Final Report Summary - MERLIN (Sustainable and intelligent management of energy for smarter railway systems in Europe: an integrated optimisation approach)

Executive Summary:
MERLIN's main aim and purpose is to investigate and demonstrate the viability of an integrated management system to achieve a more sustainable and optimised energy usage in European electric mainline railway systems.
MERLIN will provide an integrated optimisation approach that includes multiple elements, dynamic
forecasting supply-demand scenarios and cost considerations to support operational decisions leading to a cost-effective intelligent management of energy and resources through:

- Improved design of existing and new railway distribution networks and electrical systems as well as their interfaces with the public grid and considering network interconnections
- Better understanding of the influence on energy demand of operations and operational procedures of the different elements of the railway system
- Identification of technologies and solutions able to further contribute to the optimisation of energy usage
- More efficient traction energy supply based on optimised use of resources
- Understanding of the cross-dependency between these different technological solutions to define optimum combinations for optimised energy usage
- Improving cost effectiveness of the overall railway system
- Contribution to European standardisation (TecRec)

MERLIN will also deliver the interface protocol and the architecture for energy management systems in the railway domain, combining the technical development with new business model that would enable and foster their application.

Project Context and Objectives:
Energy management is a key issue for railway systems and it has been identified to remain prominent for the foreseeable future. The variety of operational scenarios within the railway system adds complexity to the development of solutions suitable for all users. Existing assessment tools lack an integrated approach and instead focus on singular elements of the system in isolation. Network models tend to also be assessed in isolation without considering their links to other networks or any potential alternative scenarios. Critically, these tools tend to omit the variation over different periods of the timetable in emission levels, energy usage and associated costs.

Presently, the existing individual tools and network models cannot tackle the energy management issue for the entire network alone, what is needed is a network level energy-cost manager approach, which considers holistically vehicles, infrastructure components and efficient operation.

MERLIN’s main aim and purpose is to investigate and demonstrate the viability of an integrated management system to achieve a more sustainable and optimised energy usage in European electric mainline railway systems.

This main purpose is addressed in through five scenarios defined within MERLIN project by:
- developing the specifications for the reference architecture of an integrated energy optimisation approach for the design and operation of networks, both at strategic and operational level;
- developing a strategic decision making tool and operational railway energy management tool;
- simulating different use cases in each scenario using both tools developed within MERLIN scope, aiming to collect the information related to energy management and optimisation prospects;
- developing a pilot case of the integrated energy optimisation approach for evaluation and assessment;
- assessing access conditions to the energy market for railway stakeholders leading to an optimized usage of resources and equipment by identifying and defining the energy and power exchange interfaces between rolling stock, railway energy network and public energy grid;
- developing new control algorithms for rolling stock auxiliaries allowing the storage of energy on demand, using the existing surplus of energy, coming for the train itself when braking or from the grid, in storing thermal or pressure energy and release it when needed;
• quantifying, systematising and organising MERLIN knowledge, both in its approach and in the implementation of the model referred to the fulfilment of the directive that allows the access to different agents to the networks (generator, consumers), through a position paper;
• drafting the Technical Recommendation “Railway Energy Management System’s architecture and location of Energy Meter”;
• drafting the Technical Recommendation “Energy and power related information protocols at operational level”;
• preparing and developing the “Guidelines for the implementation of network integration”.

The work began with the identification and definition of the sub-systems and elements of the railway networks. The analysis of the requirements was led by operators and infrastructure managers. Based on collected information, a global consumption map per country was elaborated in order to identify where the critical problems are (WP1).

The most suitable real-life based scenarios (high-speed, mainline, mixed passenger & freight lines) were defined (WP3) by train operating companies and infrastructure managers, supported by UIC and the Rail Reference Group organised under the auspices of WP8.

Taking into account the sub-systems and elements identified in WP1, the modules required for the reference architecture were identified and specified (WP2). The technological developments were divided into strategic and operational.

From the strategic point of view, a specific optimisation tool- (decision making oriented) was created (WP5). These tool and models aimed at supporting decisions relating to strategic investment in new energy saving technologies for new lines or the retrofitting of existing ones. From the operational side, the studies targeted the development of new controllable components, modules, applications and protocols of the railway smart grid (WP4) as defined in the global architecture in WP2.

An evaluation exercise of the strategic and operational tools were carried out in WP6 via the several simulations of the predefined scenarios in WP3, leading to recommendations for implementation (WP7). In addition, some new components of the REM-S were deployed in a real-life physical environment to evaluate the feasibility and performance of the concept (WP6).

Project Results:
WP1
Deliverable D1.1 provided a general description and characterization of a generic mainline railway system. Deliverable D1.2 delivered a global energy consumption map. An energy consumption map, which represents a comprehensive and graphic way of representing the energy flows in the whole railway power supply systems.

WP2
Deliverable 2.1 described the procedure undertaken to set up the Coral Tree tool. Coral Tree is a web-based tool which is accessible by a common internet browser, having the main objective to describe and to define the overall System Architecture and allowing to maintain the traceability between sources (requirements) and each level of system breakdown structure.

Deliverable D2.2 defined and developed the components and interfaces of the architecture related to the specific strategic decision making functionality. Its content was divided into three topics:
1) Considering the influence of strategic decisions on energy usage within railway systems;
2) Assessment of suitable methodologies;
3) Detailing the architecture of the strategic decision making tool (SDMT) to be developed by the MERLIN project, based on the methodology identified.

Deliverable D2.3 aimed at describing the architecture of a “smart” solution for the optimisation of use of energy in the different parts of the railway system.

Deliverable D2.4 described the possible business models applicable in the MERLIN Railway Energy Management System (REM-S). The identification of the business models is part of the analysis of the behavioural architecture, aiming at identifying the role of the different stakeholders inside the MERLIN system.

Deliverable D2.5 illustrated, based on a specific case for which power and energy measurements are available (Scenario 3), the main cash flows related to these business models. Different cases, which correspond to different degrees of implementation of the technologies and different national regulations, were envisioned and, for each of them, the main cash flows are calculated based on different hypothesis.

WP3
Deliverable 3.1 defined a categorization of the input data, output data, key performance indicators, information from various subsystems that can interact with the REM-S and SDMT subsystems for the validation of them.

Deliverable 3.2 provided a detailed descriptions of the five scenarios which were identified and on which MERLIN tools were successively applied for validation.

WP4
Deliverable 4.1 presented and illustrated a detailed reference architecture specification of a holistic railway energy management system in terms of new smart grid structures, new management strategies and new controllable components, like new intelligent devices for energy management at infrastructure grid level or at vehicle level. The system is named as REM-S.

Deliverable D4.2 described the REM-S tool implementation according to the reference architecture. REM-S was developed in MERLIN to integrate on-board, wayside and coordination services by developing a system that monitors the energy consumption of different railway subsystems and their components, and then suggests a “smart” solution for coordinating optimal energy usage in the different parts of the system.

Deliverable D4.3 intended to describe in detail the mobile unit of the REM-S, contained inside the train, DOEM (Dynamic Onboard Energy Manager).

Deliverable D4.4 provided a description of two specific activities:
1) Analysis of the organization of the different types of electricity spot markets and its implications for electricity procurement in railways smart grids in the short term.
2) Design of a general algorithm to buy/sell the electricity in the 1-2 days term.

Deliverable D4.6 describe the scenario 1 defined in MERLIN project. This scenario concerns a French high speed mainline between Paris and Lyon, with a 25 kV 50 Hz power supply.

Deliverable D4.7 defined models to obtain an energy efficiency by the on-board auxiliary services and evaluation of the power for the different categories of service and a description of some technological solutions widely implemented in modern electrified transit systems.

WP5
Deliverable D5.1 represented the specification effectively developing the three new software modules,
namely SDMT Core Module, the Contractual Arrangements Module and the Optimisation Algorithm. Deliverable D5.2 implemented the development of three new modules, namely the Core module, the Contractual arrangements module (CA) and the Optimisation algorithm (OA). Deliverable D5.3 reported on the validation of the newly developed modules described in D5.1.

WP6
Deliverable D6.1 presented the simulations and use cases carried out in five real scenarios all over Europe. Based on Operational Railway Energy Manager System (REM-S) architecture defined with SGAM Model and the algorithms/tools developed accordingly, different optimisation missions were identified to test MERLIN optimisation prospects. REM-S software tool includes generic algorithms with Day Ahead Optimisation (DAO), Minutes Ahead Optimisation (MAO) and Energy Storage System (ESS) features. Deliverable D6.2 intended to present the discussion, evaluation and conclusions taken from simulations carried out in five real scenarios all over Europe with MERLIN developments. Deliverable D6.3 defined Malaga scenario and its features, explains adapted REM-S main components and implemented architecture and finally describes tested different use cases and obtained results. The results were used for TecRec preparation, business models definition and MERLIN developments final assessment.

WP7
Deliverable D7.1 consisted of a general SWOT analysis of the project which will need to be considered in order for the projects outcome to be successfully implemented and exploited. This document also highlighted the political and legislative aspects which ought to be considered by the MERLIN project. Deliverable D7.2 represented a position paper to describe the technical and economic aspects of the adaptation of electricity distribution in the railway sector when a railway smart grid is implemented. Besides, this position paper specifically will argue for a modification of the structure that allows the integration of the different agents when a railway smart grid is put into service. Deliverable D7.3 is a proposal of Technical Recommendation This proposal of Technical Recommendation which considered and analyzed the architecture of the Railway Energy Management System (REM-S), including functions/components layers and the key elements of the sub-systems of a mainline railway system. The components layer will help identify where measurement equipment (energy meters) should be placed in the grid in order to achieve an integrated energy management. Deliverable D7.4 is a proposal of Technical Recommendation which identified which information protocols at operational level should be collected in order to achieve an integrated energy management. Accurate energy consumption information will enable RUs and IMs together with MERLIN developments to measure/collect data on energy flows and help them decide on what components of the infrastructure grid to intervene in order to have better usage of energy/energy savings. Deliverable D7.5 aimed to provide guidelines for the practical implementation of the different subsystems of a MERLIN-based railway electrical smart grid. In addition, those results of project MERLIN (especially from WP2 and WP6) are systemized and organized.

WP8
Deliverable D8.1 described the templates (PPT, deliverable template, flyer) to be used by partners for all internal and dissemination purposes as well as the logo of MERLIN.
Deliverable D8.2 achieved the purpose to set up a MERLIN public website (www.merlin-rail.eu/) in order to reflect the MERLIN design styles. Its goal was to be used for dissemination material to be shared and it was made of a number of areas. It was divided into ten areas covering all the aspects, from the overview to the project’s structure, from Deliverables to download area and so forth. The website was created by UNIFE and has been technically maintained by itself as well. Instead, the regular information update for the public website has been ensured by the collaboration of UIC and UNIFE.

Deliverable D8.3 described the brochure to inform the general public in a synthetic way on the background, overview, project organization, major outcomes, consortium members, facts and figures and contact data (e-mail address and website).

Deliverable D8.4 described the project newsletter (Making Railway’s Energy smart) summarizing the main technical results achieved during the first two years of MERLIN.

Deliverable D8.5 described the final project publication which has been delivered in the form of a project final newsletter and summarized the main technical results achieved during the last 21 months of the MERLIN project.

Potential Impact:

Final Results showing below entail the entire project (as this period is the last one)

- A characterisation of the main subsystems of the main railway networks (25kV 50Hz high speed, 15kV 16.67Hz 3kV-1.5kV and 750V DC railway system) was carried out defining fixed installations, infrastructures and wayside related components and subsystems, and Rolling stock subsystems. The standardisation and calibration of energy meters and data communication, from on-board energy meters to smart grid components, was analysed and assessed due to the lack of applicable standards. In order to analyse the state of the art of the railway system, the energy consumption map of four different representative networks was developed. An energy consumption map is a comprehensive and graphic way of representing the energy flows in the whole railway power supply systems. The analysed countries were the followings: the French network of RFF, the Swedish network of Trafikverket, the Spanish network of ADIF, and the British network of Network Rail.

From these countries, different scenarios were chosen as representatives. In each of the scenarios, different energy management cases and optimisation prospects were to be assessed. Different networks, different strategies and different needs are analysed in order to validate the architectures, which are being defined in MERLIN.

Five scenarios were defined as following:

1. French scenario: High Speed 25kV 50Hz network, from Paris to Lyon: 389km long;
2. Swedish scenario: Intercity service on 15KV 16.7 Hz AC networks, Malmö-Lund – Hässleholm – Alvesta, 181km;
3. Spanish scenario: Suburban service on 3kV DC network, from Fuengirola-Malaga-Bobadilla: 100km long;
4. First British scenario: Mixed passenger and freight traffic on 25kV 50 Hz AC networks, from Carlisle to Golbourne Junction;
5. Second British scenario: regional passenger traffic on a 750V DC line between Weymouth and Bournemouth.

- The reference architecture of the REM-S was developed and also reflects the Smart Grid Architecture Model (SGAM), issued by the CEN-CENELEC-ETSI Smart Grid Coordination Group. The smart grid plane
is made up of “Zones”- representing the hierarchical levels of power system management (Process, Field, Station, Operation, Enterprise and Market) and “Domains” covering the complete electrical energy conversion chain; Bulk Generation, Transmission, Distribution, DER and Customers Premises. The five interoperability layers (Business, Function, Information, Communication and Component) cover the whole Plane representing the third dimension of the Smart Grid model.

• The reference architecture of Strategic Decision Making Tool (SDMT) was also issued. This identifies the missions, functions, products and relevant stakeholders. There are several key strategic areas in which decisions must be taken to fulfil the objectives set in a given railway system. These decisions were derived from the structure of the railway system, an analysis of where energy is used and the factors that affect this energy use. All these, contributed to the design of the system in which the REM-S operates to fulfil its own objectives.

• Two Technical Recommendation (TecRec) proposals were developed within MERLIN. Business, function and component layers are described and specified in the first TecRec Railway Energy Management System’s architecture and location of Energy Meter while communication and information layers are specified in the second Energy and power related information protocols at operational level.

As far as Dissemination is concerned, the aim was threefold:

• To ensure the project outputs reach the relevant rail stakeholders enabling them to implement these;
• To ensure the project output reaches targeted decision makers at EU, national and local level for input in the standardisation and regulation work where applicable;
• To guarantee the delivery of high-quality results and sound technical solutions with the help of a ‘Users group’.

MERLIN delivered a high number of dissemination activities including presentations of main outputs during EU and International level events (InnoTrans 2014, workshops, MERLIN Mid-term and Final Conference, RRG meetings), scientific and general publications in European and International magazines, posters and video clips (available at www.merlin-rail.eu/?p=600). The MERLIN consortium has ensured the highest level of promotion of the main results by targeting both railway experts and the general public. The following are the main dissemination activities carried out during the whole duration of the project:

• InnoTrans 2014. The MERLIN project was showcased on the UNIFE stand last week during the InnoTrans event. InnoTrans is the largest international rail fair in the world, and this year over 100,000 visitors attended. Visitors had the opportunity to have the MERLIN project presented to them as well as pick up MERLIN brochures giving information on the project.
• Transport Research Arena – TRA2014. TRA2014 was held between 14 and 17 April 2014 in Paris. MERLIN project was presented by Mr. Franco Cataldo, UNIFE Project Coordinator, who focused on the main objectives of the project and the expected outcomes.
• Rail Reference Group meetings. Four meetings were organized along the duration of MERLIN with the members of the Rail Reference Group partner, namely Deutsche Bahn AG, Infrabel, National Railway Infrastructure Company of Bulgaria, Norwegian National Rail Administration, ÖBB-Infrastruktur AG and the Swiss Federal Railways – SBB. Selected deliverables and the proposal for TecRecs were presented and discussed during these meetings in order to incorporate the feedback and proposals coming from the external experts.
• MERLIN Open Workshop. Almost 30 rail experts from Europe attended the MERLIN Open Workshop,
entitled MERLIN opens its doors. Be witness to the Spanish Scenario Demonstrator was organised the evening of 5 October in Malaga. The event was jointly organised by ADIF, CAF, RENFE, RWTH Aachen University, UNIFE and UIC. Following a welcome speech by UNIFE Project Coordinator Andrea Demadonna, Javier Goikoetxea (CAF) and Monica Pelegrin (ADIF) presented an overview of the test scenario the participants would experience in the next hours. During the demonstration between Benalmadena and Fuengirola stations, the DOEM was able to communicate with LOS, receive power limitations and calculate the Minutes Ahead Optimisation (MAO) Estimation to be sent to ground, completing the negotiation process between train and ground.

- MERLIN Mid-term conference. It took place on the 17th of June 2014 at the Antwerp Zoo during the UIC Energy Efficiency Days and it saw the participation of over 60 participants. The highlights of the conference were the following:
  - the five MERLIN Scenarios and their objectives;
  - the architectures of the MERLIN railway energy management system;
  - the strategic decision making tool;
  - the operational energy management system;
  - the legislative and standardization interactions that MERLIN will intend to have.
  All panel sessions gave rise to very lively question and answer sessions between speakers and participants, raising relevant issues about smarter use of energy in the railway system.

- MERLIN Final Conference. Almost 100 participants from across Europe attended the MERLIN Final Conference, which took place on 10 December 2015 in Madrid. Jointly organised by UNIFE, UIC and FFE the event was the opportunity for the project partners to present the final results and discuss the exploitation potential of the main outcomes with external participants.

- MERLIN dissemination brochures. A leaflet and two newsletters were prepared and distributed during public events along the whole duration of MERLIN.

- MERLIN article: “Making energy management in the railway system smarter”, published in the European Railway Review. D’Appolonia and RWTH Aachen University provided a general overview of the architecture of a Railway Energy Management System (REM-S) and then focuses on a new business model for the system. To read the article click here.

- MERLIN video clips. MERLIN partners produced two distinct series of video clips aimed at widening the audience of MERLIN followers.
  - The first group of videos focused on the five case scenarios developed in MERLIN. In each scenario, the problem and the identified solutions were described by using the tools developed in MERLIN.
  - The second group of clips represents the full movie of the MERLIN Final Conference. All presentations and Q&A sessions have been included.

The video clips have been made available on the MERLIN website at this link: [http://www.merlin-rail.eu/?p=600](http://www.merlin-rail.eu/?p=600)

List of Websites:

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