PROJECT FINAL REPORT

Grant Agreement number: 234015

Project acronym: PantoTRAIN

Project title: PANTOgraph and catenary interaction: Total Regulatory Acceptance for the Interoperable Network

Funding Scheme: Collaborative project

Date of latest version of Annex I against which the assessment will be made: 04/05/2012

Period covered: **from** 1st June 2009 **to** 31st May 2012

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PantoTRAIN

PANTOgraph and catenary interaction: Total Regulatory Acceptance for the Interoperable Network

D0.5 – Final Report

WP0 – Projet Management

Document Information

Leader of the deliverable	UNIFE – Ross Hanley
Due date	M36
Submission date	M36
Document ID	PANTOTRAIN-WP0-D0.5

Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	**X**

Document Status

Version	Date	Modification	Authors
V0	27.05.12	First issue	C. Potton
V1	20.07.12	Transmission to the Technical Management Team	WP leader
VF	25.07.12	Date of approval by the Technical Management Team	

4.1 Final publishable summary report

a. Executive summary

The use of different overhead equipment across European nations, and hence the different requirements placed on pantograph systems, represents one of the major barriers to rolling stock interoperability. The PANTOTRAIN project aims at removing this barrier by a twofold approach: on one hand, by revisiting the pantograph homologation procedures considering the use of innovative instruments ('virtual homologation') to simplify the trans-national homologation and cross-border service of pantographs. On the other hand; by assessing the impact on interoperability of innovative pantograph designs with advanced mechatronic functionalities.

The project PantoTRAIN set out to develop concepts, procedures and tools to deduce values of these parameters from software simulations and test rig measurements without recourse to in-line test runs.

The mean value of the contact force is composed from a static component with can be easily measured in a workshop and an aerodynamic component. Within PantoTRAIN the aerodynamic component of contact force was examined with three different methods of CFD simulations. The results of the simulations were analysed and the best suited method indentified.

The conformity assessment parameters standard deviation of the contact force, uplift of the catenary wire at the supports and vertical movement of the contact point are accessible to test rig measurements and simulations of the dynamic interaction of pantograph and catenary The results of the different approaches coincide remarkably well with each other and with data from measurements preformed during previous line test runs. This gives high confidence in the accuracy of the proposed methods. During the three years of PantoTRAIN three different pantographs Faiveley CX, Contact ATR 95 and Stemmann ASP were tested on the test rigs and the simulation programmes with the catenaries SNCF LN2, RFI C270 and DB Re330.

In the field of tools PantoTRAIN achieved a remarkable success in the accuracy of the multi body model of the pantograph by simulating the non ideal behaviour of the joints by introducing realistic bushings into the model.

Furthermore the first two available prototypes of active controlled pantographs the Stemmann ASP and the active variant of the Contact ATR95 were analysed on the test rigs and with simulation programmes.

A rigid mathematical optimisation procedure was performed on the simulation models of the pantographs in order to fathom the potential of optimisation for the real pantographs.

The field conformity assessment procedures PantoTRAIN proposes the homologation map to give a consolidated view of the mean value and the standard deviation of the contact force and the value of the uplift and a measure of the safety margin achieved by a conformity assessment.

Furthermore frequency band selected values of the dynamics properties of the pantographs are proposed to augment the up to now used standard deviation.

As there are five years to the next revision of the TSI we plan to accumulate knowledge with the new tools and procedures when performing conformity assessments on real train. This knowledge will support the appropriate changes in the TSI and the European standards.

b. Project context and objectives

Concept of the *PantoTRAIN* Project

The certification of a rail vehicles according to Technical Specifications for Interoperability (TSI's), European Standards (EN norms) and national safety rules represents a significant element of both vehicle cost and time to market.

The introduction of Technical Specifications for Interoperability takes precedent over national rules within the European Union and sets specific limits, and therefore requires one method of evaluation. This effectively works to harmonise national requirements and thereby reduces costs of certification for rail vehicles intended to operate in more than one country. The focus of the project is therefore on using the TSI route to consolidating the methodologies which will allow the free exchange of certification data.

Whereas the current HS RS TSI involves tests for all requirements, the rapid development of numerical tools and computer resources has lead to simulations being an integral part of the design process of new trains.

The *PantoTRAIN* project proposed to transfer the pantograph / catenary certification work as much as possible away from current line testing towards laboratory testing and simulation. This will not only improve pantograph interoperability, but will also increase train performances on the existing infrastructure (by enabling optimized pantographs to run at higher speeds on existing catenaries) and to achieve considerable savings in terms of costs and time required for the homologation of new pantographs.

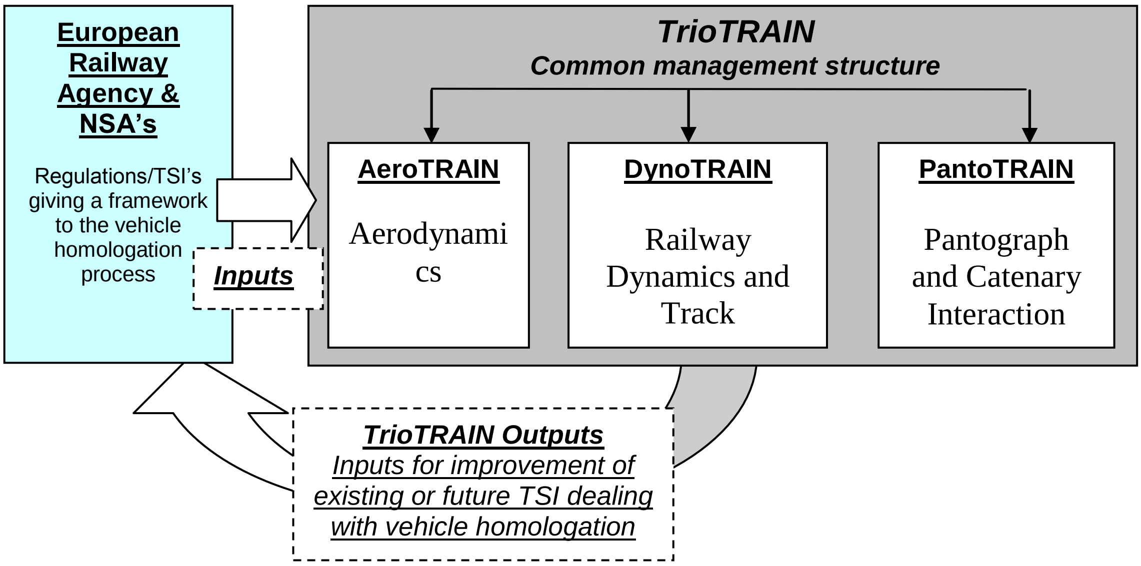
PantoTRAIN is part of the TrioTRAIN cluster of projects. TrioTRAIN, is an acronym for Total Regulatory Acceptance for the Interoperable Network, dealing with key railway interoperability issues. The objective of these projects is to propose an innovative methodology that will ease rail vehicle certification process in Europe to become a faster, cheaper and better process for all involved stakeholders.

The *TrioTRAIN* overall objectives are as follows:

- to close Open Points related to the Cross-Acceptance of railway systems;
- to close Open Points in TSI's;
- to reduce the cost, shorten the time and overall ease the network approval process in Europe introducing and/or exploring:
    - virtual homologation (replacement of assessment by testing with assessment by simulation),
    - transfer of certification results in one country to another,
    - virtual extension of homologation (for minor changes to existing homologated solutions).

The *TrioTRAIN* concept comprises 3 related projects: *DynoTRAIN, AeroTRAIN, PantoTRAIN*.

Aerodynamics (*AeroTRAIN*), Railway Dynamics and Track Interaction (*DynoTRAIN*) and Pantograph / Catenary Interaction (*PantoTRAIN*) are the fields where it is believed that network approval process can be improved in a very positive way. These fields share common points that can be exploited in a unified way for the facilitation of the network approval process. Indeed, with the current state-of-the-art, the only sensible way for transposition of test results is via computer simulation/ virtual homologation and that is a CORE SKILL to be developed in *TrioTRAIN*.



High-level objectives

The overall objectives of the *PantoTRAIN* project are:

- to improve pantograph interoperability, also by fostering the use of innovative pantographs having mechatronic functionalities. This will remove one of the major barriers to rolling stock interoperability;
- to reduce the costs associated with homologation of new and modified pantographs;
- to shorten substantially the time required by the homologation process of pantograph / catenary systems;
- to achieve a high level of integration between design and homologation processes for pantographs.

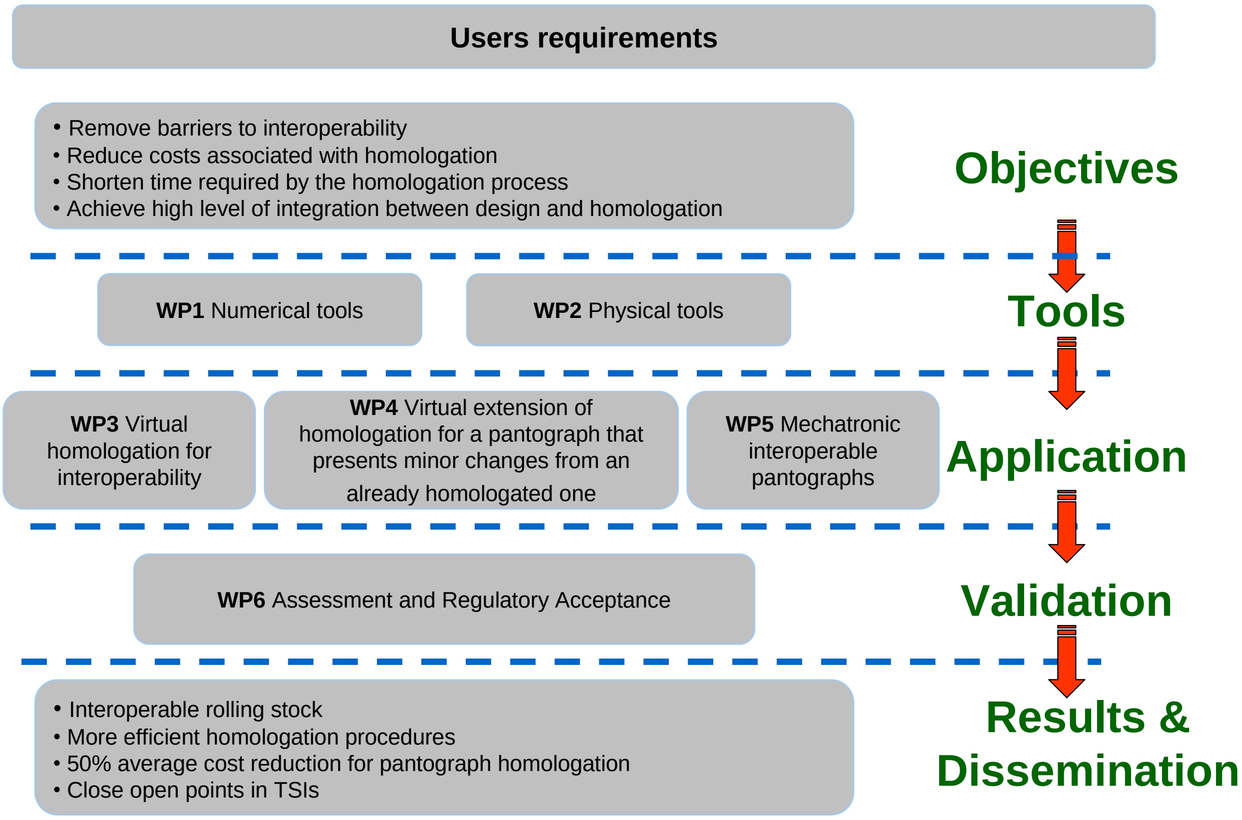


Figure 2: *PantoTRAIN*: From Objectives to Results.

c. Main S&T results/foregrounds,

Introduction

The *PantoTRAIN* project aims at developing and introducing a computer-aided certification process to allow the reduction of the time and cost of pantograph certification against ENs and TSI by transfering current physical track tests to laboratory testing and numerical simulation. The same procedure is also envisaged to greatly improve the interoperability of pantograph systems across EU Nations, since virtual homologation techniques will be applied to extend pantograph homologation across different National railway networks (*WP 3*). The collection of pantograph and catenary database at European level (also envisaged in *WP 3*) will be an essential step towards this ambitious goal.

The project is organised according to the following Work Packages list:

- **WP 1: Criteria to build and validate pantograph / catenary numerical simulation tools;**
- **WP 2: Hardware-in-the-Loop testing of pantographs;**
- **WP 3: Virtual homologation for interoperability;**
- **WP 4: Virtual extension of homologation for a pantograph that presents minor changes from an already homologated one;**
- **WP 5: New innovative pantograph designs with control functionalities;**
- **WP 6: Assessment of virtual homologation procedures and Regulatory Acceptance.**

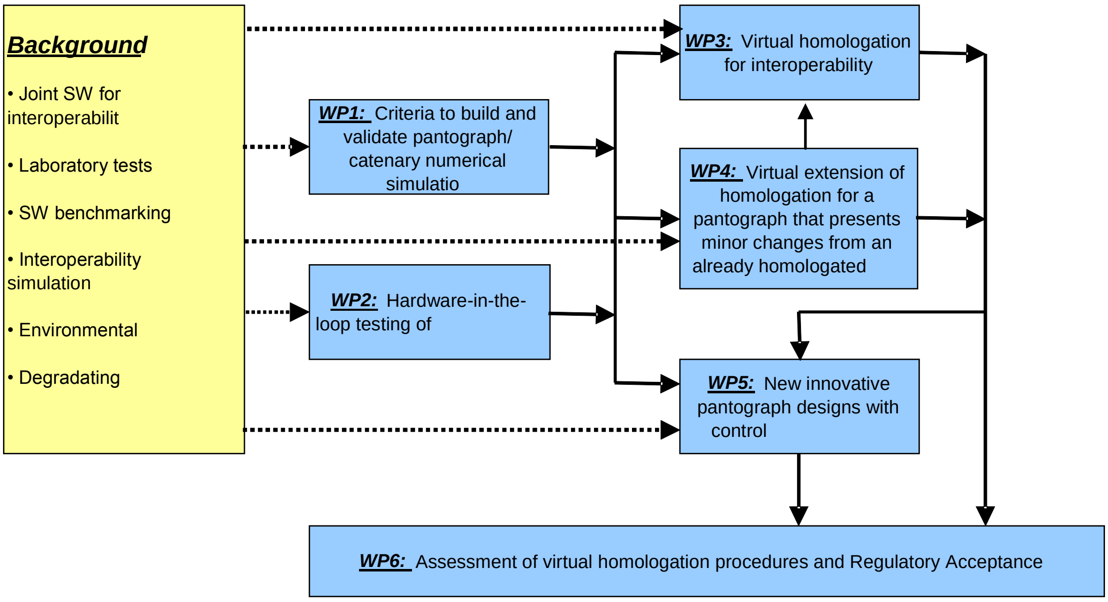


Figure 3: Simplified PERT Diagram.

Description of the deliverable content and results

The objective of this WP was to define a methodology by which virtual models of pantograph / catenary interaction can be assessed and qualified for use in a virtual homologation process. This was done by identifying which physical phenomena had to be simulated and the general requirements of the models to be used (e.g. 3D catenary model, slackening of droppers, multi pantograph operations). Similar requirements were set for the pantographs, which should include deviations from their nominal construction and operational specifications (masses, inertias, geometry, spring stiffness, damping coefficients and friction forces).

Modelling aspects and software construction factors relevant for the behaviour of the pantograph and catenary were characterized and those with a more relevant role were identified. This work package addressed the effect on accuracy of different modelling choices for the same pantograph-catenary couple being based on the use of the CX Faiveley pantograph lumped and multibody models and on the SNCF 25kv catenary.
Four functional parts have been considered addressing: (a) pantograph software and models key parameters; (b) catenary software and modelling key parameters; (c) extraction of contact forces from sensors and accelerometers; (d) mapping of experimental and numerical results. The work was performed with reference to two pantograph-catenary interaction cases: (1) Faiveley CX pantograph, running under the French High-Speed catenary LN2; (2) the same pantograph running under the German High-Speed catenary Re330.

First, a sensitivity analysis was performed, to investigate the effect of the main parameters in the catenary model and contact model affecting the results of pantograph-catenary simulation; then, a more focussed convergence analysis was performed, concerning the effect of the number of elements in the contact wire and the effect of stiffness and damping parameters in the contact model. The list of parameters of the pantograph software analysis and models to be analysed included: Numerical parameters of software (Time step); Lumped pantograph models (masses, springs, dampers); Multibody pantograph models (Masses, Inertias, Friction, Springs, Dampers, Geometry parameters). A program of simulations is developed for: Varying all parameters for -10%, nominal, +10%; Variations of Speeds: 200 km/h, 250 km/h, 300 km/h and 350 km/h.

This Work package included the development of a procedure to define / calibrate pantograph models based on laboratory experiments ensuring the highest possible accuracy of pantograph models, as part of the numerical simulation of pantograph-catenary interaction. The work undertaken in this task entailed the dynamic characterisation of three different pantographs, on two different test stands, one at DB, the other at POLIMI. The three pantographs considered in this task were: the Faiveley CX pantograph; the Contact ATR95-25kV pantograph; the Stemmann ASP pantograph, having mechatronic functionalities.

Data obtained from laboratory experiments both based on the measure of pantograph response to known inputs in terms of Frequency Response Functions (FRFs) were used to identify the parameters of lumped parameters and multi-body models of the considered pantographs.

A set of test cases intended to demonstrate model capabilities for virtual homologation and to quantify the related accuracy were carried out, namely that the representative results produced by the simulation of the test cases lie in a specified band of acceptable values when compared to reference values (test results or reference simulations). These representative results must include the quantities specified in the relevant TSIs - technical specifications for interoperability.
Models representative of the actual catenary types (with or without stitch wire, high-speed or classical catenaries, etc.) were defined, and after they were validated, they constitute a database to be used for virtual homologation'.

A benchmark with existing pantograph and overhead contact line for supporting the procedures of validation of pantograph-catenary simulation tools is proposed. Together with recommended procedures on how to support the EN 50318 in order to validate the pantograph-catenary simulation tools for virtual homologation.

Multiple pantograph operations were also addressed based on the allowed separation range between the leading and trailing pantographs, described in EN 50318, a study of a matrix of cases for which several separations at different operation speeds is presented. The results allow the understanding of the compatibility of the operation conditions in face of the overhead systems used and to envisage conditions for the enhancement of criteria in regulation.

State of the art and innovation brought

Numerical models are used to understand the process of extracting collector/contact wire contact forces from accelerometers and force transducers using standard data treatment procedures with the objective to understand the foreseeable variations on the contact forces based on the deviations of the measured accelerations on the same pick-up points used to acquire the accelerations on the experimental tests.

Procedures for semi-automated parameter identification were defined for the lumped parameter pantograph models used in the project. These were successfully applied on the pantographs tested. The comparison of the results obtained using experimental data coming from the DB and POLIMI test benches showed that the pantograph model can be successfully extracted from each of the two testing procedures. Hence, a good robustness of the procedure for model identification can be inferred from the results of this task.
The development of a virtual testing procedure that consists in a computational environment in which the physical testing procedures adopted by DB and POLIMI are faithfully modelled, is a result that sets the framework for the development of virtual prototypes of pantographs with prescribed dynamic characteristics or even to design tests that allow identifying any particular behaviour of a pantograph. This constitutes another level of contributions beyond the State-of-Art.
The existing TSI and norm (EN50318) that specify validation criteria for pantographs and catenary models do not include the knowledge developed in EUROPAC, PantoTRAIN and other projects. During the course of works of recent projects new knowledge has been gathered that helps re-thinking the criteria described in the norms and eventually to enhance them. In particular, task 1.1 provides a matrix of tests in which the variations on

the pantograph/catenary contact results vary as function of the perturbations of the models and task 1.2 provides the procedures for the validation of pantograph models.

Selected results and recommendations

The results obtained show that operational conditions, such as speed and static contact loads, are a very important factors influencing the pantograph-catenary interaction. In fact, as the speed increases, the amplitude of the contact forces grows significantly, despite the average value remaining similar to the static force plus the aerodynamic forces. However, pantograph and catenary design parameters also influence the contact performance to a measurable degree.

Regarding lumped mass models, despite smaller, influences are also observed when varying the masses m_4 (top mass), the spring stiffness $_{k2-3}$ and k_{3-4}, connecting the two intermediate masses and the top mass to one of the intermediate masses, and all the damping coefficients c_{1-2}, c_{2-3} and c_{3-4}. Nevertheless, these components mainly affect the maximum and minimum force values. The sensitivity of the other statistical parameters to the variation of the pantograph model elements is less significant, at least for variations in a range of +/- 10%.

Relatively to the elements that compose the CX pantograph model, significant influences are observed when varying the masses of the lower arm, top arm and Contact strip body.

Using a sufficiently high value of the contact stiffness is essential to obtain a correct description of the contact force; a rule of thumb to define an appropriate value of the contact stiffness for a lumped parameter pantograph model is that the natural frequency of the collector mass, suspended on the contact stiffness, shall be sufficiently larger than the maximum frequency of the analysis.

A methodology is defined to specify a validity range for simulation parameters independently from the simulation software used. Examples of the methodology are provided considering the discretization of the contact wire and the time step for numerical integration. The overlap sections can play an important role on the main parameters describing the behaviour of the pantograph / overhead line interaction.

The measurement description file template that has been created to collect all the measurement specifications collected for the PantoTRAIN project allows to reproduce in virtual tools similar conditions of homologation inline tests like for instance the same operational conditions and measurements processing and, if required, equivalent environmental conditions.

A methodology to define / calibrate pantograph models based on laboratory experiments was defined in this Task. Wherever possible, this procedure shouldl be applied when building lumped parameters pantograph models. Wherever possible, the characterisation of the pantograph shall be undertaken at different amplitudes of excitation, to outline the importance of non-linear effects in the dynamic behaviour of the system.

Pantograph multibody models based solely in design data can provide worthy reference models. Their reliability can be improved provided that the hardware implemented in their manufacture and the design data agree and that mechanical components, such as imperfect kinematic joints, are taking into account in the models. In any case, complementary measurements of some mechanical elements characteristics are necessary to ensure that the modelling data corresponds to that of the physical prototype.

The use of the current TSI and regulation is tested for the test cases proposed in this work and the relevant criteria required are evaluated. The description of the methodology proposed constitutes a map on the usage of the regulation.

The scenarios described and demonstrated in this work constitute a base for the validation of any software tool used for virtual homologation and for the models developed. The multiple pantograph operation raises compatibility issues that cannot be only addressed by ensuring a fixed separation between pantographs, irrespective of the catenary in which they have to be operated. A more focused study in this aspect is recommended to understand the phenomena and allow including its evaluation in any enhancement of the current TSI and regulations criteria.

WP2 Hardware-in-the-Loop testing of pantographs

Hardware-in-the-Loop (HIL) simulation, also known as "hybrid simulation" is based on simulating the operational behaviour of a dynamic process, where a part of the process (the "hardware") is represented by a physical prototype, and the remaining part of the system is represented virtually using a mathematical model which, by means of a suitable test set-up, is set in interaction with the prototype.

In the PantoTRAIN project, this concept was applied to the simulation of pantograph-catenary interaction by interfacing a real pantograph to a mathematical model of the overhead equipment. The advantages of this approach to homologation are clear in terms of economic benefits and time to market of new products: in fact laboratory tests can be performed at much lower costs and in a more reliable and controlled environment than line tests. Still, the pantograph undergoes a physical test, which largely avoids the implications of model uncertainties on the homologation procedure.

In particular, the advantage of the HIL testing compared with line tests is basically the reduction of the number of line tests and the reduction of the costs for the homologation of pantographs. The laboratory tests can be performed at lower costs, in much shorter times and more reliable compared with line tests under fluctuating environmental conditions.

Two alternative HIL testing methods were considered in the project: "open loop" HIL and "closed loop" HIL. In the "open loop" HIL testing method a simulated or measured time history of collector motion is fed on the pantograph, and the corresponding contact force is measured. Eventually, the measured force reacted by the pantograph can be introduced (off-line) into a mathematical model of the catenary to provide a better estimate of collector motion and the test repeated with the new collector motion estimate. In the "closed loop" HIL testing method the actuation system is driven by a real-time board where the force applied by the collector head to the contact wire is processed according to a catenary model, to derive the displacements produced on the collector strips, which are then fed back on the pantograph head. This second approach accounts for the effect of pantograph reaction force on collector head displacements, but may require the use of a simplified catenary model to achieve real-time computation time.

The "open Loop" HIL testing was introduced based on the available resources of the test rig of Deutsche Bahn AG. The innovation brought by the project consists of the optimisation of the simulation method of the overhead line dynamics using various input signals coming from software simulations and line measurements of different types of overhead lines. The numerical calculation of input signals to drive the servo-actuation system was optimised and the limitations of the test rig were examined.

Furthermore the results of the “open Loop” HIL testing were compared with results from line tests and software simulations for the whole frequency range from 0 Hz to 20 Hz. Additional frequency bands especially for the span and dropper passing frequencies have been evaluated. While the deviation of the “open Loop” HIL testing with respect to line measurements can be reduced to ±10% for the whole frequency range up to 20 Hz, the evaluation of the frequency bands especially above 10 Hz shows an increased deviation cause by the dynamic limitations of the test rig and its hydraulic actuator.

As far as the “closed-loop” HIL technique is concerned, starting from initial concepts developer before the start of the PantoTRAIN project substantial advances were introduced by considering the effect of the contact wire stagger, independent actuation of the two collector strips and especially through the optimisation of the real-time numerical model of the catenary.

Based on comparisons performed on two mechanically different pantographs, the Faiveley CX and the ATR95-25kV, it can be concluded that the deviations of the “closed-loop” HIL method with respect to line measurements can be quantified as ±10%, both in terms of contact force and of dynamic contact wire height at the pantograph, in the whole 0-20 Hz frequency range considered in this research. This is comparable with the uncertainty implied by line tests, and qualifies the “closed-loop” HIL testing methodology as a suitable approach to the virtual homologation of pantographs and catenaries.

WP3 Virtual homologation for interoperability

The work achieved in this work package arises from scientific and numerical developments based on current computing technologies and railway standards for certification purposes. This challenging project aimed at cutting global costs and duration of a pantograph catenary couple homologation by developing a virtual homologation procedure independent from computing tools or test benches used and respecting the following assumptions:

- Inline test are required as a starting point: the target of this work is exclusively focused on extension of homologation using HIL testing. This means that the proposed procedure can exclusively be performed only starting from already homologated couples and available track measurements.
- No new criterion is proposed: only the criteria required by the current homologation process are used, considering the same limit values for the homologation quantities prescribed by the current regulations.

The Task 3.1: "Collection of pantograph and catenary database at European level" aimed at creating and describing a comprehensive database for European catenaries network and pantographs to be used in virtual homologation process.

A catenary database template has been proposed and explanations supplied to easily use the different functionalities of the created Excel file. This unique template file is adapted for all kinds of European catenaries. It collects all identified data (mechanical, geometrical, material properties,...) necessary to describe and model the catenaries with partners virtual tools. The required specialised and standard data is underlined. This work has been partially based on the previous results from EUROPAC project where these questions had begun to be explored.

Catenary and pantograph models provided by partners in the project have been described and compared. The exhaustive list of catenaries provided within PantoTRAIN project includes the LN2 French catenary, the OCS4 Spanish catenary, the Re330 German catenary, the Mark3B British catenary, the C270 Italian catenary. These catenaries have been evaluated as interoperable constituent through criteria partially based on the Technical Specifications for Interoperability requirements including geometrical specifications, steady arm uplift space and elasticity range of variation. Same activities have been carried out for the pantograph database template including the French Faiveley CX, the German Stemmann DSA380, the British Brecknell & Willis and the Contact ATR95, this time with a standardized input file in ASCII format.

The task 3.2: "Procedure to extend pantograph homologation of different catenary systems by numerical simulation" aimed at defining and validating a procedure based on numerical simulation to extend pantograph homologation in a cross-border operating context.
To propose the most suitable procedure, advantage and limits of current standards have been investigated and discussed among partners. In order to overcome the main drawbacks and keeping in mind the need to simplify while extending the homologation process, a three step procedure has been proposed.
The first step of the procedure, called "Validation", consists in assessing that both the software and the numerical models are accurate enough to reproduce the real system behaviour. Simulation results and inline measurements are compared with available data. Statistical criteria coming from current standards are completed with two enhanced signal comparison tools applied in the homologation procedure namely the frequency bands analysis to ensure the physical validity of the simulation results, and the coherence function defined as a complementary tool giving very pertinent information for signal shape analysis.
The second step "Modification" takes into account minor changes mandatory to adapt design characteristics of pantograph to the gauge imposed by the network or by the national rules. It entails, for instance, changing the length and as a consequence the weight of the bow. This step is optional because some pantograph can run under different catenary profiles without major dynamic behaviour changes.
The third step "Extension" aims at building a new pantograph/overhead line couple by merging ones previously validated and by assessing numerically the homologation criteria in order to virtually homologate the current collection quality.
To get a maximum of confidence making the numerical models closer to the realistic operating conditions, several kinds of irregularities are applied to the numerical models such as contact wire height, aerodynamic forces, or also dropper and span lengths for periodical catenary models. Their impact on spectral components is studied highlighting the best and the worst cases that can be encountered considering realistic maintenance tolerances and physical variability.
To get more simplicity and to help the final decision, a new graphical and numerical tool is proposed, based on the current criteria used during line tests. This new mapping tool called “Homologation Map” is applied and an enhanced acceptance criterion is proposed. Based on this, three levels of acceptance are defined “Accepted”, “Rejected” and “Inline test required”.
In a near future, this procedure may be applied before real track pantograph homologation campaigns, as a “blind test”, in order to increase the confidence and to remove weak points.

The task 3.3: "Procedure to extend pantograph homologation of different catenary systems by HIL testing" aimed at defining and testing a procedure based on HIL testing methodology to extend pantograph homologation in a cross-border operating context.
The resulting procedure for homologation extension by closed-loop HIL tests is made of three different steps. The first step, addressed as "Validation", consists in assessing that the HIL testing methodology, and in particular the real-time model adopted for the catenary representation, is able to reproduce the real system behaviour. This step is performed on the basis of the validation criteria prescribed by EN50318 and of the enhanced frequency bands analysis developed in WP2 and WP3.

The second step, "HIL testing and uncertainty analysis", addresses the estimation of the homologation quantities for the new pantograph-catenary couple and the analysis of the influence that some of the possible source of uncertainties, namely the droppers' stiffness and contact wire irregularity, on HIL test results.
The third step "Virtual homologation decision" is aimed at defining whether the new pantograph-catenary couple should be considered as virtually homologated or not, on the basis of the results coming from the "Validation" step and from uncertainty analysis.
In order to get a suitable confidence on the obtained results, a strategy of "worst case combination" was adopted, with the aim of not rejecting new couples that could be successfully homologated through classical track tests and, on the other hand, of not accepting new couples that could be rejected through track tests
Moreover, a combination of numerical simulations and open-loop HIL tests was adopted to address multiple pantograph operation, which cannot be considered in the current implementation of the closed-loop HIL test-rig. In particular, the influence of different pantograph distances and articulated-frame dampers was investigated.

To illustrate these methodologies, several interoperable couples are studied from data collected in the tasks T3.1 and T1.2 of the PantoTRAIN project. Thus, the proposed procedures were applied to different couples: three pantographs were considered, the French CX (Faiveley), the Italian ATR95 25kV (Contact) and the German DSA380 (Stemmann), coupled with three different catenaries, the French LN2 catenary (SNCF), the German Re330 (DB AG) and the Italian C270 (RFI, data provided by POLIMI).

WP4 Virtual extension of homologation for a pantograph that presents minor changes from an already homologated one

The objective of WP 4 is to clearly define the specific cases when a pantograph that was submitted to minor changes could be virtually homologated, in which operational conditions, and the procedure to extend the certification, particularly in terms of model building. The work carried out covers simulations to assess the mechanical properties and simulations to assess the aerodynamic properties of a pantograph.

The obtained results demonstrate that there are several factors inherent to the railway operation that influence the quality of the pantograph-catenary interaction, namely by increasing the contact loads and by promoting more frequent contact losses. By understanding the consequences of these factors, clear rules can be set to define the limit operating conditions of high-speed trains according to the physical circumstances that the railway vehicles experience in service.

The activities performed consisted of three kinds of analysis:

1) First a sensitivity analysis was performed to investigate the effect of the main parameters in the pantograph model affecting the results of the pantograph-catenary simulation. For this purpose, several parameters that can vary during trainset operation are identified and the effect of such variation on the pantograph-catenary interaction is studied. The list of parameters considered includes the mass and stiffness of the pantograph head and the lower damper of the pantograph. The methodology adopted here consists of a 'one-at-time' parameter variation. The results obtained in this manner are compared with respect to the reference model.

2) The second type of analyses performed here consists in studying the overhead power system performance when the high-speed train is equipped with two pantographs. The purpose of these studies involving multiple pantograph operations is to assess how the passage of the front pantograph affects the performance of the rear one. Furthermore, such studies allow analysing if the presence of the rear pantograph influences the contact quality of the leading pantograph. Several distances between pantographs are considered, namely: 31 m, 100 m, 201 m and 400 m. These distances between pantographs correspond to different train set assemblages that occur in service.

3) The third type of analysis performed here deals with the task of predicting the aerodynamic forces on a pantograph in operation. For the assessment of that quantity CFD simulations were done and compared to wind tunnel experiments. The results indicate a sensitivity of the aerodynamic lift on the deformation of the pantograph head. The outcomes of this task are very promising and provide the basis for further investigations.

The numerical simulation provides the tools that allow the enhancement of the regulation criteria and to consider other operational aspects besides the single pantograph operation. The results shown here indicate that the questions of compatibility between pantograph and catenary in some operational conditions can be addressed by numerical tools. For predicting the aerodynamic properties of a pantograph further investigation are required.

WP5 New innovative pantograph designs with control functionalities

WP5 objective was to perform a systematic appraisal of current pantograph design solutions with respect to their main functionalities.

It carried out systematic design optimization with the aim of reducing weight and to improve the overall contact force under normal and extreme conditions. Feasibility studies were carried out to exploit control technologies to actively reduce the overall contact forces without loss of quality of the contact. The WP also explored how the homologation process could be adapted in the case of innovative/active pantographs.

The work was split between two tasks:

1. **'Pantograph structural optimisation',** which had the task of providing optimisation of the active pantograph and proposing a methodology whilst taking into account operational constraints.

2. **‘Homologation of a mechotronic pantograph’** focused on defining a suitable environment for the homologation of innovative pantographs. It also investigated how mechatronics could improve interoperability and assess the impact of pantograph optimisation and the use of active control on interoperability.

The above tasks resulted in three reports, **“**Pantograph Structural Analysis”, “Homologation of a mechatronic pantograph” and “Assessment of pantograph optimisation and the application of active control on interoperability and “TSI limits for innovative active pantographs” which describes the actions undertaken within the work package.

Additional activities were also carried out, these being the ‘Dynamic characterisation tests and closed-loop HIL tests on an active ATR95 laboratory prototype’; and the “Development of Validated Multibody Pantograph Models using Clearance and Bushing Joints”.

Pantograph Structural Analysis.

Evaluation was performed by carrying out two different simulation methods, the comparison of the dynamic impedance; and the assessment of the pantograph dynamic interaction under standard overhead lines.

The methodology used was composed of the identification of relevant parameters for optimization, a study of pantograph dynamic impedance, which is performed for each set of components comparing separately the impact of stiffness and damping changes. The pantograph / catenary interaction is simulated and the best set of components identified by comparing statistical results with defined objective functions. This new numerical model is evaluated through its dynamic impedance before being used for final analysis in single unit and multiple units operation.

The objective of the optimization process was to find the best head setting for each pantograph that leads to the best contact characteristics represented by the Standard Deviation of the contact force.

The virtual homologation procedure could be used either to ascertain the optimal tuning for a pantograph in a trans-network operation or to demonstrate that a pantograph seeking approval has the best features for the network in it has to operate on

Homologation of a mechatronic pantograph

The ASP400 mechotronic pantograph was tested using both the open and closed loop test bench methods and the results from these compared. An active control strategy was developed and a simulation model was ascertained, simulations were then carried out and compared to the test results.

The Dynamic Characterization of the ASP 400 pantograph was carried out utilising the open loop method with post processing; closed-loop HIL tests were then performed with the Re330 catenary.

The computer implementation of the control strategy and the simulation of the mechatronic pantograph ASP400 in different scenarios were then carried out. Instead of using a physical model of the actual actuators the solution found on the project consisted in the identification of the transference functions via laboratory testing of the ASP400 pantograph.

3 “Assessment of pantograph optimisation and the application of active control on interoperability and TSI limits for innovative active pantographs”.

As part of the above pantograph structural optimisation was performed in a rigid mathematical way using a genetic algorithm and two mechatronic pantographs, the ASP and the ATR95 were studied using simulations and measurements carried out on test rigs.

Additional work - Development of Validated Multibody Pantograph Models using Clearance and Bushing Joints.

The purpose of the work was to further develop the Multibody models of pantographs, in order to include the modelling of bushings and clearance joints, and their validation via virtual laboratory testing.

The implementation of bushing/clearance joints in the improvement of Multibody pantograph models had the following methodology:

An overview of the formulation used for the computational implementation of these special joints in a Multibody environment;
The original pantograph model is constructed, using the classical Multibody methodology with rigid joints, and its dynamic response is assessed in the virtual test laboratory and compared against the experimental measured responses obtained in the test rig with the real prototype; and
The construction of improved Multibody pantograph models with bushing/clearance elements in the mechanical joints and the identification of the respective constitutive laws.

WP6 Assessment of virtual homologation procedures and Regulatory Acceptance

The main purpose of WP6 has been to make sure that the project results are in a form that is suited to the need of its end-users - mainly, ERA and CEN-CENELEC. This purpose is related to the "regulatory acceptance" expression in the title of the WP. Research results are in fact often written in a "language" - that of the scientific community - aimed mainly at allowing the research to be reproduced by anyone wishing to do so. Moreover, researchers seldom focus directly on the direct implications that their work may have in terms of the regulatory framework; rather they stop at the strictly technical issues. Although essential for uptake in regulatory documents, documents written in "scientific language" are not practical for the people responsible for such documents to pick up the essential aspects in a reasonable time thus understanding whether it is a useful contribution or not. Therefore, in PantoTRAIN a significant amount of further work was done on the output. Usually this additional work is done outside the project, most often less efficiently not being able to rely on the help of the researchers. In the TrioTRAIN projects, the idea was that if the work produced results that could immediately be of interest for uptake into the regulatory framework, it would be more efficient to have the people producing the results take their work further by interacting with the end-users, understanding their needs, and going as far as possible in documenting the results in a format suited to them, including targeted and structured information on the accuracy of the proposed processes. At the same time, this would imply a useful revision of the scientific work performed with positive repercussions on the quality of the output.

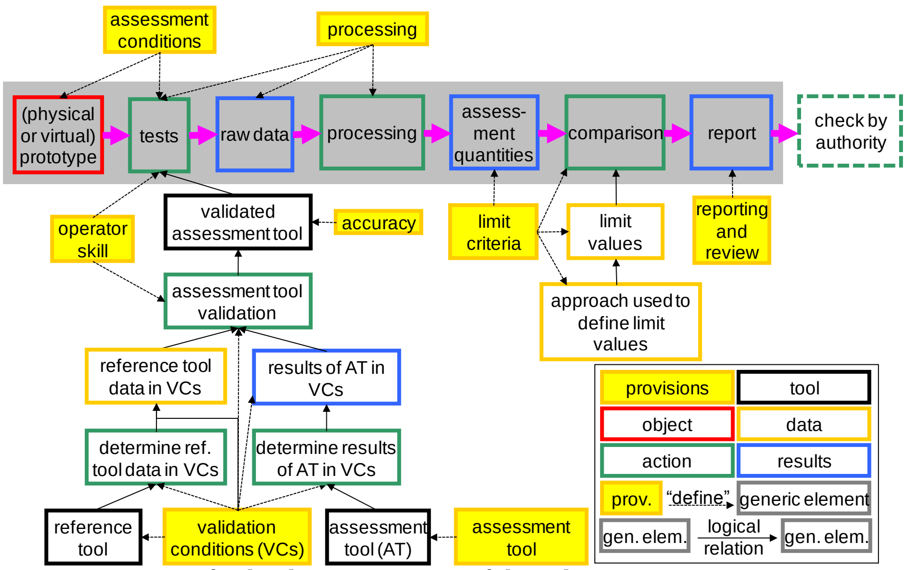
The strategy adopted in TrioTRAIN to ensure the effectiveness of the transfer of results to end-users rests on three conceptual pillars:

- structure: a structured representation of the current status of the regulatory framework related to the three projects and of the proposed status which could derive through implementation of the results;
- accuracy, that is careful quantitative considerations (where possible, uncertainty figures) of the tools used for the assessment, whether experimental or virtual;
- liaison and dissemination: the information and knowledge from the projects needed to be targeted to and shared with the end-users where possible as they were generated, to ensure due consideration of end-user advice and an early identification of their concerns.

These three points were reflected in the three "tasks" of Work Package 6 (respectively tasks 6.3, 6.1 and 6.2), with a structure common across the three TrioTRAIN projects - that is why the WP is also known as "WPX".

In addition to liaising, analysing and reviewing, WPX also produced interesting results mainly in terms of frameworks and methods for use in future projects. Moreover, the task targeting accuracy aspects led to outputs in terms of quantification of indicators related to assessment accuracy, which is seldom found in the current state of the art for these highly complex assessments. All of these aspects are described in detail in the outputs of the WP, i.e. the deliverables associated to the three tasks.

In the early stages of the WP the current state of the art was examined in order to identify the underlying principles of the processes to place in service new or modified designs. These processes have been evolving significantly in recent years. The technical aspects of such processes ("Technical Sub-Process" TSP) are the ones dealt with in TrioTRAIN.



The activities associated with such TSPs are summarised in the block diagram below. This diagram identifies the logical elements that are common to the regulatory framework addressed in TrioTRAIN. With this classification, the regulatory framework itself was analysed provision by provision. A comparison was then performed with the integrations proposed by the project.

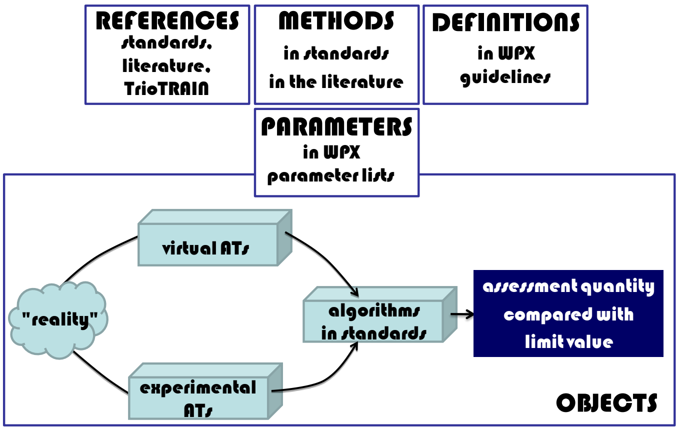
In fact, it was believed to be particularly important, given the potential use of the project's outputs, to have the outputs themselves carefully analysed. Five types of analysis were performed:

- a formal logical analysis (FLA), in which the proposal was systematically compared with the existing part of the regulatory framework to which it is addressed;
- a quality assurance and NSA/NoBo perspective analysis (QAA), in which editorial and regulatory acceptance aspects such as consensus or confidentiality issues were dealt with and through which a systematic check was made for issues that would make a third-party check difficult or impossible;
- a feasibility check, in which the core of the proposed process was performed again on a different pantograph-OCL couple to make sure that the process does not conceal any requirements that are difficult to put in practice (e.g. availability of data, excessive duration etc.);
- an internal peer review (PR) by independent project Partners (i.e. not having actively participated in the technical work), to varying degrees according to the available time-frames, in which all project Partners had the chance of commenting particularly on the technical aspects;
- an uncertainty analysis, in which the quantitative aspects of assessment accuracy (i.e. numerical indicators of uncertainty) were addressed.

The latter analysis was performed within Task 6.1, described hereafter.

Among the provisions of the regulatory framework and the proposed PantoTRAIN provisions, the ones regarding the accuracy of the assessment tool were the focus of particular attention and a specific task (Task 1). The aim was to provide structured and concise information on these aspects, as they are key for many aspects.

A key part of this demonstration is based on the analysis of the accuracy, or rather of its quantitative counterpart, uncertainty. The accuracy associated with the assessment of a specific physical quantity has been recognised to be the scientific aspect which most influences the confidence people have in the assessment results.



Given the large scope of the projects, the issues regarding uncertainty were managed through a "TrioTRAIN Uncertainty Framework". The block diagram illustrates the content of the framework. The objects of analysis shown in the diagram are essentially:

- today's assessment tools;
- the new assessment tools;
- the inherent structure of the algorithms prescribed by today's standards.

The uncertainties thus quantified were compared and assessed so as to support the use of the new assessment tools whose accuracy has proven to be consistent with that required by the algorithm used and with that of today's assessment tools.

The "super-structure" described in the previous sections would be useless if it were not linked on one side to a foundation, which is the substantial amount of work performed in the "technical Work Packages" of PantoTRAIN, and on the other side to the projects' target group. The latter link is ensured by a specific liaison and dissemination task (Task 2). With the work of the dissemination task, the target group was invited to be as close as possible to the project group. The main stakeholders were represented in an Advisory Council which met regularly with the project management to provide input and examine outputs. The Advisory Council meetings represented the official links with the stakeholders. In this way, the information was targeted to and shared with the end-users as they were generated in TrioTRAIN, to ensure due consideration of their advice.

In conclusion, WPX led to a structured assessment of the output and contributed to its quality, taking into consideration as far as possible end-user input, and created a framework for future research projects with potential implications on the regulatory framework.

Conclusion

In the field of tools PantoTRAIN achieved a remarkable success in the accuracy of the multi body model of the pantograph by simulating the non ideal behaviour of the joints by introducing realistic bushings into the model.

Furthermore the first two available prototypes of active controlled pantographs the Stemmann ASP and the active variant of the Contact ATR95 were analysed on the test rigs and with simulation programmes.

A rigid mathematical optimisation procedure was performed on the simulation models of the pantographs in order to fathom the potential of optimisation for the real pantographs.

The field conformity assessment procedures PantoTRAIN proposes the homologation map to give a consolidated view of the mean value and the standard deviation of the contact force and the value of the uplift and a measure of the safety margin achieved by a conformity assessment.

Furthermore frequency band selected values of the dynamics properties of the pantographs are proposed to augment the up to now used standard deviation.

As there are five years to the next revision of the TSI we plan to accumulate knowledge with the new tools and procedures when performing conformity assessments on real train. This knowledge will support the appropriate changes in the TSI and the European standards.

The following table present the main results of the project (in relation to be deliverables) to be integrated into standards:

Deliverable name	Standard	Main results to be integrated
D1.3: Validation requirements for pantograph / catenary simulation tools	EN 50318	list of test cases intended to demonstrate model capabilities and to quantify the related accuracy validation with measured values
D3.2: Report describing the procedure to extend pantograph homologation to different catenary systems by numerical simulation	EN 50318	proposal of virtual testing procedure modelling of pantograph, modelling of overhead contact line, parameters of simulation, output, validation with measured values, reference model
D3.2: Report describing the procedure to extend pantograph homologation to different catenary systems by numerical simulation	EN 50367	proposal for modification of allowed procedures in EN 50317, EN 50318 interaction dynamic performance
D3.2: Report describing the procedure to extend pantograph homologation to different catenary systems by numerical simulation	TSI HS ENE	proposal to extend the use of simulation for mean contact force, standard deviation and peak to peak vertical displacement of the collector '- mean contact force, - dynamic behaviour and current collection quality, - vertical movement of the contact point
D3.3: Report describing the procedure to extend pantograph homologation to different catenary systems by HIL testing	EN 50317	proposal of procedure: provisions for lab measurements - measurement of contact force, - measurement of displacement
D3.3: Report describing the procedure to extend pantograph homologation to different catenary systems by HIL testing	EN 50318	proposal of procedure: provisions for real-time computer model modelling of pantograph, modelling of overhead contact line, parameters of simulation, output, validation with measured values, reference model
D3.3: Report describing the procedure to extend pantograph homologation to different catenary systems by HIL testing	TSI HS ENE	proposal of procedure for the use of HIL testing - dynamic behaviour and current collection quality, - vertical movement of the contact point
D4.1: Pantograph / catenary sensitivity analysis for virtual	EN 50367	proposal to allow virtual testing within a specified range

extension of homologation		interaction dynamic performance

d. The potential impact of the project and main dissemination activities and exploitation of results

Enhancement of the interoperability on existing infrastructure and development of new interoperable rail equipment

The simplification of approval procedures for railway rolling stock is widely recognized as one of the main obstacles which substantially hinder cross-border rail transport. Increases in cross-border railway traffic place very high demands on pantographs to allow running at higher speeds on existing infrastructure and to operate satisfactorily on a range of different catenaries. The PantoTRAIN project, by introducing virtual procedures to simplify and shorten the homologation process of the pantograph, is in full compliance with the above approach. The results generated by the PantoTRAIN project promise much in terms of facilitating interoperability, which will lead to even greater integration within the European rail system, massive cost savings to industry and Railway Undertakings and will help to improve the situation regarding cross-border rail transport.

It is expected that the work completed within PantoTRAIN will help to extend pantograph certification to catenary systems from different nations leading to a massive saving of effort for the acceptance of a new vehicle that has previously been accepted in a different country This will save up to several million Euros for the rolling stock manufacturers, as well as responding to the needs of railway undertakings for the placing in service of new rail vehicles more quickly. The positive impact for passengers and taxpayers of this last point is clear for all to see.

Furthermore, PantoTRAIN explored the possibilities for using innovative pantographs to raise operational limits of the existing infrastructure and to compensate for the large differences in catenary properties across European countries. This work can contribute to the revision of homologation (now we should say 'certification') procedures and TSI limits to consider the case of new pantographs with mechatronic functionalities, which can adapt to the various catenary properties or operational conditions.

By these measures**, PantoTRAIN represents an essential step in view of the effective design of new pantographs able to enhance the interoperability of existing overhead equipment and to allow for interoperable use across national borders**.

Reduction of the migration time for the implementation of new interoperable solutions

The certification process that is required before putting in circulation new rolling stock is today very time-consuming and expensive. In a case documented around the time of the submission of this project proposal, the certification of a high-speed pantograph in a country different from the one where it was originally homologated lasted about 5 months and cos around 0,5M€. Furthermore, although rolling stock may be authorised to operate in one Member State, railway undertakings and/ or rolling stock manufacturers must seek additional approvals for the operation of the same rolling stock in another Member State. This lack of recognition in interoperability leads to useless additional costs and delays in delivery.

As stated in ERRAC's Strategic Rail Research Agenda as revised in 2007[1], **a virtual certification process using computer models of the finished products could lower the "time-to-market" lead-time significantly**. Implementation of the interoperability standards will also reduce the range of goods and services required and generate economies of scale. Both of these measures will lead to reduce the cost and the time of development and manufacture.

Hence, a certification process based on simulation rather than on physical track tests only could yield the following benefits, with maintained or increased levels of safety:

- increased competitiveness of the railway mode;
- increased interoperability;
- reductions in the cost of train ownership;
- improved availability and reliability of rolling stock.

The PantoTRAIN project targeted the overall objective to use computers and laboratories for around. 50% of the work done today with real trains and this could speed up migration time and reduce cost by approximately. 40%. Furthermore, PantoTRAIN, by establishing a direct link between the virtual homologation process and the pantograph / catenary design stage, allows for the substantial reduction of the time-to-market for new pantographs and catenaries.

Development and implementation of Technical Specifications for Interoperability

Helping to close open points in the TSI's was another major impact expected from the PantoTRAIN project. In particular, the following issues were addressed by the project:

- **Homologation of pantographs with mechatronic functionalities:** this is a situation not considered by the TSI's at present, so that active pantographs have to meet the same requirements as traditional ones in terms e.g. of mean value of the contact force between the pantograph and the contact wire, whereas the active pantograph allows for a substantial decrease of the mean contact force on account of the reduction in the dynamic contact force component produced by active control. The introduction of appropriate objectively based and realistic limit values for active pantographs **will enable very important savings in terms of wear in the contact strips and in the contact wire, and will reduce contact wire uplift which may represent an operational constraint**.

[1] ERRAC, *"A Joint Strategy for European Rail Research 2020 - Towards a Single European Railway System"*, September 2001.

- **Multiple pantograph units operation:** the present TSI's prescriptions do not consider explicitly the situation of a train having more than one single pantograph in contact with the overhead line. However, **the operation of multiple pantograph units needs to be carefully treated at the regulatory level**, since the leading pantograph will produce a disturbance in the overhead line, which will affect current collection on the following pantographs. The limit/target values for the contact force shall therefore be adjusted taking into consideration these interaction effects, and the possible existence of critical distances between the pantographs, depending on the spacing between pantographs and the specific properties of the catenary.

- **Maximum contact wire uplift:** in their present form, the TSI's prescribe the maximum value of the contact wire uplift at the steady arm to be within 50% of the maximum allowable displacement of the steady arm which is compatible with vehicle gauge. Therefore, a safety coefficient of 2 is used to compensate for unknown/non-repeatable phenomena such as extreme weather conditions, effect of irregularities in the geometry of the catenary etc. It is expected that by the use of appropriate modelling and simulation tools, the project will provide means to lower the value of this safety coefficient, thereby removing one major obstacle to the full exploitation of the pantograph/ catenary system capabilities.

Impact on the operational and technical integration of the different national railway systems in the European Union and accession countries

The existing condition, at the time of the submission of this proposal,of the pantograph and overhead equipment in Europe is extremely fragmented, as represented by the table below, and a complete solution to the problem can be expected only in the long term. PantoTRAIN nevertheless represents a step towards creating conditions for the integration of the different national railway systems. WP3 of the project specifically addressed the issue of virtual homologation for cross-national service: this could allow in the short-medium term to have the possibility to design new pantographs so to maximise their ability to operate on the widest possible range of different catenaries existing in Europe. The instruments developed in the project, including the European catenary database, will provide SNCF and DB, two of the major European operators, with instruments to simulate and assess cross-national service on a more extended basis than the existing one and will contribute to the efficient solution of problems posed by the integration of national railway networks.

	600 V DC	750 V DC	1.5 kV DC	3 kV DC	15 kV 162/3HZ	25 kV AC
Austria		C			C	
Belgium				C		HS
Bulgaria						A
Czech Republic			C	C		C
Denmark			C			C
Estonia	C					
Finland	C					A
France			C			A
Germany		C			C	A
Greece						A

Hungary						A
Ireland			C			
Italy				C		HS
Latvia				C		C
Lithuania				C		C
Luxembourg						C
Netherlands			C			HS
Poland				C		
Portugal			C			All
Romania						C
Slovakia	C		C	C		C
Slovenia				C		
Spain			C	C		HS
Sweden			C	C	C	
United Kingdom	C	C	C			C

Legend: C = Conventional
HS = High Speed
A = All

Figure 4: List of current systems for electric traction in EU-27 (not applicable to Malta and Cyprus).

Impact on competitiveness

According to the website of the Federal Ministry of Transport, Building and Urban Affairs of the Federal Republic of Germany, around the time of the submission of this proposal, "A critical task that needs to be managed along the complicated path to establishing technical standards and compatibility between the various systems is the simplification of the approval procedures, which are currently drawn out and costly. **Failing to change the approval procedures currently in place in the various EU Member States will cost the industry around €400 million between now and 2015**. This figure emphasizes the importance of taking prompt action."

In particular, homologation costs for pantographs are associated with the following main cost drivers:

- commissioning the pantographs on the rolling stock;
- measurement runs with real trains, and
- homologation by the notified bodies.

The homologation cost for a high speed pantograph in one single country is in the range of 500.000 EUR and a new homologation is required whenever the design of the train is affected by even slight changes, since these may have big influences on aerodynamics. Homologation may also be required to allow operation under a different catenary system or traction voltage.

Saving cost improves the overall competitiveness of the European Rail sector, encourages modal shift and protects the environment.
The exploitation of PantoTRAIN results in terms of simplification of homologation procedures will therefore result in a stronger and more competitive rolling stock

manufacturing industry with major cost reduction and reliability gains for railway undertakings.
The cost and time saving which the work in PantoTRAIN makes possible will increase competitiveness of rail transport within Europe, as well as the competitiveness of the European industries across the world. By bringing better new rolling stock to the market faster, which is quicker and more cost-efficient to produce, the project contributes to the rail mode becoming more attractive and competitive, aiding modal shift. If cost savings are passed along the entire value chain, trains will be cheaper for Railway Undertakings and for passengers. This will help bring people onto rail.
By promoting interoperable solutions which are quicker to bring to the market and more cost-effective to implement, the European railway industry will be more competitive in terms of supplying rolling stock to world markets. By aiding the development of pantographs able to run on several networks, the European industry is helping to make international, cross-border journeys across Europe more attractive and practical. This helps rail and surface transport compete with aviation.

- **Strategic impact of Virtual Certification on the rolling stock manufacturing industry**
  PantoTRAIN will have a huge impact on the European rolling stock manufacturing industry. The main expected benefits are:
  - **facilitation of the cross-acceptance of railway pantographs** by drastically simplifying procedures for cross-acceptance,
  - **reduction of the duration and the costs of certification procedures** thanks to the transfer of most of the expensive and time-consuming physical track tests to numerical simulation and/or laboratory tests,
  - **reduction of the time-to-market for new products,** as discussed above**;**
  - **harmonisation of certification procedures and mutual recognition of certificates across Europe,**
  - **optimisation of R&D resources and identification of priorities for future innovation in the field of certification.**

- **Strategic impact of Virtual Certification on railway undertakings**
  In the other hand, the project will bring also a lot of benefits to the railway undertakings:
  - **reductions in the cost of vehicle procurement and ownership,** as discussed above;
  - **reduction of costs associated to wear of the collector strips and contact wires,** thanks to revised and optimised limits on pantograph/ catenary contact force**,** this increases therefore the availability and reliability of rolling stock, two very important considerations for Railway Undertakings;
  - **decrease of time consumption and costs for further certification of renewed materials: it is expected that** not all the testing will have to be repeated,, only some parameters should be changed in the simulation.

The lack of competitiveness of the rail transport one can observe in Europe is partly due to increasing delays in delivery caused by the necessity to change the locomotive and drivers each time that the border is crossed Enhancing interoperability, PantoTRAIN will allow railway undertakings to be more competitive in both freight and passengers transport: they could propose faster, wider and cheaper journeys across the enlarged Europe.

Furthermore, by stimulating a collaborative approach among the European system integrators, the PantoTRAIN project will generate competitive gains on a worldwide basis. This will make European railway products attractive to emerging or established markets (e.g. Asia, North America) and developing economies in serious need of affordable rolling stock (Asia, Africa, Latin America).

Addressing community societal needs

The project sought to facilitate the certification of railway rolling stock against EN standards and TSI's. The introduction and increased used of simulation-based certification tests should contribute to improve the attractiveness of rail vehicles, and therefore of rail-based transport as a whole. This will participate to promote rail transport both for passengers and freight purposes as an alternative to other modes thus fostering environmental and economic sustainability of transport.
It is clear that society needs sustainable, green forms of transport which can be achieved at an attractive price for passengers and at an acceptable cost to the taxpayer. Rail traffic is best placed among all transport modes to respond to this demand for green and sustainable transport. Seeking to increase interoperability will also lead to a greater reliability of cross-border rail transport. By showing that certification of rail vehicles can be done either by simulation or by an optimised combination of simulation and on-track testing, PantoTRAIN is contributing to increasing the attractiveness of rail vehicles and therefore rail transport in general. This is extremely important for society, as the European Union's transport and environmental objectives can only be met through a significant modal shift from other transport modes to rail. By contributing to the attractiveness of rail transport, PantoTRAIN is playing a role in this.
In terms of cost savings, which increased interoperability and simulation-based certification can bring about, the economic sustainability of rail transport can be increased. Assuming that cost reductions for the manufacturing industry are passed to railway undertakings, and that railway undertakings' cost savings are in turn passed onto passengers and taxpayers, we can see that the work undertaken in PantoTRAIN is contributing to a great many societal needs within the European Union.

Health and quality of life: Higher safety and availability at lower cost for the users

The main expected benefits for the European citizens are:

- reliable and safe services through increased availability and reduced time-to-market of high-performance rolling stock. In particular, changing in the expectations by passengers of the quality of their journey due to various factors including affluence, ageing and increasing mobility - as forecasted by ERRAC in SRRA II - would be better met;
- better quality of scheduled service by avoiding operational disruption caused by physical track test;
- enhanced utilisation of rail-based traffic capacity on the basis of free choice of transport mode and thanks to the quality/ price ratio increase.

Moreover, the rail transport mode is now becoming the natural airlines partner for international flight connections: high-speed lines are replacing short flights (under 500 km). Reinforcing the competitiveness of rail transport could in this case bring a considerable contribution to the reduction of overall noise levels for neighbouring communities by replacing the excessive use of flight, in particular night flights[2].
In this way, PantoTRAIN is contributing to the push to improve safety in the European transport system and is also part of the trend towards less disturbance for those who need to life close to transport infrastructure. This leads to an overall increase in quality of life for European citizens.

Environmental issues

The shift for both passengers and freight transport from road to railways will have an important impact on environment through:

- **reduction of green houses gases**: NOx, SOx, and particles emissions from trucks and cars. Road transport is responsible of 40% of GHG emissions in Europe, and it is without saying a word about contribution of air transportation;
- **reduction of energy consumption**: freight trains consume less energy than the equivalent number of trucks for a same mass transported. The same statement can be made for passenger trains and cars.

Furthermore, in the framework of short and middle range distances journeys, the competitiveness of the transport by train compared to air transportation must be highlighted, knowing that commercial air transportation produces 2.5% of the global CO_2 emission due to human activities[3].
By making the rail transport mode more cost-effective and therefore more attractive and competitive, this project is helping the environment. It is helping in the 'greening' of surface transport.

Main dissemination activities and exploitation of results

In order to maximise the yield and to provide information between societies, the partners of project used several effective communication systems: participation to congresses, technical fairs, publications in scientific journals, design and operation of a public area in the web site.

Efforts were addressed to specific targets for the dissemination of the results: authorities and public institutions, universities, scientific societies, professional and industrial associations.
A specific action was taken to disseminate the project results to the standardisation authority:

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[2] ERRAC, "*A Joint Strategy for European Rail Research 2020 - Towards a Single European Railway System",* September 2001.
[3] Institut Français de l'Environnement (IFEN), *"Les Données de l'Environnement"* n°97 11/2004.

The project interacted with the European Railway Agency and CENELEC on a regular basis through the Advisory Council, which met approximately once every six months. This allowed the project to present its work on a regular basis throughout the life of the project. It also gave the project the opportunity to benefit from advice and feedback from the regulation and standards bodies. The co-ordinator was in regular contact with the European Railway Agency, and the project was also presented at an ERA Energy TSI Working Party meeting and at meetings of CENELEC.

The project held a final meeting in May 2012, to which CENELEC Working Group and ERA Working Party members, as well as ERA Working Party Project Officers were invited. There was a good level of participation from these at the final meeting. The work done and results achieved in each of the technical Work Packages was presented at this meeting, with interesting exchanges taking place between the project partners and audience. Contacts with CENELEC and ERA were strengthened during this meeting.

A project public website was maintained throughout the life of the project, and this was updated with relevant information as the project progressed through its life cycle. Within the railway industry, awareness of the project was strengthened due to its being presented at UNIFE Technical Plenary meetings (at least twice a year) and at UNIFE General Assemblies (one per year). This ensured that UNIFE members not involved in the project were informed about it. Project brochures were available at the UNIFE General Assembly 2012, and many of these were taken away by the participants.

The project was also presented at Innotrans in Berlin (every two years); and at the World Congress for Rail Research (also every two years). In April 2012, PantoTRAIN was presented on the European Commission stand at the Transport Research Arena (TRA). This was at the specific request of the European Commission. Brochures were available for the conference attendees to take away, while an audiovisual presentation showing some of the work undertaken within PantoTRAIN was displayed at the European Commission stand. In September 2012, TrioTRAIN will be presented on the UNIFE stand at Innotrans.

PantoTRAIN was also discussed briefly with representatives of the American Federal Railroad Administration, during meetings at ERA. The FRA was interested in some of the railway research being undertaken in this field in Europe.

e. Project website address and coordinator details

More information is available on the project's website: www.triotrain.eu

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