Non-contact Laser Based Ultrasonic
Rail Flaw Detection System

Project no. **507622**

Project acronym: **U-Rail**

Project title: **Non-Contact Ultrasonic System for Rail Track Inspection**

Instrument:
HORIZONTAL RESEARCH ACTIVITIES INVOLVING SMES
CO-OPERATIVE RESEARCH PROJECT

Title of report

FINAL TECHNICAL ACTIVITY REPORT

Period covered: from 01/11/2004 to 31/01/2007
(24 months + 3 months extension)

Start date of project: 01/11/2004

Duration: 27 months
(including 3 months extension)

Project coordinator name: Luciano Marton
Project coordinator organisation name: Tecnogamma SpA

Revision: 1

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Publishable executive summary

Periodic in-track rail inspections are performed to detect critical defects before they grow enough to cause structural failure. Non-destructive inspection technologies currently used worldwide rely mainly on contact ultrasonic methods that, even though extensively used and proved to be reliable, are not perfect. In an effort to improve rail flaw detection, the U-Rail project proposes a non-contact ultrasonic system for periodic inspections of rail tracks that has many advantages over conventional technologies currently available to the railroad industry. In particular, the main objectives of the project are:

1. To develop a non-contact ultrasonic technique for in-track rail flaw detection.

One of the main limits of conventional ultrasonic system is the coupling between the transducer and the rail. Defect detection may be affected by the wear of the rail profile, lubricated and/or dirty track, transducer orientation, and coupling conditions. Non-contacting inspection technology is attractive for rail inspection because contact probes undergo also extreme wear conditions against the rail surface. The laser-based ultrasound is a non-contact technology where the equipment is kept at a certain distance system from the rail. It is unique in that ultrasonic energy can be introduced to the rail at any location accessible to the laser beam whereas conventional dynamic rail inspection systems are currently limited to applying ultrasonic energy from the top surface of the railhead.

2. No use of water.

Currently used detector cars use water filled rubber wheels that contain transmitter-receiver piezoelectric transducers kept in continuous rolling contact to the rail surface. Extensive use of water is required to maintain constant coupling. By using a non-contact technology the need of water is eliminated together with the service stops required to fill the water tank.

3. To perform high speed inspection.

Acoustic contact between probes and rail is difficult to maintain with conventional technology as inspection speed increases, resulting in loss of signals. With the non-contact system high inspection speed is possible using a high frequency pulsed laser beam to generate ultrasonic waves in the rail. Increasing the testing speed will greatly reduce the cost of rail flaw detection and enable testing to be carried out between normal railway operational traffic, reducing at the same time management costs.

4. To bring the system into the market.

The new technology increases flaw detection reliability by providing a more complete inspection of the entire rail section to include the head, web, and base, thereby increasing safety by lowering the risk of service failures. The laser-based system is highly innovative and responds to the expectations of the market. In fact, there is no existing system in the market comparable with the U-RAIL application.

This is the project logo:

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2. Quantel, Les Ulis Cedex, France
3. JENAer Meßtechnik GmbH, Jena, Germany
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5. RATP - Régie Autonome des Transport Parisiens, Fontenay Sous Bois, France
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1 Section 1 - Project objectives and major achievements during the reporting period

Non-destructive inspection technologies used worldwide rely on contact ultrasonic methods.
Even though they are proved to be reliable, they have limitations such as:

- in motion testing allows to inspect a quarter of the head area, the whole web extended up to central part of the rail base; altogether the inspected area of the rail is about a third of the entire section;
- defect identification may be affected by rail surface condition, railhead geometry, defect geometry and orientation, electrical and/or mechanical noise introduced into the transducer, inadequate transducer-to-rail surface coupling;
- high number of false calls.

In the effort to improve railway transport safety, the **general project objectives** are:

- to increase the inspected area of the rail cross-section;
- to detect cracks that are not detectable with methods currently available to the railroad industry;
- to reduce the number of false calls;
- to increase the inspection speed.

The **main objectives** of the project, addressed during the **FIRST REPORTING PERIOD** are:

1. to develop a non-contact ultrasonic technique
2. to reach high-speed inspection
3. to measure the interest of the market.

The first two points represent the main advantages of this new inspection system and consist in the main important targets to be reached during the full development of the project.
The rail inspection with the contact methodology has been cause of many limitations. First of all the impossibility to inspect the whole rail section, since the ultrasonic signal can be introduced only from the top rail head. The weakness of the contact system is mostly in the difficulty to maintain a constant coupling between the transducer and the rail.
The development of a non-contact ultrasonic technique allows to overcome these limits, and at the same time to perform rail flaw inspection at high speed reducing the time required.
All the contractors have been involved in the activities of this period and the main achievements in the period are:

- design of generation and detection units
- comparison between the conventional and the laser-based systems
- design of the rail position measurement system
- design of the automated motion system
- development of software packages.

The third objective of the project is the introduction of the system into market. End-users have shown great interest and the market expectation about this new inspection system is very high.

Results achieved in the **first reporting period** of activities are:

- Definition of technical specifications that the system must satisfy
- Results of analysis on rail steel ablation with high power laser
- Design of source/receiver configurations for the inspection of the complete rail section
- Assessment of sensitivity of the laser-based technology and comparison with the conventional contact method

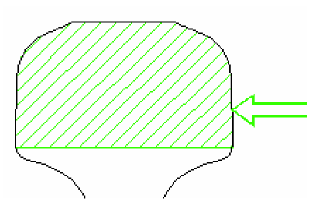
- Design of the rail position measurement system and related software
- Design of the automatic positioning system
- Design of the ultrasonic inspection unit
- Signal processing software

The U-Rail system has provided excellent results in detecting cracks that are not detectable with methods currently available to the railroad industry. Overall inspected area is about 80% of the entire rail section.

For the inspection of the complete section the final configuration was defined as follow:

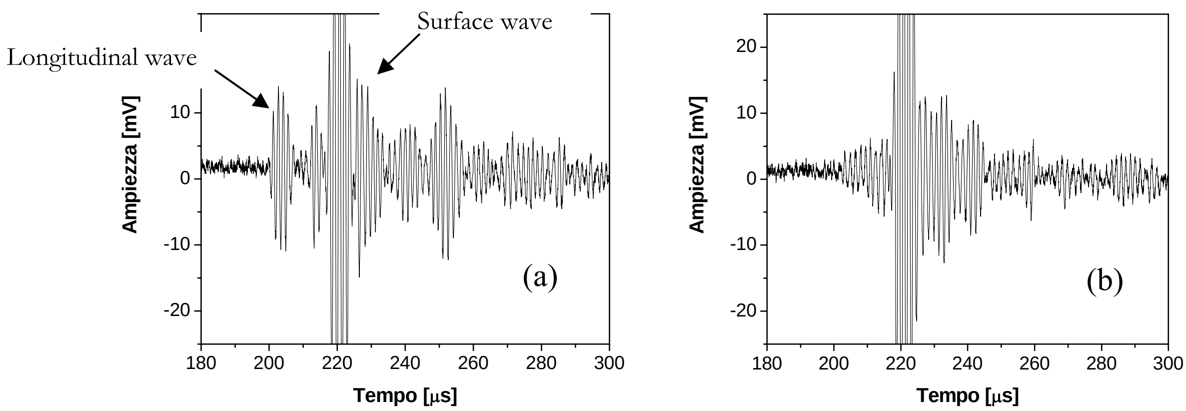
Rail head inspection

Head inspection for internal and surface defects has been performed focusing the laser beam into the gage side of the head. Longitudinal and surface waves, simultaneously generated, propagate through the bulk and the surface of the head allowing its complete inspection.



Acoustic waves are acquired by the air-coupled transducers in pitch-catch configuration. To guarantee a high reliability the configuration uses six air-coupled transducers for a single laser pulse. Flaws that have been detected in the rail head with this configuration are:

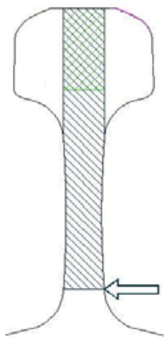
- horizontal and vertical split head
- transverse defects
- head checking
- shelling.



Acquired signals from a rail head without defect (a) and with internal defect (b).

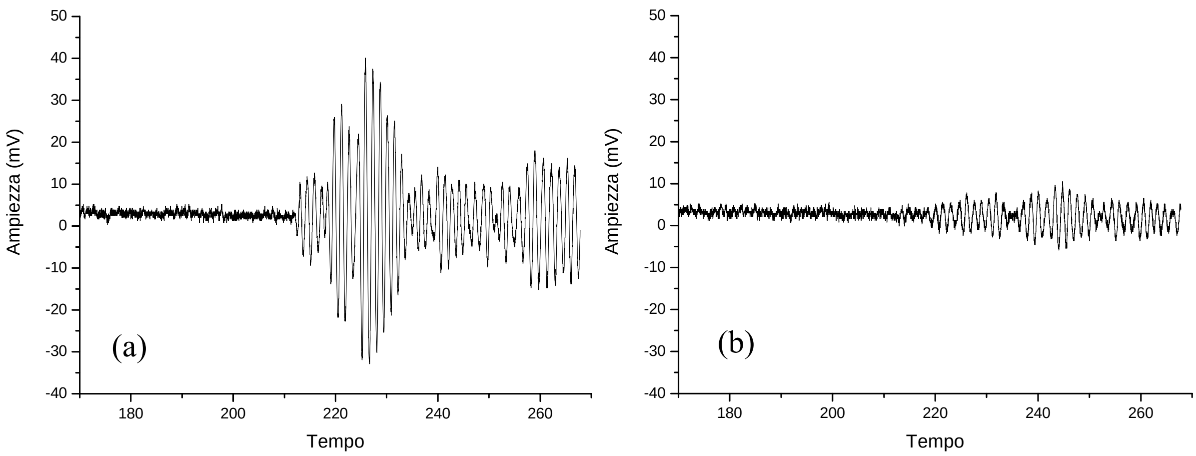
Rail web inspection

For the web inspection the laser beam is focused at the bottom of the web, on the gage side. Bulk waves propagate through the web up to the rail head, where they are detected by the air coupled transducer.



Internal flaws that have been detected in the web with this configuration are:

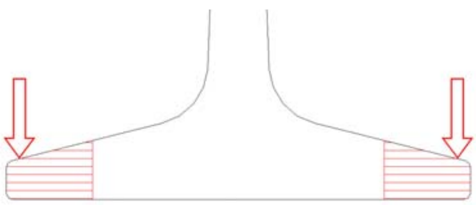
- split web
- horizontal split crack (included head and web separation).



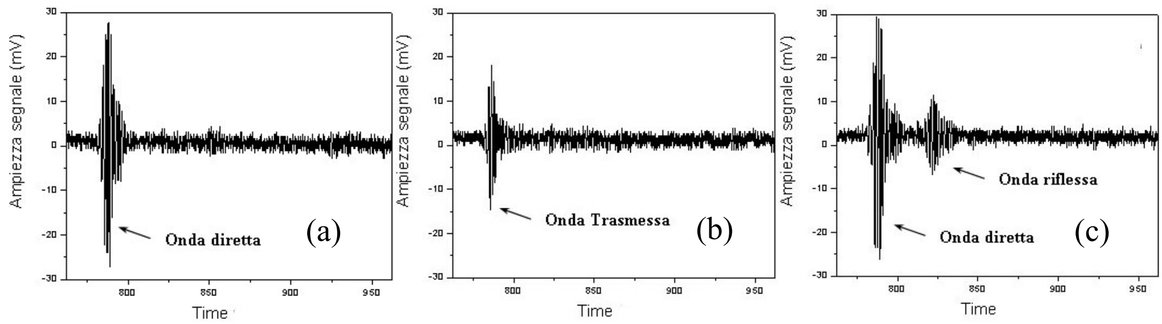
Acquired signals from a rail web without defect (a) and with internal defect (b).

Rail base inspection

For the base inspection the laser beams are focused, from above the rail, on the gage and the field sides. Two surface waves, created by each laser source, propagate along the base in opposite directions and are detected by the air-coupled transducers located in pitch-catch configuration, symmetrically respect to the generation point.



Transverse defects at the outer edge of the base have been detected with this configuration.



(a) Acquired signal from both transducers without defect; (b) and (c) acquired signals from both transducers with a defect in the base.

Work in progress activities is directed to manufacture the prototype and then to perform in field tests on known and well-characterized defects. The practical application of the U-Rail project foresees the installation of he system on any railway vehicle.

Information about the U-Rail project can be found at the website www.tecnoeurope.it (enter Research, European Projects, U-rail)

Main **objectives of the SECOND REPORTING PERIOD** were:

- Laboratory tests of assembled components
- Development of software to control laser triggering, acquisition and processing of signals
- Development of software for the characterization of defects
- User interface design
- Design and production of the final system
- Assembling of components (optics, electronics, hardware, etc…)
- Functionality tests of the prototype
- Modification of the rail vehicle provided by RFI
- Installation of the system in the rail vehicle
- Validation of system functionality
- In-field tests on selected flaws to validate the inspection system
- Test for repeatability of measurements
- Promotion and spreading of project outputs.

All the contractors have been involved in the activities of this period and the **main achievements** of the project in the **second reporting period** are:

1. design and production of the inspection system
2. installation on the rail vehicle
3. in-track test on selected flaws.

2 Section 2 - Workpackage progress of the period

2.1 Introduction

During the project some changes to the proposed Working Program (Annex I) have been produced as well as some extension to few workpackages to allow the achievement of modified or implemented objectives.

As reported on Mid-Term Report, after the beginning of the project some changes to the proposed Working Program (Annex I) have become necessary in order to achieve successfully project objectives. We hereby focus the reasons for these changes and highlight the related technical outputs.

- As reported in the Annex I, we previewed to buy 6 lasers (at 30 Hz, 700 mJ) and 15 transducers but we realised that, in order to get to market requirements, the technology must be proved to work at high speed. As a result, we decided to get more powerful lasers (at 120 Hz, 400 mJ) that will allow higher speed. As price is higher we will buy less units (2 instead than 6) and the inspection of the complete rail section will be performed in two steps.
  As for the transducers, the initial design previewed 15 of them; better configurations - decided in these past months - require 11 transducers.

- For the prototype manufacturing most of the partners are involved in buying some of the parts necessary to build it (in the budget, under the issue "other costs"); the above mentioned changes will determine that some of the partners will buy parts different from the ones previewed at page 58 – under the paragraph "Budget breakdown description". The new lasers are much more expensive and for this reason one of them will be bought in cooperation by RTD partner ENEA and by RTD partner ULG; the other laser will be supplied by Quantel at the end of the project.

Further changes have been added to the original Working Program during the annual meeting. In particular, some workpackages have been modified in order to complete the activities antecedent the manufacturing of the prototype.

Laboratory tests on independent components and preassembled parts were extended in workpackage n.9, as resulted more complex than what was planned.
Objectives achieved in each workpackage are illustrated in the next paragraphs.

2.2 Workpackages

Workpackage number: 1
Regards management and it is fully reported in the Management Reports.

Workpackage number: 2
Start date or starting event: Month No. 1
End date: Month No. 2
Title: Definition of technical specifications for rail track inspection
Participant Short Name: TG, ENEA, RATP, EUT, AMEL, RFI, ULG
Objectives: Definition of the technical specifications of the system and needs of the different railroad companies

Progress towards objectives: Information has been collected from several railroad companies. Specifications for the system such as types of defects to detect, minimum size, reliability ratio, and inspection speed differ. To be considered by the railroad service companies the new technology must guarantee at least the same performance of the conventional system. A basic guideline, common to the main railroads, has been defined. About the installation, end users give preference to a standard rail car dedicated to perform the inspection service at a maximum speed of 80 km/h.
Analysis of costs related to rail failures has been provided together with a comparison of maintenance costs between the conventional and the new inspection system.
Deliverables:
D1: Report on the system technical specifications (supplied together with this MidTerm Report)
D2: Report on the market technical requirements (supplied together with this MidTerm Report)

Workpackage number: 3
Start date or starting event: Month No. 1
End date: Month No. 8
Title: Study and Design of each generation unit
Participant Short Name: QL TG ULG
Objectives: To define the effects of laser beam forming on acoustical signal generation and to design the generation unit.
Progress towards objectives: Laser beam forming can control the radiation pattern of ultrasonic waves in the rail. Point, line, and line array source have been investigated to improve inspection capabilities considered the particular geometry of the rail. The choice of the proper laser source has been defined according also to the particular type of defect.
Laser beam must be focused to obtain a high energy density to generate acoustic waves in the ablative regime. Tests have been performed to determine the minimum energy density to obtain a good signal to noise ratio, found at 5 J/cm^2. This value allows the use of high power laser with fiber optics instead than optical guides. In this way the laser beam can be steered very easily from inside the vehicle to the rail track. Laser required for this application must have at least 400 mJ energy at a repetition rate of 120 Hz. Improvement in the design of the generation unit has been achieved.
Deliverables:
D3: Report on laser forming effect on acoustical wave generation, and on design of proper optical guide for each defect (will be supplied together with the MidTerm Report)
D6: Report on the design of each generation unit and of the complete one (will be supplied together with the MidTerm Report)

Workpackage number: 4
Start date or starting event: Month No. 1
End date: Month No. 7
Title: Study of material ablation with high power laser
Participant Short Name: ULG, TG, QL
Objective: To study the effect produced in the material by generating ultrasonic waves with the laser in the ablative regime.
Progress towards objectives: Generation of ultrasonic waves in the ablative regime causes a slight surface discoloration at the spot hit by the laser beam. While the aesthetic effect is negligible for the rail application, it must be examined if working in the ablative regime can compromise the rail track integrity. Microhardness tests and optical micrographs have been performed on ablated rail samples. Results show that laser beam shots do not change HV measurements. Micrographs show the material ablation in the impact area but no other modifications.
Deviations from the workpackage program: Since rails undergo fatigue loads, ablated and not rail samples need to be also tested under rolling loads. This additional test are directed to determine if fatigue cracks can initiate and growth from the ablated spot, and to compare the lifetime of the two rail samples.

The following activity would not be considered as a deviation but it is anyway a added activity: fatigue tests will be performed by ULG.
Deliverables:
D5: Report on the investigation of steel structure after laser ablation (supplied together with this MidTerm Report).

Workpackage number: 5
Start date or starting event: Month No. 1
End date: Month No. 6
Title: Study and design of sensors configuration according to each type of defect
Participant Short Name: DIMA, TG, QL, ENEA
Objective: Definition of the sensor number and configuration for each type of rail defect.
Progress towards objectives: Transducer configuration impacts system performance. In order to define the optimum one for the inspection of the whole rail section, tests have been performed to define the signal strength as function of lift-off distance from the rail sample, and of the orientation respect to the surface. This investigation has been performed with two types of air-coupled sensors, at different frequencies, for both longitudinal and surface waves, and varying the source-to-receiver distance. The complete configuration integrates eleven transducers, all in pitch-catch configurations.
Deliverables:
D4: Report on the design of each detection unit and of the complete one. (will be supplied together with the MidTerm Report)

Workpackage number: 6
Start date or starting event: This task should have started on month No. 7 but actually the beginning of activities have been anticipated to Month No. 3
End date: Month No. 9
Title: New system performance comparison with conventional and already in use contact technology
Participant Short Name: ENEA, TG, DIMA
Objectives: To assess the system sensitivity in detecting each type defect and to validate the system performance.
Progress towards objectives: In order to compare the ultrasonic conventional system to the non-contact laser-based, tests have been performed using contact probes in pulse-echo configuration from the rail running surface of samples with defects that are usually difficult to detect (shelling, vertical split head and transverse defects). Results showed that surface defects cannot be detected as well as vertical split head and transverse defects with unfavourable orientation. Tests have been performed on the same samples with the laser system achieving excellent results. Moreover, additional tests on samples with rail base defects have been added. Many measurements have been collected to assess the performances of the laser-based system as well as reliability and repeatability.
Deliverables:
D7: Report on the performances of the new ultrasound technique (supplied together with this MidTerm Report).

Workpackage number: 7
Start date or starting event: This task should have started on month No. 7 but actually the beginning of activities have been anticipated to Month No. 4
End date: Month No. 11
Title: Study and Design of the mechanical automation of sensors and laser orientation
Participant Short Name: CM4, TG, JMT, DIMA, TRASTEC
Objectives: Design of the automation that will move sensors and laser beam orientation according to rail profile and position.

Progress towards objectives: The measurement of the rail position is required to maintain the ultrasonic unit in the proper position above the rail. As a result, the design of the inspection unit includes thus two sub-units that are respectively - the first - a laser optic triangulation unit and - the second one - an automatic positioning system. The first unit determines the position of the rail, processes in real time the data and drives the automatic positioning system. Once the real-time position of the rail is measured, the software controls the servo-motor of the automatic positioning system. A servo-motor has been chosen to compensate the position of the detection unit according to movement of the vehicle over the rail and according to the rail gauge variation.

Deliverables:

D8: Report on the design of the sensors and laser beam automation system (supplied together with this MidTerm Report).

Workpackage number: 8

Start date or starting event: This task should have started on month No. 9 but actually the beginning of activities have been anticipated to Month No. 5

End date: Month No. 11

Title: Hardware and software development for each system

Participant Short Name: TRASTEC, TG

Objectives: Design and development of the hardware components and software packages

Progress towards objectives: A centralized acquisition unit has been designed in order to acquire all the analogic signals coming from the eleven transducers. In this way the raw signals are digitalized and available for the upper level that manages all the final elaboration. The final elaboration is done by another industrial PC that, connected to the acquisition system, uploads all the acquired data in order to perform the final signal discrimination. Hardware components for conditioning of signals have been integrated in the receiver units. Filtering and amplifying of acoustic waves can range on a wide scale. Signals are further cleared by using a voltage regulator/isolator. The processing software algorithm is tailored for the inspection of rail head, web and base. Raw signals and the eventual flaw identification are stored in a single system database.

Deliverables:

D9: Hardware components and software packages for each system (supplied together with this MidTerm Report).

Workpackage number: 9

Start date or starting event: This task should have started on month No. 12 but actually the beginning of activities have been anticipated to Month No. 9

End date: Extended to month No. 18

Title: Laboratory tests on assembled subsystems

Participant Short Name: TG, QL, JMT, CM4, TRASTEC, DIMA

Objectives: To test and to evaluate in the lab the assembled components.

Progress towards objectives:

Tasks worked on are:

9.1 Subsystems assembly
9.2 Subsystem components integration tests
9.3 Reliability tests
9.4 Repeatability of measurements
9.5 Tests on components assembled in subsystems

Achievements made with reference to planned objectives

The main objective of this workpackage was to verify in the laboratory context that the assembled subsystems worked properly and to assess their functionality.

After production at the machine shops, mechanical parts were pre-assembled to form each independent sub-system (including optical and electronic components) to be able to perform the tests in the

laboratory. The laser unit was independently tested to verify the endurance, cooling of laser bench and head, beam focalization and laser power at the working distances.
Functionality of the lifting system of the inspection unit was proved, together with the mechanical positioning system, calibration of the motor and setting of its parameters.
Reliability tests were also performed for the rail profile measurement unit, to verify functionality of the electronic boards, with calibration and integration tests. Same procedure was carried out on the different components of the acquisition system.
Repeatability of measurements was investigated also changing the conditions of the environment, to determine how external influences could affect.
Deliverables
D11 Report on laboratory tests (it will be supplied together with the Final Report).

Workpackage number: 10
Start date or starting event: This task should have started on month No. 12 but actually the beginning of activities have been anticipated to Month No. 10
End date: Month No. 14
Title: Design of the complete system
Participant Short Name: TG, QL, JMT, CM4, TRASTEC
Objectives: Definition and design of the complete system.
Progress towards objectives:
<u>Tasks worked on are:</u>
10.1 Definition and design of the final configuration for generation and detection units
10.2 Design of electrical and mechanical systems
10.3 Integration of designs of various components
10.4 Definition of rail vehicle modifications
10.5 Design of the complete system
<u>Achievements made with reference to planned objectives</u>
Most of the activities of this workpackage were almost completed in the first year of the project; on the second year only the definition of rail vehicle modifications and design of the complete system were addressed, after having defined the integration of the various components.
The design of the inspection unit as well as the design of its mechanical interface to the rail vehicle was carried out in its final version only after the rail vehicle for the installation was assigned.
A lifting system for the inspection unit underneath the rail vehicle was added at the mechanical interface to the rail vehicle in order to raise up the unit when not in use.
Deliverables
D10: Report on the final design of the complete system (it will be supplied together with the Final Report).

Workpackage number: 11
Start date or starting event: This task should have started on month No. 13 but actually the beginning of activities have been anticipated to Month No. 10
End date: Month No. 14
Title: Design of software for neural network characterisation of defects
Participant Short Name: TRASTEC, TG
Objective: To design a neural network system for defect characterization.
Progress towards objectives:
<u>Tasks worked on are:</u>
11.1 Definition of the library of rail track defects
11.2 Neural network development
11.3 Assessment of neural network functionality
11.4 Neural network validation
<u>Achievements made with reference to planned objectives</u>

Neural network has the ability to derive meaning from complicated or imprecise data; can be used to extract patterns and detect trends otherwise too complex to be noticed. The training phase of the neural network was achieved in part with a reference library of well-characterized rail track defects. However, as it was difficult to collect a large number of in-field measurements to define the library of the defects, the knowledge base for the network was requiring the use of a complex simulator to create a wide base of different input cases to be used for the auto learning procedure, in order to validate the performances of the network realized.
As this job was not expected and was requiring too time a more simple algorithm has been developed in order to characterize the standard rail flaws that can be characterize using the two classes of acquired signals. Thanks to this approach we were able to validate the performance of the Urail prototype, and we had the possibility to begin the process of storage of acquired signal from field to build the training database for the neural network.
The final Urail system software for the characterization of defect will use the combination of this two algorithms, the first one related to the standard flaws and the neural network that will compute the same acquired signal again to supply at the end the final result, achieving in this way the full coverage of the detection of possible flaws types and orientations, and with the high reduction of the number of the false calls.
Deliverables
D12: Neural network software (it will be supplied together with the Final Report).

Workpackage number: 12
Start date or starting event: This task should have started on month No. 14 but actually the beginning of activities have been anticipated to Month No. 12
End date: Month No. 17
Title: Software development to control the system
Participant Short Name: TG, QL, JMT, CM4, TRASTEC
Objective: To design and to develop the software to control the system.
Progress towards objectives:
<u>Tasks worked on are:</u>
12.1 Definition of functions to be controlled
12.2 Design of software modules
12.3 Development of software modules
12.4 Software testing
<u>Achievements made with reference to planned objectives</u>
Activities of this workpackage started with the identification of the functions to be controlled (e.g. managing the communications with the lasers, the control of the box position, the ultrasound data flux, the communications between the various pc's and the alarms, etc..). The box controller is realized through a software procedure that calculates the command signal starting from the position error and the absolute position of the box.
Software modules were also developed for the real time display, the analysis of the data and the storage, diagnosis reports printing. Moreover such modules have the following further features:

- show the status of the various subsystems, giving to the operator the capability of understanding if everything is going ok;
- show to the user the results of the computations made on the acquired ultrasound signals coming from the transducers;
- give useful information about the vehicle status.

The synchronization between the data coming from the rail tracking system, the ultrasound data acquisition/processing system and the data from encoder was controlled by the supervisor PC with the tailored software module that was developed.
All these different module packages were controlled by a single integrated user-interface.
Deliverables
D13: Software components to control the system (it will be supplied together with the Final Report).

Workpackage number: 13
Start date or starting event: Month No. 20
End date: Month No. 23
Title: Prototype manufacture
Participant Short Name: TG, QL, JMT, CM4
Objectives: Manufacturing of the prototype
Progress towards objectives:
<u>Tasks worked on are:</u>
13.1 Optical components and guides manufacturing and assembling
13.2 Electronics parts manufacturing and assembling
13.3 Mechanical components manufacturing
13.4 Hardware components and positioning sensors manufacturing
13.5 Software packages and software to control the system
13.6 System assembling
<u>Achievements made with reference to planned objectives</u>
Manufacturing of components (optical, electrical, mechanical, etc..) was in part performed by Tecnogamma and in part by third parties. Optical parts were mounted after manufacturing to verify that paths of laser beams were maintained with the movement of the inspection unit. Electronic boards were manufactured by Tecnogamma. Some hardware parts for amplification and filtering of ultrasonic signals that showed problems by introducing noise had to be properly modified by Tecnogamma personnel. Algorithms and software modules to control some functions of the system (control of motor for box movement, stop of laser firing under a speed limit, etc..) were defined.
Assembling of system was done only for the independent sub-systems in order to be tested and verified before installation in the rail vehicle at the test facility.
Deliverables:
D14 Final prototype

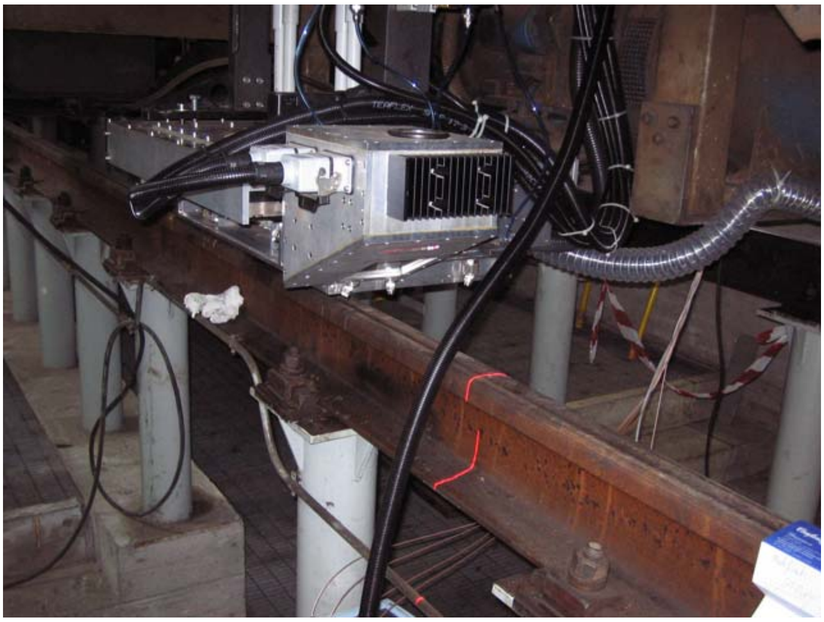
Workpackage number: 14
Start date or starting event: Month No. 17
End date: Month No. 22
Title: Laboratory tests on prototype
Participant Short Name: TG, QL, JMT, CM4, TRASTEC
Objectives: To perform functional testing of the prototype
Progress towards objectives:
<u>Tasks worked on are:</u>
14.1 Tests on prototype
14.2 Tests of prototype on different types of defects
14.3 Repeatability measurements
14.4 Statistical results
14.5 Collection of remarks on tests
14.6 Problem solving
14.7 Test results
<u>Achievements made with reference to planned objectives</u>
The tests in the laboratory were performed to evaluate the functionality of the system in detecting the different types of defects selected for the rail head, web and base. The entire inspection system was assembled in the laboratory to recreate the real vehicle configuration, to simulate rail tracking with the rail position measuring system and to perform the ultrasonic inspection.
Calibration of the rail tracking system and of the ultrasonic unit was carried out on a brand new rail section. Switching of optics for the different configurations (head, web, gage and field side of the base) was tested. Each test on the selected defect was repeated at least ten times to determine repeatability in the same conditions and number of false calls.
System reliability, repeatability of measurements and statistic of results were assessed together with the functionality of all other parts, included automated controls (such as laser firing and emergency stop

control, data acquisition, etc.). Effects and error on measurements in case of the inspection unit out of position respect to the rail were evaluated; most critical conditions were found to be for the rail base inspection due to the great transducer air-gap.
Problems encountered during test of the prototype and relative troubleshooting were collected.
Deliverables:
D15 Report on results of laboratory tests

Workpackage number: 15
Start date or starting event: Month No. 22
End date: Month No. 25
Title: Assemblage on rail vehicle
Participant Short Name: TG, QL, JMT, CM4, RFI
Objectives: Installing the prototype of the system on a train to validate its performance.
Progress towards objectives:
<u>Tasks worked on are:</u>
15.1 Structural changes of rail vehicle
15.2 Mechanical assemblage
15.3 Electrical installation
15.4 System installation
15.5 Validation test
<u>Achievements made with reference to planned objectives</u>
The main objective of this task was the installation of the system into a dedicated rail vehicle to perform in-track testing. The design of the unit was done following the regulations provided by the railroads. The rail vehicle on which to install the system was provided by RFI; once the rail vehicle was made available few minor modifications were carried out, as defined in workpackage 10.
Modification of layout in the vehicle was done to create the room for the components that must be installed inside the vehicle but also underneath it, to better arrange the equipments, and to fit the console for the operator.
Once completed mechanical and electrical installations and proper wiring, tests were performed to ensure proper working of all components and systems.
Pictures of the system installed in the rail vehicle are shown below.
Deliverables:
D16 System mounted on the rail vehicle

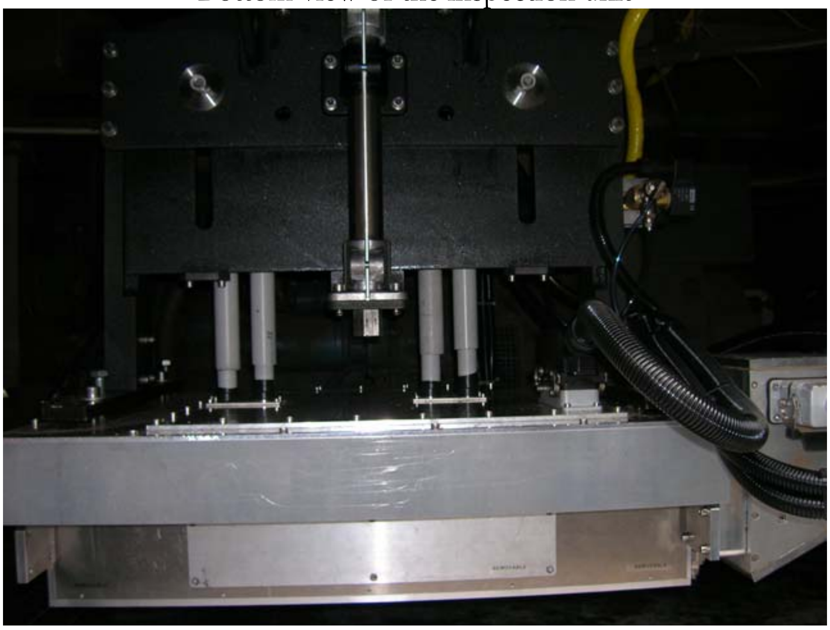
U-Rail inspection unit as installed under the rail vehicle "Galileo" provided by RFI


Detail of equipment under the rail vehicle



Detail of the inspection unit

Bottom view of the inspection unit



Detail of the lifting system to raise up the inspection unit when not used

Workpackage number: 16

Start date or starting event: Month No. 23
End date: Month No. 25
Title: Field tests
Participant Short Name: TG, RFI
Objectives: Validation of the inspection system through in-field experiments for on-line defect detection.
Progress towards objectives:
<u>Tasks worked on are:</u>
16.1 In-field tests on catalogued defects
16.2 High speed demonstration
16.3 Repetitiveness trials
16.4 Statistical results (POD, sizing accuracy)
16.5 Assessment of system performance and limitations
<u>Achievements made with reference to planned objectives</u>
After system design and optimization phase in the laboratory, the system was at the second phase of evolution, consisting in in-track defect detection.
NDT evaluations on track were performed quasi-statically on selected rail flaws, defined as the most important by the end users. Selected defects were first characterized by using hand-scanning contact angled transducers. Procedures to perform the inspection of rail head, web and base were defined as well as safety procedures for use of the laser, belonging to class IV.
Tests were repeated over the same track section to determine repeatability of measurements. Repetitive trials on the selected flaws provided, under the same conditions, repeatable pattern indication of defect.
Demonstration of system performance at high speed was achieved up to 30 km/h, testing the automated rail tracking system. However, laser-based ultrasonic inspection has still to be proved at high speed.
Rail area inspection coverage for the current configuration was determined to be 58 percent; it was proved that 96 percent of the cross-section is achievable implementing the configuration.
Deliverables:
D17 Report on procedures and results of the field tests

Workpackage number: 17
Start date or starting event: Month No. 25
End date: Month No. 27
Title: Final checking
Participant Short Name: TG
Objectives: To ensure that the system works properly at all levels.
Progress towards objectives:
<u>Tasks worked on are:</u>
Task 17.1 Independent check at all levels
Task 17.2 Assessment of overall system functionality
Task 17.3 Final approval
Task 17.4 Technical report
<u>Achievements made with reference to planned objectives</u>
After installation and in-track testing of the system, a complete system checking was carried out to list all the observations, problems and trouble shootings that came up against during the design, development and validation phases.
Assessment of system functionality was first evaluated at each independent level, and then for the complete system. Limitations of the system were reported in order to be addressed and implemented with proper solutions. The final approval of the system was achieved, with the knowledge of capabilities and limitations of the designed prototype.
A complete technical report, as collection of all deliverables, was prepared.
Deliverables:

Workpackage number: 18
Start date or starting event: Month No. 27
End date: Month No. 27
Title: Spreading and promotion
Participant Short Name: TG, QL, JMT, CM4, DIMA
Objectives: To develop a specific marketing plan and to promote the project output. To concretely finalize the final version of the exploitation plan.
Progress towards objectives
During the project course, dissemination of achieved results was done through conferences and seminars. Tailored meetings to show system functionality and performances were organized with potential railroad customers. Papers were published in specialized magazines with international spreading.
Further meetings as well as participation at fairs will be organized in the future to show results achieved during in-track testing.
The marketing plan realized by the consortium is based especially on the use of the Urail demonstrator to show and to report to the market the new possibility in the NDT field. The first actions will be related to the four End-Users to understand their intention to acquire this new systems and to evaluate their requirements especially in terms of mechanical installation point of view.
A new testing campaign will be performed in the future with the actual demonstrator on the Italian network using both installed system (Urail demonstrator and Galileo ultrasonic conventional system) to inspect the network at the same time under the same conditions and with the manual verification of the identified defects, in order to perform systems and techniques comparison (this activities is waiting to have all the authorization to be performed)
The results of the Prototype tests campaign will be used in combination with the results obtained during the same inspection session by the Galileo ultrasonic conventional system in order to build a benchmark between the two technologies to demonstrate the efficiency, the accuracy, reliability and repeatability of the new implemented technique in order to convince the market and to start the process of standardization of this new ndt technique especially for what concern the railway sector.
In the main time also other activities will be done to promote the new ndt technique in USA, Australia and Asia and some initial discussion has already been done with TTCI the Transportation Tecnology Center in order to start the USA market evaluation from technical and economical point of view.
Some exhibitions has already been planned and technical brochures of the system are in preparation to explain the system performances and to supply an overview of the industrial stage of the development.
Further information is contained inside the specific Plan for Dissemination (Deliverable 19).
Deliverables:
D19 Plan for use and dissemination knowledge

2.3 Deliverables list:

Deliv. No	Deliverable title	Delivery date	Nature	Dissemination level	Status
D1	Report on the system technical specifications	2	R	RE	Accomplished
D2	Report on the market technical requirements	2	R	RE	Accomplished
D3	Report on laser forming effect on acoustical wave generation, and on design of proper optical guide for each defect.	8	R	RE	Accomplished
D4	Report on the design of each detection unit and of the complete one	6	R	RE	Accomplished
D5	Report on the investigation of steel structure after laser ablation	4	R	PU	Accomplished
D6	Report on the design of each generation unit and of the complete one	8	R	RE	Accomplished
D7	Report on the performances of the new ultrasound technique	11	R	PU	Accomplished
D8	Report on the design of the sensors and laser beam automation system	11	R	RE	Accomplished
D9	Hardware components and software packages for each system	13	O	RE	Accomplished
D10	Report on the final design of the complete system	27	R	PU	Accomplished
D11	Report on laboratory tests	27	R	PU	Accomplished
D12	Neural network software	27	O	RE	Accomplished
D13	Software components to control the system	27	O	RE	Accomplished
D14	Final prototype	27	P	CO	Accomplished
D15	Report on results of laboratory tests	27	R	RE	Accomplished
D16	System mounted on the rail vehicle	27	O	CO	Accomplished
D17	Report on procedures and results of the field tests	27	R	PU	Accomplished
D18	Final technical report	27	D, R	PU	Accomplished
D19	Plan for using and disseminating knowledge	27	R	RE	Accomplished

3 Section 3 - Consortium management

Regarding U-rail project management activities, every issue has been specifically reported in the Management Report.
In this section it is enough to underline that **no main problems have happened during project development**.
The only little problems have been the ones concerning the delay on submitting the Final Audit Certifications by some partners but not because of negligence but mainly because of some internal organizational problems mainly due to changes in project management structure.

During project development every partner has properly participated in project activities as foreseen.
Only changes to the proposed work programme are related to partner DIMA, whose activities necessary to succeed in the first year tasks have been less then foreseen during the first year. This partner have been involved in tasks n. 9 and 18 even if not previewed at the beginning of the project.

A complete paragraph regarding the explanation on budget usage has been written in the specific Management Report with all the expenses features and eventual reallocations occurred.

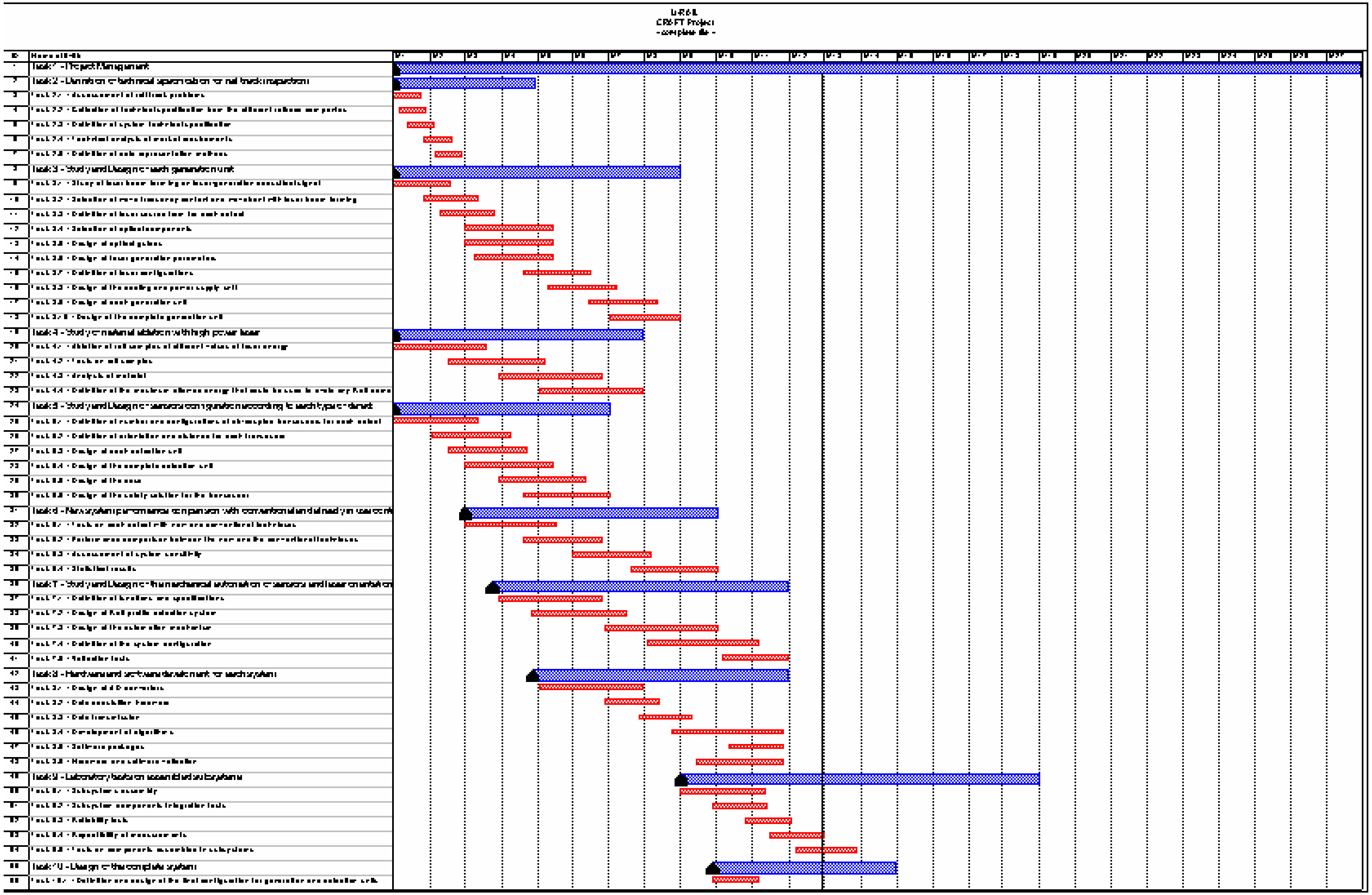
Contractors: during the first year changes of some Project Responsible have occurred in the following partners structure:

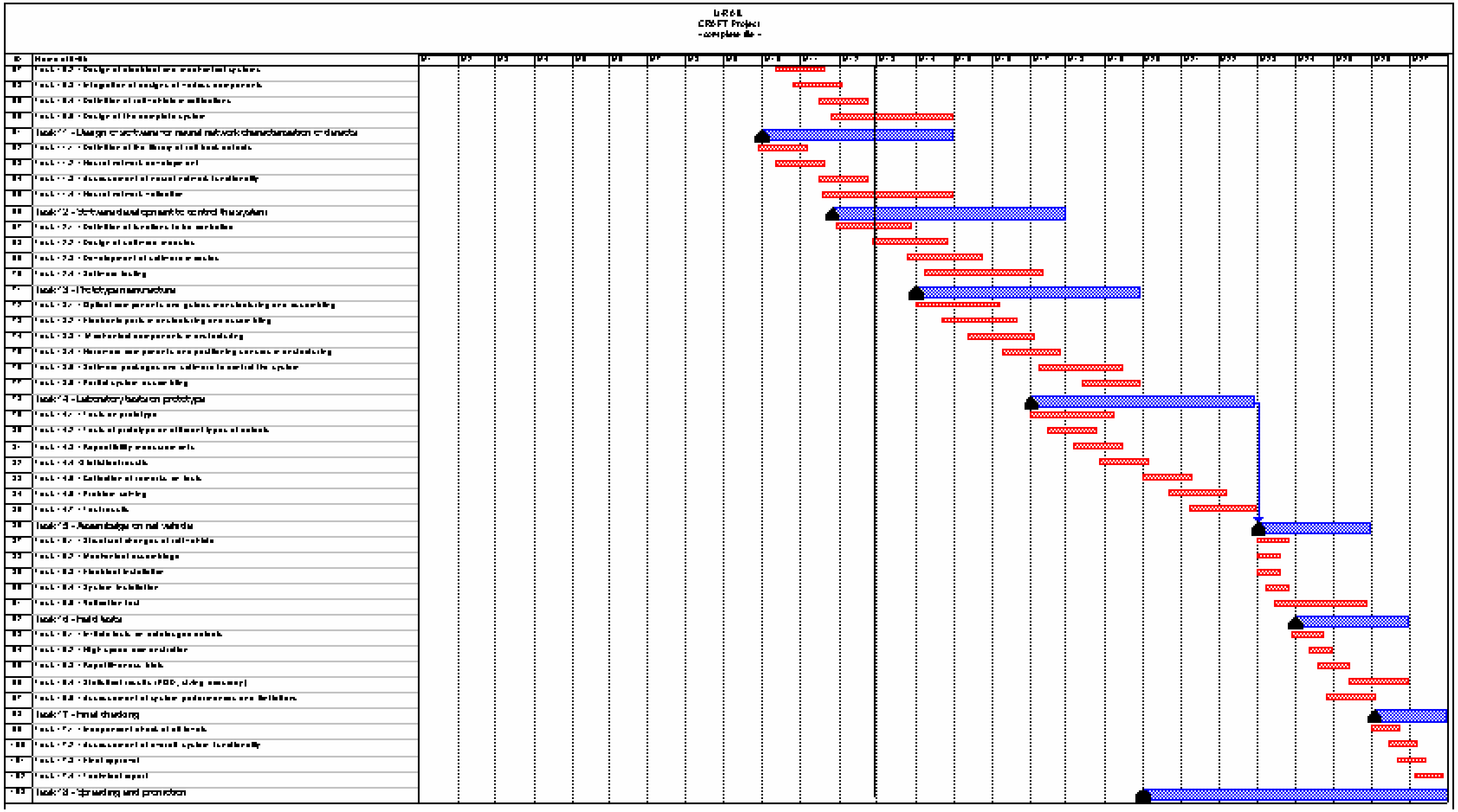
- in Tecnogamma Mr Ettore Casagrande (former Tecnogamma President) has been substituted by Mr Luciano Marton (General Manager);
- in RFI Ing. Gabriele Maffei has been substituted by Ing. Domenico Cocciaglia (even if the Form C has been signed by Mr Maffei because it was regarding;
- in Eurotunnel the new Technical Project Responsible is Mr Patrick Joyez, Mr Michael Groves will still be in charge for Administrative duties;
- in DIMA Palermo the former Director Prof Francesco Cappello has been substituted by Prof Antonino Pasta.

Official documents related to the above mentioned changes have been attached to the Management Report of the First Year.

Communication among partners has usually been concrete and direct. Partners have cooperated among themselves also without the necessity of Tecnogamma coordination.
Regarding meetings, the complete list of meetings held during the first year is reported in the Management Report.

See the attached GanttBar: comments have been included in the Management Report


CRAFT Project



4 Section 4 - Other Issues

A table on work performed by each partner is hereafter attached.

Regarding the benefits provided by the RTD Performer activity, we can confirm that their results have been necessary for the development of the various activities.

WP	Workpackage title	1 TG	2 QL	3 JMT	4 CM4	5 RATP	6 EUT	7 AMEL	8 DIMA*	9 TRASTEC*	10 ULG*	11 ENEA	12 RFI
1	Project management - Exploitation/Dissemination	Overall project coordination	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng	Own adminstr. mng
2	Definition of technical specifications for rail track inspection	Collection of technical specifications and market requirements				Supply of technical specifications	Supply of technical specifications	Supply of technical specifications			Assessment of rail track problems	Analysis of market requirements	Supply of technical specifications
3	Study and Design of each generation unit	Study and design of laser generation units	Laser beam forming study								Study of laser generation units		
4	Study of material ablation with high power laser	Ablation of rail samples	Definition of the maximum laser energy								Analysis of rail ablated material		
5	Study and Design of sensors configuration according to each type of defect	Definition of transducer configurations	Verification of sensor configuration						Definition of transducer orientation and distance			Transducer configuration for each defect	
6	New system performance	Assessment of system							Tests with the laser-			Tests with the	

	comparison with conventional and already in use contact technology	sensitivity							based system			conventio nal system	
7	Study and Design of the mechanical automation of sensors and laser orientation	Design of the rail position detection system		Design of the rail position detection system	Design of the rail position detection system				Design of the automatio n mechanis m	Validation tests			
8	Hardware and software development for each system	Hardware and software development								Development of algorithms and software packages			
9	Laboratory tests on assembled subsystems	Integration tests	Tests on optical subsystem s	Tests of electronic subsystem s	Tests of electronic subsystem s				Reliabilit y and repeatabil ity tests of sensors	Integration tests			
10	Design of the complete system	Design of the complete system	Design of the final configurat ion for generatio n unit	Design of electrical systems	Design of the vehicle mechanic al interface					Integration of designs of various components			
11	Design of software for neural network characterization of defects	Definition of the library of rail track defects								Neural network development			
12	Software development to control the system	Definition of functions to be controlled	Definition of functions to be controlled	Definition of functions to be controlled	Definition of functions to be controlled					Design of software modules			
13	Prototype manufacture	Mechanical and electronic parts	Laser delivery	Optic guides realizatio	Productio n of the moveable								

		realization and prototype assembly		n	parts and mechanical interface								
14	Laboratory tests on prototype	Support to the test activities	Support to the test activities	Support to the test activities	Support to the test activities					Test on assembled prototype and characterization of the static performances obtained			
15	Assemblage on rail vehicle	Installation of the Prototype on Galileo Vehicle	Installation of the Laser on Galileo Vehicle	Installation of the optical guide on Galileo Vehicle	Installation of the prototype Mechanical interface on Galileo Vehicle	Validation on the installation approach		Validation on the installation approach					Validation on the installation approach and support during the installation phase
16	Field tests	Verification of the prototype performances during field tests activities											
17	Final checking	Verification of the prototype status after filed test activities											
18	Spreading and promotion	Worldwide Marketing activities and industrial dissemination	Marketing activities related to the new developed laser	Promotion f project results in Germany	Promotion f project results in Spain				Publications				

5 Annex I Plan for using and disseminating the knowledge[1]

A complete report on dissemination has been done on the specific Plan for using and disseminating the knowledge - Deliverable 19