FAIL-SAFE, INNOVATIVE, COST-EFFECTIVE, SATELLITE-BASED

TRAIN PROTECTION, CONTROL AND COMMAND

LOCOPROL

IST 2001-28103

Low Cost satellite based train location system for signalling and train Protection for Low density traffic railway lines

Deliverable D 1.1

Final Report

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Author(s):	Robert Libbrecht ALSTOM, Helge Sturesson ERTICO,
Project manager:	Pierre Mertens - ALSTOM Tel: +32 71.44.55.08, fax: +32 71.44.94.41 E-mail: pierre.mertens@transport.alstom.com

Abstract: This deliverable presents an overview of the LOCOPROL project from its motivation and objectives to the achieved results.
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Glossary of used abbreviations

ATC	Automatic Train Control
ATS	Automatic Train Supervision
BG	Balise Group
BTM	Balise Transmission Module
CAB	Cabin
CAN	Controller Area Network
CANAPE	CAN tools for GATC projects
CETI	Can Ethernet Interface
CFD	Compagnie des Chemins de Fer Départementaux
CFTA	Chemins de Fer et Transport Automobile
CP	Chemins de Fer de Provence
CSVC	Centralised Signalling Vital Computer
CTC	Control Traffic Center
DMI	Driver Machine Interface
DGPS	Differential Global Positioning Service
DSL	Digital Subscriber Line
ERTMS	European Railways Traffic Management System
ETCS	European Train Control System
EVC	European Vital Computer
FS	Full Supervision mode
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
ID	Identifier
INU	Inertial Unit
ISDN	Integrated Services Digital Network
LAN	Local Area Network
LCS	Local Control Station
LDR	Legal Data Recorder
LOCOPROL	LOw COst satellite based train location system for signalling and train PROtection for Low density traffic railway lines
MB	Marker Board
MMI	Man Machine Interface
NTG	Network Transmission Gateway
OS	On Sight mode
PABX	Private Automatic Branch Exchange
PCMCIA	Personal Computer Memory Card International Association
PMC	Packet Mode Channel
PRI	Primary-Rate Interface

RBC	Radio Block Centre
ROC	Radio Object Controller
RTM	Radio Transmission Module
SDMU	Speed and Distance measurement Unit
SMART	Self Monitoring Analysis and Reporting Technology
SR	Staff Responsible mode
SYMA	Syndicat Mixte Méditerranée Alpes
TCP/IP	Transmission Control Protocol/Internet Protocol
TIU	Train Interface Unit
TPC	Train Positioning Computer
TSR	Temporary Speed Restriction
UN	Unfitted mode

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1 Executive Summary

This document gives an overview of the development of the work carried out in the LOCOPROL project partially funded by the EC under the IST programme part of the fifth framework programme.

The project has developed an innovative cost-effective satellite based fail-safe train location system as the core of a train protection, control and command system, thereby achieving a significant cost reduction by concentrating more intelligence on-board.

The proposed innovations have achieved a significant reduction of the cost aiming to short term applications for low density traffic railway lines. The developed system enhances and extends the ERTMS/ETCS system, currently covering high density lines, to low density lines.

Chapter 3 describes the evolution of the work and how the administrative difficulties, mostly resulting from internal reorganisations of some partners, were solved and the technical obstacles were removed. This resulted in adopting two amendments to the contract resulting in a slight reorientation of the technical work essentially towards a better integration of the end product into the existing ERTMS/ETCS standards for European railway signalling systems. Two versions of the system were defined: a EU version for the European market and a World version with no constraints to ERTMS standards. Another result was the extension of the delay of the project from the initial 36 months to 44 months bringing the project end date on 31 March 2005.

Technical results & achievements are described in Chapter 4, starting with a description of the main innovation, i.e. the "1D"positioning algorithm and how it evolved from a first version needing 6 visible satellites to its final version needing only 4 visible satellites. This chapter also describes the tools that were developed and used for the tests and simulations, such as amongst others the track database generation tool, the real time visualisation tool specifically developed for the demonstrations, the satellite communication tool and the integration & test tools. It gives also an idea of how the tests were performed and their results in the three test sites.

The Belgian tests showed the appropriateness, in terms of accuracy (± 150m) and availability (better than 95%), of the LOCOPROL approach for fail safe train location. The safety evaluation team gives good hope that the LOCOPROL satellite based train location process will achieve the SIL 4 requirements.

The "RFF" tests have shown the possible integration of an "odometric" module based on the LOCOPROL concept in an existing ERTMS/ETCS on- board equipment.. This first phase demonstrated that a failsafe GNSS based positioning subsystem could be integrated into an ETCS equipment (level 0) without impacting the existing applicative software. The second phase confirms the first phase conclusions and extends these positive results to the ETCS level 2 application tested in the CFTA line. The added value of this new odometry has been demonstrated in both test tracks (RFF and CFTA), demonstrating therefore that is possible to locate the train safely in line sections without the need of balises (with a positioning accuracy independent of the travelled distance).

The CFTA tests demonstrated effectively the complete LOCOPROL safety signalling system (satellite based positioning, positive train detection and token based interlocking)

Tests have shown that the specific behaviour of the algorithm (random variation of a confidence interval) does not affect the existing applicative software of the trackside and train borne ETCS equipment (RBC and EVC). The performance provided by a simplified odometry based on wheel sensors and GNSS sensor is fully compliant with LDTL requirements, this solution offering, in addition, a way to locate a train between stations with a sufficient accuracy without installation of additional trackside equipment.

The Token based IXL associated to the positive train detection has been as well successfully experimented demonstrating that the very simple token principle is adequate for such line characterised by a simple topology and by a limited set of functional requirements.

The document concludes that the LOCOPROL project has successfully developed and tested a complete Low Life Cycle Cost railway safety signalling system for LDTL railway lines based on satellite positioning.

Since the system was demonstrated as a mock-up only, some refinements and further developments are still necessary to bring it to the level of an industrial product.

2 Project presentation

2.1 Abstract

The project has developed an innovative cost-effective satellite based fail-safe train location system as the core of a train protection, control and command system, thereby achieving a significant cost reduction by concentrating more intelligence on-board.

The proposed innovations have achieved a significant reduction of the cost aiming to short term applications for low density traffic railway lines.

The developed system enhances and extends the ERTMS/ETCS system, currently covering high density lines, to low density lines.

2.2 Objectives

The four main objectives of the project are strongly interconnected:

- to define a new multi-technology location system based on satellite positioning combined with fail-safe on-board track mapping and interlocking;
- to study and prove its application to ERTMS/ETCS;
- to study and prove its short term applicability in Low Density Traffic Lines;
- to study its applicability in order to increase track side workers protection.

2.3 Description of work

The development process for the LOCOPROL project was slightly different from a pure top down approach. The reasons to do so were the following:

- the main objective of the project focused on the development of new sub-systems with reference to a complete signalling system
- the aim of the project was to validate the system principle as well as the application engineering guidelines from a safety point of view but not to validate the sub-systems or components.
- the project reused existing sub systems or modules already developed e.g. ERTMS components
- this procedure shortens the duration of the whole process.

It takes into account three types of processes:

- The already existing processes, performed in the frame of former projects. It is applicable to the component that do already exist and that has been used in our “new” system.
- The parallel process, performed in the frame of the project. It is applicable to sub systems for which the development work may start at an earlier time of the project with minimum risks, without waiting for the time were it should start according to a pure top down approach. The main aim for having this kind of process is to shorten the duration of the project. It is usually possible to do it with a minimum of risk on the basis of the company experience in the domain of application or on the basis of preliminary (not formal) studies already performed.
- The third process, also performed in the frame of the project, is the “well known” formal top down process that has to be performed in any case to be compliant with CENELEC standards. During this last process, all the work performed using one of the two other processes has to be validated based on the results of the top-down system formal approach. Discrepancies that are detected during this check point process are fed through to all lower level design phases that have already been performed. When there are such divergences, corrective actions have to be performed to put in conformity all the outputs of the two “early” processes.

Once these activities are validated and /or put in line with the top down approach the parallel process ceases to exist for the concerned sub-system and its development continues following the top down approach.

The Overall Development Process for the LOCOPROL project, resulting from the previously described development processes, has been as follows:

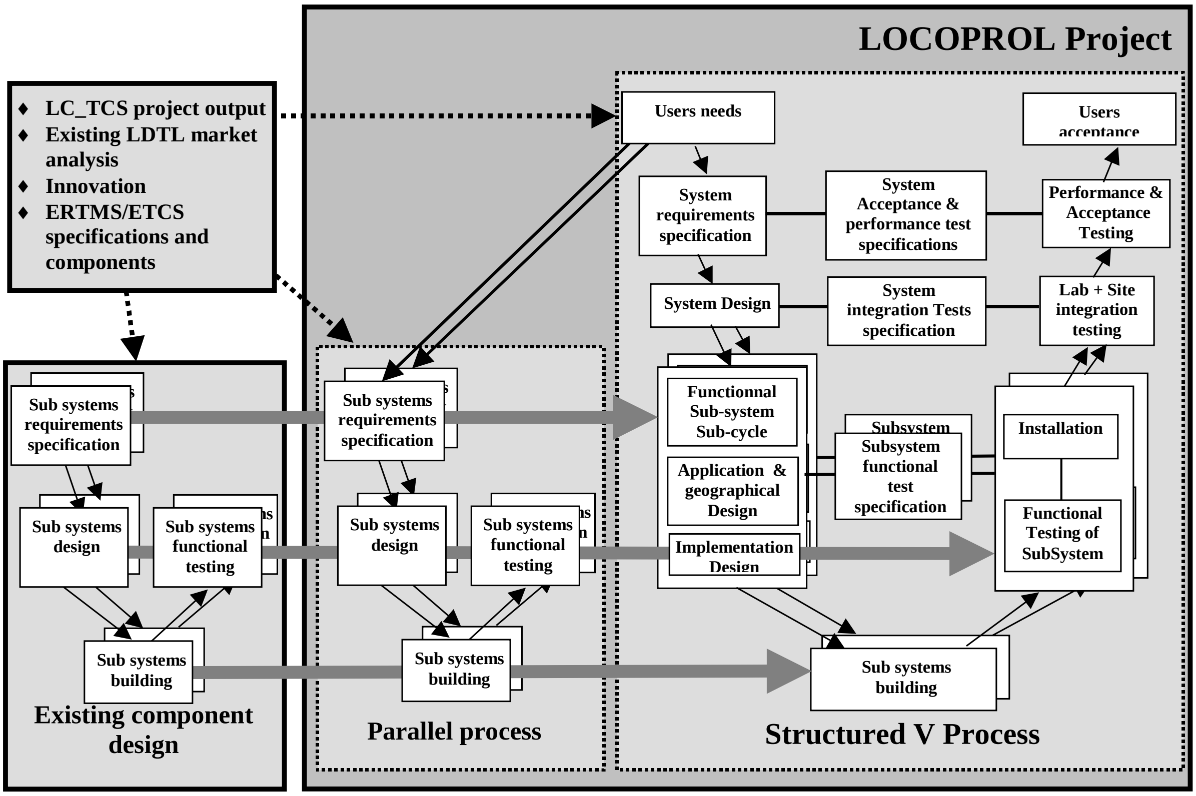


Figure 1 – Overall development process

2.4 Milestones

December 2001	Definition of user needs
March 2002	System requirement specification
July 2002	Specification of Architecture
August 2003	Satellite positioning mock-up developed
October 2003	Results from Belgian test track
October 2004	System mock-up developed and integrated
December 2004	Results from RFF test track
December 2004	System Safety Validation
February 2005	Results from CFTA-Connex test track
March 2005	Evaluation of results from each test track
March 2005	Final system specifications

2.5 Project results

The main results of the project are as follows:

1. **A new multi-technology satellite based train location system based on satellite positioning combined with fail-safe, on-board track mapping & interlocking.**

   The principles used for the new train location system are:

   - safe digital mapping of possible trajectories;
   - fail-safe positioning on a given trajectory (line-based mode), using redundant and independent satellite pairs;
   - step by step determination of the pertinent trajectory via a dialogue with the points and/or the interlocking system (topologic mode).

   This approach is drastically different from the recently emerged train-aided satellite location systems where the safety is expected to be based on the concurrent use of satellite signals and information from additional sensors, combined with Kalman filtering techniques.

   In LOCOPROL, the safe location is directly based on satellite signals GPS, EGNOS and future GALILEO, on which no specific integrity requirements are imposed. According to the hazard identification performed and the proposed mitigation measures to reduce failure risks, the preliminary safety case gives good hope the satellite measurement process for train positioning developed in LOCOPROL will achieve the 6.10^{-11}/h objective and the SIL 4 requirements

2. **A new control & command system** including a token-based simplified interlocking system and positive train detection.

   The solution is a global control/command solution and performs all the functions required for an efficient railway operation. I.e. traffic supervision and command (ATS), automatic train command and control (ATC), automatic control of objects in the tracks (point machines and level crossing protection) and all necessary functions for a follow-up of the maintenance of the rolling stock.

   Different ways of transmitting data between the moving trains, the trackside objects and the central radio block centre (RBC) have been studied. The main objective here was to reduce the cost as well for the equipment as for the operation cost (communication cost). Therefore different solutions have been tested essentially based on publicly available and existing infrastructures such as public GSM and packet based solutions like GPRS. Off course GSM-R can also be used. However typical LDTL lines are not equipped with GSM-R. We have shown that for these lines an important investment in GSM-R infrastructure is not necessary.

3. **Interoperability with ERTMS** – Integration of satellite based odometry in ERTMS/ETCS on-board architecture

   The project has proven that it is possible to integrate the LOCOPROL satellite based location and speed calculation module into the ERTMS/ETCS on board. This paves the way to use the LOCOPROL odometry not only for applications on low density lines, but also to substitute the high-cost classical (mostly radar based) odometry by the much cheaper LOCOPROL satellite based module even on high density lines.

4. **End user interface**

   The ATS module developed for the Nice – Digne demonstration includes also the necessary interface allowing the end user (the hauler or addressee of the transported goods) to follow the progress of the transport over an internet connection.

5. **A fail safe worker terminal** (specification)

   The project has given much consideration to the problem of the worker's safety along the track. A hand held device has been studied and fully described in a specific deliverable.

6. **A tool for geographical database creation** for railway lines.

The track data base generation is absolutely necessary to have an accurate geographical description of the track in order to be able to deliver data used by the 1D algorithm in connection with the information delivered in real time by the satellite sensors.

The track data based is obtained on the basis of amongst others GPS measures during a specific test campaign, and a better accuracy is obtained by a specific post processing.

Globally, the tests done on site 1 showed that the process of the track date base was better always than 5 meters and better than 2 meters in most cases. It was also demonstrated than a 1 meter accuracy was possible by improving the post processing algorithms and/or by using DGPS/RTK.

2.6 Project Participants

Principal Contractors	Country	Role
Alstom Belgium SA (Alstom BSI)	B	CO
INRETS	F	CR
Honeywell Regelsysteme Gmbh	D	CR
Alstom Transport Spa (Alstom STL)	I	CR
TRASYS SA	B	CR
Alstom Transport SA*	F	CR
BPV	D	CR
SEPTENTRIO NV	B	CR
RFF	F	CR
NMBS/SNCB	B	CR
Northern Jiaotong University	CN	CR
ERTICO	B	CR
CFTA **	F	CR

*** Initial Partner left consortium 30-August 2003**

****Joined consortium on 1-September 2003**

3 Methodology and approach

The work was organised in seven work packages (WP) as briefly presented in the table below

Overview of LOCOPROL work packages

WP#	Title and short description
WP1	**Project management**
WP2	**Definition of User Needs** To compile a comprehensive overview on user needs to be fulfilled by the system to be developed. To achieve a consensus among the project partners and among relevant experts outside the project consortium on the completeness of the results of this WP.
WP3	**System Specification** To define the system requirements, the system architecture, and the internal and external interfaces of the system.
WP4	**System Development** To design and develop the system modules, the necessary hardware and software and their integration, including the necessary tools for testing. To implement and test different variants in different trial sites.
WP5	**System Safety Validation** To continuously monitor, integrate and validate the safety aspects of the system during the whole development phase from the early stages until the end of the test period.
WP6	**Evaluation** To develop an evaluation methodology based on the CONVERGE guidelines To design a comprehensive set of validation criteria for the evaluation of the performances of the system at the different test sites. To perform a comprehensive evaluation of the performances at the three different test tracks.
WP7	**Dissemination and Implementation** To organise and carry out different dissemination actions during the course of the project set out in a produced Dissemination and Use plan. To produce a conclusive Technology implementation plan describing potential applications for the produced LOCOPROL results

3.1 WP1 Project management and co-ordination aspects

3.1.1 Objectives of this Work package

The objective of the central activity was to provide sound internal project management with an efficient interface to Commission services and to ensure that the project was capable of reaching its objectives.

The day-to-day management was undertaken by a Project Co-ordinator who was assisted by the Project Management Group and under the supervision of a Steering Committee.

The Project Steering Committee which includes all project contractors was responsible for all contractual issues and decisions. It met only once for the signature of the Consortium Agreement.

The Project Management Group (PMG) which includes the company project managers of all partners was responsible for the management of the project, detailed monitoring of the project's progress and the formulating of recommendations about the project as necessary. Taking into account the complexity of the project, it met 33 times, on average every 6 to 7 weeks.

Quality Management

At the operational level, the management rules were defined in the "Technical Annex (Annex 1 to the contract). All partners used this internal document as a reference, which ensured the quality of all LOCOPROL deliverables.

Were included in the Technical Annex:

- Contractual references
- Project objectives
- Project organisation and responsibilities

In addition the co-ordinator provided the partners with all usefull guidelines and templates for progress reports, cost statements deliverables, peer review reports, etc…

3.1.2 Development of work, main problems encountered and delays

After getting organised which took a longer time than initially planned due to the start of the project in the middle of the annual vacation period, the work started with the definition of the users needs (see WP2) and setting up the framework for the dissemination (see WP7). As from fall 2001, the project organisation and responsibilities, the project documentation guidelines for deliverables as well as for management and progress reports were available and the work has reached its "cruising speed".

The first major difficulty was encountered in 2002 when TRASYS, because of internal change of priorities, requested to reduce drastically its participation in the project. Different rounds of intense negotiations resulted in a drastic reduction of TRASYS' participation in the project. The biggest part of the work was taken over by Alstom BSI including the leadership of WP4.

Another challenge has been the decision of RFF/SNCF, to postpone the renewal of their low density and regional networks. This reduced the interest of RFF/SNCF to find low cost solutions for the renewal of the safety signalling systems on low density lines. As a consequence RFF/SNCF also requested for a reduction of their participation in LOCOPROL.

As a result, since their participation was directly linked to the tests initially foreseen on the RFF, Alstom France requested to withdraw from the project.

All these problems were intensely discussed with the project co-ordinator and different solutions were envisaged. Finally the situation was completely clarified, with the intention to subdivide the test activities in France into two test sites :

- o An RFF test site, mainly dedicated to the demonstration of the application of fail-safe satellite based location to ERTMS/ETCS;
- o Another test site on a stretch of the CFTA operated line Nice – Digne in the South of France, dedicated to the demonstration of the comprehensive LOCOPROL ERTMS compatible signalling system under real conditions.

This overall solution has been proposed to the EC in Amendment N°1 which has been accepted by the EC end of August 2003. The amendment foresees essentially:

- A reduction of the participation of TRASYS
- A reduction of the scope of the RFF test site
- The introduction of a new partner CFTA and a new test site near Nice operated by CFTA
- The withdrawal of ALSTOM SIF from the project
- An augmentation of the participation of Alstom BSI
- A additional delay of 6 months bringing the total delay of the project from 36 to 42 months
- The limitation of the work on the worker terminal to the specification of the module to be described in a specific Deliverable Del 4.3.1 "Worker Terminal Specification".

The technical aspects of this Amendment N°1 have been clarified in the description of the work in the different WP's.

After the conclusion of this first amendment the work was again resumed at cruising speed. However a few months later a new challenge emerged, indeed:

In Amendment N°1, it was foreseen to carry out the French tests on the ERTMS French Test Track located on a stretch of line just North of Paris. This section was specifically fitted for testing ERTMS equipment. These tests aim to check the compatibility between the LOCOPROL satellite based odometric module and ERTMS.

At the moment scheduled for the tests on the RFF site, due to the deployment of the ERTMS on the RFF/SNCF High Speed Lines, the ERTMS equipment along the test line had been dismantled (mainly Radio Block Centre and GSM-R).

Taking into account the high density of high speed traffic along this line, re-establishing the equipment by installing specific balises would have involved costly interventions during the very short traffic interruptions (max. 4 h) during the night. Moreover the cost for re-adapting the track equipment was far above the available budget. This cost was estimated too high and incompatible with the limited budget foreseen in the LOCOPROL project.

Again several alternative solutions have been investigated. The most efficient solution agreed by all partners appeared to be to perform the RFF tests in level 0 on the well known line 144 Gembloux – Jemeppe in Belgium, by equipping it with a basic ERTMS kit (i.e. approx. 10 balises along the track).

This solution has the following advantages:

- Compatible with the objectives of the tests (integration of the LOCOPROL satellite based positioning into the ERTMS odometry).
- No interfaces to trackside equipment and therefore no on-board equipment update required.
- The line has a much higher availability for tests and is close to Alstom Belgium.
- The tests could be performed during daytime.
- The track database was already available from the Belgian tests and could be reused, and the line is well known from a topographic point of view as a lot of tests have already been realised.
- The whole operation could be performed without any major influence on the overall timescale of the project.
- Trackside equipment limited to some passive ERTMS balises.

This solution imposed an extra workload concerning the supply and installation along the Belgium line of some 10 ERTMS balises. Fortunately these were obtainable at Alstom.

Of course, the tests had to be performed with the ERTMS equipped RFF autorail (fitted with specific LOCOPROL equipment) which had to be brought to Belgium for the test runs.

Performing the tests in Belgium entailed a minimum of intervention from SNCB for :

Fitting the balises along the line, Homologation of the French autorail for running on SNCB lines, and preparing the operation of the test runs and overall logistic support of the proper test runs.

This solution, together with a number of minor administrative modifications such as the authorisation for Honeywell to subcontract some programming work and an extension of the project management budget (due to the complexity of the project), was submitted to the EC in November 2004 in Amendment N°2. This Amendment N°2 was accepted by the EC in December 2004 and concerned:

- An internal budget shift for partner Honeywell
- A budget shift from RFF/SNCF to SNCB allowing SNCB to participate in the RFF tests on the Belgian test track
- An internal budget shift for partner Alstom BSI increasing the budget for project management
- An extra 2 months for the project duration bringing the total project duration to 44 months

The project effectively ended on 31 March 2005 without delay according to the duration defined in Amendment N°2.

In parallel to the LOCOPROL project another project called LOCOLOC was also active in the field of satellite based fail -safe train location. The LOCOLOC project was funded by the European Space Agency ESA with funds originated from the Belgian Government. The partners in this project were:

- Alstom BSI (B) Co-ordinator of the project
- TRASYS (B)
- Septentrio (B)
- SNCB/NMBS (B)

The project ran over a period of two years from July 2002 till September 2004.

Both projects were complementary in the sense that LOCOPROL has been concentrating on the pure *location* aspects based on available GPS and GNSS signals where LOCOLOC has been working on the calculation of the *speed and acceleration* of the trains.

Both EC and ESA have shown a strong co-operation amongst their respective services concerning the monitoring of the progress of the work in both projects. According to the wish of both entities a co-ordination plan between the LOCOPROL and LOCOLOC projects has been presented to the EC and ESA in March 2003. Regular follow-up meetings have taken place during the whole course of both projects. A common demonstration of the main results of both projects took place in March 2004 in Gembloux.

3.2 WP2 Definition of User Needs

3.2.1 Objectives of this Work package

This work package was set up to define and investigate the system functionality, performances (including the RAMS aspects), degraded situation from an operational point of view, end user interface and other users specific constraints based on a user point of view. The output of this task provided the LOCOPROL project with a unique set of user preferences and needs ensuring the end user a wanted service.

In a first step an overview was given about the state of the art in the domain world-wide and in particular an overview of the results of previous and current EU R&D projects related to the LOCOPROL work.

3.2.2 Development of work, main problems encountered and delays

WP 2 focused on a common framework for user preferences, acceptances and possible benefits from offered LOCOPROL services. This WP included not only the specific situation and functional requirements at each site, but took specifically into account the generic needs for Low Density Traffic Railway Lines. Therefore a user forum was set up with representatives of different countries and different continents. The forum worked using electronic communication means (email and internet) in order to eliminate travel costs. In this framework a team of LOCOPROL experts made a visit to China to meet representatives of local Chinese railway Authorities(from Beijing as well as a large number of local actors from the Chinese inland railways) to discuss their specific needs in the domain of low density railway signalling.

The systems requirement was based on a business paradigm in order to ensure that the further work would provide the operators with an added value in terms of enhanced line capacity, enhanced safety and reduced energy consumption.

The final aim of this task was to develop user needs to serve as a basis for the definition of system requirements. The analysis of user needs considered the different category of users that will be using the services for different purposes. In this case, the infrastructure owners, the railway operators at management level and at operating staff level, and authorities.

The results of the whole exercise were presented and discussed during a two day workshop with over 60 representatives of the railway world all over the world. A large consensus was reached amongst the participants. The results of this operation have been summarised in Del 2.1 and constituted the basis for the start of WP3.

One of the main findings of this exercise is that two specific markets can be distinguished:

- The European market with its constraints related to the interoperability with systems on medium and high density lines based on ERTMS standards
- The rest of the world market (which constitutes the largest part of the market) where these constraints are not imposed

This situation is likely to lead during the commercialisation phase to the production of two variants of the LOCOPROL end product. It will also have its influence on the continuation of the product where we will give some more attention to the interoperability of the new system with the European ERTMS standards.

In addition to that, a thorough study has been undertaken in order to produce a detailed and comprehensive synopsis of finished and on-going work in the domain of satellite-based location and safety for railway applications. The work includes also the domain of communication technologies that could be applied to the LOCOPROL work. The result of this work is compiled in Del 2.2.

3.3 WP3 System Specifications

3.3.1 Objectives of this Work package

This work package dealt with the specification of LOCOPROL system aspects. The system work performed in the frame of this Work Package aimed to verify that the requirement for the components to be developed in the frame of the project, working together in a system configuration, will allow this system to meet the users requirements in terms of performances, degraded situation, end user interface, users functions and other users specific constraints as resulting from the work done in WP2.

In a first stage, the “External Interfaces” at the system level were defined and specified.

The result of this activity was used as input for the System Requirement Specification (SRS) where all the functional requirements were identified and used as output for the definition of the “Specification of the System”.

The definition of the system architecture took into account the system requirements as defined in WP 3.1/3.2.

It was built on the existing philosophy of the ERTMS/ETCS developments. As such, it was the intention to make a maximum use of existing and already proven modules of the ERTMS/ETCS concepts.

The aim was to assure a maximum level of interoperability between the LOCOPROL system components and ERTMS/ETCS equipped vehicles.

The “Internal Interfaces specification” ensured that all the interfaces between the different parts and modules of the LOCOPROL system were clearly identified and defined.

The last activity of WP3 performed the amendments of the other WP 3 deliverables on the basis of the results of the WP 4 and WP 5.

3.3.2 Development of work, main problems encountered and delays

The work in WP3 started with the clarification of the tasks to be performed by each partner based on the work description in the technical annex of the contract.

During this exercise and for efficiency reasons it has been decided to split the work in two clearly defined parallel processes. This allowed the two tasks to be executed in an independent way with less planning interaction.

The two tasks are defined as follows:

- The satellite navigation sub-system development, focusing specifically on the development and implementation of the fail safe satellite train location sub-system. A special working group called the Satellite Position Working Group with representatives from LOCOPROL Partners such as Alstom BSI, INRETS-LEOST, Honeywell and Septentrio, and also external experts i.e. representatives of the university of Troye, was set up. It was also decided to produce an extra Deliverable “GNSS Railway Positioning Algorithm Analysis”. This Deliverable contains the result of this exercise, which extends beyond WP3 and covers also part of WP4. Organising the work this way enabled us to run the tests on test site 1 (SNCB) on schedule. Regarding the Belgian test site, the following main activities have been undertaken:
  - Preparation of a preliminary safety report for the location sub-system;
  - Mitigation of the alternate paths issue (including co-operation with the French DGA);
  - Specification of the 1D algorithm.
  - Specification of the track database

- The train management system (including signalling) development focusing more on the implementation of the innovative distribution of functions. This part initially intended to be tested on test site 2 (RFF/SNCF) has finally be tested on test site 3 (CFTA). In order to fully accomplish this task, and among others, more specifically to allow all partners involved in the process to share a common understanding of the system behaviour it was decided to add a new task initially not explicitly identified. I.e. a description of some 30 operational scenarios of the new system. The result of this work has been integrated as an appendix in Del 3.3

In 2002/2003, a first set of four Deliverables describing the system specifications was submitted to the EC namely:

- **Del 3.1 External Interface Specification v 2.0,**
- **Del 3.2 System Requirement Specification v 2.0,**
- **Del 3.3 System Architecture Specification v 2.0,**
- **Del 3.4 Internal Interface Specification v 1.0,**

This set of Deliverables described the original concept of the system, later called the “export solution”.

In Amendment N°1 the work of the project was reoriented to an enhanced compatibility with ERTMS/ETCS. Therefore a revised architecture, called the “EU solution” was defined. At the end of the project, a revised set of Deliverables was again submitted to the EC. A specific Deliverable containing recommendations for ERTMS adaptations was added. The following set was delivered to the EC at the end of the project:

- **Del 3.1 Final External Interface Specification v 2.1**, (content identical to v 2.0)
- **Del 3.2 Final System Requirement Specification v 2.2**, (an updated version of v 2.0 with some enhancements resulting from the CFTA experimentation)
- **Del 3.5.1 Final System Architecture Specification v 1.1**, (This Deliverable combines D3.3 & D3.4 and describes the full new (EU variant of the) system architecture including the internal interface specification).
- **Del 3.5.2 Recommendations for ERTMS Adaptations v 1.1**

This second set of deliverables constitutes not only a full description of the EU “version” of the system, but it integrates also all enhancements of the system resulting from the CFTA tests and the safety analysis performed in WP5.

3.4 WP4 System development

3.4.1 Objectives of this Work package

This work package was divided in 2 sub-WP's:

- WP 4.1: Build/ adapt System modules.
- WP 4.2: Implementation of integrated pilot System.

Based on the out-coming specifications of WP 3 and on already existing components specification e.g. from ERTMS/ETCS, the system components development or adaptation started at an early stage of the project. These modules were developed in such a way that they allowed the validation of the system in terms of functionalities and operational modes. But it was not required that these equipments met the final cost, packaging, ergonomic, environmental and RAMS requirements expected from a final industrial product: prototypes delivered in the frame of the project did not have to be approved by an official certification process. Regarding certification or safety approval, the prototype suppliers are committed to provide the necessary support for the safety approval of the system.

Each component supplier also performed individually the testing of each system component in the frame of this work package. In order to reduce development time and costs, the necessary laboratory tests before on-site implementation were included in WP 4.1 build/adapt system modules. These laboratory tests included also tests necessary for verifying the correct integration of the different modules in a full system. Another important task achieved in this WP consisted in the "data preparation" and the application engineering. The tools necessary for system component tests were developed in such a way that they were reusable for the overall system integration tests.

In the frame of this activity, the system defined in WP 3, the components developed and tested in WP 4.1 were implemented in three test sites in order to allow performance, integration and validation testing. Each test site tested and validated different subsets of the LOCOPROL functions and consequently different configurations of LOCOPROL components. Off course for each separate test track, a "track database " needed to be generated and a preliminary "horizon mask" was generated in order to have an initial idea of the number of satellites visible along the track.

3.4.2 Development of work, main problems encountered and delays

The work in WP4 has started with the clarification of the tasks to be performed by each partner based on the work description in the Technical Annex and also taking into account the split in two parallel activities as decided in WP3.

Regarding the Belgian test site, the following activities have been undertaken:

- Development of the track data capture tool and the associated post processing software;
- Development of the real time reference system i.e. integration of the GNSS receiver including DGPS/RTK (Real Time Kinematic) features with the Inertial Navigation Unit (INU);
- Specification of the integrated test bench for the Belgian test track;
- Development of the DGPS/RTK and multi-antenna features of the GNSS receiver;
- Purchase and first tests of satellite modem
- Software design and development of the Satellite Navigation Algorithm;
- Design & development of the basic software for the satellite location sub-system mock-up (adaptation of operating system to various interfaces);
- Implementation of the satellite navigation algorithm in the real mock-up.
- In addition, preparatory work related to the proper tests has been performed :
    - Selection of the stretch of line on the SNCB network (15 km on Line 144 between Gembloux and Jemeppe-sur-Sambre);
    - Selection of the rolling stock
    - Definition of the detailed architecture of the test Bench
    - Cabling the test train
- The proper test runs took place between October 2003 and March 2004.

The detailed analysis of the data recorded using the first version of the 1D algorithm (which needed an availability of 6 satellites) showed a poor availability of the location function due to the fact that 6 satellites are rarely accessible simultaneously.

The refined version of the 1D algorithm necessitating only 4 satellites simultaneous accessible has been developed and tested on site. It has also been applied on the rough data collected on the Belgian test track. (for more details see chapter 4)

The outcome of the tests and the comparison of the results of the two versions of the 1D algorithm are described in Deliverable 4.2.1 submitted officially to the Commission on 29 July 2004.

In parallel, activities on this test site have been devoted to the technical preparation of the demo scheduled on 24 March 2004. This real time demonstration has been organised in close co-operation with the EC DG INFSO and the European Space Agency ESA. The aim was to show the results of the close co-operation between the two complementary projects LOCOPROL (co-funded by EC DG Infso) and LOCOLOC (funded by ESA). Due to the overwhelming response of participants (more than 160 registrations from all over the world) and taking into account the limited capacity of the test train, a supplementary day had to be added on the 25th of March (the next day). Both on board the train and in the conference room, participants have been informed about the LOCOPROL principles and could follow on different screens the real time variation of the “confidence interval” of the LOCOPROL satellite location function and the LOCOLOC associated speed calculation.

Regarding the RFF test track (Integration of LOCOPROL odometry in ERTMS/ETCS on board equipment):

Due to the fact that the initially foreseen ERTMS equipment along the anticipated test track (High speed line North of Paris) is no longer available (it has been dismantled), the tests could not be performed under the initial contractual conditions. Different alternative solutions have been examined. As a result it has been envisaged to perform most of the tests on the well known Belgian SNCB line 144. Therefore this line has been equipped with ERTMS balises allowing testing of compatibility with ERTMS level 0 operation. The tests were undertaken with a French ERTMS equipped auto rail.

Therefore the RFF tests have been rescheduled till September/October 2004, however with no impact on the overall timescale.

The preparation of the tests included.

- The definition of the technical configuration of the tests bench;
- Clarification of the installation issues on the French auto rail;
- Development of the interfaces between the EVC and the Train location computer (Hw and Sw).
- Adaptation of the applicative SW (fusion part) of the EVC core computer
- Prepare the necessary software adaptations.
- Develop the necessary integration tools adapted to the trainborne equipment part in order to include the new sensor (the satellite based positioning). This new test tool needs to allow the play back of complete scenarios in lab (with real recorded GNSS data).

Additional tests were realised on an RFF line in the neighbourhood of Maubeuge specifically oriented to test the satellite base positioning algorithm at higher speed (160km/h) and in a different environment ("blue sky" type).

These tests and their results are described in Del 4.2.2 . The Deliverable contains also the results of the non contractual additional tests that were performed on the odometric module on the CFTA test site.

Regarding the CFTA test track (LOCOPROL signalling system):

In the CFTA test campaign the complete LOCOPROL system comprising the integration of the LOCOPROL satellite location system integrated in the on-board ERTMS/ETCS standardised equipment and integrated in a token based safety signalling equipment was tested.

The preparation of the tests included.

- Preparation of the on-board equipment in the two test vehicles.

- o Definition of the installation specifications,
- o Definition of the test organisation,
- o Preparation of the application engineering,
- o Specifications of the whole test procedure including different test scenarios.
- o The analysis of the satellite visibility based on the data acquisitions made in May 2004.
- o The track database capture (had to be finished before the start of the denser seasonal tourist operation where all rolling stock is required for the operation).
- o The corresponding database generation.

The test runs started in October 2004 and finished early February 2005. All detailed information about the organisation and the implementation of the tests can be found in Del 4.2.3.

3.5 WP5 System Safety Validation

3.5.1 Objectives of this Work package

The objectives of this safety evaluation were to check if:

- o The system meets its intended purpose and it conforms to the required standards,
- o The safety requirements (safety functions and integrity levels) are set, correct, complete and traceable to hazard and risk analysis and they comply with the requirements set out in the standards,
- o The system architecture which apportions safety functions between the different sub-systems is adequate,
- o The system is required to safety the requirement of SIL 4 and this has been derived from the system safety requirements and system architecture,
- o The tools and support environment used for the production of the system are of required quality and do not introduce new hazards to the process.

3.5.2 Development of work, main problems encountered and delays

The following activities have been performed for this WP5:

3.5.2.1 Task 5.1 System Validation Plan

The management plan has been produced by INRETS-ESTAS and approved by all involved partners. It has been updated during the course of the WP5 activities.

3.5.2.2 Task 5.2 Safety Requirements Specification- Referential Identification

This activity has been carried out by INRETS-ESTAS. The aim of this task was to identify the safety requirements in close consultation with Alstom and SNCF IES. It identifies the standards, specifications and other information that will form the basis of the safety validation.

The outputs for the realisation of the LOCOPROL reference proposal are the list of the applicable documents and the list of the studies to be conducted in order to assess and validate the safety of the system principles of the LOCOPROL concept.

Another part was to take the life cycle as the entry of this study. The precise parts take into account are the following:

- User’s requirements – Evaluation criteria – System acceptance

  This includes the specification of the user’s requirements and the redaction of the operational validation document of the system

- User's requirements – User's needs analysis – System requirements

  This includes the specification of the user's requirements, the redaction of the safety plan, the preliminary hazard analysis, the hazard log and the specification of the system requirements.
- System requirements – External interface specification and system requirement specification – System design

  This includes the preliminary hazard analysis, the hazard log, the specification of the RAM requirements and the safety requirements and the specification of the architecture.
- System design – Architecture specification and internal interface specification – Sub-system requirements

  This includes the realisation of the failure mode and effect analysis and the realisation of the fault tree analysis.

3.5.2.3 Task 5.3 Safety Requirements Specification – Criteria and Depth of Analysis

On one hand this task has identified the criteria to use for the validation of the compliance of the LOCOPROL system with the CENELEC standards. As the design and realisation of the LOCOPROL system is a mock-up, hardware and software aspects have not been taken into consideration.

For the satellite positioning sub-system, the safety requirement specification was based on the LOCOLOC preliminary safety case and one LOCOPROL deliverable. The safety requirement for the satellite positioning has been analysed and the result of the analysis is exposed in chapter 4 of Del 5.1.

For the low cost LOCOPROL signalling system, as no detailed safety requirement specification have been set in the deliverable "*System Requirement Specification*", other deliverables have been reviewed for safety requirement extraction purposes. From this extraction, a static analysis has been performed and the remaining questions on those deliverables have been set.

3.5.2.4 Task 5.4 Analysis and modelling of the safety requirements

After the static analysis performed in the previous task, a cause consequence like analysis has been performed. The first goal of this analysis was to find any lack in the specifications if any. Then the second goal was to examine the interactions between the LOCOPROL functions and the interactions between the LOCOPROL system and its external entities and to identify items where safety may be questionable.

This analysis was mainly performed on the basis of the "*System Architecture*" deliverable and using a dedicated tool *Telelogic DOORS*. *Telelogic* DOORS™ is a system designed to capture, link, trace, analyse and manage changes to information to ensure a project's compliance to specified requirements and standards.

The results of those analysis combined with the ones of task 5.3 are developed in chapter 5 of Del 5.1.

3.5.2.5 Task 5.5 Safety test specification

This task has been reduced to the review of the test specifications to be performed for LOCOPROL on the Nice-Digne test track. The results of those tests are available in Del 4.2.3.

3.5.2.6 Task 5.6 Compliance with CENELEC standards: Analysis and review

The products and elements of development process of the system has been analysed and reviewed to check if it satisfies the criteria identified during Task 5.3.

The aim of this task was to validate the compliance with the safety requirements and releant standards.

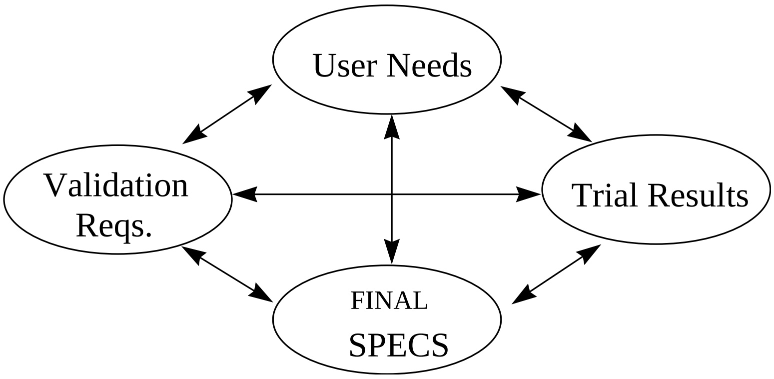
3.5.2.7 Task 5.7 Validation Report

The results of the analysis are reported in Del 5.1 giving a documented review taking into account the answers given by WP3.

3.6 WP6 Evaluation

3.6.1 Objectives of this Work package

In this work package, the performance of the different parts of the system and in a later stage the overall system was evaluated in the different test sites. Validation within the context of this project refers primarily to the validation of the system, e.g. the verification of successfully fulfilling the user requirements as expressed in the WP2.
The "pilot system" verification was the culmination of the local and integration testing. This stage showed that all elements of the system have been correctly integrated and support the expectations as defined in the system specifications. The successive evaluation stage involved "pilot system" tests during field trials.
During the full execution of tasks within this WP, references were made to and extensive correlation was laid between the User Needs, the Validation Requirements, the trial results and the LOCOPROL specifications in order to help prove that the user requirements and associated benefits can be realised in a near-operational environment. In a relational diagram the above aspects can be viewed as follows:



The work of this WP had to ensure that the right criteria are applied and the conclusions at the end of the project were robust and clear.

3.6.2 Development of work, main problems encountered and delays

According to the above, the following tasks were performed inside this WP:

3.6.2.1 Inside WP6.1 Evaluation Methodology

- Definition of an evaluation framework (based on the CONVERGE[2] guidelines) and establish the validation references and objectives;
- establish an over-all validation methodology;
- prepare an evaluation plan for each individual site through the definition of evaluation objectives and methods and provide guidance on the design, conduct and analysis of surveys;

The results from the real-life trials were evaluated as WP6 bottom-up activities against the validation reference (WP6 and WP2 activities) as established in the top-down part of the project. In each test site, the results of the different measurements were recorded according to the different criteria and indicators as defined in Del 6.1 Evaluation methodology. Different groups of criteria were defined according to the main aspects of the system:

- Technical assessment
- Impact assessment
- User acceptance
- Financial assessment

The result of this work were presented and examined in an open workshop and resulted in Del 6.1 Evaluation plan submitted to the EC by the end of 2002.

3.6.2.2 Inside WP6.2 performing the evaluation

- collect data survey from each site (from WP4) and analyse their results;
- provide consistent evaluation results.

The evaluation results must allow the project consortium to assess the overall LOCOPROL system concept and the users' reactions. Therefore the same methodology was used in all three test sites. This eases the comparison of the measurements from the different test sites. All measurements and conclusions were assembled in an overall table which can be found in Del 6.2 "*evaluation of all test sites*".

This work has lead to recommendations for improving the specifications and was used as an input to WP3.5 for the definition of the Final System Specifications.

3.7 WP7 Dissemination and LOCOPROL deliverables

3.7.1 Objectives of this Work package

Dissemination activities played an important role within LOCOPROL and started at an early stage within the project. The dissemination activities involved all partners contributing to the project and include:

- to present project results at relevant events (e.g. Concertation Meetings, Conferences, etc.).
- to ensure a wide dissemination of the Projects' results through the Web, newsletter, ITS magazines.
- to provide a brochure of the Project for a non-technical audience.
- to participate in relevant meetings that could help in getting a wider acceptance of the Project results.

3.7.2 Development of work, main problems encountered and delays

Throughout the project the consortium has also actively been presenting LOCOPROL at different related events and prepared articles for its own newsletters (total 7) and other magazines as can be seen in Annex 2, and at the LOCOPROL website (www.locoprol.org).

In addition, to strongly promote the LOCOPROL innovative concept two highly appreciated and successful events including live demonstrations were organised at two different occasions. Targeted invitations were made covering the main stakeholders and potential customers in the field. On both occasions there was an overwhelming response of participants and both events had to be organised in two consecutive days, and the latest event included simultaneous translations, to accommodate all participants:

- Gembloux, March 2004: The demonstration was organised in the city of Gembloux, one of the end stations of the SNCB line 144. Theoretical presentations took place in a hotel near the station and practical on-line demonstrations were organised on-board the test train.
- Nice, January 2005: Hosted by CFTA-Connex the event featured key-note speeches from the EC, ESA, SYMA and CFTA-Connex on the strategic importance and potential for the LOCOPROL, as well as presentations on final results from the different test tracks. The complete LOCOPROL system was also successfully demonstrated live on the CFTA test track.

Another significant event was a one-day conference organised in Beijing in November 2004, to strengthen cooperation with China and promote the LOCOPROL results in this major potential market. The event was visited by 70 Chinese delegates and was very well received.

As a result of these three organised events organised by LOCOPROL, the project has received a lot of positive attention in the press and several newspapers and specialised magazines have published articles on the project results and its potential for market deployment.

4 Results and achievements

4.1 Technical and commercial feasibility assessment

4.1.1 System concept & Architecture

4.1.1.1 Overall system description

The LOCOPROL pilot system focuses on the lower segment (non-headway critical traffic lines). The lower segment is referred to in this description as the LDTL segment. The basic idea of the system is to reduce as much as possible the different expensive elements and to reach a sufficient safety level for the entire system.

In order to achieve the objectives, the system is built on:

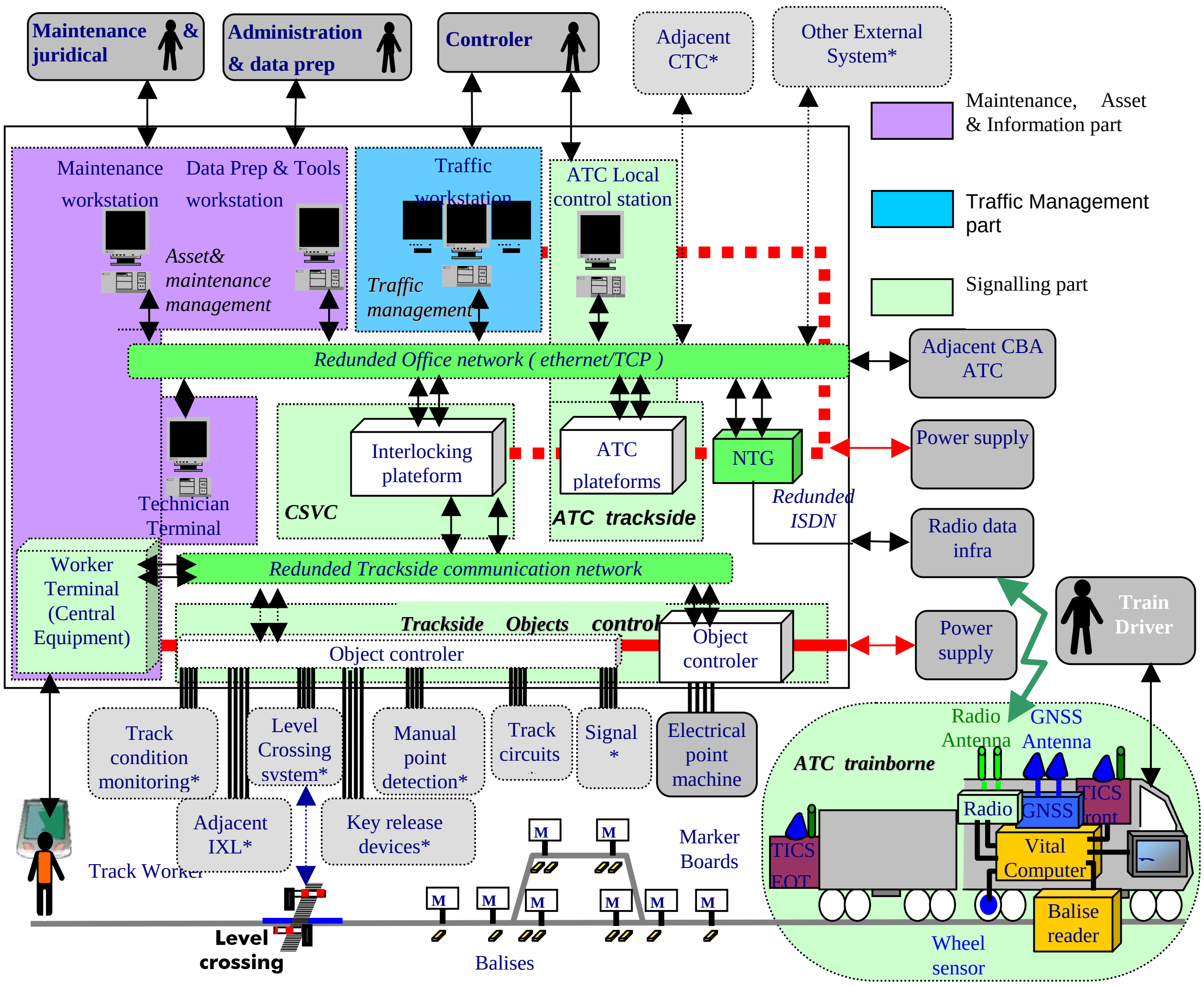
- positive train detection based on satellite location,
- token-based interlocking and ATP functions,
- a non-continuous, non-dedicated radio link between on-board and track-side equipment,
- a reduced stream and reduced size of safety messages between the different modules of the system.

4.1.1.2 System concept

The LOCOPROL system is based on an “evolving” modular concept similar to the one used in the ERTMS/ETCS approach. This will help in addressing different customers with different needs and constraints. The simplest solution could be one with nothing in the track (e.g. a track with only spring points), a train equipped with a Low Cost Train Location system (based on satellite location) and an intermittent radio link between the train and a control centre.

Another concept is to give a higher autonomy to the moving train based on an innovative distribution of the fail-safe functions, which here are more concentrated in the train and in the object controllers. As a consequence, safety critical software and hardware are minimised and this will reduce the volume of the communication and allow for a lighter communication infrastructure.

The LOCOPROL system (maximum concept) is presented in the Figure below:



4.1.1.3 Interface to end user

Interfaces will be prepared taking into account the final users in order to enhance the quality of service to passengers, train operators and freighters and enable enhanced inter-modal solutions:

- Train operator

  The separation of train operation and infrastructure means that charges have to be made for using the line. Line use together with other train data transmitted, such as axle load or type of train, will be used to determine charges, to be billed to the operator.

- Freighters

  A Web interface will be defined in order to inform the train freighter of the status of the transported.

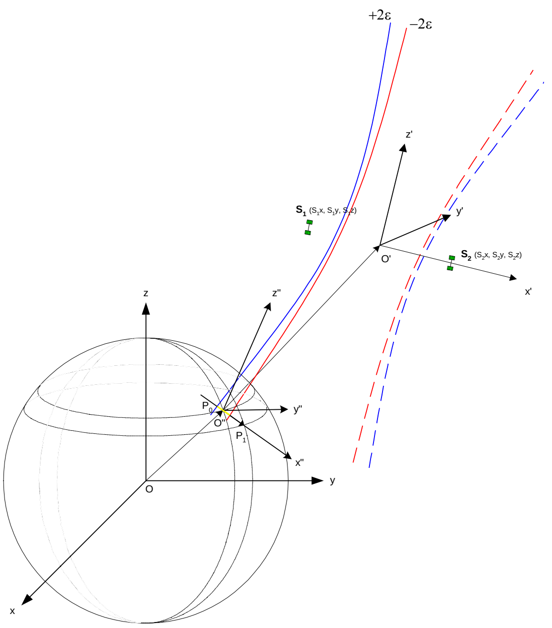
- Passengers

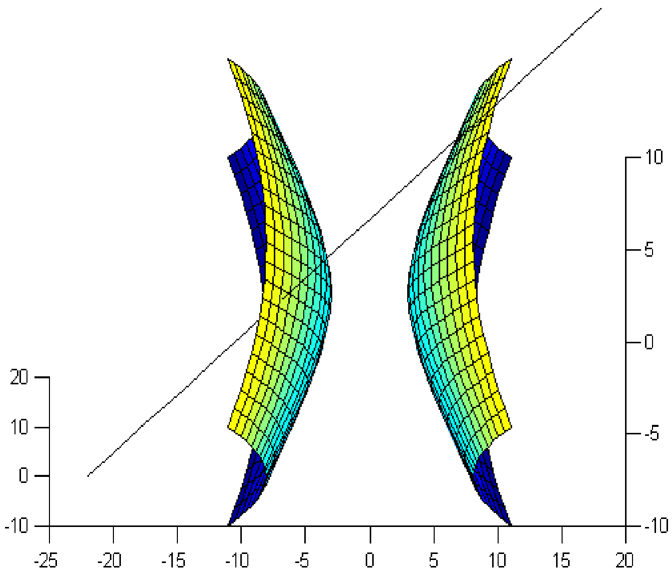
  The display of journey information such as the next station, arrival platform, delays and possible connecting services are collectively described as passenger information. In addition, passengers waiting for connecting services could be informed about possible alternative connections.

4.1.2 Odometric subsystem overview

4.1.2.1 The “1D” algorithm

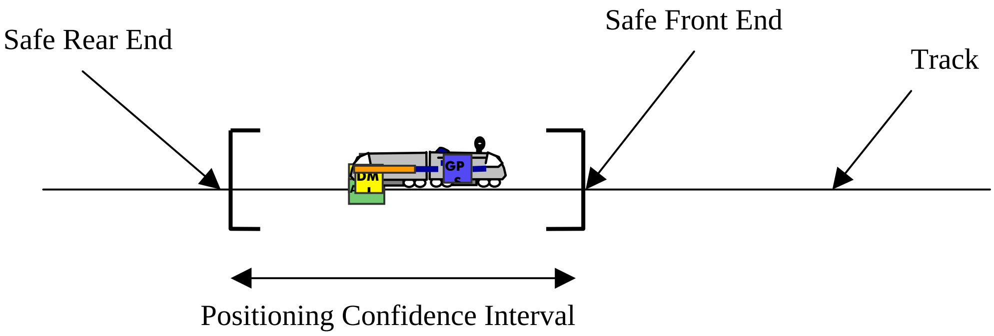
The positioning algorithm developed in the frame of the LOCOPROL project is based on a principle radically different from the classical GPS location algorithm that is running in anybody’s car or PDA. To meet the safety requirements of the railways sector, a new principle has been developed to add redundancy in the measurements and to improve the integrity level of the computed position.





This algorithm is called 1D algorithm because it uses one of the particular characteristics of the rail transport: its one degree of freedom movement. As the track equation is fixed and can be known by the system, the positioning is brought back to a 1D problem. In fact, the algorithm uses several combinations of pairs of satellites, one pair of satellites being able to determine a position locus in the form of a hyperboloid in the space (see figures above). The intersection of this hyperboloid with the track equation can determine a position interval on the track. The union of 6 of these intervals (corresponding to 4 satellites and 6 dependent pairs) will provide a safe position interval of the train position.

The calculated position, as explained, is actually an interval, composed of a safe front end point and a safe rear end point. The developed algorithm guarantees, in safety, that the actual train location is situated between these two limits.



The guideline for the algorithm was not to achieve the best accuracy (positioning confidence interval length) as possible, but to meet the integrity level required for SIL4 applications. Therefore, the obtained accuracy and availability figures are different from the accuracy and availability figures obtained with classical GPS systems. The tests performed during the Belgian Test Track were intended to evaluate this new algorithm performances, i.e. length of the position confidence interval, and availability of the position measurement in a “real-life” environment (realistic track environment with masking by trees, buildings, hills,…)

Today, trains are located, for train occupancy detection functions, with the help of trackside equipment such as track circuits (devices which, by measuring the effect on an electrical current fed through the rails, can detect when the train is short-circuiting the two rails and therefore determine whether a section of track is occupied or not) or by axle counters (devices which, by counting number of train wheels axles entering and leaving a section, can determine if this section is free or occupied). These trackside equipments are widely used, but are very expensive to install and to maintain (such a device is needed about every km of track, which means a large number for long freight lines).

For automatic train protection (ATP/ATC) purposes, trains are classically located with odometry sensors (radars, wheel sensors, accelerometers,…), which are not only expensive, but provide an absolute accuracy which is decreasing with the distance, and thus computed position calculated with this kind of sensors is only usable within a short distance from a reference point. Balises are thus needed regularly along the line (about every 2 km, depending on required accuracy).

The Satellite positioning proposed in the LOCOPROL project is studied as a replacement of these existing technologies, to decrease the cost of the signalling system of low-density traffic lines. The study of the 1D algorithm performance has the objective of validating the principle as being compatible with the requirement of low density traffic lines signalling and train protection functions. Obtained figures could be compared with existing techniques (track circuits, odometry) performances.

4.1.2.2 Several versions

Starting from the basic principle of the 1D satellite positionning algorithm, the train location issue can be decomposed in several layers, corresponding to several additonnal functionalities to be implemented, debugged, and tested.

LAYER
1: Basic 1D positionning algorithm
2: Filtering: train data
3: Use of additionnal sensors
4: Augmentation
5: Signalling System

The first version that had to be tested is the “rough” 1D satellite positioning: the position is computed from the satellites signals only. The position is only available when a sufficient number of satellites is available.

A first improvement is possible by taking into account the maximal acceleration of the train, as well as the last computed speed (this calculation is part of the LOCOLOC project), to “extrapolate” the current position interval. With this additional feature, the interval length is increasing when not enough satellites are available, but a failsafe position interval is countinuously available. The limitations regarding maximal acceleration and current speed can also be applied when the limited position is better than computed with the satellite algorithm.

A second improvement can be achieved by using additional sensors like wheel sensor or accelerometers.

The use of augmentation mechanisms (Egnos, Waas, …) can possibly increase the safety and/or accuracy.

The last step in the development of the location subsystem is the integration in a complete signalling system (train borne equipment)

4.1.2.3 The “Fusion” algorithm

The “fusion” algorithm aims at combining the data resulting from two independent safe positioning systems:

- The Train Positioning Computer (TPC), which computes position and speed intervals based on Global Navigation Satellite System (GNSS), in this case essentially GPS and EGNOS;
- The European Vital Computer (EVC), which computes position and speed intervals, based on classical odometry, using wheel sensors.

It is possible to gain precision by taking advantage of the best-computed data available from both systems while keeping the required safety level.

With this aim in view a module will be developed inside the EVC system to compare TPC data with EVC data and merge it. This module is developed inside the EVC to be able to continue to use all the other functionalities of the EVC.

To be comparable, TPC data must be expressed in the same reference frame as EVC data. It means same measurement time and reference to the same balise group ID:

4.1.3 Tools

4.1.3.1 Track database generation

The 1D algorithm of LOCOPROL requires two main inputs: the present position of the train delivered by a GPS receiver and a digital track map.

Within the track data capture phase the necessary input data for the generation of the map had to be captured as the main goal in several runs on different test lines.

This data was:

- DGPS receiver 3D position output during runs
- INU 3D position output during runs
- DGPS receiver 3D position output for the four reference points
- INU 3D position output for the four reference points

The advantage of the INU is that a 3D-position output is available all the time. This is different for GPS, which cannot output position information if the GPS signals are blocked (in tunnels, by walls etc.) or jammed. Therefore the goal was to combine the benefit of precise inertial (or relative) position measurement with the benefit of GPS actual position measurement.

4.1.3.2 Real time visualisation tool (RVT)

Another tool, and not the least important, was developed by Alstom in the frame of the LOCOPROL project to be able to display in real time some GNSS information and the result of the “fusion“ process.

The RVT has been developed in Delphi language.

Among the main features:

- It can display the time measurement, the position confidence interval length and coordinates of the front and the rear end points, the velocity low and velocity; Velocity confidence intervals as a function of the time; Position confidence intervals as a function of the time; Confidence interval length as a function of the time;

It can also display:

- A graph of the results of the “fusion” process in real time. The graph displays, as a function of the nominal travelled distance, the front and rear end points of the position confidence interval given by the classical odometry, the front and rear end points of the position confidence interval given by the GNSS odometry and the corresponding result of the “fusion”, which is used by the system;
- A graph representing, as a function of the nominal travelled distance, the position confidence intervals lengths given by the classical odometry and by the GNSS odometry. It is then possible to observe in real time when a “fusion” process start;
- A flag indicating if it is classical odometric data that is used as a result of the “fusion” or GNSS odometric data.
- Total number of satellites used in the solution and best combination of four satellites used in the solution (when more than four satellites available);

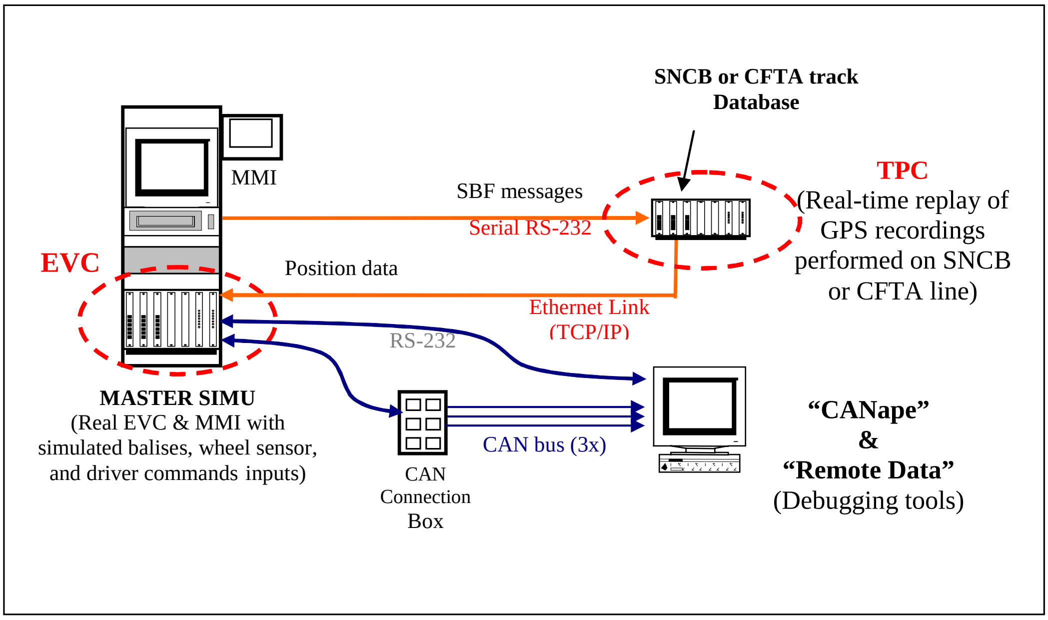
Screenshot of the RVT odometric graphical display

4.1.3.3 Integration & test tools

Before going on site to test the system in a real operation, equipments have been tested carefully in the laboratory. Tests have been divided in several steps, from the simplest configuration until the full architecture involving all equipment modules.

Following modules and functions have been tested:

- Fusion module in the EVC: computing of the safe position as from the TPC 1D algorithm position together with the output from the existing odometry based on a wheel sensor.
- TPC relative positioning: Position computed by the satellite subsystem is relative to the last crossed balise group
- TCP/IP communication interface between the EVC and the TPC.



Train Positioning Computer, Master Simulator and EVC integration

<u>The Master Simulator</u> bay is actually a real EVC connected to a dedicated hardware capable of delivering emulated sensors signals to the EVC (wheel sensor pulses, accelerometer signal, balise reader messages). Movement of the train is based on recorded sbf files (GPS receiver output files). SBF messages are sent by the simulator to the TPC (1 per second), while the corresponding stimuli sent to the EVC are based on the 3D position of the train retrieved in these sbf logs.

It has to be mentioned that the Master simulator software has been adapted, in the frame of the LOCOPROL project, to be able to work with the TPC.

Balise positions are recorded in a configuration file. The new odometry can thus be tested with several different balise configurations, along the SNCB or CFTA line.

The simulated classical odometry (radar, wheel sensor, and accelerometer) is generated with the ASCII file. Consequently, the master simulator will generate the classical odometry and associated balise message for a real travel.

Some tools are necessary to fulfil the pre-processing function:

- One tool, in order to retrieve the useful data blocks, required by the TPC, from the recorded sbf (Septentrio Binary Format) files – ephemeris data blocks, navigation message blocks, measurement message blocks and possibly SBAS message blocks.

- Another tool must extract data from the recorded sbf (Septentrio Binary Format) files and produce an ASCII file with for instance the Cartesian position, speed and time. This way acceleration data can be computed easily, from the speed, for the master simulator

4.1.3.4 Satellite Communication

4.1.3.4.1 Objective

The communication system implemented in the Belgian test track was used to simulate data transmission to the Central Office. The objective was to realise the end-to-end connection between TPC and ATS.

4.1.3.4.2 Instrumentation Description

The test set used in the Belgian Test Track allows to verify the end-to-end performances of data calls in the communication chain. It also measures system parameters related to QoS (i.e. Character Error Rate, round trip delay, call set up time etc.) of the satellite link.

Test Track Mobile Terminal

The Test Track Mobile Terminal (TTMT) is a dedicated tool basically composed of a PC where the measurement software is installed and a satellite modem connected via RS232. This software is called TTMT that means Test Track Mobile Terminal. It also manages a port expander when more than one serial port is required.

TTMT can perform measurements only on train, only on trackside and also train to trackside (in this case two TTMT PC's are required). It can also collect position information if a GPS device is connected to the PC.

Instrumentation Description

The test set used in the Belgian Test Track allows to verify the end-to-end performances of data calls in the communication chain described in chapter 3.

It also measures system parameters related to QoS (i.e. Character Error Rate, round trip delay, call set up time etc.) of the satellite link.

4.1.4 Safety Assessment

As many railway systems, LOCOPROL is targeting systems which require a high level of safety. For instance the safety target to be reached by the overall LOCOPROL system is 10^{-9}/h (wrong side failure per hour) and the one for the positioning sub system is about 6.10^{-11}/h. This target may seem very high, but such targets in the railway field ensure for years already a recognised high level of safety of railways in Europe. Moreover the LOCOPROL system should comply with a "safety integrity level" 4 (SIL4) as defined in CENELEC safety railway standards.

In order to have an independent safety evaluation, a team constituted of railway safety experts has been constituted in a dedicated work package, and has been working independently from the development team to constitute an independent safety evaluation, as required by the SIL4 standard. They came to the following conclusions:

- Based on the available LOCOPROL Deliverables giving an overview of the available functionalities on the one hand and the preliminary safety case made available within the project, one can say that the adopted scheme is in line with the CENELEC safety railway standards.
- Taking into account that the positive train detection principle affects some main safety related functions such as:
    - The Automatic Train Protection (ATP) that avoids the train will overpass its rights in terms of maximum speed, movement authority etc…
    - The interlocking which directly affects the safety of all trains and track workers in the concerned area
    - The Cab signalling for the driver which depends on the position of the train for safe operation

- The safety evaluation team came to the conclusion that the safety objectives as set in the preliminary safety case for the overall tolerable hazard rate (10^{-9}/h) and the one for positioning (6.10^{-11}/h) are consistent with the French GAME (overall at least equivalent) principle in use in French railways (official proof still to be provided).
- According to the hazard identification performed and the proposed mitigation to reduce failure risks, the preliminary safety case gives good hope that the satellite measurement process for train positioning using 6 satellites (3 independent pairs) or using 4 satellites (6 dependent pairs) will achieve the 6.10^{-11}/h objective and the SIL4 requirements.
- Regarding the signalling, assuming the train's initialisation has been performed correctly, the communication link is available and the network is under normal operation, the exclusive token allocation validates the token interlocking principle used in the LOCOPROL solution. The safety evaluation team also validated the fact that the use of at least passive eurobalises is necessary to mitigate the risk during train position initialisation, but also at singular locations such as points or in the vicinity of stations in order to counter the lack of accuracy of the satellite train positioning.
- The main purpose of the LOCOPROL project was to demonstrate the feasibility of the LOCOPROL innovative concepts. The final live public demonstration in Nice has shown, using mock ups, how fundamental concepts like satellite based train positioning, positive train detection and electronic token based logic can be implemented. Mock up based equipment cannot prove a full compliance to the CENELEC railway safety standards and best practices in the railway field. However it was shown that the LOCOPROL project life cycle management has been done compliant to the CENELEC railway safety standards for a research project, and in particular to EN50126 Chapter 6.1 (train positioning). Concerning the signalling part, the work has to be completed in a real case framework with appropriate safety studies. This strongly depends on the commercial project environment like national legislation, national safety rules railway network configuration etc…

4.1.5 Commercial Assessment & Market overview

The potential market for the LOCOPROL solution is with the train and railway operators. In Europe, there are over 450 companies in railway transport with an annual total turnover of over 43 billion euros owning over 35.000 locomotives. European railway network annually transits 240 billion tonne kilometres of freight and almost 300 billion person kilometres of passenger traffic. The total railway network length is around 150.000 kilometres in EU and over 1.2 million kilometres in the world roughly distributed geographically as presented in table below. Of the total world railway network it is estimated that 70% are LDTL lines, which represent potential LOCOPROL markets.

	EU	Accession countries	Rest of Europe	Asia & S. Pacific	Africa	North America	South America	Total World
Railway Network Length (kmx1000)	150	70	200	340	80	280	90	1200

The market for LOCOPROL is characterized by single track lines with simple stations and a low density of traffic typically in the range of 1-2 trains per hour. Large opportunities for the system have been identified for both freight, passenger and mixed lines. Among freight lines can be specifically mentioned e.g. the potentials for mining lines in South Africa and Brazil. Regarding passenger lines some examples are the secondary network in Nordic countries, Germany and UK. The lines in eastern European countries (excluding TEN corridor lines) represent also substantial potential as the infrastructures of these countries will undergo a modernization. The strong growth in China and the consequent demand for a more efficient railway will also offer opportunities to exploit the LOCOPPROL system.

It is estimated that the current potential investments are approximately 600 M€ distributed between market regions as presented below.

Region	Investment (M€)
Western Europe	130
Eastern Europe	40
Asia	80
Africa	30
Australia	20
North & South America	300
Total investment (M€)	600

Since in Europe many Low density lines are in fact feeder lines for the higher density railway network which in a near future will be equipped with (or is already equipped) with ERTMS compatible equipment, a substantial part of the European market demands for an interoperability with the ERTMS standard.

This constraint generally does not exist on the international market.

4.2 Overview of the different test tracks

Within the framework of the LOCOPROL project, the equipment & system testing was part of WP4, related to the implementation of a failsafe low cost railway signalling system.

One of the main tasks of this work package is the implementation of pilot systems on three test tracks:

- The Belgian test track, which had for main objective to test and validate the principles related to the safe positioning of the trains using satellite positioning
- The RFF test track, which had for objective to test and validate the application of the balise relative safe satellite based train location solution in ERTMS/ETCS standard systems.
- The CFTA test track, which had for objective to test and validate the innovative functions of the complete LOCOPROL system (EU solution), including the functions that use the safe satellite based positioning.

All these tests are described below.

4.2.1 Belgian test track

4.2.1.1 Introduction

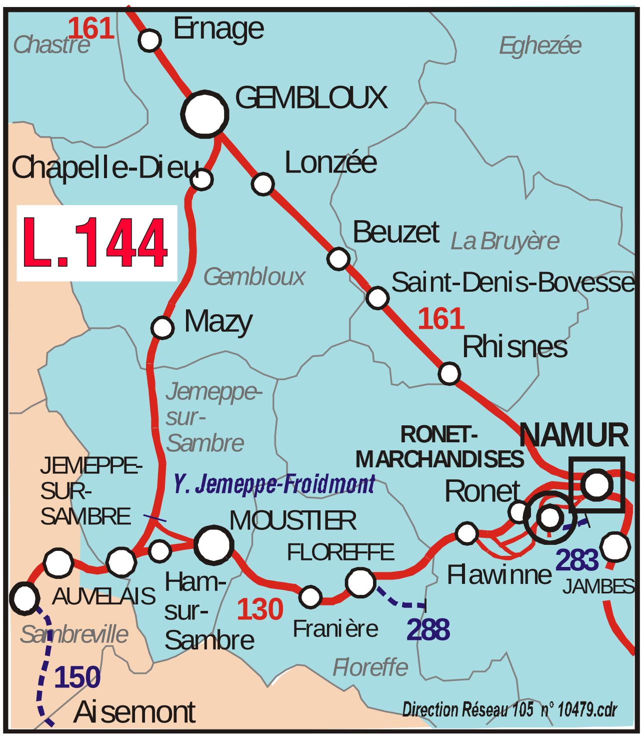
The first tests which have taken place on a low density traffic line in Belgium, were globally focused on the satellite failsafe location subsystem, but covered several objectives.

The main aim of the tests on this test track was to demonstrate the feasibility of the principles of fail safe train positioning based on satellite location. The test track was devoted to the 1D satellite positioning sub-system, intended to be used as the means to locate the trains in the failsafe LOCOPROL signalling system. A first version of this new algorithm was tested in real-time, in real conditions.

Finally, the third part of the Belgian tests consisted in an official demonstration of the new concepts studied in the LOCOPROL project, involving a real-time demonstration of the satellite positioning, and its integration in a signalling system.

4.2.1.2 The SNCB Line 144

The line is a double lightly hilly line with low-density traffic (length ± 15 km). Each track of the line can be operated as a single-track line. As a consequence all test runs always use the same track. Two signal boxes are placed at each extremity of the line, without any other active signal. The line is electrified; the maximum speed is 90 km/h.



Line 144 area map view

4.2.1.3 Track Data Capture

The 1D algorithm of LOCOPROL requires two main inputs: the present position of the train delivered by a GPS receiver and a digital track map. Within the track data capture phase the necessary input data for the generation of the map had to be captured as the main goal in several runs on the Line 144 test track.

Data sources were:

- DGPS receiver 3D position output during runs
- INU 3D position output during runs
- DGPS receiver 3D position output for the four reference points
- INU 3D position output for the four reference points

Sub goals were

- integration of the two main tools “Inertial Navigation Unit” (INU) and “DGPS receiver”
- integration of track data collection computer, interface units and speed radar

The advantage of the INU is that a 3D position output is available all the time. This is different for GPS, which cannot output position information, if the GPS signals are blocked (in tunnels, by walls etc.) or jammed. Therefore the goal was to combine the benefit of precise inertial (or relative) position measurement with the benefit of GPS actual position measurement.

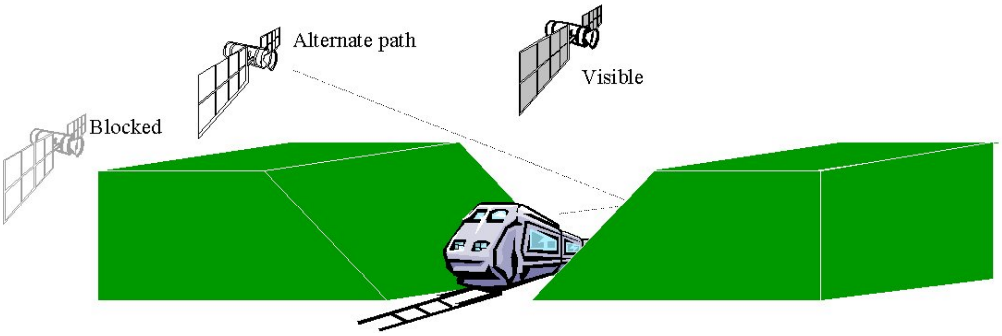
4.2.1.4 Elevation Mask data capture

The availability of most satellite-based location processes of terrestrial mobiles is considerably degraded in transport environments because of significant mask effects. In these environments, the availability of positioning information is not always guaranteed. Indeed, a classical receiver requires a minimal number of four satellites for triangulation and the LOCOPROL one will require 4 [ALSTOM patent]. That will not always be reached in railway cuttings.

In a railway masking environment, the conditions of each satellite signal reception can be classified into three states. As presented in the figure below, they are :

- Direct perception when no obstacle occurs between satellite and receiver (Line Of Sight),

- Alternate path : the direct signal cannot be received and another one, received after multipath, is used as the only data for pseudo-range extraction (No Line Of Sight),
- The signal is completely blocked and cannot be used.



States of satellite reception

To predict satellite availability, a tool has been developed , based on the merging of an image processing approach providing the knowledge of the land environment, and the output of a satellite tracking program (Satellite Tool Kit) predicting satellites positions in the sky. Thanks to this tool, we know which satellites will be visible from the moving vehicle.

4.2.1.5 The PREDISSAT tool

A video record allowed us to characterise the environmental conditions of satellite reception along the test track. We use these data in the PREDISSAT tool.

The goal of the PREDISSAT tool is to predict the satellite availability along the track for a train mission, using :

- the image analysis extracted from ONE video record of the track environment
- the prediction of the satellites positions with the STK (Satellite Tool Kit) software

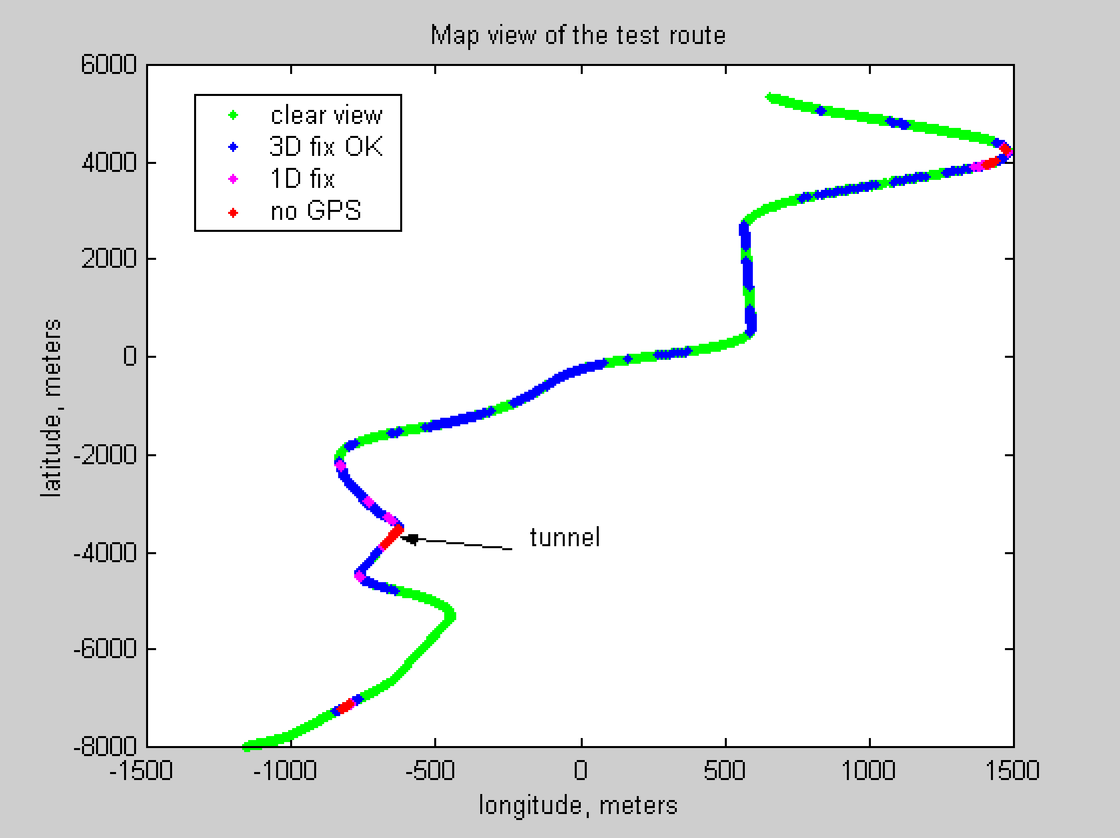
The simulation tool is a solution to reduce the experimental requirements of the task. Indeed, the train will run once only. However, due to the simulation facility, availability will be produced for a large number of simulated runs.

The intersection of these data will allow us to produce at every time of the mission, and from every point of the track, the number of visible satellites and their state of reception.

In this part we have presented an experimental and statistical analysis of the availability of the GPS constellation satellites along the train line of Jemeppe-Gembloux.

Experimental study showed the number of satellites received along a run of the train and the geometry of the satellites. Some critical areas for the reception (insufficient number of satellites) as well as difficulties of precision localization caused by environment were brought to the fore.

Moreover, we used this same run to simulate, with our tool PREDISSAT and STK software, the number of satellites that should be received for other start times of the same day, in order to extract statistical data of visibility. These simulations highlight critical runs of the vehicle, and identify the areas where the reception will be difficult whatever the constellation geometry. Thus, we notice that the number of satellites is lower than 4 about 1.5% of time. These percentages are concentrated in few points because few sections of the run are concerned.



Map view of the test routes. Colours show segments of the route with particular visibility conditions.

4.2.1.6 Assessment of tracking behaviour of different receivers

The purpose of this test was to compare the tracking behaviour of Septentrio's PolaRx2 receiver to two models of the same receiver class from other manufacturers: NovAtel's OEM-4 and Topcon's Legacy. All three are geodetic-grade receivers and produce L1 and L2 phases, C/A and P2 codes and Doppler measurements for both frequencies. Availability and continuity of code/phase data is to be compared.

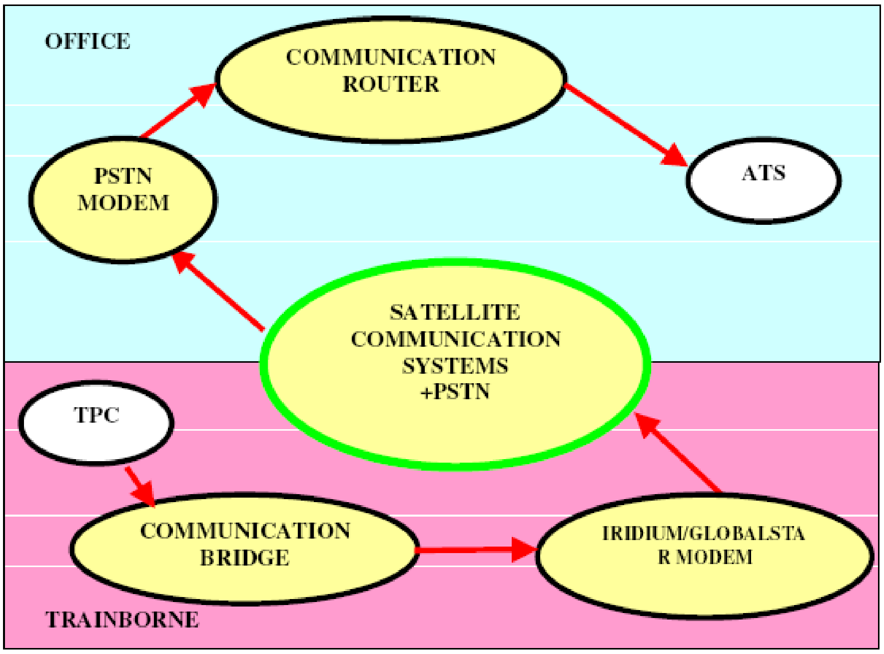
4.2.1.7 Preliminary GPRS performance test

The communication system implemented in the Belgian test track was used to simulate vital data transmission to the Central Office. The objective was to realise the end-to-end connection between TPC and ATS.

Only IRIDIUM and GLOBALSTAR satellite systems have been compared. Train borne and track-side link has been realised using satellite and PSTN connections.

To implement this link two software module has been developed:

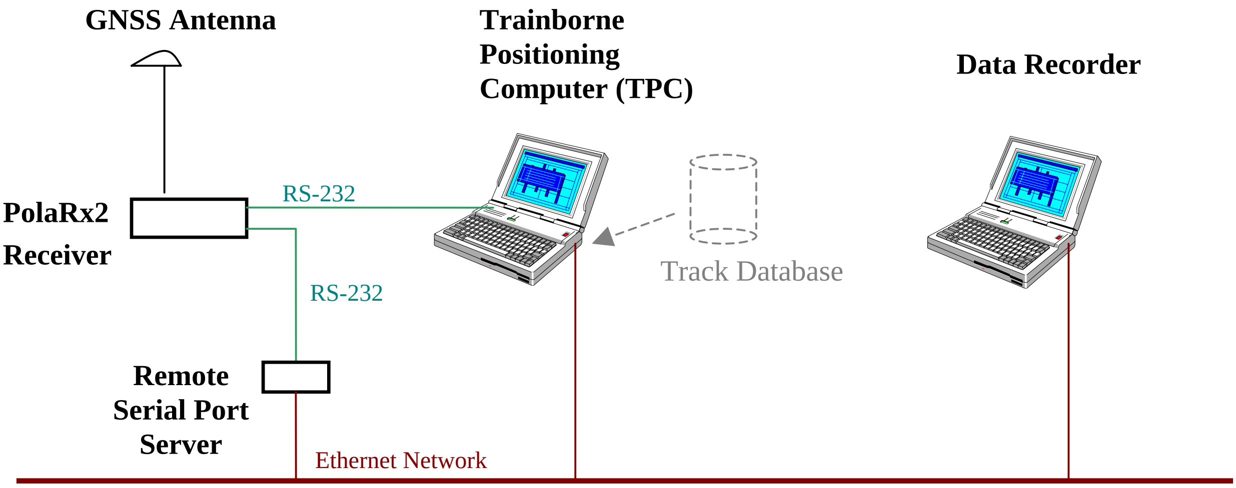
- The communication bridge (CB), which is the interface between TPC and satellite modems.
- The communication router (CR), which is the interface between PSTN analogue modem and the ATS.



Communication Chain used for the tests

4.2.1.8 TPC and Data Recorder Architecture

During the first runs made with the AM106 auto rail on the line 144, the architecture of equipments was as presented in the figure below.



The 1D positioning algorithm itself is running on a laptop PC, called TPC (Trainborne Positioning Computer). The GPS receiver (Septentrio PolaRX2) is connected to the PC through a serial connection (RS-232). The output of the TPC is available on a train LAN network (Ethernet). The algorithm has been coded in C, and runs on top of the QNX operating system. This operating system has been chosen for its excellent real-time performances and for its stability.

The display of the TPC shows in real-time the internal variables of the software in text format (see picture hereunder). It is thus possible to check the functionning of the algorithm in real-time and to detect easily the origin of a potential problem. Among others, following data are displayed:

- number of visible satellites
- azimuth and elevation of satellites (satellite geometry)
- individual intervals of each pair
- final interval characteristics
- …

4.2.1.9 1D Positioning Algorithm

The satellite based positioning is an important part of the LOCOPROL System. The 1D positioning algorithm provides the train borne signaling equipment with a failsafe confidence interval of the train position, by making use of satellite range signals coming from a GNSS receiver.

Several implementations of this algorithm have been tested on the belgian test track. The tests aimed first at debugging the software and identifying the potential issues while running it in a real environment. The other important objective was to evaluate the algorithm performances (accuracy, availability, …) to validate the principle, taking into account the characteristics of the line 144 (bad visibility, …).

4.2.1.10 Test Results 1D Positioning Algorithm

4.2.1.10.1 Satellites visibility

One of the objectives of the Belgian test track was to evaluate the expected visibility on a typical rural line. Concerning this point, the visual environment of line 144 is not ideal regarding the satellite visibility. The line crosses indeed most of the time a thickly wooded landscape, and bridges regularly lean over the rails. Hereunder are presented some pictures of the environment found on the test line 144:

This environment can be considered as difficult, as this high amount of trees (and bridges) along the line act as a “wall” from the point of view of the GPS antenna. The result is a decreased satellite visibility compared to ideal “blue sky” case.

The average availability (percentage of time where a good solution was computed), for all the runs that have been performed with the 1D algorithm was about 95 % (on about 7800 measurements). This result is directly related with the bad visibility of the line.

4.2.1.10.2 Use of train dynamics

The first implementation of the 1D positioning algorithm showed some limitations: after a GPS signal loss, the re-initialization of the algorithm was difficult without knowing the new current actual position of the train.

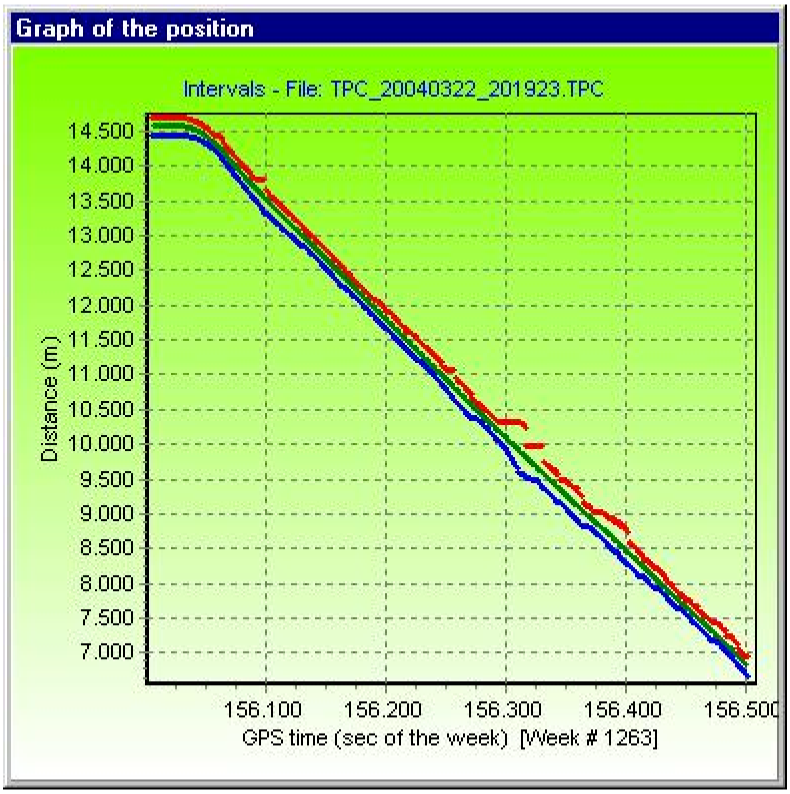
This issue has been solved in a later version of the software, taking into account the dynamics of the train (maximal acceleration, last known speed) to extrapolate a position when the GPS signal is lost.

This helps to re-launch the algorithm after a GPS signal loss, but also improves the accuracy at bad satellite geometry locations, by decreasing the position interval length. This helps also to increase the final availability of the position: a position is indeed always available, even in locations where the satellite position cannot be computed (bad visibility) – however, in this case, the interval is increasing continuously.

4.2.1.10.3 Typical run results

The “data recorder” tool allowed to evaluate the position interval in real-time, and to compare the 1D algorithm-computed position with the reference position (coming from the Honeywell real-time reference sub-system).

A graph can be plot, showing both the upper and lower boundaries of the position interval, and the reference:



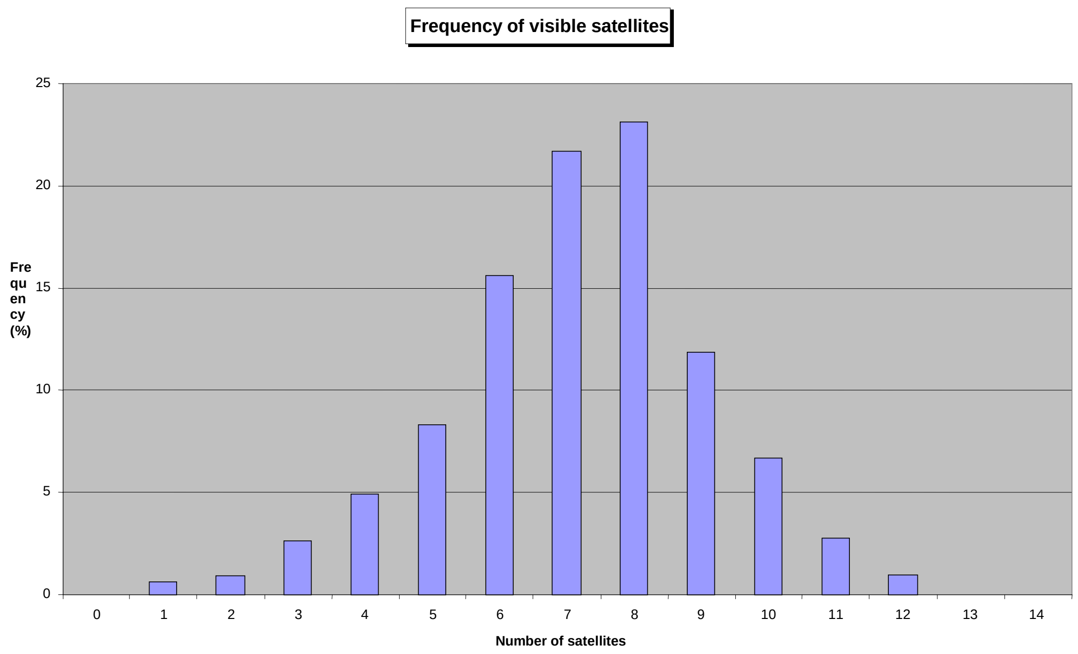
The figure above represents a typical run from Jemeppe-Sur-Sambre to Gembloux. The red line is in this case the safe rear end of the position confidence interval, the blue line is the safe front end of the confidence interval, and the green line is the reference position.

4.2.1.10.4 Satellite availability distibution

A first analysis that can be made is the distribution of the number of satellites that were visible for each measurement.

<u>a) Global Results</u>

Statistical distribution of the number of visible satellites along the whole line is presented in the graph below.



This distribution is based on **76737** measurements made during **83** runs.

>= 4 satellites	**96 %**
>= 6 satellites	83 %

This result is obviously directly related to the availability of the position (see below). However, some satellites cannot be used for the computation of the position (for instance, the satellites for which the doppler measurement is not available). This explains why the position availability figure is slightly lower than the satellite availability figure.

b) Good visibility area

For a good visibility area the figures based on **14633** measurements made during **83** runs are as below:

>= 4 satellites	**98 %**
>= 6 satellites	95 %

c) Bad visibility area

For a bad visibility area, based on **62104** measurements made during **83** runs, the figures are:

>= 4 satellites	**96 %**
>= 6 satellites	80 %

d) Conclusion

These results shows that we have most of the time at least 4 satellites visible, even in the worst part of the line regarding the visibility masking.

We can see that a 6 satellites availability is possible in a non masked environment (which could be the case in desert areas), but the availability of 6 satellites is not guaranteed in a less ideal situation like this typical Belgian line.

It is obvious that the 1D algorithm (working with minimum 4 satellites) is well adapted to a realistic railway environment.

4.2.1.10.5 Positioning performance analysis

General remarks

The two main characteristics which are used to assess the positioning performance are the availability and the accuracy.

It must be noted that the analysis only takes into account the position intervals that are the result of a 1D satellite algorithm. Position intervals which were computed by extrapolating the position with the last speed and interval (second layer in the development – see above) are not taken into account for this analysis. It means that conclusions on this analysis are valid for the 1D algorithm alone ("gross" results)

a) Good visibility area

A total of **5703** measurements have been taken into account for this analysis.

The accuracy is:

- better than **+/-135 m** for **50 %** of the time
- better than +/-**210 m** for **95 %** of the time

b) Bad visibility area

A total of **51626** measurements have been taken into account for this analysis.

The accuracy is now:

- better than **+/-160 m** for **50 %** of time
- better than +/-**400 m** for **95 %** of time

Conclusion

The position accuracy is most of the time around 300m. In a "blue sky" environment, the accuracy does not vary in a large range around this value. In a more masked environment, the mean accuracy is almost the same, but the main difference is a longer interval length.

4.2.1.10.6 Evaluation of 1D algorithm

The analysis of the results from the 1D algorithm is quite good.

The global availability of a position is better than 95%. To obtain a 100% availability, the position can be extrapolated taking into account the maximum acceleration of the train, and the last computed speed. In any case, it has been practically proven that the availability is not a problem on a typical railway line.

Regarding the positioning accuracy, the obtained figures show that the 1D algorithm is a realistic solution for the positioning of the train. The obtained accuracy is indeed at least as good as what is obtained with classical solutions using track circuits. Moreover, the results presented in the previous chapters are not the final ones and have been improved in the 2 other test tracks.

It is however clear that the satellite positioning performance meets the requirements of a low density traffic signalling system.

4.2.2 RFF test tracks

4.2.2.1 Introduction

The present Chapter describes the tests performed in the frame of the work package 4.2.2. under the leadership of RFF and includes all tests related to the GNSS based odometry. i.e.:

- The migration of the RFF test track from France to Gembloux.
- The test of the 1D algorithm integrated into ETCS in level 0 (test of the interfaces and of the behaviour of the fusion algorithm).
- The test of the new sensor configuration into an ETCS train borne equipment operating in level "2" associated to the positive train detection (impact on the application SW).
- The test of the 1D algorithm (in its Belgian TT configuration) in higher speed.

In this chapter, the different tests performed in the frame of the RFF test and partially of the CFTA test track are detailed.

The RFF tests practically performed on the SNCB line were concentrated on the evaluation of the fusion algorithm and its impact on the applicative software of the vital train borne computer (EVC). The tests were performed in the so-called ETCS level 0, for which equipments are limited to passive balise installed in the track. But on the other hand, in this level the train borne functions dealing with positioning are active as in level 1 or 2 allowing a correct evaluation of this new odometry. Particular attention was paid to the behaviour of the sub-system in the masked area (tunnels) and during the transition between the masked and non-masked area.

In addition to these tests, some elementary tests have been performed between Creil and Maubeuge. The objective is to evaluate the behaviour of the satellite positioning sub-system alone (without fusion with other sensor and without integration into the trainborne equipment) in a different environment and at higher speed (160 km/h).

Finally the CFTA tests concentrated on the test of the satellite based positioning subsystem integrated into a fully LOCOPROL equipped train. The objective was first to evaluate the behaviour of this new algorithm in the specific environment that characterises the line Nice-Digne (canyon, hill, mountain, and tunnels) and second to analyse the behaviour of ETCS train borne equipment in level 2 integrating this new odometry.

4.2.2.2 Subject

As written in the LOCOPROL technical annex, the objective of this WP4.2.2 is:

- To implement and test the LOCOPROL safe satellite location sub-system applied to ERTMS/ETCS system under real conditions as available in this site;
- To validate the technical, organisational and operational aspect of the sub-system;
- To evaluate the users' acceptance;
- To demonstrate the viability (financial, quality,…) of the sub-system.

Intentionally this chapter is not limited to the so-called RFF test track but refers to the complete set of tests that have been performed in the frame of the experimentation of the LOCOPROL safe satellite location subsystem on both RFF and CFTA test tracks. Particularly, even if the tests performed in the frame of the CFTA test track was contractually only addressing the LOCOPROL system experimentation, additional tests focused on the behaviour of the satellite based positioning subsystem has been done and are reported.

For the first test track (RFF), the trackside equipment is limited to a small amount of eurobalises installed between the rails and therefore allows tests only in ETCS level "0".

For the second test track (CFTA), the LOCOPROL GNSS based odometry subsystem is implemented in the complete LOCOPROL system and the odometric tests are performed in ETCS level "2".

4.2.2.3 Specific Objectives of the RFF test track

The objectives of the RFF Test Track are to test the application of the balise relative fail-safe satellite based train location solution to ERTMS / ETCS standard system.

The purpose of this solution is, when beacons exist trackside, to use satellite based data together with beacon synchronisation received when a train is passing a beacon to elaborate a beacon relative train position, e.g. as required by ERTMS/ETCS standard.

The RFF Test Track is equipped with balises all along the line.

The solution tested in the RFF test track is based on a mixed positioning: absolute positioning and relative positioning. In case of loss of visibility (loss of satellite availability), the location algorithm will continue to calculate the train position by extrapolating train data. If, in this case, the relative positioning leads to too big errors, the system will switch to absolute positioning and deliver this positioning data referenced to the previous balise.

The objectives for the RFF test track include:

- Complete debugging of hardware and the Data I/O
- Successful runs of a fully equipped configuration
- Record the complete run details for off-line analysis.
- Test of the positioning algorithm at higher speed (160 km/h)

Additionally, during the transfer of the RFF train from France to Belgium, we had the opportunity to test the GNSS 1D algorithm in a different environment and at high speed (up to 160 km/h).

4.2.2.4 Specific Objectives of the CFTA test track

The main objectives of the CFTA Test Track were to test and validate the innovative functions of the LOCOPROL project (EU solution), including the functions that use the safe positioning based on satellite positioning.

In addition, CFTA tests included pure odometric tests in order to evaluate the behaviour of the satellite based positioning sub-system in the specific Nice-Digne environment (characterised by the presence of large tunnels and mountains) and particularly the impact of the fusion algorithm on the ETCS trainborne equipment operated in the ETCS level 2.

The objectives for the CFTA test track include:

- Complete debugging of hardware and the Data I/O
- Successful runs of a fully equipped configuration
- Record the complete run details for off-line analysis

The economical aspect of using additional wheel sensors was evaluated in the evaluation report Del6.2.

4.2.2.5 The SNCB Line 144

For a detailed description of the SNCB Line 144 please refer to the previous chapter.

4.2.2.6 The line Paris-Maubeuge

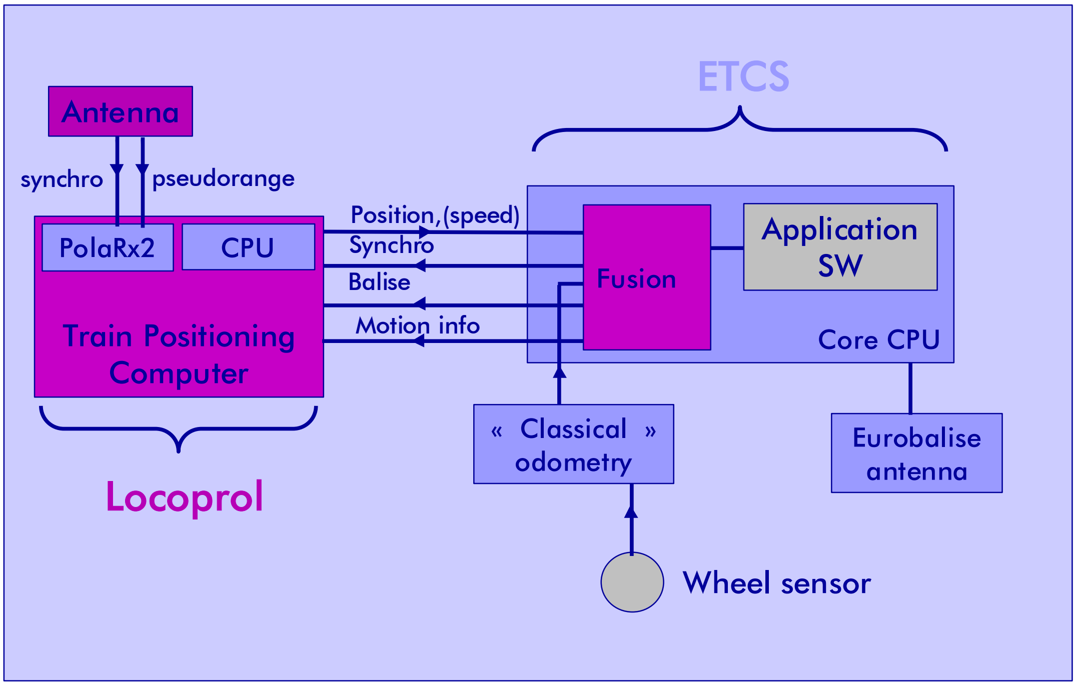
Paris-Maubeuge-Gembloux line map view

4.2.2.7 The RFF autorail

Autorail X1501 in Gembloux station

4.2.2.8 Train borne architecture

The installed train borne equipment is ETCS equipment. The odometric part of this equipment is modified and adapted to the LOCOPROL tests. The radar, which is a standard ETCS part, has been removed and replaced by one GNSS 1D sensor (GNSS receiver + TPC). Then the simplified LOCOPROL configuration works only with one eurobalise antenna reader, one wheel sensor, one GNSS 1D sensor and one modified ETCS (see figure below).



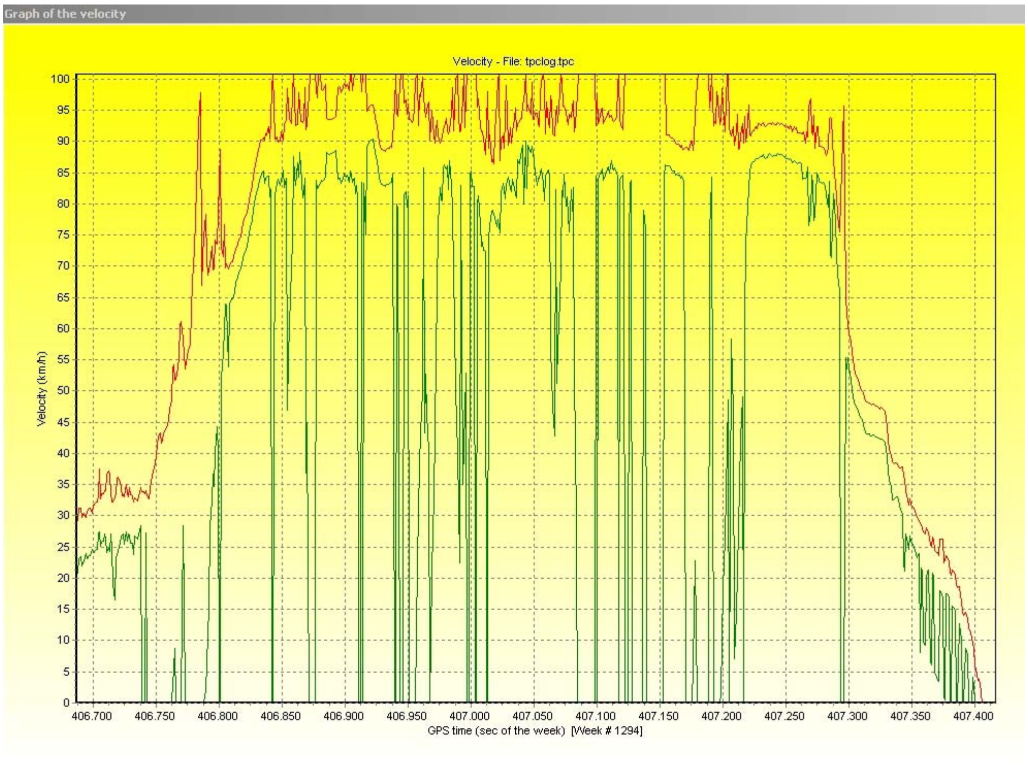
Train borne architecture block diagram

4.2.2.9 Test Results

A large number of test have been done on separate modules as well as on the integrated system. These tests included laboratory tests as well as simulations, dynamic as well as static. In the frame of this report we limit ourselves to reporting on the dynamic overall results.

4.2.2.9.1 Test in level ETCS “0” (RFF)

The first dynamic test is performed at 90 km/h constant speed shows the evolution of the TPC satellite based velocity confidence interval during the test (the red curve correspond the upper limit of the speed confidence interval, the green one correspond to the lower limit) :

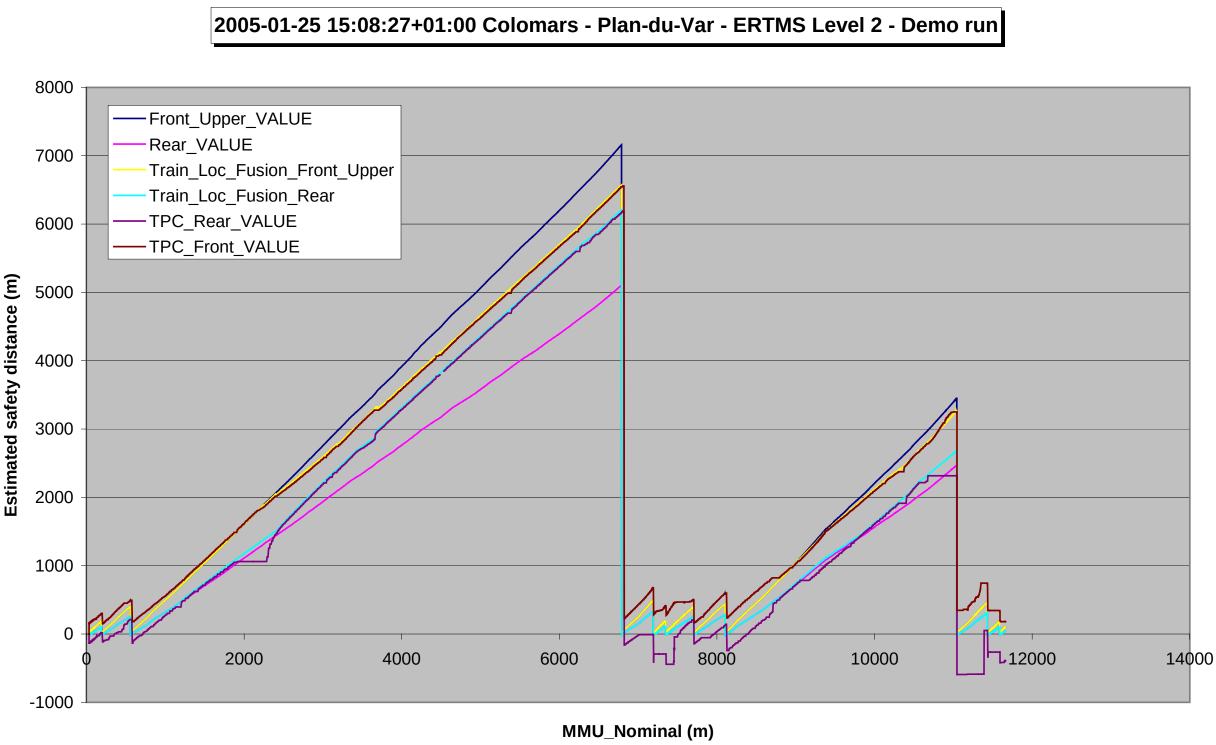


Constant speed profile

4.2.2.9.2 Test in level ETCS "2" (CFTA)

The following test corresponds to the 2005-01-25 demonstration run of the X306 autorail, from Colomars to Plan-du-Var.

The results are very similar to that described above.



Estimated safety distance computed by the "fusion" process (3)

As can be seen in the figure above three families of curves are displayed:

- One family correspond to the front and rear end points of the position confidence interval given by the classical odometry (dark blue and magenta) over the nominal distance given by the classical odometry;
- One family correspond to the front and rear end points of the position confidence interval given by the GNSS odometry (brown and violet) over the nominal distance given by the classical odometry;
- One family correspond to the results of the fusion process for the front and rear end points of the position confidence interval (yellow and cyan) over the nominal distance given by the classical odometry;

The estimated safety distance is computed relative to the last relevant balise group crossed. It is the reason why at some places the distances are reduced to near zero. At these points the precision is very good with the classical odometry (the position of the balise is known with a very good precision and the error on position is very small). As we move away from the balise the incertitude on the position increases and the curves diverge.

On the other hand, the TPC computes a position confidence interval (PCI) which is relatively constant over the time - in the same environment - and when it relocates over a balise the precision is not improved. The PCI is just offset relatively to the balise.

So, near a balise, classical odometry provides better precision than GNSS odometry and as we move away from the balise, the GNSS odometry, at some point (typically after about 1000 m), becomes better than the classical one. The “fusion” process analyses continuously which is the best and switch on it.

If the balises are close to each other, classical odometry will remain dominant. If the balises are separated from each other, at one moment GNSS odometry will become dominant.

In masked areas the GNSS algorithm uses a “dynamic limitation “ algorithm, which makes the PCI rear end point, remaining at the last known position, and the PCI front end point to accelerate until the maximum allowed speed is reached and maintained. When back in non-masked areas, the PCI is normally computed. The consequence is that the PCI front end point could remain at the same position until a new one is greater, and that the PCI rear end point could shift abruptly to the new computed one if better.

The fusion took place on two areas where balises are well separated from each other. The first region, between Colomars and St-Martin-du-Var, where balises are separated by about 6500 m, and a second region, between St-Martin-du-Var and Plan-du-Var, where balises are separated by about 3000 m. In figure 29 the fusion process starts, in the first region, approximately 900 m after the third balise (MMU ≈ 1500 m) and in the second region, approximately 650 m after the eighth balise (MMU ≈ 8650 m).

As shown in the figure abov, the fusion worked as expected.

4.2.2.9.3 Playback of algorithm

Playback of the algorithm could be done on the Master Simulator when no direct fusion results where available on the field. It was the case during the development phase of the “fusion” algorithm during the RFF Belgian tests. Some charts presented here, corresponding to the Belgian RFF tests, were realised after playback on the Master Simulator.

The playback needs to first prepare the following things:

- One acceleration file computed from the 3D velocity provided by the GNSS receiver and recorded during the tests in the Septentrio proprietary “sbf” binary format;
- One ephemeris file that contains satellites ephemerides necessary to start the TPC computations. Data can be retrieved from recorded files during the tests, or reconstructed from data downloaded from dedicated sites, which are responsible for providing accurate and timely GPS satellite ephemerides ("orbits") to the general public (example: National Geodetic Survey);
- One data file provided by the GNSS receiver recorded during the tests in the Septentrio proprietary “sbf” binary format. This file must be filtered in order to contain only the relevant log information to be able to replay the scenario.

The results of the playback are as good as the ones obtained in real time.

4.2.2.9.4 Satellite coverage, availability and reliability

RFF test area (Belgium)

During the period starting from 2004-10-22 up to 2004-10-28 the satellites visibility in the Gembloux – Jemeppe-s-Sambre area was as shown in the picture above.

Some tests were dedicated to tunnel simulations. It was then decided to subtract from the distribution the corresponding outage as it distorted the natural distribution.

The unavailability corresponding to less than four visible satellites is 4.5 % of the time.

The average length of the position confidence interval during this period was around +/-195 m, which is consistent with the results obtained during the 2003 test campaign

Note concerning the EGNOS integrity monitoring: it was normally turned on in the TPC but, due to the fact that a lot of satellites were not monitored at that moment by Egnos, it was not taken into account in the computations to avoid a problem of satellites availability.

CFTA test area

As most of the tests were carried out between Colomars and Plan-du-Var, it is more representative to show the statistical distribution of the number of visible satellites along this part of the line only, where the total number of observations was important:

This area can be considered as a "blue sky" area. The unavailability corresponding to less than four visible satellites is 0.2% of the time.

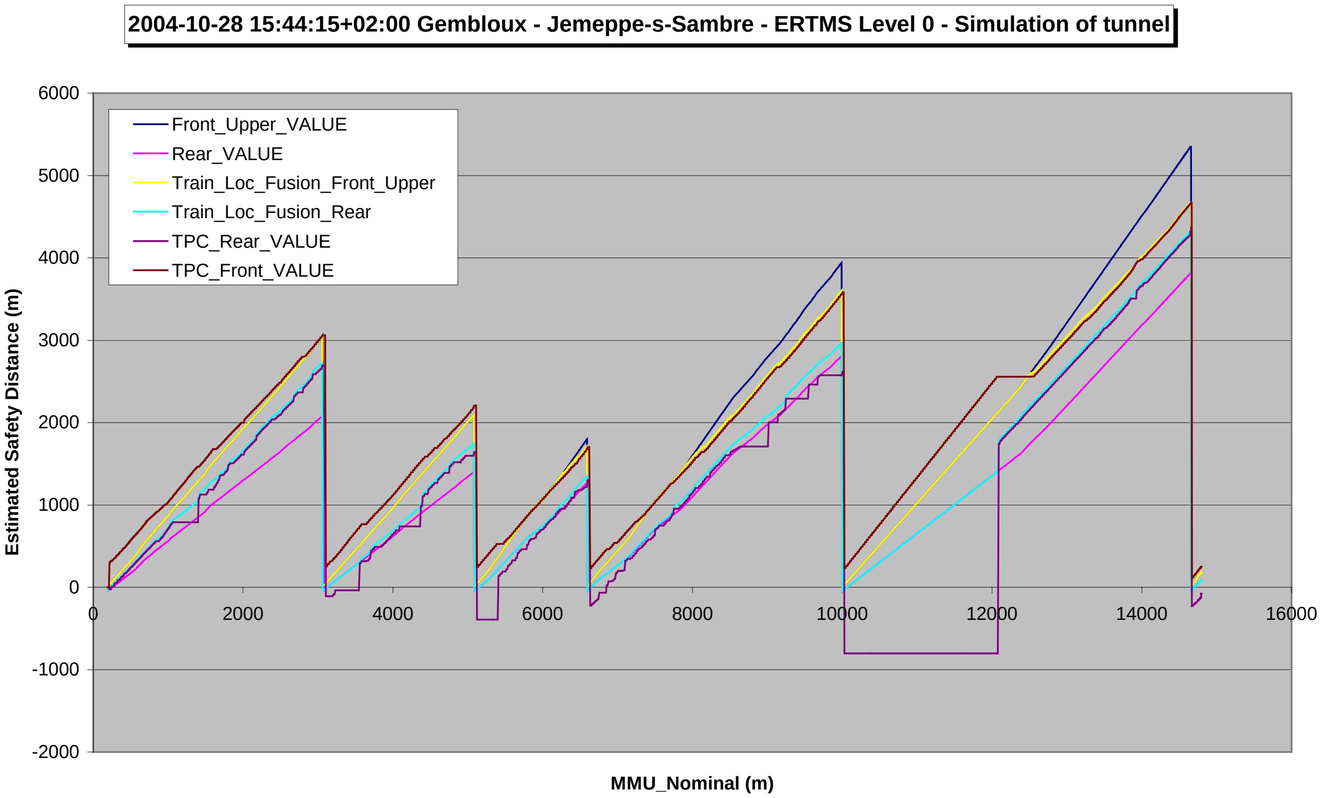
The average length of the position confidence interval during this period was around +/-190 m.

Note concerning the EGNOS integrity monitoring: it was normally turned on in the TPC but, due to the fact that a lot of satellites were not monitored at that moment by EGNOS, it was not taken into account in the computations to avoid a problem of satellites availability.

4.2.2.9.5 Behaviour in masked area/tunnel

For testing the behaviour of the system in a masked area or a tunnel, a test with a constant speed is made. The tunnel simulation is realised by disconnecting the GNSS antenna from the receiver during the time necessary to cover the 2000 m and a re-connection after that.

A typical result of the fusion in the EVC is given below:



Estimated safety distance computed by the "fusion" process

As can be seen in the figure above three families of curves are displayed:

- One family correspond to the front and rear end points of the position confidence interval given by the classical odometry (dark blue and magenta) over the nominal distance given by the classical odometry;
- One family correspond to the front and rear end points of the position confidence interval given by the GNSS odometry (brown and violet) over the nominal distance given by the classical odometry;
- One family correspond to the results of the fusion process for the front and rear end points of the position confidence interval (yellow and cyan) over the nominal distance given by the classical odometry;

In masked areas the GNSS algorithm uses a "dynamic limitation " algorithm, which makes the PCI rear end point, remaining at the last known position and the PCI front end point to accelerate until the maximum allowed speed is reached and maintained. When back in non-masked areas, the PCI is normally computed. The consequence is that the PCI front end point could remain at the same position until a new one is greater, and that the PCI rear end point could shift abruptly to the new computed one if better.

The tunnel simulation is carried out in the 10000 - 12000 m area as it can be seen from the figure. During this time the classical odometry remains dominant until a little bit after the end of the simulated tunnel.

As shown in the figure above, the fusion worked as expected, the tunnel simulation having no particular impact.

4.2.3 CFTA – Connex test tracks

4.2.3.1 Objectives

The objective of the CFTA test track was to test and validate the innovative functions of the LOCOPROL project implemented in its EU configuration. The experimentation focused mainly on the following aspects:

- The satellite based odometry integrated into a ETCS trainborne equipment: this subsystem previously tested in ETCS level 0 in the frame of the RFF TT is now tested in a ETCS level 2 environment.
- The positive train detection: the IXL functions are managed on the basis of the positioning information received directly from the trainborne equipment.
- The Token based IXL: the IXL functions implemented on the basis of the token principles.

In addition to these main objectives, additional tests have been organized in order to evaluate the behaviour of the satellite based odometry subsystem into the very specific visibility environment of the Nice-Digne line. Those tests are reported in the deliverable D4.2.2 .

Regarding communication aspects, a complementary objective is the evaluation of the GSM system as an alternative to the standard GSM-R network used classically in ETCS solution: both GSM-data and GPRS are to be tested and compared in terms of performance and availability.

4.2.3.2 Specific Objectives

The CFTA line is currently operated through specific procedures by which significant safety responsibilities are given to the train staff and the signaler in Nice station. The SYMA intends to modernize the line in order to increase the safety of the operations but also to increase at middle term the traffic density (particularly in the lower part of the line). Specific requirements for the Nice-Digne line have been taken into account during the experimentation.

4.2.3.3 The Nice-Digne line

Part of the Chemins de Fer de Provence (CP) in the Southwest region of the Alps, the CFTA test track (Nice - Digne, France) is a typical secondary, railway line that is operated with a low traffic density. Built at the end of the 19th century, it is a single metric track line with no signaling system and all crossings are managed on a time basis. The line is not electrified and the maximum speed is 75 km/h. With a total length of about 150 km, the line mainly follows the curve of the deep valley and Var river canyon and contains twenty six tunnels ranging from 35 meters to 3,5 km (total length: 11 km), 16 viaducts, 92 metallic bridges, 165 stone bridges and other constructions.

Nice-Digne-les-Bains line

A major reason for selecting the test track was its difficult profile in the rocky canyon along the line and poor GPS visibility. Currently, the line operates 25 locomotives and rail maintenance vehicles -including passenger trains. The rail traffic along the line includes more than 13 crossings per day on the first 25 km near Nice and 6 crossings per day between la Vésubie and Digne. CFTA aims to improve its safety aspects and overall traffic management.

The 150 km line will be selected on the basis of its daily traffic, its topology (26 tunnels – line with difficult profile in the Var river VALLEY) and their environment (GPS visibility). In particular, specific situations as the tunnel and rocky canyons along the line will be tested using this procedure.

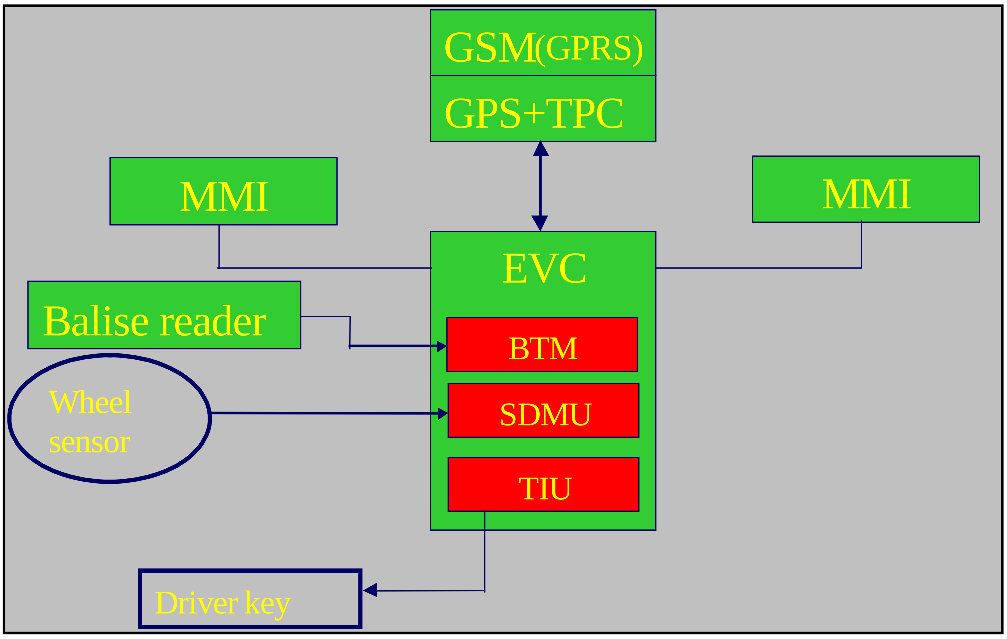
Autorail X306 in Plan-du-Var station

4.2.3.4 Trainborne equipment:

Two autorails had to be fully equipped with LOCOPROL equipment for the tests.
This equipment includes per train:

- One GNSS antenna on the train roof including cabling in order to receive the signals from the satellites; and one specific GSM antenna on the train roof, to be able to receive differential correction data from the DGPS base station by means of the GSM network;
- One cubicle containing:
  - One EVC rack modified for LOCOPROL (The European Vital Computer (EVC) is a computer-based system that controls the movement of the train to which it belongs, on basis of information exchanged with the trackside sub-system and performs the on board train protection functions. The EVC module provides cab signalling to the driver and supervises the driver reactions through the MMI module);
  - One TPC rack and one GNSS receiver. This part computes the position from the satellites;
- One DMI in cabin A and one DMI in cabin B. The DMI provides the interface between the Train borne Sub-System and the driver. The main functions of the DMI are:
  - To display information to the driver (measured speed, target speed, maximum authorised speed, target distance, train borne mode of operation...):
  - To receive driver inputs to be transmitted to the EVC (e.g. acknowledgement of message, data entry…);
- One Balise antenna reader. The balise antenna provides the communication from trackside balises to train;

- One Wheel sensor. The wheel sensor is the equipment that allows to capture the rotation of the train wheel;



The train borne equipment is completed by test equipment necessary for the test evaluation and for the data record. Personal computers are connected to the standard equipment above-mentioned.

These different test equipments are not connected to any nominal train equipment except the electric feeding system.

4.2.3.5 Track equipment

The LOCOPROL solution is characterized by a reduced number of equipments in the direct vicinity of the track: no track circuit, no axle counter, no signal… Moreover, for the Nice – Digne line, the points are trainable and don't need any command equipment. Therefore LOCOPROL equipments are limited to trainborne and Control center

As a consequence, trackside equipments, only passive, are limited to:

Passive beacons (type "Eurobalises") installed in the track: mainly in the stations and near the long tunnels, which represents 35 beacons. These beacons are tele-powered by the train and doesn't need any interface with others equipments. They are installed in conformance with the standard specifications for Eurobalises installation.

Marker boards : these are passive signposts characterized by an identification number and installed along the track. In the LOCOPROL solution, they are used only for unequipped trains or degraded modes.

For the needs of the tests evaluation (odometric tests), a DGPS ground station is installed in a good place concerning GPS reception in the region of Nice and in the vicinity of the track. This equipment is composed by a GPS antenna and a GPS receiver, a notebook PC and a GSM mobile. It is in communication with the train and allows to provide in real-time an information on the position and the speed of reference to the train. The only interface of this equipment with the world is its alimentation and the interface with the GSM public network.

4.2.3.6 Test Results

The present chapter presents general results and conclusion of the different tested scenarios.

4.2.3.6.1 Nominal mission of one train

This test has been used as a "basic" test allowing the debugging of the different components of the LOCOPROL system. Moreover, the train initialization process, the end of mission process and most of the system functionalities have been experimented during this scenario.

This test took place for the following trips:

Colomars – St Martin du Var

St Martin du Var – Plan du Var

Plan du Var – St Martin du Var

St Martin du Var – Colomars

In a first phase, this nominal mission has been conducted with a standard ETCS odometry (without integration of the satellite based positioning). This phase allowed validating the basic principles of the CSVC operation, particularly the functions dealing with the token management.

In a second phase, the satellite positioning subsystem has been integrated into the train borne vital computer (EVC) in order to verify the impact of the fusion process and of the satellite positioning on the system behaviour. This nominal mission has been extensively and deeply tested at various speed levels and in various type of visibility environment (cf D4.2.2).

Particular attention has been paid on the fusion algorithm behaviour and its impact on the odometry part of the applicative software. The variation of the confidence interval computed by the 1D positioning algorithm and depending on the visibility environment and the GPS constellation configuration was initially identified as a potential source of perturbation.

All test performed didn't allow to identify any influence of this new fusion algorithm on the train borne applicative software and particularly during the transition phase between the wheel sensor based odometry and the satellite based odometry. This conclusion is valid for both ETCS level 0 and ETCS level 2.

This is one of the major results of the CFTA experimentation.

4.2.3.6.2 Speed supervision with one train

The supervision of the static speed restriction has been tested for the following cases:

line speed of 65 –75 km/h between the station

Speed limit of 15 km/h on the entry point of a station

Speed limit of 25 km/h on the point when leaving a station

Speed limit of 40 km/h on the platform.

For all these speed limitations, a warning and then a brake intervention ware triggered if the driver ran above this speed limit. A dynamic braking curve is computed on board, and the DMI displays the permitted speed at any moment, to guarantee that the train will respect the limitations when crossing the border between two areas with different allowed speeds.

In a second step, the introduction of temporary speed restrictions (TSR) has been tested. Different TSR have been tested, along the Colomars – Plan du Var track section. Some TSR have been introduced before the start of mission, and some have been introduced after the start of mission, while a train was already running on the section where the TSR was introduced. In every case, the train has received the speed restriction information and the allowed speed has been updated accordingly, with a supervision similar to the static speed profile supervision.

4.2.3.6.3 Crossing operation

Several crossing operations have been performed. The time taken by the system between the moment when one train leaves the point section and the moment when the other train receives the new movement authority to enter the section that has just been released is very short (less than 15 sec). This scenario has been successfully tested and results indicated that performance observed (even if tested with mock-up equipment) is completely compliant with CFTA user's requirements. The introduction of the LOCOPROL system has no disadvantageous impact on the performance of the crossing operation, compared to the current situation. This crossing operation has been deeply experimented and optimized in preparation of the live demonstration that has been held in the Nice conference in January 2005.

4.2.3.6.4 Overtaking

This overtaking scenario has been successfully tested with a level of performance compliant with the CFTA requirements.

4.2.3.6.5 Protection against a face-to-face situation

The tests have shown that in this case, the train does not receive any movement authority. The driver has however the possibility to start in “staff responsible” mode, under its own responsibility. This is due to the current implementation of the ETCS system and is not related to particularities of the LOCOPROL functions.

4.2.3.6.6 Protection against a catching-up situation

The Dynamic test 6 checks that the LOCOPOL system protects the train against a situation of catching-up : the train SY06 is approaching the station “St Martin du Var”, still occupied by the train SY04. The system will authorize the train SY06 to enter the station “St Martin du Var”, only after the platform S52 will be free and the route available.

4.2.3.6.7 Unequipped train management

The main tests have been made with an unequipped train together with an equipped train. This test allowed in particular the evaluation by the CFTA local staff of the system man-machine interfaces as well as the operational procedures defined jointly with CFTA.

4.2.3.6.8 Virtual Block Management

Virtual block has been implemented between Colomars and Plan du Var. The tests have been conducted following strict operational procedures defined with the CFTA safety authority. The test has been successfully conducted and has very clearly pointed out the added value of the virtual bloc functionalities that allows two or more trains to run simultaneously between two stations without addition of any equipment in the track.

As conclusion, the virtual block implementation associated to the satellite based positioning allows a level of performance equivalent to a traditional block system but without any equipment in the track (no track circuit, no axle counter, no balise except in the station).

4.2.3.7 Tests on Operational rules and procedures

Besides the testing of the functional aspects of the system, the operational aspects have been evaluated. A number of operational procedures have been set jointly with CFTA local staff and evaluated during the testing period. This evaluation has been jointly performed with the train staff, the drivers and the signaller. Those procedures concern mainly the spring point management, the start of mission, the non equipped train management for which specific responsibilities have been allocated to the operation staff.

4.2.3.8 Communication tests results

Nice on site test of the communication sub-system has been successfully carried out. The main results of this test are that :

- the coverage level of the public GSM network installed by Orange along test track is sufficient to establish a stable link
- public GSM network has worse performances in terms of connection delay and error rate than a dedicated GSM-R network used in ERTMS. Nevertheless the system has been able to recover the errors and provide a effective communication link
- The GPRS has already provided performances comparable to the GSM data service but still leaves some margin for improvement especially in terms of connection time

- In case of intense utilization of the GSM network, it is possible to experience denial of service due to the lack of free GSM channels. GPRS could probably represent a solution for this kind of problems.

Future investigation could address the possibility to reserve GSM channels on a public network for railway use and the optimization of the RTM state machine for the GPRS service.

4.2.3.9 User's acceptance evaluation

In addition to the evaluation of the functionalities of the generic LOCOPROL system implemented in its EU configuration, some particular attention has been paid on the specific requirements expressed by the CFTA operational staff of the Nice-Digne line.

The main conclusion is that the system as implemented in the test section fully meets the requirements in terms of functionalities. By a significant increase of the safety in the operation of the line, the staff can be re-affected to other activities less related to the safety.

Most of the user's requirements are met and the associated operational procedures have been accepted, and at the same time, the solution allows a large increase of the safety level and a possible improvement of the line performance by introducing the virtual block concept.

In parallel, such a system can be implemented with few trackside investments: no track devices except passive balise and marker board in the station area.

Finally, the experimentation has investigated the possibility to use existing public communication infrastructure (GSM data or GPRS) avoiding therefore big investment in proprietary communication infrastructure.

5 Conclusions and outlook

5.1 Satellite Positioning: coverage, availability and reliability

The position accuracy is most of the time around +/-150m at 10^{-11}/h. In a "blue sky" environment, the accuracy does not vary in a large range around this value. In a more masked environment, the mean accuracy is almost the same (slightly worse), but the main difference is the more important variation of this accuracy. The interval length increases indeed in low visibility area, as the few available satellites could present a bad geometry leading to a longer interval length. In a good visibility area, as the number of available satellites is higher, satellites presenting a bad geometry are not chosen for the position computation.

All figures provided in the previous sections are associated to a safety level that corresponds to a wrong side failure rate of 10^{-11}/h. For information, some analysis has been done in order to estimate the accuracy that corresponds to a wrong side failure rate of 10^{-9}/h. This analysis indicates that the +/-150m@10^{-11}/h becomes +/-125 m @10^{-9}/h under the same conditions.

Satellite coverage in the three test phases is good. Most of the times between 6 and 9 satellites were visible.

The global availability (>95%) of a failsafe position is quite good by using the 1D algorithm (working with minimu 4 satellites). To obtain easily a 100% availability, the position can be extrapolated taking into account the maximal acceleration of the train, and the last computed speed. A better solution would be the use of an external low cost sensor (this solution will be studied later). In any case, is has been practically proven that the availability is not a problem on a typical railway line.

Regarding the failsafe positioning accuracy (performance), the obtained figures show that the 1D algorithm is a realistic solution for the positioning of the train. The obtained accuracy with a 10-^{11}/h integrity level is indeed at least as good as what is obtained with classical solutions using track circuits. Moreover, the results presented in the previous chapters are not the final ones.

Some improvements on the satellite positioning algorithm are indeed still possible. It is however clear that the satellite positioning performance meets the requirements of a low density traffic signaling system.

Regarding the behaviour of the satellite based positioning algorithm, the RFF and CFTA tests tracks confirm the figures obtained during the SNCB test track (an average accuracy better than +/-200m).

5.2 Test of the GNSS odometric subsystem integrated into ETCS

Tests have been performed in 2 phases:

The first phase dedicated to the debugging of the new algorithms and the preliminary test of complete ETCS train borne equipment integrating this new odometry in the so called ETCS level 0. This first phase demonstrated that a failsafe GNSS based positioning subsystem could be integrated into an ETCS equipment without impacting the existing applicative software.

The second phase confirms the first phase conclusions and extends these positive results to the ETCS level 2 application tested in the CFTA line.

The added value of this new odometry has been demonstrated in both test tracks (RFF and CFTA), demonstrating therefore that is possible to locate the train in safety in line sections without the need of balises (with a positioning accuracy independent of the travelled distance).Inversely, the balises could be considered as an augmentation means allowing an increase of the accuracy where it is necessary (e.g. in the station area).

Finally, the test results highlights that the combination of wheel sensor and GNSS constitute an interesting and promising way to solve the tunnel problem.

5.3 The system

After a test period of more than 6 months during which:

- the system components (CSVC, TPC, mini-ATS) mock-ups have been successfully tested
- the complete system has been successfully integrated in laboratory
- the system has been tested and evaluated on site through a significant amount of scenarios
- an evaluation of the system has been performed by the CFTA users
- a live public demonstration of the system has been held,

we can conclude that the objectives of the LOCOPROL project have been largely reached.

The principles of the LOCOPROL system i.e.:

- the integration of the satellite based positioning
- the positive train detection,
- the token based interlocking,

have been successfully experimented during this CFTA test phase.

The introduction of the satellite positioning into a standard ETCS equipment has been demonstrated and the tests have shown that the specific behaviour of the algorithm (random variation of a confidence interval) does not affect the existing applicative software of the trackside and train borne ETCS equipment (RBC and EVC). The performance provided by a simplified odometry based on wheel sensors and GNSS sensor is fully compliant with LDTL requirements, this solution offering, in addition, a way to locate a train between stations with a sufficient accuracy without installation of additional trackside equipment.

The Token based IXL associated to the positive train detection has been as well successfully experimented demonstrating that the very simple token principle is adequate for such line characterised by a simple topology and by a limited set of functional requirements.

Consequently, the data preparation activities are significantly reduced compared to classical IXL systems. This largely contributes to the overall low cost of the solution and allows for an easy and cost effective geographical extension of the solution

Finally, even if further investigations have to be undertaken with public operators regarding the quality of service, our LOCOPROL experimentation allowed to identify a new alternative to the standard GSM-R: the use of public GSM and particularly used in GPRS mode.

5.4 Compliance with users requirements:

A live public demonstration of the system has been held, and a large number of participants underlined the interest (technical, economical, operational and safety aspects) of the system for low traffic density line.

During and after the tests on the CFTA test track, the group of CFTA users (all levels of operating staff) gave a very positive evaluation of the system.

The main global aspects that the users CFTA, SNCB and RFF/SNCF considered as very positive are:

- it is really possible to operate a low traffic density line with LOCOPROL,
- the system responds to safety constraints even if some complementary studies have to be done to formalize in due from the safety file of satellite locations,
- the availability of the system depends on the visibility of satellites. With GPS this availability is a little bit low in some areas but it is clear that the problem will be solved by the GALILEO constellation working together with GNSS;
- in principle the use of complementary other sensors (through a fusion algorithm) enhances the availability in difficult areas (tunnels). This can constitute a good solution for the traffic management problems. In any case, other solution (e.g. pseudo lithe) exists, which have perhaps to be investigated,
- the use of public cellular radio transmission offers several solutions (GSM or GPRS) in order to obtain an efficient low cost system,
- it appears to be possible, by adding specific modules, to take into account satellite location to operate on a LOCOPROL line with an ERTMS equipped train,

- the system is able to integrate other functionalities such as traffic management, trackside maintenance operations, and clients information.

5.5 Comparison with "classical odometry"

A new sensor configuration has been implemented and successfully tested in both test tracks. This new train borne sensor configuration point out the added value of the introduction of the satellite based positioning. This new sensor allows a reduction of the amount of sensors compared to what is classically used today, and particularly the very expensive one in terms of Life cycle cost. It has been demonstrated that the combination of wheel sensors and GNSS sensor associated to the 1D algorithm developed in the frame of the project allows a level of performance at least compatible with LDTL requirements at a significantly reduced Life Cycle Cost.

In addition, the GNSS technology allows a positioning in the block section with an accuracy independent of the travelled distance reducing therefore the amount of balises to be installed between the rails: balise installation can be limited to the station area.

5.6 Comparison with existing solutions

The LOCOPROL solution provides an ideal solution filling the gap between the very low cost traditional solutions characterised by a very poor level of functionality and safety, and the very expensive ETCS based solution adapted for the main lines.

The LOCOPROL solution provides a global system including not only the basic signaling functions but also an ETCS Automatic Train control providing a very high level of safety at a low cost as expected for such LDTL lines assuring simultaneously ETCS interoperability.

In its basic configuration as implemented in the Nice-Digne line, the equipment is limited to the control centre and to the train borne equipment limiting consequently the trackside equipment to passive balises in the station and marker boards. In order to increase the performance of the line, the points can be upgraded with control or command sub-systems that can be controlled by the LOCOPROL system through object controller installed in the station. In the same way, level crossing control can be handled by the LOCOPROL system.

As a global solution, the system can migrate in functionalities by integrating more complex traffic supervision, maintenance and information functions.

5.7 Economical viability

The CFTA experimentation has successfully demonstrated the complete LOCOPROL system in all aspects and consequently has confirmed the main added value of the concept and in particular its economical viability providing the Low Life cycle cost expected for LDTL applications.

5.7.1 Acquisition cost

The acquisition cost will be lowered by the very limited amount of equipment in the track and in the station: Passive balises, marker boards and object controllers in case of motorised points. The installation cost and the maintenance cost will be consequently reduced due particularly to the small quantity of cables to be placed which can be reduced to zero in the case of the Nice-Digne line. The operational cost can be reduced essentially by a reduction of the manpower in the station and by a significant reduction of the communication cost.

Finally, the introduction of the satellite based positioning into the train borne system will allow a simplification of the sensor configuration by eliminating the expensive radar and as a consequence a reduction of the acquisition cost and the maintenance cost.

5.7.2 Global economic viability

As it is the case for ERTMS, in the LOCOPROL system, compared to a classical signalling installation, the cost of infrastructure devices is very reduced and the cost of on board devices increases due to the fact that the main safety functions are on board.

Therefore it is clear that the global appreciation on the economical interest of the LOCOPROL solution depends on the ratio between the length of the line and the number of vehicles to be equipped. From a global point of view it seems, and all users agree, that the balance sheet is positive for low traffic density lines circulated by dedicated trains. In other cases detailed economical studies have to be taken into account. The results depending firstly on the ratio number train per km of track, secondly on the cost of the on board device and thirdly on the economical interest of other functionalities not provided by a classic system, but easily included in the LOCOPROL system.

5.8 Outlook

The multiple tests experienced in the three test sites have proven that:

- The LOCOPROL approach concerning the use of a positive train detection associated to a satellite based train location is viable and can be used in practical applications under normal operating conditions on low traffic density railway lines.
- The odometric module calculating speed and acceleration based on satellite train location can be easily integrated in a standard ERTMS/ETCS on board unit to be used on LDTL lines, and in combination with other sensors on high density lines as well.
- The above mentioned train location & speed module can straightforwardly be integrated in an electronic token based interlocking system and thus constitute a complete low cost safety signalling system specifically adapted to low density traffic railway lines.
- The same system can simply be adapted to include a worker terminal to be used for the protection of workers occupied along the operational railway line and automatically indicate the location of the workers and apply a temporary speed limit around the area where the workers are.

All these applications (except the workers terminal) have been realised and tested as a mock-up equipment. To upgrade the whole system to and industrially available system some steps are still to be done.

Here we must make the distinction between the two different applications i.e.

The EU solution compatible with ERTMS/ETCS equipped lines. This solution is particularly interesting for low density lines interconnected to high density lines mostly in Europe which are already equipped with ERTMS/ETCS standard equipment and where trains are expected to run on both type of lines.

The NON EU solution where there are no constraints concerning other equipment. This solution will mostly be intended for export to other continents, but can also be applied in Europe to isolated low density lines with no contact to main lines (e.g. the line Nice – Digne used as test track 3 in this project).

For the NON EU solution the following steps still need to be undertaken:

- To adapt the 1D algorithm to be compliant with the applicable railway safety standards
- To develop the hardware electronic board also to be compliant with the applicable CEN railway safety standards
- To validate this first genuine complete integrated application
- To submit this first genuine application to the specific acceptance safety case for the first specific country

For the EU solution the same steps still need to be undertaken with the addition of an extra step related to the compatibility with the ERTMS standard. i.e.:

- To adapt the 1D algorithm to be compliant with the applicable CEN railway safety standards
- To develop the hardware electronic board also to be compliant with the applicable CEN railway safety standards
- To adapt the ERTMS/ETCS standard in order to accept the specific interchange telegrams needed for the LOCOPROL system to communicate with the standard ERTMS on board modules.

- To validate this first genuine complete integrated application
- To submit this first genuine application to the specific acceptance safety case for the first specific country

6 Project data and contact details

Project Data

Contract: IST - 2000 - 28103

Starting date: 1st August 2001 **End date:** 31st March 2005

Total Cost: 8.004.084 € **EC Contribution:** 4.047.467 €

Project web site URL: www.LOCOPROL.org

Project Participants

Principal Contractors	Country	Role
Alstom Belgium SA (Alstom BSI)	B	CO
INRETS	F	CR
Honeywell Regelsysteme Gmbh	D	CR
Alstom Transport Spa (Alstom STL)	I	CR
TRASYS SA	B	CR
Alstom Transport SA *	F	CR
BPV	D	CR
SEPTENTRIO NV	B	CR
RFF	F	CR
NMBS/SNCB	B	CR
Northern Jiaotong University	CN	CR
ERTICO	B	CR
CFTA**	F	CR

* = left the consortium on 30/08/2003

**= joined the consortium on 01/09/2003

Contact details

Project Co-ordinator:

Name: Pierre Mertens

Organisation: ALSTOM

Address : 50-52, rue Cambier Dupret – 6001 Charleroi Belgium

Tel: +32 71 44 55 08

Fax: +32 71 44 94 41

E-mail: pierre.mertens@transport.alstom.com

Appendix 1 – Description of deliverables

LOCOPROL deliverables and corresponding web links for public ones

Deliverable number and title		***Dissemination level***	***Electronic reference / web link***
D1.1	Final Report	Public	www.locoprol.com
The present report.			
D1.2	Project Presentation	Public	www.locoprol.com
This document gives an overall description of the LOCOPROL project including main objectives, work done and contact details			
D2.1	User needs Analysis	Public	www.locoprol.com
This document provides analysis of the LOCOPROL work package on user needs for system requirements.			
D2.2	Former Projects analysis report	Public	www.locoprol.com
This document gives analysis of the state of the art developed in former Projects.			
D3.1	External Interfaces	Confidential	
This document describes the LOCOPROL specification of interface between the system and external world; train, track, operators and drivers, existing equipments, environment etc.			
D3.2	System Requirements Specification	Confidential	
This document describes the specification of system requirements on the basis of users' needs and constraints.			
D3.3	System Architecture	Confidential	
This document describes the specification of system architecture.			
D3.4	Internal Interfaces	Confidential	
This document provides the specification of interfaces between CBE, ROC(s), CTC, LX, Switch, NETI, WT, AXK			
D3.5.1	Final Systems Specifications	Public	www.locoprol.com
This document gives the Final SRS, External and Internal interfaces and Architecture Specifications			
D3.5.2	Recommendation for ERTMS adaptations	Public	www.locoprol.com

This document gives consolidated set of recommendations for compliancy with ERTMS			
D4.1.1	Build Modules	Confidential	
This document describes the Prototypes: CBE(x5), ROC(x6), CTC (x3), CSVC (x2).Tools: Track coordinates measurement tool (1x), laboratory integration tools (2x), site1 test tools (1x), site 2 test tools (1x)			
D 4.1.2	Modules User's manuals	Confidential	
This document describes installation and testing procedures			
D4.1.3	Worker terminal specification	Confidential	
This document provides the specification of the Worker terminal.			
D 4.2.1	Belgian Test Report	Confidential	
This document describes the LOCOPROL trial that was performed on the Belgian track.			
D 4.2.2	RFF Test Report	Confidential	
This document describes the LOCOPROL trial that was performed on the RFF track.			
D 4.2.3	CFTA-Connex Test Report	Confidential	
This document describes the LOCOPROL trial that was performed on the CFTA-Connex track.			
D 5.1	System Safety Report	Public	www.locoprol.com
This document describes the Safety aspects of the system during the whole project.			
D 6.1	Evaluation Plan	Public	www.locoprol.com
This document proposes a methodology for the evaluation of the LOCOPROL project.			
D.6.2	Compiled evaluation results	Public	www.locoprol.com
This document present the compiled evaluation results from the three test tracks			
D 7.1	Dissemination and Use Plan	Confidential	
This document describes the plans for dissemination of knowledge gained during the project as well as the use plans of this knowledge.			
D 7.2	Project Brochure	Public	www.locoprol.com
The project brochure describes the project objectives and expected results			

D 7.3	Information Conference	Public	www.locoprol.com
This document will provide a collate of information related to the planned conference			
D 7.4	Technology Implementation Plan	Public	www.locoprol.com
The Technology Implementation Plan covers the intentions for dissemination and exploitation of the industrial partners in LOCOPROL related to the potential knowledge generated under the project.			
D 7.5	Six monthly Newsletter	Public	www.locoprol.com
Newsletter 2-5 have been distributed electronically			
D 7.6	LOCOPROL Web-site	Public	
The project web-site http://www.LOCOPROL.org, open since fall 2001 has been regularly maintained and updated with publicly available documents.			

Appendix 2 – Conferences and publications

The main conferences where LOCOPROL has been presented and published articles on LOCOPROL results are listed in the following two tables:

LOCOPROL Presentations and Conferences

Date / Location	Title	Description / Number of persons attended + other information
26-27.Feb.02	Workshop on user requirements	Attended by about 40 railway company representatives
06.Dec.02	Civil GPS Steering Interface Committee meeting	A general presentation of the LOCOPROL concept – attended by 40 persons in Brussels.
22-25.Apr.03	GNSS 2003 Conference" in Graz(A)	Presentation on LOCOPROL satellite location principles Attended by 70 people.
23-25.Sep.03	IRSE ASPECT 2003" Conference in the UK	Presentation on LOCOPROL approach
29 Sep. 2003	WCRR (World Congress on Railway Research)	The LOCOPROL concept has been presented in this Congress in Edinburgh attended by 80 persons
16 Nov 2003	ITS World Congress, Madrid, Spain	A general presentation of the LOCOPROL concept has been given attended by 80 people.
28 Nov 03	"SRBE/KBVE Study day"	A general presentation of the LOCOPROL concept – attended by 80 people.
Dec 2003	TILT Conference Lille	Paper presented
24-25 March 2004	LOCOPROL/LOCOLOC live demonstrations	Live demonstrations organised in Gembloux (B) with over 160 attendants
21-22 Apr 2004	GNSS project presentation days organised by ESA on in Noordwijk, NL	Paper presented
22-23 Nov 2004	"Location referencing" Congress in Beijing	± 80 participants presentation on LOCOPROL location referencing principles
08-10 Dec 2004	NAVITEC conference, Noordwijk, NL.	Paper presented
25-26 Jan 2005	LOCOPROL conference in Nice	150 participants over two days participated to this conference with technical presentations as well as live demonstrations.

LOCOPROL Publications

Date	Type	Details
March 2002	Article in ERTICO Newsletter	March 2002
May 2002	LOCOPROL Newsletter 1	
May 2002	Article in ERTICO Newsletter	May 2002
October 2002	LOCOPROL Newsletter 2	
April 2003	LOCOPROL Newsletter 3	
August 2003	Article in Railway Gazette	
	Brochure	The LOCOPROL Brochure has been distributed during the *NavSat 2002* (Nice/F), the *GNSS 2003* (Graz/A), the *NavSat 2003* (Geneva/CH) and the *ION GPS 2003* (Portland/OR) conferences.
		As a result of the March demonstration, many newspapers and specialised magazines have published an article on the LOCOPROL project.
March 2004	LOCOPROL Newsletter 4	Introducing Belgian test track, Introducing new partner CFTA
September 2004	LOCOPROL Newsletter 5	Report from Gembloux event, Results from Belgian test track
February 2005	Rail & Transports	7 page article featuring LOCOPROL results, Nice conference, and interviews with different industry stakeholders
February 2005	Rail Passion	4 page article featuring LOCOPROL results and Nice conference
February 2005	IRJ	Article covering LOCOPROL results and Nice conference
30 January 2005	Nice Matin	Article presenting Nice conference and the LOCOPROL results
March 2005	Signal+Draht	Article presenting Nice conference