GaLoROI smart railway localisation

GaLoROI Galileo Localisation for Railway Operation Innovation Project Number: 277698-2					
D8.3: Final Report					
CLASSIFICATION:	Public	**ISSUE:**	1.0	**DATE:**	28/08/14

DOCUMENT REFERENCE				
Project	**Work Package**	**Partner**	**Type**	**Number**
GaLoROI	WP 7	iQS	Final Report	8.3

Partner doc reference (optional)

SEVENTH FRAMEWORK PROGRAMME

GSA

Project managed by the GSA in the name of the European Commission.

DOCUMENT CONTROL			
Role	**Name / Organisation**	**Signature**	**Date**
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Reviewers			
Approver			

DOCUMENT CHANGE LOG			
Issue	**Date**	**Affected Sections**	**Comments**
0.1	18/08/14	All	First Version
0.2	20/08/14	3	WP description
0.3	26/08/14	All	Revision
1.0	28/08/14	All	Finalisation

DOCUMENT DISTRIBUTION		
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EXECUTIVE SUMMARY

In this final report the project results of GaLoROI are summarised. This includes the requirements, specifications, development and the approach to certification. Furthermore, the results of testing are presented.

1. INTRODUCTION

This final report of the project GaLoROI concludes the results and achievements of the project.

1.1 Purpose & scope

The purpose of this document is to present the results of the GSA (European GNSS Agency) funded project GaLoROI to a broad audience.

1.2 Intended audience / Classification

This document is public. It is intended for the publication of the project results of GaLoROI and the dissemination of the European GNSS Agency (GSA).

1.3 Associated documentation

DOW GA No. 277698-2

1.4 Abbreviations, acronyms and symbols

CENELEC	Comité Européen de Normalisation Électrotechnique (European Committee for Electrotechnical Standardization)
CIA	Central Intelligence Agency
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GaLoROI	Galileo Localisation for Railway Operation Innovation
GLONASS	Глобальная Навигационная Спутниковая Система (Global Navigation Satellite System)
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communications - Rail(way)
IM	Infrastructure Manager
RU	Railway Undertaking

2. PROJECT CONSORTIUM

The project consortium is led by the Institute for Quality, Safety and Transportation (iQST). The partners in the consortium are Septentrio, BBR Verkehrstechnik, IFSTTAR, iVA and KIT which are introduced in the following subchapters.

2.1 iQST

The Institute for Quality, Safety and Transportation (iQST) is a Braunschweig based SME working in the field of quality and safety in transportation.

2.2 Septentrio

Septentrio is a Belgian based SME developing high quality and precision GNSS receivers.

2.3 BBR Verkehrstechnik

BBR Verkehrstechnik is a Braunschweig based SME creating solutions for passenger information systems and safety relevant applications in railways.

2.4 IFSTTAR

IFSTTAR is the French institute of science and technology for transport, development and networks and conducts in the project research in the area of satellite based localisation and railways.

2.5 iVA

The Institute for Traffic Safety and Automation Engineering of TU Braunschweig has a longstanding expertise in the field of safety in transportation.

2.6 KIT

The Institute for Measurement and Control of Karlsruhe Institute of Technology contributed its experience in sensor fusion to the project GaLoROI.

3. TARGET OF GALOROI

The target of GaLoROI was the development of a certified safety relevant satellite based on-board train localisation unit to be used on low traffic density railway lines. This should foster the use of branch railway lines and as well the train and fleet management, green driving and precise track maintenance. For this purpose, the European GNSS Galileo and its SBAS EGNOS should be used. With these general targets, GaLoROI should support sustainable transportation, increase the cost benefit ratio in railways leading to strengthen European economy. To be useful in the railway environment, GaLoROI shall comply at least with the requirements for a SIL 3 system.

With satellite based localisation in railways, the diversity which is a barrier for interoperability can be overcome. Today, the use of more than 20 different train control systems in Europe require expensive equipment on locomotives to deal with different train control systems or the change of locomotives at the border of two train control systems.

The target of GaLoROI includes the aim to overcome track side signalling and localisation equipment currently used in railways. Track side equipment have higher manufacturing, installation and maintenance costs. Furthermore it is exposed to the environment and therefore to vandalism and weather influences. Additionally, because of their long life cycle, track side system are a barrier for innovation.

Based on the presented targets, the work presented in chapter 4 based on the work packages has been carried out.

3.1 GNSS State of the art

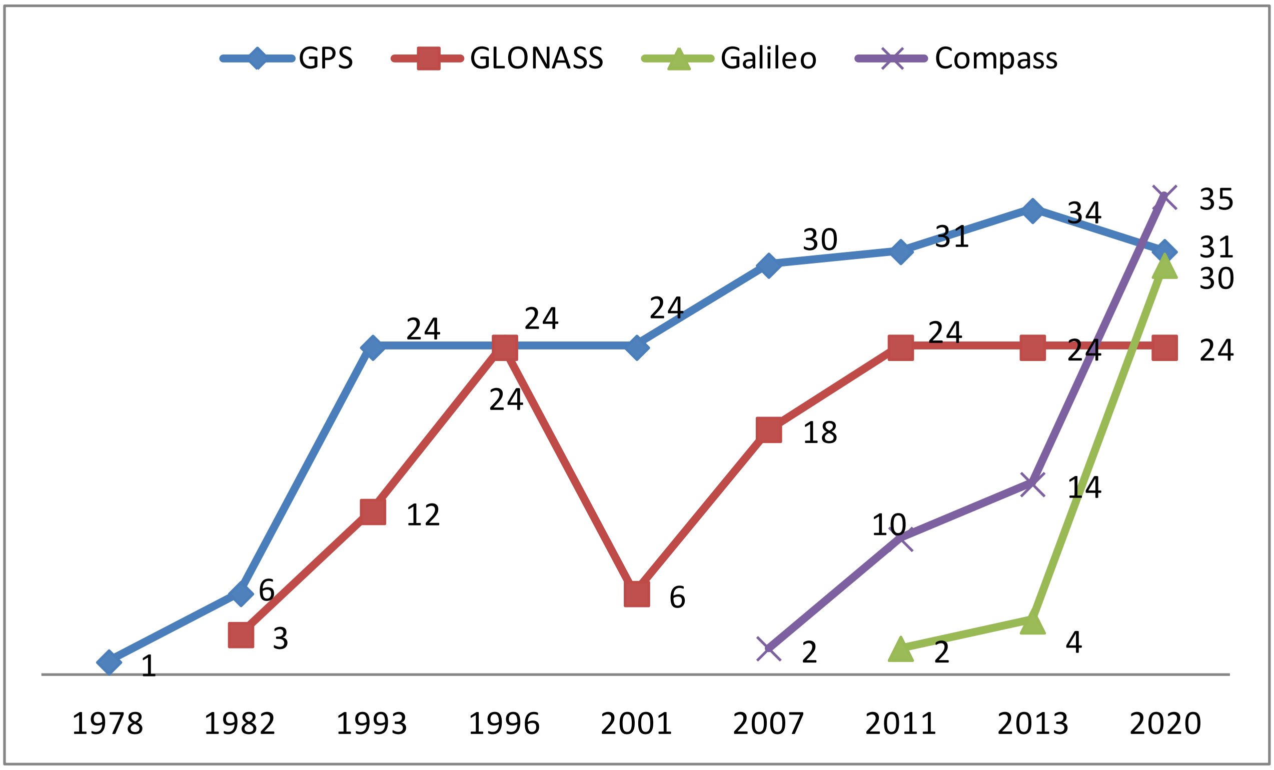

Figure 3-1: Satellites in space and expectations

Satellite based localisation is not used for safety relevant purposes in railways butter offers a great potential, therefore it is introduced in this subchapter to understand its benefits. The introduction shall serve as basis for railways and for other means of transportation but especially for the safety relevant certification of satellite based localisation in railways. With the rising number of end user terminals, the demand in transportation for satellite based localisation is increasing as well. Before GNSS can be applied in the according domains, a safety relevant certification is necessary. To get an overview of the satellite based localisation systems the applications shall be certified for, GPS, GLONASS, Galileo and Compass are introduced in this subchapter. Furthermore the corresponding satellite based augmentation systems are introduced whose task is the improvement of accuracy in a geographically restricted area. This work aims at the worldwide application of its result but has nevertheless a focus on the special features of Galileo and EGNOS because of the European funding and European partners in this project.

3.2 Worldwide GNSS

Currently, the American system GPS and the Russian systems GLONASS can be used for satellite based self-localisation of objects. Both systems are developed by the military of the countries like the Chinese system COMPASS which is under development. The European system Galileo, which is as well under development, is developed independent from military interests.

The satellite based localisation systems already in use and those currently developed focus on the user needs with their different services. The US-American GPS offers two services, civil and military. The military system is restricted to the US-American military; the civil service can be used by every person and institution without any guarantees [US Government 2012]. The focus on military applications can be observed at the Chinese system COMPASS and the Russian system GLONASS as well. Only the European system Galileo has – because of its civil focus – other application groups targeted.

Satellite based localisation systems provide their users while moving and during standstill everywhere on the earth or nearby information about their three-dimensional position, their speed and the time [Bauer 2011]. Every GNSS work accordingly with the basic principle resulting from the system concept. The requested information about position, navigation and time [Mansfeld 1998; Hofmann-Wellenhof et al. 2008] is provided permanent and reliable independent from the external conditions [Bauer 2011]. To provide these functions, GNSS consists of three segments – the space segment, the ground segment and the user segment [Dodel/Häupler 2009].

The user segment consists of an unrestricted number of persons or technical equipment using a GNSS-receiver. To calculate the position as exact as possible, the receiver has to receive signals from direct sight to a minimum of three satellites. This calculation is based on the running time of the signals from the satellite to the receiver. The time in the receiver is mostly not as accurate as in the satellite because of no atomic clock in the receiver. Therefore, the direct sight to a fourth satellite is necessary to solve a system of four equations (x, y, z of the receiver and δt, clock bias) [Mansfeld 1998]. The resulting requirement to each GNSS, that a minimum of four satellites have to be visible at any time from all places on earth [Dodel/Häupler 2009] leads to the number of satellites shown in Table 3-1. The satellites are monitored by the ground segment consisting of one or two centres and several (approx. 20) monitoring stations. The results of the monitoring might lead to a change of the orbits of the satellites leading to an accuracy of the orbits of one or two meters [Bauer 2011].

To achieve a good visibility of the satellites, an optimal inclination and height of orbits is necessary. Higher orbits lead to a better coverage of the earth with less satellites but require more technical and financial effort. A higher inclination of the orbit leads to a better visibility of the satellites on the North and South Pole together with less accumulation of satellites at one place. All conditions lead to an orbit time of 12 to 14 hours and an estimated life time of the satellites of seven to 15 years [Hartl/Thiel 1984].

The Chinese system COMPASS consists as special characteristics furthermore of five geostationary satellites and three satellites with „Inclined Geosysnchronous Orbit (IGSO)“ [Bauer 2011].

Table 3-1: System parameters nominal value of the operational and planned GNSS [Bauer 2011]

System parameter	GPS (USA)	GLONASS (Russia)	Galileo (Europe)	Compass (China)
Number of satellites	24	24	27	27 + 5 + 3
Orbits	6	3	3	3/ 1/ 3
Inclination of orbit [degree]	55	64.8	56	55/ 0/ 55
Height of orbit [km]	26,560	25,508	29,601	27,480/ 42,146/ 42,146

For some applications in transportation but as well in geodesy the accuracy of GNSS is not sufficient. A possibility to improve this situation is the civil International GNSS Service (IGS) providing different data to improve accuracy [Bauer 2011]. The underlying data are provided by seven analysis centres in Europe and North America. Details of IGS are summarised in Table 3-2.

Table 3-2: IGS GPS-products [Bauer 2011]

Product		Ultra-Rapid (precalculated)	Ultra-Rapid (monitored)	Rapid	Final
Availability		Real time	3 hrs	17 hrs	13 days
Accuracy	Orbit	10 cm	5 cm	< 5 cm	< 5 cm
	Clock	< 5 ns	~ 0.2 ns	0.1 ns	< 0.1 ns
Interval	Orbit	15 min	15 min	15 min	15 min
	Clock			5 min	5 min/ 30 s

For the usage of this data, a respective communication connection to the according service is necessary. To use this service, a separate interface would be necessary incurring extra effort and costs. Therefore the correction data could be transmitted via satellite. This approach is followed by satellite based augmentation systems introduced in the following paragraph.

3.3 Worldwide Augmentation systems

Satellite Based Augmentation Systems (SBAS) are used worldwide to increase the accuracy of satellite based localisation with geostationary satellites. Those systems are [Schnieder 2007]:

- Wide Area Augmentation System (WAAS) – USA
- Canada Wide Area Augmentation System (CWAS) – Canada
- European Geostationary Navigation Overlay Service (EGNOS) – Europe
- Multi-Functional Satellite Augmentation System (MSAS) – Japan
- Satellite Navigation Augmentation System (SNAS) – China
- GPS-Aided Geo Augmented Navigation (GAGAN) – India
- Quasi Zenith Satellite System (QZSS) – Japan
- Russian system of differential correction and monitoring (SDCM) – Russia [Federal Space Agency 2013]

In the following subchapters, the European GNSS Galileo, its SBAS EGNOS and their services shall be focused in detail.

3.3.1 Galileo

Galileo is a satellite based localisation system which has been initiated by the European Union together with the European Space Agency. The target is the European independency from military systems like GLONASS (Russia) and GPS (USA). Galileo shall be used for civil applications being interoperable with GPS and GLONASS [European Commission/European Space Agency 2002].

To enable the usage of Galileo by a large number of applications, several services are offered. Though Galileo is sending on similar frequencies as GPS and GLONASS, the chosen signal structure ensures a low overlap and multipath.

3.3.2 EGNOS

Geostationary satellites as used by EGNOS do not change their position relative to earth. They move with a height of 36,000 kilometres synchronic to earth. Because of their great height they are visible on almost half of the globe.

3.3.3 Services of Galileo and EGNOS

To consider the requirements of a large number of applications, as well those with safety requirements, during the development stage of Galileo five services have been included [European Commission/European Space Agency 2002]:

- Open Service – OS
- Commercial Service – CS
- Public Regulated Service – PRS
- Search and Rescue – SAR
- Safety of Life – SoL

These services are introduced briefly. It has to be considered, that a full service cannot be guaranteed based on current information.

Open Service

The open service is comparable with the civil GPS service. It offers localisation information without guarantee.

Commercial Service

The commercial service is not well defined for the moment. It should be subject to a charge and shall provide higher data rates.

Public Regulated Service

The public regulated service shall provide an encrypted signal for governmental users like police providing a higher accuracy and reliability.

Search and Rescue

The search and rescue service enables a fast and worldwide localisation of emergency devices. Furthermore, the Rescue Coordination Centre can answer to the sender of the emergency signal.

Safety of Life

Originally it was planned to include the Safety of Life Service directly into Galileo. During the development process of Galileo this has been switched to EGNOS, this means SoL is now integrated into EGNOS. This service will be according current information the only service beside the open service which will be introduced according its specifications. If this will come as planned, it is best suitable for safety relevant applications in transportation. Because of the target of GaLoROI on safety relevant applications, the main focus is on this service. To use the Safety of Life service according its specifications, an according certification and approval is necessary. Furthermore, the liability in case the service does not work as specified needs to be clarified [Schnieder 2009]. The approval can be done by a generic certification of satellite based localisation or by a domain specific certification of single applications.

Further certification aspects are considered in deliverable 6.2.

3.4 Potential customers

Today, the responsibility for localisation and train control is at the Infrastructure Manager (IM) and the Railway Undertaking (RU). The IM is responsible for track side localisation and signalling equipment, the Railway Undertaking for the on-board localisation and signalling equipment. When applying satellite based train control, the responsibility for localisation will shift to the Railway Undertaking, therefore they are potential customers. Nevertheless, the IM has to be included into the considerations as well because he needs to be involved into the process of shifting responsibilities. Therefore lines with a close cooperation of railway undertaking and the infrastructure manager seems to be most appropriate for the first implementation of GaLoROI. Those lines are regional lines or networks as well as long distance remote lines.

In the following chapter, the project results of GaLoROI will be presented categorised by the work packages to present the work conducted.

4. PROJECT RESULTS

4.1 WP 1 – Specifications of localisation unit

Work package 1 was led by iQST, its duration was from month 1 to month 4 of the project. As further partners, Septentrio, BBR and IFSTTAR participated in this WP.

4.1.1 Objective of work package 1

The objective of work package 1 was to derive the specifications of the localisation unit to be developed within the project. These specifications are an essential base for the subsequent work within the project, they are derived based on the requirements. The development of the localisation unit is consequently based on the specifications.

4.1.2 Task 1: Requirements analysis of applications

The main requirements within this task have been derived from the normative background which are mainly EN 50126, EN 50128 and EN 50129. The normative background is a well-established state of the art and recognised by both the scientific and development community.

From the normative background, checklists with generic railway requirements which need to be applied to the localisation unit have been derived. These requirements could be grouped into safety and availability and as well into system conditions, operating conditions and maintenance conditions.

In railway standardisation, the life cycle with 14 phases is shown as base for the whole life of a product including its development phase. For the development within the project GaLoROI, the phases one to six have been identified as relevant.

With the target of GaLoROI to comply with the safety requirements of a SIL 3 system, special according techniques have to be implemented and used. This applies to the documentation, the architecture and software requirements as well as verification validation and testing.

As further localisation specific requirements, the head of train accuracy, the accuracy for continuous automatic train-running control and for GPS localisation has been specified. Because of the intended use of the localisation unit to be developed the tolerable hazard rate and the safety behaviour has been specified together with data fusion and system design.

4.1.3 Task 2: Requirements to the digital map

GaLoROI is aiming for a high accuracy localisation which requires a high accuracy of the digital track map. To increase the accuracy of the digital map which is an important base for high localisation accuracy, it is concluded that the track needs to be measured geodetically conform to railML requirements with accuracy at the level of DGPS with coordinates in ERTS89 and WGS84 format. To maintain the according achieved level of accuracy, the card based reference points have to be checked and updated regularly. Accordingly, the following items need to be included into a digital track map for GNSS applications in railways:

- Length of straights
- Begin and end of level crossing
- Hazard areas
- Begin and end of switch
- Clearance points in switches

- Buffer stop
- Open end
- Stations

4.1.4 Task 3: Generate specifications of localisation unit

In this task, the localisation unit has been defined, its functions have been specified. It shall provide a number of safety relevant functions, mainly the determination of the position of the train on the digital map and its velocity. The localisation unit shall as well notify its user if within one second no location can be determined. In regular operations, the localisation should be done within five seconds. The first localisation output after the start of the system is specified with 180 seconds.

In this task, it has been specified how the GaloROI-system is working. It gives explanation of the needs and the architecture and requirements for the system. Furthermore some sections give references to more detailed and specific documents. In parts, the requirements have been derived from current railway engineering standards, adapted from previous, already existing projects and upgraded regarding the digital map. In doing so, the relevant standards fixed in norm EN 50126:2000 which are demanded for SIL 3 railway projects have been taken into consideration.

The system described shall just access to passive wayside elements for localisation purposes. Any further information shall be retrieved by means of satellite localisation, combined with track section information stored in the vehicle control system and additional sensor data for refining the obtained localisation. In general, this system shall be operable on various kinds of transportation means. It shall be applicable up to a top speed of 160 km/h and thus be suitable for operation on regional lines.

4.1.5 Results Achieved

In Table 4-1 the finalised deliverables of WP 1 are summarised.

Table 4-1: Deliverables of WP 1

Deliverable No.	Deliverable Name
D1.1	***Requirements of localisation unit***
D1.2	***Specifications of localisation unit***

4.2 WP 2 – Technical development of localisation unit

Work package 2 was led by BBR, its duration was from month 3 to month 16 of the project. As further partners, iQST, Septentrio and KIT participated in this WP.

4.2.1 Objective of work package 2

The objective of work package 2 was the development of components for the localisation unit and their assembly. The localisation unit should be easy to fit into trains to be easily adoptable on existing lines. To guarantee a later certification, the development should be carried out according to the V-Model of EN 50128.

4.2.2 Task 1: Customise eddy current sensor

The eddy current sensor is a components-off-the-shelf produced by Bombardier Stockholm (Sweden). It has been unfortunately only delivered very late in the project. It has been used without changes, the project specific adoption has been done by the implemented software.

The main function of the eddy current sensor used in the project GaLoROI is the induced electromagnetic field which is sensed by differentially coupled pickup coils in the MSU. The resulting voltage is measured and digitalized to receive according velocity and distance information.

The challenge within the project was the development of a driver for the eddy current sensor because the delivered sensors are prototypes. The driver is able to record raw data for future experimental offline use or to provide it to the GaLoROI software for real time velocity estimation. Subsequently, the eddy current sensor required careful adjustment of three parameters to be operational, these are two angles and the effective distance of the two used sensors.

The customization of the eddy current sensors could be completed successfully. Although the sensor version delivered by the manufacturer differed very much from previous sensor versions it was possible to calibrate the sensors, to implement a driver to obtain data from the sensors, and to set the sensors in operation.

4.2.3 Task 2: Manufacture GNSS receiver

The GNSS receiver is a components-off-the-shelf produced by Septentrio. By Septentrio, the receiver has been delivered together with antenna and cabling. The mounting has been done by the project partners. Within GaLoROI, different information provided by the receiver are used. These are PVTGeodetic, PosCovGeodetic, DOP and EndOfPVT.

4.2.4 Task 3: Structure of localisation unit

In this task the integration of the localisation unit into a train/vehicle is focused. Because of the intended test in Czech Republic on a class 814, it is mainly made reference to this type of train in this task.

The main part of this task was the assembly of the hardware. Therefore, the on-board components of the eddy current sensor and the GNSS receiver were integrated into the rack together with the BBR-computers which are two fusion computers and a safe controller. The result is shown in Figure 4-1. The sensors – eddy current sensor and GNSS antenna – are mounted outside of the train.

Figure 4-1: Localisation unit

4.2.5 Results Achieved

In Table 4-2 the finalised deliverables of WP 2 are summarised.

Table 4-2: Deliverables of WP 2

Deliverable No.	Deliverable Name
D2.1	***Progress report on hardware development***
D2.2	***Customised eddy current sensor***
D2.3	***Customised GNSS sensor***
D2.4	***Assembly plan of localisation unit***

4.3 WP3 – Software development of localisation unit

Work package 3 was led by BBR, its duration was from month 3 to month 16 of the project. As further partners, iQST and KIT participated in this WP.

4.3.1 Objective of work package 3

The objective of work package 3 was the development of a real time software generating a valid position in the localisation unit. To guarantee the targeted certification of the localisation unit, the development has been carried out close to EN 50128.

4.3.2 Task 1: Definition of common data structure

At the beginning of this task, a common data structure for a convenient data handling has been defined by the project partners. Therefore the output data structure of the eddy current sensor and the output data structure of the GNSS receiver are described. For the data handling two data formats are described which will be used for the data communication for the eddy current sensor and for the GNSS receiver.

4.3.3 Task 2: Development of localisation algorithm of eddy current sensor

The localisation algorithm of the eddy current sensor has been developed based on its requirements which are the reliable estimation of the velocity, a real time communication with the sensor and to detect errors in computation and react in a safety-oriented manner. To be implementable into the available hardware and testable, the developed localisation algorithm needs to be executable on a HistV3 embedded computer with 500 MHz processor under Windows XP and Linux.

To use the software on the train and accordingly in the localisation unit, interfaces have been defined. The final result is a velocity estimation and a self-surveillance with a graphical user interface and a data log. The graphical user interface is shown in Figure 4-2. There the magnetic reactions can be seen in the upper diagram as well as velocity (green line) and acceleration (blue line) in the lower diagram.

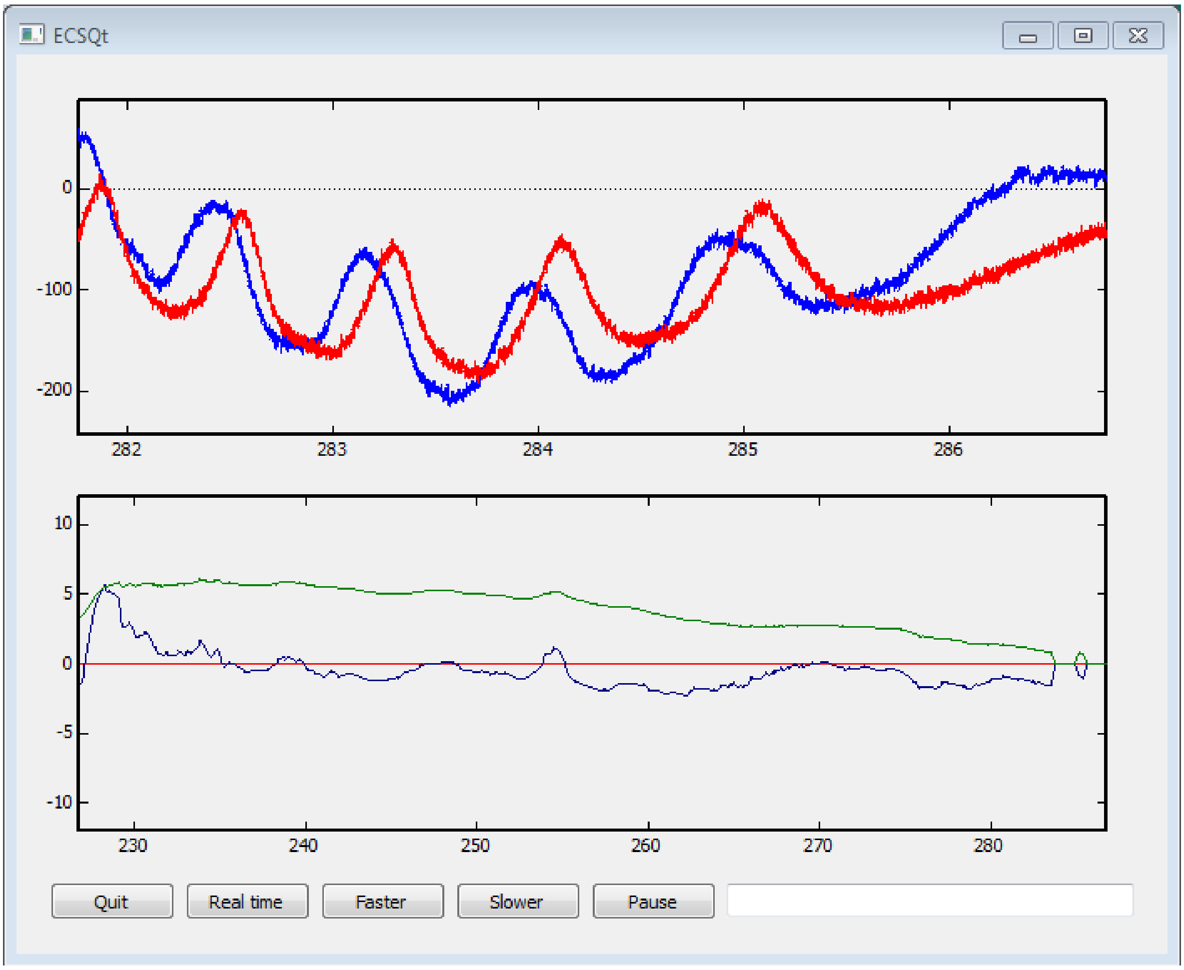

Figure 4-2: Screenshot of the graphical user interface

4.3.4 Task 3: Development of localisation algorithm of GNSS receiver

The original plan of the project GaLoROI was to have separate algorithms for the GNSS based localization and the map matching. However, during the design phase of GaLoROI it turned out that an integrated approach that does not separate both parts has a larger potential for accurate train localization. The final software design contains one large component internally called the “fusion” component which contains all parts of the software which are related to GNSS based localization, map matching, and sensor fusion.

The overall approach is comparable to the localisation algorithm of the eddy current sensor. In Figure 4-3 the according graphical user interface is shown.

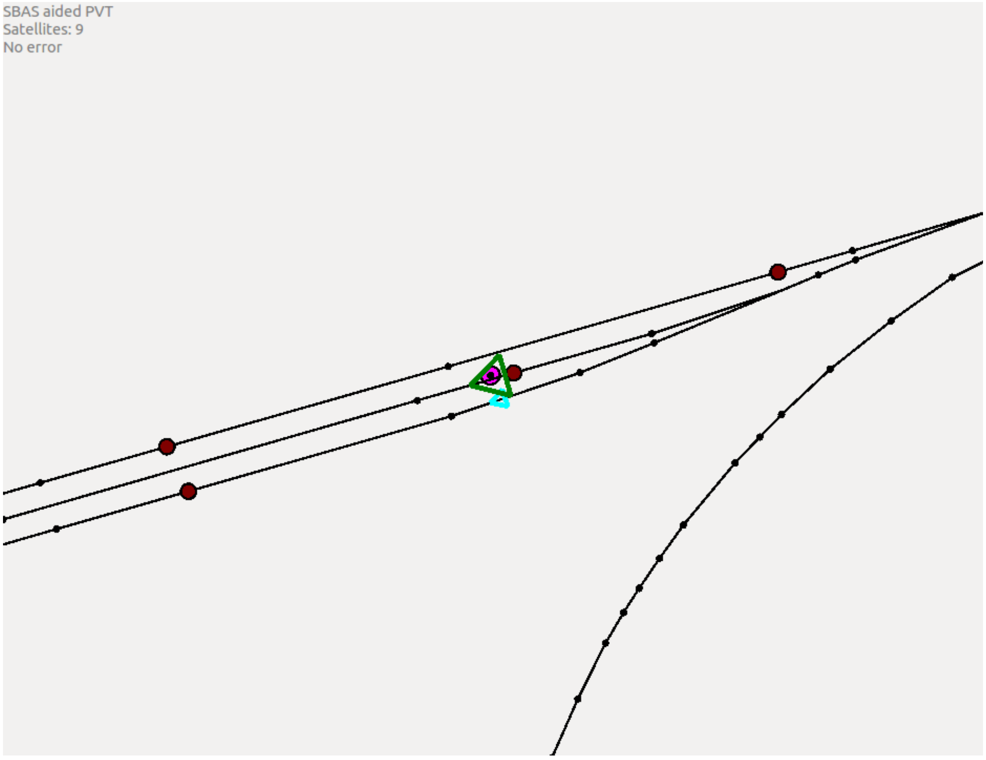

Figure 4-3: GNSS graphical user interface

4.3.5 Task 4: Development of digital map structure

The digital map shall be automatically derived from the AutoCAD files which are based on Google Earth. Within this process, the AutoCAD is prepared with a special coding for the according parsing to generate the railML files which are used for the map matching process.

4.3.6 Task 5: Development of map matching algorithm and data fusion

The internal map represents a track map by an array of track segments and an array of connector nodes. A track segment is represented as a polyline with the vertices of the polyline represented in ETRS89 coordinates. The connectors describe the topology of the track map. Moreover, the map memorizes a list of virtual balises and has several interface functions.

4.3.7 Results Achieved

In Table 4-3 the finalised deliverables of WP 3 are summarised.

Table 4-3: Deliverables of WP 3

Deliverable No.	Deliverable Name
D3.1	***Data structure for sensors and components***
D3.2	***Progress report on software development***
D3.3	***Localisation algorithm for eddy current sensor***
D3.4	***Localisation algorithm for GNSS receiver***
D3.5	***Digital map***
D3.6	***Map matching algorithm***

4.4 WP4 – System integration

Work package 4 was led by BBR, its duration was from month 11 to month 18 of the project. As further partners, iQST, Septentrio, IFSTTAR and KIT participated in this WP.

4.4.1 Objective of work package 4

The objective of work package 4 was to mount the localisation units on the railway vehicle to have the equipment ready for testing. This includes the integration of software and hardware components as well as the installation in cooperation with manufacturers and operators.

The components to be integrated and therefore installed and mounted on the train are the following:

- ATP-Rack
- 2 SAT-Receivers
- 2 SAT-Antennas
- 2 ESC-Sensors
- 2 ESC-Sensor-Demodulation-Units
- Fuses and mounting equipment
- 2 Ethernet-Switches (M12)
- Fitted cable between the components

4.4.2 Task 1: Integration of software components

The system contains different software on the HIST-V3 unit and on the A212 double controller. The software on the HIST-V3 unit is based on the PZB-222 system with a smaller configuration in functions. On it, the software for the eddy current sensor and the fusion unit is installed. The A212 double controller contains software to receive and send telegrams as well as some tests. The software and its configuration has been tested in test runs at a Braunschweig based shunting area in November 2013 before being shipped to the operational test area in Czech Republic.

4.4.3 Task 2: Integration of hardware components

The ATP-rack from the BBR-PZB-222 ATP system is the base for the hardware installed on the train. Some components not needed were disabled or unmounted from the Rack to save weight.

4.4.4 Task 3: Technical integration of software/ hardware system

The technical integration of the software and hardware system is strongly based on the normative background which is specified in EN 50129. The result of the technical integration is shown in Figure 4-4.

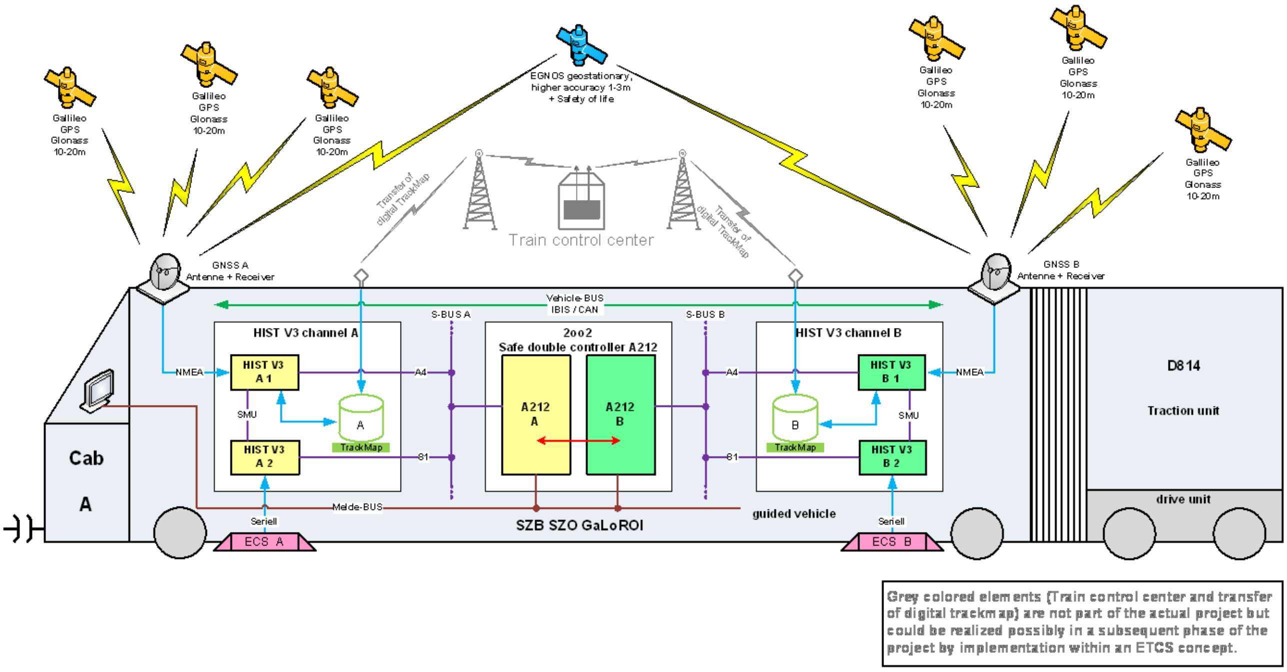

Figure 4-4: Implementation of system structure into railway vehicle

4.4.5 Task 4: Installation in cooperation with manufacturers and operators

The installation of the localisation unit was carried out by and at Pars Nova in Šumperk. There a class 814 rail vehicle of Czech Railways was fitted with the localisation unit in an area in the passenger compartment which is not accessible for passengers but for the project partners for test purposes.

4.4.6 Results Achieved

In Table 4-4 the finalised deliverables of WP 4 are summarised.

Table 4-4: Deliverables of WP 4

Deliverable No.	Deliverable Name
D4.1	***Report of HW/SW-Integration***
D4.2	***System Integration – Localisation unit***

4.5 WP 5 – Validation/ Tests/ Demonstration

Work package 5 was led by IFSTTAR and had its duration was over the whole time of the project. As further partners, BBR, and iVA participated in this WP.

4.5.1 Objective of work package 5

The objective of work package 5 are tests of the functionality and quality of the localisation unit. The received data is collected for later evaluation. As base for the data evaluation, a plausibility check should be carried out to evaluate the RAMS parameters.

4.5.2 Task 1: Plausibility check of data

Based on the recorded data from VBV campus, KIT started an evaluation that is described in the following sections.

4.5.3 Task 2: Evaluation of RAMS parameter

During the tests it could be concluded that the GaLoROI train localisation approach based on GNSS, the eddy current sensor and the digital track map is feasible, a continuous train localisation is possible. In order to have a failsafe design of all components the software provides uncertainty measures for all data. The localization approach is able to deal with position uncertainties along the track by using confidence intervals. The localisation output of both the GNSS receiver and the eddy current sensor have good quality and do comply with the project requirements. The railML format used by the digital map is regarded as useful format for the purpose of satellite based localisation.

4.5.4 Task 3: Tests in cooperation with operators

Successful long term tests of all components in the laboratories of KIT and BBR enabled the project consortium to start the field tests in a railway environment within the GaLoROI project. Therefore, a railway vehicle and a carriage have been used on a shunting area in Braunschweig on a weekend in November 2013. This gave us the opportunity to prove the results of the prior development before we migrated the system to the final setup on a railway vehicle in the Czech Republic. Within the tests, the localisation unit was set up and configured to test the localization performance. Some interesting issues at the tests was the track selectivity on multi-track segments, the performance in forests and under bridges.

To test the localisation unit under operational conditions, track number 315 of Czech Railways from Opava to Hradec nad Moravicí was chosen. After the installation, a test period of about four month is planned. The track is eight kilometres long and has two stations additional to the terminus stations.

4.5.5 Results Achieved

In Table 4-5 the finalised deliverables of WP 5 are summarised.

Table 4-5: Deliverables of WP 5

Deliverable No.	Deliverable Name
D5.1	***Results of simulation and tests***
D5.2	***Rail vehicle equipped with localisation unit***

4.6 WP6 – Safety Case

Work package 6 was led by iVA, its duration was from month 3 to month 16 of the project. As further partners, IFSTTAR, iQST, Septentrio and KIT participated in this WP.

4.6.1 Objective of work package 6

The objective of WP 6 was to carry out an efficient safety assessment finishing with a confirmed assessed safety case. This safety case should be accepted by governmental authorities for operational applications in Europe.

4.6.2 Task 1: Continuous safety assessment

An important part of WP 6 was the continuous safety assessment carried out during the whole length of the project. This was done by regular meetings mainly of the Institute for Traffic Safety and Automation Engineering (iVA) of TU Braunschweig with BBR Verkehrstechnik, partly with participation of KIT and iQST. During these meetings not only the safety and quality management system of the manufacturer was assessed by iVA, the product development has as well been followed closely to guide it towards a safety related product.

4.6.3 Task 2: Assessment of requirements specifications

The safety assessment targeted in WP 6 is basically the assessment of internal documents and check if they comply with the safety requirements of railway standardisation. This means that WP 6 heavily depends on the results of the other work packages and their delivery of documents in time. Unfortunately, important project documents have only been delivered very late within the project or even after the extended length of the project. These documents have of course been assessed, but not as intensively as targeted. This does not only apply to the assessment of the safety case but as well to the RAMS analysis because for the according work according project results are necessary as well. In total, ten documents have been assessed.

4.6.4 Task 3: Assessment of system specifications and its validation

The structure of the certification process is given by European standards, mainly EN 50126, EN 50128 and EN 50129. The CENELEC standards describe the life cycle process for safety relevant railway systems and especially the EN 50129 concerns the safety acceptance and approval conditions including the safety case. Therefore this standardisation applies as well for the project GaLoROI. Additionally to this legal framework, the certification has to be conducted in close cooperation with the regulating authorities. The requirements specification has been assessed after the documents have been made available to the assessor. It has been ensured that the requirements have been derived according the normative requirements and that the process implemented in the development have been conducted according to the V-model of EN 50128.

4.6.5 Task 4: Assessment of software specification

The assessment of the software specification has as well been done in WP 6. In course of this task, the correct functionality of the software has been assessed starting at the very first tests in Braunschweig and of course at the final dissemination event. The main according finding was that the software provides a robust and accurate localisation information as output which can be used for safety relevant applications in railways. Therefore this software shall serve as important base for further developments of the localisation unit. Within the software development of the project GaLoROI a large amount of research work was included because the eddy current sensor needed to be included new into the localisation unit because it has been new developed itself.

4.6.6 Task 5: RAMS safety analysis

The RAMS safety analysis is a major part of the proof of safety of the localisation unit. In a well reflected in depth analysis using accepted methodologies the failure rates of the single components have been combined within a fault tree analysis resulting in the proof that the localisation with its current technical architecture complies at least with the requirements of SIL 3 in railways.

Within the RAMS analysis, the GNSS requirements have been mapped into RAMS requirements to make the railway community understand how GNSS can be used for train localisation. To use this approach, an already published methodology that presents the possibly analogy between the two domains has been used. Because of the probability of being unavailable in different zones like tunnels, urban areas, forest and railway cuttings, it was a good system to use additional sensors as odometer (eddy current sensor) in the project GaLoROI.

After identifying the characteristics of the GaLoROI localisation system and the identification of the conditions of the GaLoROI system failure and the RAMS analysis objects, the qualitative and theoretical quantitative RAMS analysis could be carried out. As part of this, the following not states of GaLoROI have been focused:

- Dangerous detected case: The localisation function is incorrect but detected by the safe controller. It is a correct and safe reaction of the safe controllers.
- Fail-safe reaction case: The localisation function is correct but there is a failure of the safe controller. That leads to an interruption of the system service.
- Dangerous undetected case: The localisation function is incorrect and undetected by safe controllers in operation. This could cause an accident.
- Latent failure case: The localisation function is correct but there is an incorrect reaction of safe controllers in operation.

4.6.7 Task 6: Safety case assessment

The assessment of the safety case has been done as last task of WP 6. In this task, the available documentation has been assessed and hints have been given how a safety relevant certification can be feasible. A major issue of this task was the integration of components-off-the-shelf (COTS) into the railway certification process. The COTS equipment used in GaLoROI are the GNSS antenna “Septentrio PolaNt MC”, the GNSS receiver “Septentrio AsteRx3 HDC”, the eddy current sensor (MSDU) from Bombardier, the digital processing unit (DPU) from Bombardier and the digital map provided by iQST. Their integration has been solved within GaLoROI with a redundancy and diversity concept. Especially within the RAMS analysis carried out by IFSTTAR it has been proved that with the architecture applied in GaLoROI a safety level of satellite based localisation in railways of at least SIL 3 can be reached.

Because of the integration of COTS, a new approach to integrate external components into the safety assessment was necessary. This approach can be applied to other (COTS) as well.

With the proof of compliance of the localisation unit developed in GaLoROI with the normative safety requirements of railways, one of the next step should be the approval by a railway authority. Within the assessment of the safety case, some requirements, conditions and hints have been found which need to be solved before it can be approved by the safety assessor. This is then followed by the approval of a railway authority. Because of the current normative background and the structure of railway authorities in Europe, the approval needs to be done by one authority in one country. Preferable, the according result can be used by cross acceptance in other European countries. To shorten this complex process, it would be desirable that a unique European body – like to European Railway Agency (ERA) – would have the duty to approve a developed device for the railway network of several European countries. Another option would be to use the existing certification of GNSS in aviation for railways. EGNOS, which is used by the GNSS receiver and GNSS antenna, is certified already for some aircrafts and at some airports. A cross acceptance of the according certification would enable the usage of this equipment as certified and safe in railways.

Another aspect which might be of safety relevance is the shift of safety responsibility from the infrastructure manager to the railway operator. The traditional localisation at branch lines is done discrete mainly by track side equipment. Accordingly, in this traditional case the safety responsibility is in the hand of the infrastructure manager. With the approach of GaLoROI, the train is locating itself with onboard equipment, therefore the safety responsibility is shifted to the operator. This aspect has been considered in WP 6 and the whole project but needs further consideration by the involved parties. The track side localisation and train control equipment of the infrastructure manager is not needed anymore but the equipment of the railway operator is used which might have financial effects.

4.6.8 Results Achieved

In Table 4-6 the finalised deliverables of WP 6 are summarised.

Table 4-6: Deliverables of WP 6

Deliverable No.	Deliverable Name
D6.1	***Report on RAMS parameters***
D6.2	***Report on safety case including verification and validation report***

4.7 WP7 – ECONOMICAL IMPACTS

Work package 7 was led by iVA and had its duration was over the whole time of the project. As further partner, BBR participated at the project.

4.7.1 Objective of work package 7

The objective of work package 7 was the evaluation of the economical impacts of the localisation unit as base for the later market introduction. Furthermore, the market situation should have been evaluated and the market introduction of the GaLoROI localisation unit should have been prepared.

4.7.2 Task 1: Market Analysis: Possible Applications

The main goal of this task was to identify the relevant railway market, where a GNSS-based train localization technology like developed within the GaLoROI project can be found with its potential customers, rival and substituting markets and possible entrance barriers, like legal viability.

In order to identify successfully, the market analysis method analyses first the available GNSS technology infrastructures, e.g. availability of EGNOS, Galileo, etc. Afterwards a technical benchmark is performed in order to define, which competing technologies to the GaLoROI project are on the market or planned. Several train control and operation systems could have been identified, which use GNSS based technologies. Those are ITCS, KLUB-U, RZL, ATMS, ADTCS, ITC, NTC, CRTD, SATLOC, and ALOIS. None of this systems is using safe positioning data, which are certifiable. Therefore the competition is weak in contrast to GaLoROI. Afterwards a semi-quantitative market analysis has been performed, analyzing and aggregating data from Africa/Middle East (AM), Asia (AS), Australia/Pacific (AUS), Commonwealth Independent States (CIS), Easter Europe (EE), North America (NA), South and Central America (SC), and Western Europe (WE). For each country area has been created a market relevance factor, which is evaluating within itself four factors concerning the attractiveness and need of the railway transportation systems to make usage of GNSS-based safe train information. These four factors are the traffic means relevance, traffic objects relevance, infrastructure relevance, and organization relevance for GNSS application. Here the highest interest in applying GNSS from the technological and functional perspective (not solely financial perspective) are Australia and North America, as well as Western Europe. The relevance score show high interests with more than 70%, therefore these markets should be addressed with GaLoROI technology in the short-term. In contrast to that South and Central America, Eastern Europe, and Africa/Middle East show less need for improving railway operation by GNSS applications. These country markets are categorized as long-term markets. Finally the Commonwealth of Independent States and Asia show here the least attractiveness, since their relevance scores do not show the need for improvement of railway operation by GNSS applications. The market analysis is concluding with an expert interview, showing the requirements by railway operators and infrastructure managers what is expected by GNSS solutions in railway.

4.7.3 Task 2: Target Costing Estimation

The goal of the target costing its o establish a basis for a fast market penetration. Therefore it supposed to identify necessary costs, which are required resources for manufacturing, installation, operation, and maintenance. This is to set in contrast with existing cost infrastructures of running railway systems.

After having identified within the market analysis, which markets show the highest need for GNSS application in railway transport, it is here to analysis, if the expected benefits, will actually thrive into a monetary benefit for the railway operation. The target costing estimation is based on the available data from the country regions. Therefore estimations and intensive calculations have been performed, which show the actual cost improvement, as well as the available budget (target costing) within the country areas. Up to 4.900€ can be saved per track kilometre within one year in Western Europe, with a net present value of 1.11€. The improvement of the cost-effectiveness here is highly significant. Due to the decommissioning of infrastructure based localization equipment, the maintenance cost can here be reduced to a minimum. Also country areas like Asia and Eastern Europe show high potential in reducing costs per year. The other country areas show less monetary benefits, but what needs to put highlighted, that not completely all costs could be allocated within the target costing. The market analysis e.g. showed a high interest of Australia and Northern America into GaLoROI, since the management of the system can significantly improve, which may justify a moderate financial benefit in the short-term, but will save costs in the long-term. The experiences within the project showed that a GaLoROI-based localization unit will cost up to 50k€. Within the analysis it could have been showed, that a lent investment here makes it advantageous actually for all country areas to apply GNSS. The actual potential of beneficial improvement are summarized in Table 4-7.

Table 4-7: Potential of beneficial improvement

Country Code	Cost Improvement per Track Kilometer per year	Available Investment for new technologies within 10 years
Africa/Middle East	*2,46 €/km*	*32.246,72 €*
Asia	*640,81 €/km*	*1.659.592,98 €*
Australia	*79,61 €/km*	*116.562,73 €*
Commonwealth Independent States	*20,95 €/km*	*60.579,40 €*
Eastern Europe	*626,95 €/km*	*30.033,61 €*
North America	*27,10 €/km*	*26.019,94 €*
South and Central America	*4,10 €/km*	*33.708,04 €*
Western Europe	*4.870,30 €/km*	*179.051,22 €*

4.7.4 Task 3: Applications and Operational Benefits

This analysis task aims to give insight into economical, financial, and social benefits, including governmental and societal benefit analysis.

The structure to be applied differs therefore between benefits by infrastructure, retrofitting, customers (private and business), safety, and ecological, integrating the aforementioned benefit dimensions. It is assumed that GNSS application in railway will increase traffic capacity through enabling moving block control, also beneficial is the deletion of signalling systems, saving costs. The retrofitting enables energy efficient train control and thus reduction of vehicles' wear. For customers railway system becomes more attractive due to increased availability, reduced travelling times, and ticketing costs. From the ecological perspective, an increased modal split favouring railway, will cause a reduced road congestion and noise emissions. Foremost safety is seen as a key benefit for society and government. Here GNSS will enable less railway collisions and more precise accident localization. Also maintenance personnel can be better informed by approaching railways in times of working.

4.7.5 Task 4: Cost Benefit Analysis

The task of the cost benefit analysis has special relevance for decision makers, therefore it translates the identified benefits into costs making it quantitative.

Within this task has therefore been applied the analytical hierarchy process (AHP), which enables the analysis to include quantitative and qualitative factors, which is of relevance what could already been shown within the target costing estimation. The costs which are increased are set into contrast to decreased costs. The most important findings can be found in Table 4-8.

Table 4-8: Results of AHP

	Acquisition Costs	Operating Costs
Increase in Costs	• On-board technology • Additional rail vehicles • Installation of communications devices • upgrade of interlocking	• maintenance of tracks • Operation of communications equipment
Decrease in Costs	• costs for the construction of new stations and stops (optional)	• Personnel costs of the Dispatcher • Fuel • Lubricants • Sand • Signalling

Afterwards the insights have been put together within the AHP, showing the most relevant benefits. Here safety is seen as a key decision making influence. It is assumed significantly higher than within running train operation and control systems. The findings can be found in Figure 4-5.

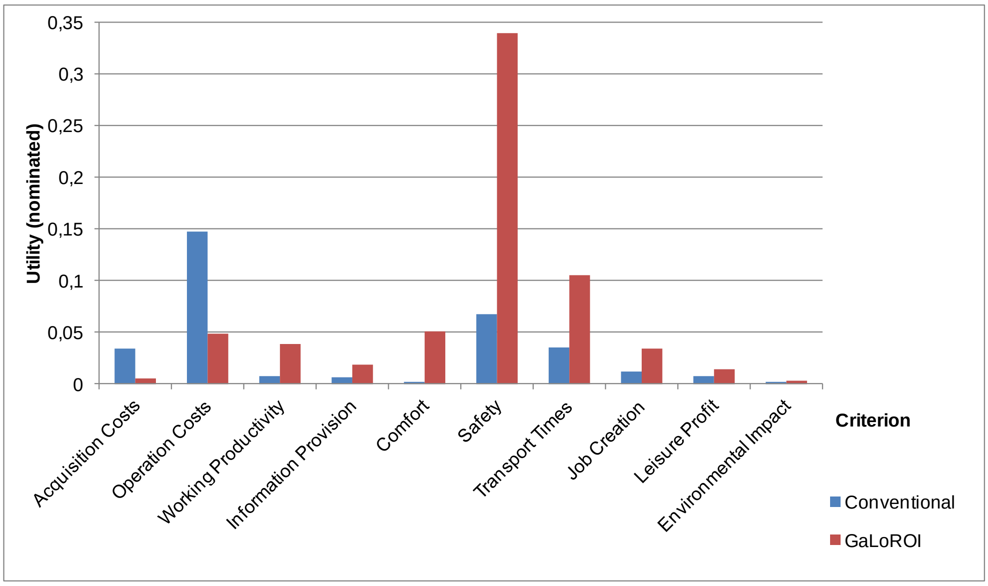

Figure 4-5: Comparison of utility of conventional system and GaLoROI

4.7.6 Results Achieved

In Table 4-9 the finalised deliverables of WP 7 are summarised.

Table 4-9: Deliverables of WP 7

Deliverable No.	Deliverable Name
D7.1	***Cost Benefit Analysis***
D7.2	***Market Analysis***

4.8 WP8 – Dissemination of results

Work package 8 was led by iQST and had its duration over the whole time of the project. As further partners, all project partners were involved.

4.8.1 Objective of work package 8

The objective of work package 8 was to organise and carry out dissemination activities.

4.8.2 Task 1: Organise dissemination activities

Within GaLoROI, a final presentation was organised were some external, potentially interested institutions have been invited. After the end of the project, the results will be presented at Innotrans 2014 in Berlin.

4.8.3 Task 2: Carry out dissemination activities

An important part of a project with participation from the scientific community is the publication of papers leading to spreading the knowledge in the scientific community. This has been done by GaLoROI at certain conferences shown in Table 4-11.

4.8.4 Results Achieved

In Table 4-10 the finalised deliverables of WP 8 are summarised.

Table 4-10: Deliverables of WP 8

Deliverable No.	Deliverable Name
D8.1	***Dissemination plan***
D8.3	***Final report***

The planned deliverable D8.2 ("Proceedings of the symposium") has not been created. Because of the late availability of project results it was not possible to organise a symposium.

Table 4-11: Disseminations in GaLoROI

Place of dissemination	Title of paper	Author
IAIN 2012, Cairo	*Safety Case Design Structure for Satellite Based Localisation in Railways*	*Hansjörg Manz, Eckehard Schnieder*
IAIN 2012, Cairo	*Hazard Analysis for GNSS-based Train Localisation Unit with Model Based Approach According to EGNOS SoL and Railway RAMS*	*Debiao Lu, Daohua Wu, Eckehard Schnieder*
GMA 7.61, Braunschweig	*Standardisierte Ermittlung der Messqualität satellitenbasierter Ortungssysteme*	*Dirk Spiegel, Eckehard Schnieder*
ICIRT 2013, Beijing	*Implementation of the normative safety case structure for satellite based railway applications.*	*Hansjörg Manz, Eckehard Schnieder*

ICIRT 2013, Beijing	*Algorithms and concepts for an onboard train localization system for safety-relevant services*	*Martin Lauer, Denis Stein*
IEEE Transactions on Intelligent Transportation Systems, accepted for publication	*A train localization algorithm for train protection systems of the future*	*Martin Lauer, Denis Stein*
AUSRAIL 2013, Sydney	*Certifiable Satellite Based Safe On-Board Train Localisation Unit*	*Hansjörg Manz, Eckehard Schnieder, Uwe Becker, Carsten Seedorff, Arne Baudis*
IEEE ITS-T 2013, Tampere, Finland.	*Dependability evaluation of a GNSS and ECS based localisation unit for railway vehicles*	*Nguyen T.P.K., Beugin J., Marais J.*
TRA 2014, Paris	*Approach to Certification of Satellite Based Localisation Unit in Railways*	*Hansjörg Manz, Eckehard Schnieder, Uwe Becker, Carsten Seedorff, Arne Baudis*
COMPRAIL 2014	*An analysis of different sensors for turnout detection for train-borne localization systems*	*Denis Stein, Martin Lauer, Max Spindler*
IEEE ComManTel 2014, Da Nang, Vietnam.	*RAMS analysis of GNSS based localisation system for the train control application*	*Nguyen T.P.K., Beugin J., Marais J.*
SMTDA 2014, Lisbon	*Quality control of GNSS-Receivers by accuracy-based analysis*	*Federico Grasso Toro, Michal Hodon, Jana* Puchyova, Eckehard Schnieder
International scientific journal Reliability Engineering & System Safety (RESS), Elsevier, ongoing publication	*Method for evaluating an extended Fault Tree to analyse the dependability of complex systems: application to a satellite-based railway system*	*Nguyen T.P.K., Beugin J., Marais J.*

4.9 WP9 – Project management

Work package 9 was led by iQST and had its duration over the whole time of the project.

4.9.1 Objective of work package 9

The objective of WP9 was basically the project management. This includes the preparation of meetings and to manage the workflow of the project.

4.9.2 Task 1: Management of the project

The management of the project was carried out by iQST during the whole time of the project. The main part was the communication between the project participants and to the GSA as well as to the technical and economical reviewer.

4.9.3 Results Achieved

In Table 4-12 the finalised deliverables of WP 9 are summarised.

Table 4-12: Deliverables of WP 9

Deliverable No.	Deliverable Name
D9.1	***Project management plan***
D9.2	***First progress report***
D9.3	***Second progress report***
D9.4	***Financial statement***
D9.5	***Final management report***
D9.6	***Final activity report***

5. CONCLUSION

In the project GaLoROI a satellite based localisation unit for the safety relevant application in railways has been developed and tested. It could be shown that safety relevant localisation with a certifiable localisation unit is possible. The chosen combination of GNSS receiver, eddy current sensor and digital map can be well used for the self-localisation of trains in railways.

The further steps after the end of this project are now the approval of the localisation unit on a track with respective demand for it. There, an operator and the relevant infrastructure manager needs to support this solution and enable the certification process.

Figure 5-1: GaLoROI team with economical reviewer and project officer in front of the test train