- EN 50121 (EMC)
- EN 50155 (Environment)
3.2.1.1 OPTIVIA Mobile  The Bombardier Transportation positioning platform, OPTIVIA Mobile, facilitates cost-effective, continuous determination of the current position and speed of rail vehicles. The construction of the vehicle equipment takes into account the harsh environmental conditions which apply to diesel locomotives and therefore is robust against large temperature variations, vibration and dust.

The sensors used for vehicle location are chosen according to the desired application and the required precision, in order to achieve an optimal solution in terms of both application and costs.

3.2.1.1.1 Sensor fusionSensor fusion forms the real nucleus of position determination. The measurement data supplied by the available sensors are processed together with the information about the line contained in the database, in order to determine the current vehicle position. For ATLAS a 8-channel GPS receiver is used and combined with special sensors.

The OPTIVIA Mobile activates itself by means of a special sensor, even if the vehicle unit is not in operational mode and is being towed. Should the position change, position reports are sent to the OPTIVIA Database until the vehicle unit is stationary again for a longer period. Thus cold vehicle movement is reliable identified.

The same is valid for double traction.

To prevent an availability problem of locomotives by low voltage the OPTIVIA Mobile reports low voltage together with the last position message to the central in Brussels.

3.2.1.1.2 OPTIVIA DatabaseThe demands made on the data required for the satellite-aided location of a rail vehicle depend upon the type of application desired. Two different levels of quality can be identified:

- applications which only require the exact line position of the rail vehicle, such as logistics systems
- applications such as disposition systems, which require the exact track position of the vehicle.

Both require a complete description of the route network in the area of the proposed applications. Otherwise, it is not possible to guarantee the consistent quality of positional information, which can only be determined with the help of the database contents. The position co-ordinates of the track network are stored in the database in the co-ordinate system, World Geodetic System 84 (WGS-84), as this involves less calculation when determining the position.

For line-accurate positioning of main-line locomotives, the accuracy requirements on the geometric data of the route network can be significantly
reduced. When using this method of description, the allocation track and the opposite track are not handled separately; only the approximate geometric progression on the line is used. In this case, an accuracy of 50-100 m is sufficient. The topology here only describes the linking of the individual lines with each other.

If the line network data are available in the target database, these have to be verified prior to use. This can be performed in various stages. Bombardier Transportation has developed software tools which can perform these tests as a customer service also.

Within the OPTIVIA Database after a certain time in the data history there is no SMS message missing because all messages are time stamped and sorted according to time.

Networked databases offers SNCB Traction the following advantages:

- Size reduction of the locomotive park;
- Reduced operational costs by avoiding non-revenue journeys;
- Higher quality of transport offered;
- Better tracking of maintenance, first step in changing from scheduled to event-driven maintenance;
- Real-time tracking of rolling stock both inside and outside the SNCB network;
- Feed-back for planning purposes;
- Automatic recording of the drivers' performance
  - to simplify personnel administration and
  - to calculate driver bonuses;
- Written information for the driver during the journey (without inconveniencing him);
- Material status report at the end of a shift;
- Economic driving (reduced energy costs);
- Automated invoicing of internal SNCB-customers;
- Possibility of modifying track allocation and speed in the case of incidents, delays or accidents.

The following advantages accrue for other customer-related areas:

- Real-time prediction of the arrival times of goods trains and delays to passenger trains (in particular, the possibility of predicting re-use);
- Tracking the goods wagons of fix-coupled trains with SNCB locomotives via access to another software system;
- Remote real-time servicing and tracking of specific rolling stock parameters (e.g., energy consumption);
- Recording operational data for checking operations and analysis;
- Determining track usage levels;

3.2.1.2 OPTIVIA Driver Terminal

In ATLAS, the driver performs the following tasks:
an MMI is installed in every driver's cab. This is linked to the on-board computer, to enable the following data input:
- train number
- personal identity number
- load being hauled
- text messages (predetermined or free text)

Every time that a driver changes trains (i.e., drives a different route or is working to a different timetable), he enters another number for the train and the load.

Every time that a driver changes cabs, he enters his identity (interval > 15 min.)

Entering the identification number in the driver's cab will be replaced at a later date by the scanning-in of the company pass.

ATLAS gives the driver the following advantages:
- The railcar driver can send and receive text messages via the OPTIVIA Driver Terminal
  - technical messages (electronic logbook)
  - operational messages
  - messages to the personnel office
- Supplementation of central monitoring by the rail service operator
- Driver information in case of problems
- Better quality of railcar servicing
- Checking aid in case of incidents or delays

The picture shows a typical installation of the OPTIVIA Driver Terminal in a drivers cab.

The four lines display is amber colored. On roughly 75% of the locomotives there are two cabs. Thus a second OPTIVIA Driver Terminal is mounted.
3.2.2 OPTIVIA Center
The incoming positions are prepared by the OPTIVIA Server, analyzed in terms of each specific application and presented to the OPTIVIA Client workplaces through several computers on commercially-available PCs. Via filters, the visible part of the vehicle park can be presented individually at every workplace. As the positional data are stored in the OPTIVIA Database and OPTIVIA can operate in a PC network, all SNCB logistics systems will later be able to access these data via the PC network.

The central unit will be capable of the following functions:
- Geographic localization of the train equipment on a sufficiently detailed railway vector map
- The possibility of contacting the driver via text messages and of organizing messages both sent and received (new)
- Detailed tracking of the status, maintenance situation and the kilometers travelled by the train using a stipulated method
- Tracking and adjustment of the planned services of the material and real-time adjustment of these services (replaces paperwork with diagrams)
- Detailed tracking of the number of line kilometers per train section - driver-combination - load-zone (partially replaces coding of the driver’s report)
- Feedback of the actual circulation, to allow comparison with the roster

3.2.3 Communication
Depending on the type of application, transmission of the current position takes place for cost reasons either at regular intervals,
- Periodical sending of SMS messages (according to train/locomotive type or according to zone)
- Transmission in case of temporal or spatial deviation or at request of the central unit.
The OPTIVIA System can be used until the train equipment is taken out of service. It may also be capable of alteration, allowing it to work in the GSM-R network.

3.2.4 Remote Maintenance
Remote servicing takes care of the minimum amount of servicing required by the OPTIVIA System, so that Bombardier Transportation can manage the software
of the central unit and, more importantly, that of the vehicle equipment, largely without any direct access.

References


Abbreviations

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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ATLAS</td>
<td>Advanced Train Location and Administration System</td>
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<tr>
<td>SNCB</td>
<td>Société Nationale des Chemins de fer Belges (Belgian Railways)</td>
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<td>NMBS</td>
<td>Nationale Maatschappij der Belgische Spoorwegen (Belgian Railways)</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<td>GSM</td>
<td>Global System for Mobile Communications</td>
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<td>SMS</td>
<td>Short Message Services</td>
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<td>DLR</td>
<td>Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)</td>
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<td>EGNOS</td>
<td>European Geostationary Navigation Overlay Service</td>
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<td>GNSS</td>
<td>Global Navigation Satellite System</td>
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<td>GPS</td>
<td>Global Positioning System (US)</td>
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<td>WGS</td>
<td>World Geodetic Coordinate Systems</td>
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<td>EC</td>
<td>European Commission</td>
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<td>BMBF</td>
<td>Bundesministerium für Bildung und Forschung (German Federal Ministry for Education and Research)</td>
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<td>MAGNET</td>
<td>Multi-modal Approach for GNSS in European Transport</td>
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<td>DG</td>
<td>Directorate General (EC)</td>
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<td>FS</td>
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<td>GPRS</td>
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<td>GSM-R</td>
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<tr>
<td>PC</td>
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<td>Glonass</td>
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