SATLOC – Innovative satellite based operation and management of low traffic lines

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Abstract
“Successful introduction of the satellite navigation technology in the railway safety needs accreditation of a new mode of thinking, innovation, convincing demonstration of concept and lifting of technical and mentality barriers.” This article will show a the final state of the art of the SATLOC project aiming at reporting on the baseline of the project according to the objectives, in line with the terms of the FP7, item Galileo.2011.1.4-1 “Use of EGNOS and GALILEO for safety-of-life applications for all transport modes”. The article summarizes the notable realizations of the project team, the advanced tests and safety demonstration principle, preceded by the concept validation in the laboratory and on the pilot line Brasov - Zarnesti in Romania. The system and the products developed have to be able to be used by different European railway infrastructure manager of low traffic lines (LTL) without functional evolution.

Key words
Railway operation and management - satellite based signalling system – ETCS level 3 – Safety demonstration - low traffic lines

Context
The railway regional lines are in danger. Covering around 30 to 40% of the total length of the European network, these lines are generally no more efficient. Two possible choices for each line, to be closed or to upgraded regarding a future efficient operation. So the railways have to find a solution making the operation of these line sheep and safe.

The financing the operation and asset management of railway lines, especially the regional lines, is more and more challenging. All the railways have to increase they performance, to reduce the costs without to reduce the operation safety level. Thanks to the digitalisation, the UIC has proposed an innovative concept in order to help his world wide members.

The SATLOC project was launched by UIC (Union International des Chemins de fer) and the European Commission to answer the expectation of many European and world wide railway infrastructure managers proposing an innovative a GNSS Safety in live rail application for the train control, speed supervision, traffic control and traffic management of low LTL.

The project was financed by EU Grant Agreement called “Satellite based operation and management of low traffic lines” and will be a basis for further UIC development on satellite navigation applications.

Research objectives of the EU-UIC SATLOC project
1) Real scale demonstration for GNSS based safe and efficient train operation on low traffic lines (operational – pilot and test-bed on RCFT-Romania). The detailed realised objectives are:
   • Integrated train control, speed supervision, traffic control and network management with SOL satellite location of trains (EGNOS)
   • Innovative operation concept based on close-loop interaction train-trackside to demonstrate high operational safety target THR better than 10^-9/ h,
Low cost On Board and track side equipment,
- Operation to support alternative use of simplified interlocking (trailable and spring switches) for crossing trains in stations,
- Proof of concept and test solution for Train Completeness Monitoring System with Route Map and GNSS.

All these objectives have been achieved.

2) Test, validation and certification methodology for the innovative GNSS based operation concept and for the On Board train locators. The detailed objectives are:
- Unified testing methodology (to evaluate actual performance)
- Analytic methodologies for evaluation in the train environment (to use mathematics and consecrated probability data for proving the achievement of SIL)
- NOBO methodology for validation applicable to SAT-LOC with enforcement of GNSS integrity in the rail standards (use of test methods to achieve validation and certification with use of standards)

Tangible achieved results of the objectives are:
- Full functional & operational demonstrator and test platform anchored in train operational reality, HW&SW on board and track-side
- Specifications – validated by rail & industry - for further realization (FRS, ORS, ARS, technical performance & requirements) in the V&V cycle
- Methodology for unified testing, validation, and certification in conformity with the rail standards and with applicability to the Notified Body

The tangible results of the objectives creates EGNOS SoL application visibility, impact, proof of feasibility and economic evidence, tested and verified in real railway functioning under the EU ruling and applied on the line Brasov – Zarnesti of the RCCF-TRANS (Romania).

Project outcome and main innovations

1) Real scale demonstration of GNSS based efficient train operation on low traffic lines (operational – pilot and test on RCCF-TRANS Romania): Integrated train control, speed supervision, traffic control and network management with EGNOS SOL satellite location of trains. The achievement of this research objective is the real scale realisation of the onboard and of the RBC+ TCC integrated system which elaborates the movement and shunting authorities for trains and supervises the execution.

The integrated RBC+TCC control centre is the core of the SATLOC system. Here the trains are registered, followed up, tracked with the GNSS coordinates and surveyed for the safe execution of the movement authorities and speed supervision. The RBC+TCC use the full compliant ETCS language and the requirements of RBC, interlocking and shunting as resulting from ETCS. The significant innovation is the survey of the trains’ position and movement from periodic sending of position / speed reports (each 5 sec for each train).
The data connection trains<> TCC is made via innovative concepts of VPN-secure and using the transmission media of UMTS / LTE 3G, 4G and beyond, with full roaming and high availability capability.

In addition to the means presented the UIC has edit a professional film dedicated to the SATLOC functionality and presentation of concrete results derived from the real operation in concrete exploitation conditions.  

![Figure 1: TCC integrated SATLOC architecture](https://youtu.be/tpIxf_O1ac4)

2) **Innovative operation concept** based on close-loop interaction train-trackside to demonstrate high operational safety target THR better than $10^{-9}$/h
In Figure 4, the "route map" (the exact and safely assessed description of track topology by absolute coordinates) enables the safe check of the train position, based on the algorithms which consider the real dynamic of a train and the observation that successive fixes are events of the same statistic population. In a second stage, the train dynamics is checked against the movement authority enforcement requirements.

Figure 3: Route map graphical representation (virtual balises and virtual block-sections)

The driver is warned and then (if no conforming reaction) the train is stopped automatically. This TCC "train tracking" function is independent from the OB similar functions (full speed supervision). The joint inter-relation of the two functions enables to reach high safety with components with a lower safety integrity class.

3) **Low cost On Board and track side equipment** are:

a) The onboard equipment is realised to strictly respond to the functions allocated onboard and to strictly correspond to the functional safety integrity class for the onboard. The onboard software components are developed on the SIL 2 requirements. The train localisation function are supported by:

- The EGNOS GNSS receiver which enforces the EGNOS SOL and transfers to the application (localisation software functionality) only the fixes which are qualified by the SOL ("use" flag),
- The train odometry realised by the DEUTA with the RED-BOX micro-controller driven programmable outputs, capable to be calibrated by the GNSS.

b) The fusion of the GNSS localisation (EGNOS qualified), the DEUTA odometry and the verification of fixes with the route map train trajectory make the location of the train a safe function, corresponding to the onboard safety requirements (functional software SIL2). The data transmission train<>traffic control centre is supported by the VPN-secured in the UMTS 3G / 4G.
mobile communication provided by the public VODAFONE-RO. The special arrangements have been achieved with the mobile telecom service provider to guarantee:

- The high service availability of > 99.8% with full coverage of the railway route,
- The redundant service in case of the primary network failure, by “roaming” on other networks with similar service quality.

The cost of the data transmission is marginal and the data transport capacity is at the level of 3G or even 4G performance.

c) The track side equipment is the traffic control & command centre (TCC) combines the ETCS RBC, the interlocking logic (for train routing and spacing functions), the telecommunication functions and the safety layer (EURORADIO) of the ETCS. The TCC is realised on the ETCS platform, applies the ETCS language in dialogue with the trains and facilitates all train control and traffic control. The special SATLOC function of inter-acting close-loop train<TCC cross check of safety status enable the realisation of the TCC functionality (software(on a lower SIL (SIL3), which is a significant cost reduction in comparison with the RBC and a remote traffic control.

The Figure 4 (bellow) shows the main areas of the agent-TCC interface which enables to fulfil the traffic control and RBC functionalities:

- Manages the operators display
- Determines the track occupancy
- Drives the MA display
- Displays the identities, position, status, and MA of all connected OBU’s
- Displays the activation and deactivation of exceptional events (e.g. Emergency Stop Area set, Track Reminder Set, etc.)

Additionally the TCC realizes the following functions:

- Handles the SATLOC GPS EGNOS data (SATLOC Packet 44)
- Checks GPS/EGNOS positions against the ETCS position reports (packet 0)
- Checks train speed against static speed profiles
- Raises emergency messages against violated speed restrictions and infeasible position reports

d) Automatic train routing in the crossing stations is realised by trailable (spring) switches installed on the existing mechanical interlocking of the line. For safety reasons the pre-positioned switches are controlled by the legacy ATP system INDUSI, which remains in a parallel function on the lines on which SATLOC trains shall reach the next main stations (e.g. Brasov in case of the line Brasov-Zarnesti). The low cost solution is significantly supported by the following:

- Preservation of the mechanical interlocking with local operation, for execution of the shunting operations of SATLOC trains (SH – shunting authority for the train and blockage of the access to/from the shunting zone). The crossing routes are pre-positioned by trailable switches (spring switches). The system using “virtual block” train separation where the virtual blocks are delimited by “virtual balises” (given coordinate achieved in the road map).

- Figure 5 shows the typical layout of the spring switches in the context of the mechanical interlocking. During the system exploitation, the mechanical signals and the signal boxes will be dismounted. It will be no personnel in stations. The shunting is realized by the shunting team which will operate the mechanical interlocking under the shunting authority order from TCC
Figure 6: main areas of the TCC which enables to fulfill the traffic control and RBC functionalities

Figure 7: typical layout of the spring switches in the context of the mechanical interlocking
Test methodology

The test methodology for the innovative GNSS based operation concept and for the On Board train locators was applied during the tests phase and to guide the further validation and certification and used three kinds of documents:

- Unified testing methodology (to evaluate actual performance);
- Analytic methodologies for evaluation in the train environment (to use mathematics and consecrated probability data for proving the achievement of SIL);
- NOBO methodology for validation applicable to SAT-LOC with enforcement of GNSS integrity in the rail standards (use of test methods to achieve validation and certification with use of standards).

The tests for the SATLOC system verification are based on the application of the standards (notable EN50126-28-29) and comprised in tests scenarios. By this way SATLOC follows the same general procedure as ERTMS/ETCS where specific scenarios are set to prove the evidence of functionality. Since SATLOC pilot is still a pre-exploitation phase, the application of safety cases will follow in the post-project phase. Correspondingly, the safety cases will be described and added to the currently defined test and verification scenarios. In summary, the tests scenarios encompass the complete system functionality verification, as following:

1) System start, train initialization, registration and de-registration. This scenario corresponds to the reference document. The functional verifications will focus on:
   - Start and initialization of the OBC (it is supposed that the TCC computer is started and functional),
   - Recognition of the authorized driver,
   - Connection into the VODAFONE network and establishment of the VPN connectivity to the VODAFONE server and the TCC,
   - Request and introduction of the train number,
   - Introduction of the train data (if the RCCF-TRANS commuter trains will have the pre-programmed data associated to the OBC, the train data shall automatically appear when connecting the OBC),
   - Registration of the train following all sequences prescribed (on a GPS location, on a non-recognised GPS location, acknowledgement by the driver -TCC, other sequences),
   - Follow up of the correct display on the drivers’ desk,
   - Follow-up of the correct display on the TCC desk.

2) Transaction of data messages Train-TCC referring to the train route and train status on the route. The test scenarios corresponds to the document D3.1 Part 2 “Test specification” especially to functions FRS10.1, FRS101.1 and FRS10.2. As a matter of fact the transaction of data messages in involved in each scenario of the SATLOC functional verification. The functional verification will test the following:
   - Messaging when the train driver asks for a on movement authority,
   - Messaging on the train status on ARRIVAL,
   - Messaging on the train status when asking for movement authority when crossing another train in a crossing station,
   - Messaging on the train status when the train is stopped on the stop flag (in stations),
   - Messaging of departure status,
   - Messaging when the driver asks for a shunting authority and all related messaging telegrams when execution, ending and replacing the shunted train on an expedition (circulation) line.

3) Verification of procedures and system status by request / allocation of a movement authority and shunting authority. The verification will test all procedures and system responses (on-board and in the TCC) related to:
   - MA request
   - Execution of the MA and train automatic control (full supervision) on the route until the MA limit,
4) Verification of transitions to degraded mode operation. This scenario does not actually correspond to the operational document. The verification shall focus on the following situations:
   - Temporary loss of data communication; the results shall enable the driver and the TCC to pass to the voice communication; the train shall normally be driven until the MA limit already transmitted,
   - Loss of GNSS location; the train shall be driven normally based on the mechanical odometry until the MA limit; afterwards the degraded operation shall be established,
   - Total failure of the OBC: the driver could be able to bypass SATLOC; degraded operation shall established with the TCC agent.

5) Documentation of tests. The documentation of tests shall be compliant:
   - With the standards requirements for complete information on the test scenario, test expected results, means employed to test, actual test results, deviations, causes, remedies and conclusion;
   - With the Romanian CFR regulations on completing a standard “Test bulletin”. The test Bulletin includes all standard information. Therefore the verification and testing teams have selected the RO test bulletin. This decision precludes the final (post-project) verification for validation, assessment and certification of the SATLOC concept, to make it available for commercial exploitation on low traffic lines of the Romanian railway network.

The following figure 7 summarises the applied tests and verification procedures and the SATLOC recommendations for specific tests for validation.

![Diagram of verification flow](image)

**Figure 8**: Summary of “V cycle” verification flow aiming at SATLOC validation

The conclusions and recommendations of the tests and verifications show the following:
- The test specification specific for SATLOC applies and is significantly complete together with ALL other requested verification and validation process, such as standards, EC prescriptions and rail authority prescriptions which shall be considered and observed,
- The validation shall be made at a SYSTEM level, and in the conditions of the intended application,
- The verification specification and the validation against the system performance are strictly applicable to the intended application.

**Cost Benefit in contrast to other Train Control Systems**

The following cost benefits have been identified by the project management of SATLOC based on experiences in the project:
The onboard equipment has no BTM (no antenna and no BTM software), this may reduce with ~ 30% the on board (OB) cost,

- The OB DMI is simplified, i.e. only the essential information is given to the driver, thus cost benefits can be achieved. SATLOC is not a “postman” for information as it is now the ETCS “standard”,

- The train-EVC interface is maintained at the essence, only the traction and brake controls are applied; The application is following the rolling-stock standard for connectivity, i.e. numerical direct actuators to the controls – cost is minimized

- The OB localization function shall be qualified on SIL 2, higher is not necessary since the TCC and trains follow up a close – loop inter-relation to reach the THR for the train even higher as in ETCS. From this point of view, TCC and trains (e.g. trains and infrastructure) build a full functional entire controlled system – as a whole. ETCS is based on “independency” of the safe behaviour of infrastructure and of the trains. The ETCS L3 will probably re-consider this vision.

- The radio-system does not rely on GSM-R but on other non-proprietary systems based on the market leading technologies (UMTS, satellite telecom...). In case of SATLOC this is an important CAPEX reduction. OPEX reduction is also important because the use of needed data messaging intensity is at marginal cost in 3G or 4G communication technologies

- The control of the radio-connection is total (by default) given the train-tracking function which demands that each train reports position and speed (with GNSS time stamp) every “n” seconds (5s selected for real time reasons) in SATLOC. Therefore the system is surveyed as a whole and simplification of the sequences is achievable (again, cost reduction). Therefore, simplified software for back-up and transitions to radio-holes, cost reduction follows.

- The “drive on sight” and “staff responsibility” (SR) regimes have been condensed in one: SR. Simplification of modes and of transitions is achieved with cost reduction.

- The shunting function is simplified (request for LTDL) with locally controlled shunt-ing and separation of the shunting area from the passing traffic. The shunting train cannot exceed the protected SH area (Important complication reductions for the RBC – cost reduction follows this concept).

- The SATLOC braking curves are adapted (simplified) to the maximum speeds (e.g. 100 or 120 km/h) and train categories of the regional traffic are applied; for the Romanian application the same braking curves as now approved for the ATP system INDUSI are applied. In difference to INDUSI, SATLOC manages the continuous braking and not only the punctual check. This arrives to cost reduction of the on board and on simplification of the RBC.

- In SATLOC applications the GNSS absolute position is an integration platform for reaching directly available additional services with high impact on rail-transport (e.g. space-related information systems, line management, traffic management and optimization. But, given the requirements of LTDL, no important increase of line capacity is expected and no moving block algorithms are envisaged in the RBC).

It has been computed that in the shown condition, the CAPEX (investment) recovery is only 1,7 years. Starting from the third exploitation year the benefit for this line is ~162 000 € /year. The potential benefits do not include the increase of the income from the transport service due to in-crease of the transport quality, reliability, timing and quality migration opportunities. It is almost obvious that SATLOC is a self-sustainable application: from the short term (~2 years benefits) the system extension is achievable. An accurate cash-flow analysis (in the hypothesis of banking involvement) shall show for the operator even a more attractive process.

**The roles of standardization in SATLOC**

SATLOC is a railway application which applies in principle ALL relevant standards, rules and regulations in force for enabling the exploitation of trains on the application sites, envisaged on low density traffic lines. An exhaustive list or regulation adaptation proposals cannot be realized with a generic address. SATLOC is a concept which application could be efficiently adapted on different railway environments, submitted to different specific ruling and technical constraints. In such perspective, standardisation
analysis and proposals focuses on specific technical standards and specifications of the SATLOC application area. SATLOC is also meant to be an enabler, with concrete and live demonstration to apply the GNSS for absolute location compatible with the ETCS. The migration path of SATLOC is in the direction of full interoperability with ETCS. Another role of SATLOC is to pave the way to the use the open telecom networks, with secured access, availability and quality as information bearer (radio-bearer) in the train TCC (RBC) information exchange. The full compatibility with the ERTMS/ETCS specifications is realised when EURORADIO safety layer is enforced. SATLOC applies this.

The main (the only needed) standardization proposal is the ROUTE MAP!

Specific to the SATLOC concept is the ROUTE MAP. The route map principles and main requirements have been drafted by the UIC in the technical report GEORAIL (UIC project No I/06/L/019). The Route Map (RM) is an important database valid on board of each train and in the traffic control centre (TCC). The RM shall be identical on each train and TCC. At train registration the TCC and the train convene to have the same valid variant of RM. Besides the description of the trains’ route and of the lines layout, including all elements (switches, platforms, significant elements, bridges…all track elements, located by their absolute coordinates) the RM contains:

- Line characteristics, associated to the coordinates (e.g. gradients, curves, transitions, speed limitations, clearing limitation, electrification network description…). The route map shall contain the basic “line static profile data” as defined in the ETCS specification.
- The RM shall translate the absolute coordinate description of the route from absolute coordinates into kilometric reference, consistent with the kilometric markers trackside. This is a difficult translation because the kilometric marks come from an old geographic reference system and are sometimes just reflecting distorted measurements. The RM preserves the old kilometric marks since they are currently used by the train drivers. The application associates the absolute coordinate positioning to the kilometric positioning.
- The RM contains the position of “virtual balises”. In SATLOC the virtual balises are NOT used for the odometry but to support and to make possible the relation of all train – TCC dialog to a “balise” reference. This enables the full compatibility to the ETCS language and train<>TCC messaging. E.g. a MA is issued with the reference to the kilometric position of the last virtual balise (VB) and indicates inter-alia the kilometric point of MA limit.
- Exception from the rule above is the close-loop interaction train-TCC. This supervision and tracking interaction is executed on absolute coordinate base and on the GNSS speed as measured on board. The absolute coordinate reference of the RM is applied identically in the TCC and onboard. In this case the RM is used as a reference base to qualify the integrity of the GNSS fixes. It shall be mentioned that the coordinate description of the RM is realized on a SIL4 integrity and has the following characteristics:
  - Accuracy of the points +/- 10 cm,
  - Resolution along the track: 5 m,
  - Verification repeatable with authorized topometric methods (e.g. triangulation using the official national geographic marks.

During the tests and validation phase of the project the information and the detailed structure of the route map has been consolidated.

SATLOC concept is compatible and consistent with the existing standardization framework and with the conception of the advanced systems of train control (ETCS). Inclusion of SATLOC into the existing national railway regulations need to be realized as intended applications are certified. The work of validation and future certification of the SATLOC applications shall endorse the validated aspects of GNSS, EGNOS and applied receivers. SATLOC recommends endorsing the EGNOS validation for aviation, in the part which refers to the Signal in Space performance. With the knowledge of the SATLOC project, the recommendation is that the extension of SATLOC and the validation to rail shall be realised on the base of the existing standardization framework.
Conclusion

The main result of the project was the application and live demonstration of the SATLOC system on the line Brasov - Zarnesti in Romania. The live demonstrator contributes to the adoption of EGNOS in rail primary safety and paves the way to the introduction of Galileo in the rail safety related domain. SATLOC trains have the same function as the existing ETCS (e.g. the full speed supervision) but with GNSS absolute positioning. The following novelties have been validated with this demonstrator:

- The SATLOC onboard system (SIL2 Loc driver display, SIL2 onboard unit, SIL4 braking system),
- The SATLOC traffic control centre (TCC) which combines the ERTMS/ETCS Radio Block Centre (RBS) and the traffic (train) control centre of the dispatching function,
- The new approach of the new telecom generation (UMTS, 3G, 4G) in Virtual Private – secured technology, for data transmission trains <> TCC, fully functional and compatible with EURORADIO,
- The SATLOC close-loop trains’ tracking and interaction with the TCC, whereas the enforcement of the full speed and movement authorities are continuously double-supervised, on board and in the TCC,
- The application of the ROUTE MAP and of “virtual balises” able of transforming the absolute coordinates’ description of the lines topology in the ETCS space related to balises;
- The simplified interlocking in the crossing stations, based on trailable switches (pre-positioned switches) controlled locally by the legacy ATP system INDUSI;
- The formal functional description of the system in order to propose an ETCS Level 3 functional definition in the framework of an IRS (international Railway Standard).

Based on 15 years of experience and theoretical research of the UIC and of the SATLOC partners, the project produces now good results. The functional, operational and technical tests have produced an important database to actually evaluate the achievement of the objectives.

SATLOC is producing a turnover in the overall mentality in favour of using the absolute positioning of trains with GNSS for primary safety, in the train control. Essential will be the use of the Route Map and the concept of virtual balises. It could be also understood that SATLOC is a compatible extension of ETCS for regional lines (ETCS equipped train have to run on SATLOC lines and SATLOC equipped trains to run on ETCS L2 lines).

Today, many European railway infrastructure managers are interested with SATLOC in the equipment of regional lines and/or ETCS L2 lines for "yellows trains" for maintenance (during track possession, the track is managed as a SATLOC line...).

References

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- SATLOC safety case and safety demonstration for the national Safety Authority
- Link to the SATLOC EU-UIC presentation movie: https://youtu.be/tplxf_O1ac4