Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 136 (2017) 408–413

Energy Procedia

www.elsevier.com/locate/procedia

4th International Conference on Energy and Environment Research, ICEER 2017, 17-20 July 2017, Porto, Portugal

Weighing-in-motion wireless system for sustainable railway transport

Bruno J. A. Costa[a], Rodolfo Martins[b,*], Magno Santos[b], Carlos Felgueiras[c], Rui Calçada[d]

[a]*EVOLEO & CONSTRUCT, Faculty of Engineering (FEUP), University of Porto, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal*
[b]*EVOLEO, Evoleo Technologies Lda., Rua Gonçalo Mendes da Maia 1350-1H, 4425-656 Pedrouços-Maia, Portugal*
[c]*ISEP, School of Engineering, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 431, 4249-015 Porto, Portugal*
[d]*CONSTRUCT, Faculty of Engineering (FEUP), University of Porto, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal*

Abstract

Railway transport is well known as one of the safest and most energy-efficient transport modes, thus favoring its strengthening as part of a sustainable transport system. Yet, the track service life and the quality of the ride on a railway are dependent upon different factors, which can be assessed by a diverse set of technology based systems. In this context, this paper presents the EVO4Rail project that seeks to design, develop and implement a wireless monitoring system for weighing-in-motion and detecting faulty wheels in railway vehicles, positively impacting railway operation, maintenance and management, ultimately aiming at a sustainable rail transport.

Peer-review under responsibility of the scientific committee of the 4th International Conference on Energy and Environment Research.

Keywords: Defective wheels detection; sustainable rail transport; weighing-in-motion; wireless monitoring system

1. Introduction

Throughout human history transport played a decisive role in its economic, technological, social and even cultural development. As it allows people and goods to commute and to travel, it stands as a major resource and

* Corresponding author. Tel.: +351 229 424 327.
E-mail address: rodolfo.martins@evoleotech.com

1876-6102
Peer-review under responsibility of the scientific committee of the 4th International Conference on Energy and Environment Research.
10.1016/j.egypro.2017.10.260

important instrument for closer and strengthened relations between countries in the same region, as it is the case of the European Union (EU) [1].

The increasing mobility provides the humankind with new opportunities in the present societies, but it also brings new challenges and serious problems [2]. It is generally accepted that sustainable development, and more specifically, sustainable transport, implies finding a proper balance between the current and future environmental, social and economic qualities [3]. The sustainability of the transport system can be evaluated by examining the positive and negative indicators of traffic and transport as they are apparent now or in the near future, which can also be used to set goals and to monitor whether the transport system is moving towards sustainability [3]. These indicators can be defined either based on the quality of the transport system (e.g. congestion delay, commuting speed, variety and quality of transport options available, accessibility, safety) or in its environmental impact (e.g. energy use, emissions of CO_2 and other toxic and harmful substances, waste, noise pollution, land use, disruption and fragmentation of natural areas) [4].

At the world level, the transport sector relies almost exclusively on fossil fuels for its energy supply, a problematic dependence since the oil crisis of the seventies. However, the increasing awareness of greenhouse gas emissions and the negative contributions to climate change from the transport sector are now perceived as the major driving challenges [5]. Between 1973 and 2009 the total amount of oil used in transport almost doubled, with its share only decreasing slightly and still remaining around 94%. In the same period, the share of transport energy use in total world energy use has risen from 23.1% to 27.3%, which contrasts with the industry sector that has reduced its consumption in 29%. Consequently, the share of transport in total oil consumption has increased from 45% in 1973 to 62% in 2009 [6].

The freight transport is continuously growing, and regrettably the least energy efficient transport modes (road and air) are the ones increasing the most, with the total volume rising by 35 % between 1996 and 2006 for EU member states. At the same time the rail and inland waterway freight recorded increases of 11% and 17%, respectively, but their market share have declined [7]. Concerning the passenger transport, the annual average of kilometers travelled by passengers in EU member countries grew by 1.3% between 1996 and 2006. While sea travel declined by 9% in the same period, air travel grew up to 5%. On the other hand, bus and coach travel have decreased from a share of 9% to 8%, whilst railways, tramways and metro systems accounted for 7% of passenger transport [7].

Almost all motorized means of transport use non-renewable energy sources and produce important externalities. Even though it is generally accepted that public transport of passengers is more sustainable than the private one, there are no simple relationships or answers, as the analysis is complex due to the dependence on multiple variables (e.g. occupancy, levels, speed of vehicles, energy consumption, and emission of pollutants) [8]. Nevertheless, some key principles are consolidated, one of which is that high-occupancy public transport, such as rail, bus, tram and metro, come out on top in terms of less energy consumption per passenger kilometer travelled. It is followed by high-speed rail and the majority of cars, with taxis and lorries appearing in the next level. Although distances travelled are long, air transport is listed at the bottom due to the use of large quantities of fuel, which constitutes a problem as it is a key growth market [8]. In what concerns the freight transport, rail is the most energy-efficient transport mode [9], cheaper and faster than road transport, mainly over long distances, suitable for bulky cargoes, and not subject to bad weather or traffic conditions [10].

The track service life and the quality of the ride on a railway are dependent upon a number of different factors, particularly on the track quality, rail quality and rail profile and the position on the railway line (curve, straight track, inclination) [11]. However, the track positioning and alignment also change over time due to the cumulative operating load, axle load and vehicle conditions, the level and structure of vehicle speeds, along with the environmental conditions [12]. Therefore, combining adequate track maintenance strategies with surveilled and optimized line operation should promote an extension of the track service life by extending renewal cycles. Infrastructures' owners are increasingly implementing a diverse set of technology based systems for assisting the maintenance and management of their resources. The large volume of data captured by these systems holds important information, which can be extracted by using proper data mining tools and modelling techniques, is the back bone for a novel predictive approach in maintenance and management [13].

In this context, the main objective of the EVO4Rail project is to design, develop and implement a wireless monitoring system for weighing-in-motion and detecting faulty wheels in railway vehicles, capable of providing important information for a sustainable railway operation and maintenance. The system is composed by three main components: i) Monitoring Equipment laterally installed on the track for measuring the quantities of interest and transmitting the digitized signals to a nearby gateway; ii) Local Station that aggregates and processes data from the monitoring equipment and transmits the key performance indicators (KPIs) to a central server database; and iii) Central Database that contains the information of all local stations installed throughout the infrastructure, which requires the implementation of dedicated software for the operation and management of the entire system.

2. The European railway

Rail transport in Europe has declined in the last decades, especially in freight. Rail's share in the freight land transport market dropped from 32.6 % in 1970 (EU-15) to just 16.7 % in 2006 (EU-27). In absolute terms, rail freight transport activity (EU-15) declined between 1970 and 2006 by about 1%, whereas freight transport by road more than tripled in the same period [14]. As regards the transport of passengers, even though rail travel has increased in absolute terms, the rail's share of land transport has fallen from over 10% in 1970 (EU-15) to a stable 6.9 % in 2006 (EU-27) [14]. Yet, the trends have experienced some improvement in the past few years. The total volume of rail freight has stopped decreasing and the decay of its market share has slowed. For this it may have contributed the significant structural changes that Europe's railways have undergone, namely the open up of the market for greater competition and the increase of technical harmonization [14].

According to the strategy for 2030 and beyond for the European railway sector the main objective is to provide a unified approach to environmental and sustainability topics in the rail sector. It outlines how this sector should be performing in environmental terms between 2030 and 2050 by establishing a clear vision and specific targets, as well as provides a framework that allows companies in the rail sector to make suitable long-term plans [15]. The strategy is built on four key environmental topics: climate protection, energy efficiency, exhaust emissions, and noise emissions. For the target year 2030 the objectives are established as follows [16]:

- to reduce the specific average CO_2 emissions from train operation by 50% compared to the 1990 base year, measured per passenger-km and ton-km (total CO_2 emission level in absolute terms should not exceed even with projected traffic growth);
- to reduce the specific final energy consumption from train operation by 30% compared to the 1990 base year, measured per passenger-km or per ton-km;
- to reduce the total exhaust emissions of nitrogen oxides and particulate matter in absolute terms by 40% compared to the 2005 base year (even with projected traffic growth);
- to target noise and vibration levels socially and economically acceptable allowing 24-hour transport of passengers and goods (2010 base year).

In recent years the decrease in the CO_2 emissions and energy consumption of rail have been reached through increasing the energy efficiency of railway services, further electrification of lines, and a reduction in carbon intensity of the electricity production by the power supply sector. With regard to exhaust emissions and noise, the evolution highly depends on innovative cost-effective technical products capable of replacing the many existing long lifespan systems [15].

In order to achieve these ambitious policy plans the EU has been issuing a number of research and support projects, firstly within the scope of the 7th framework program and currently integrated in Horizon 2020 program. The studies mainly criticized the lack of implementation of policies and investment programs with sufficient stringency, as well as have identified a lag of co-ordination between EU, Member States and railway stakeholders [17]. The massive shift of passengers and freight consignments to rail transport demands for a drastic change in business and policy cultures, and the implementation of the following measures:

- complete the European high speed and priority freight corridor network, close gaps, particularly in border crossing links, and upgrade inter-city main lines to 160 kph;
- reform railways in order to turn them attractive and useful for their customers;
- stablish an inclusive planning by bringing together member states and railway companies, promoting the full collaboration in the operation and management of the trans European network transport (TEN-T) corridors;

- claim for fair market conditions as the most of the competitors transport modes don't have to purchase the permits for CO_2 emissions or to pay for energy and value added taxes, certificates or noise reduction.

For accomplishing this major objective, the European funds for investment aim at overcoming current market failures by addressing market gaps and mobilizing private investment [18]. The main funds are available from the following programs and:

- Connecting Europe Facility with a grant budget of €24.05 billion for TEN-T projects for the 2014-2020 period;
- HORIZON 2020 budget includes €6.3 billion for smart, green and integrated transport for the 2014-2020 period;
- European Structural and Investment (ESI) funds foresee a total of approximately €70 billion for transport projects programmed in the 2014-2020 period (€35.6 billion for transport under the Cohesion Fund and €34.5 billion for transport under the European Regional Development Fund).

In the European area the main associations clustering and/or supporting the most relevant railway stakeholders are the Community of European Railway and Infrastructure Companies (CER), the Union of European Railway Industries (UNIFE) and the International Railway Association (UIC). At the national level the Portuguese Railway Platform (PFP) plays that role.

The CER is an association that joins more than 70 European railway undertakings and infrastructure companies, representing their interests towards the European institutions as well as other policymakers and transport actors. Its main objective is to foment and favor the strengthening of rail as part of a sustainable transport system which is efficient, effective and environmentally sound [19]. The UNIFE represents the European rail manufacturing industry in Brussels and advocates its members' interests also at international level. This association gathers over 100 of Europe's leading large and SME rail supply companies active in the design, manufacture, maintenance and refurbishment of rail transport systems, subsystems and related equipment. It association also brings together 14 national rail industry associations of European countries. Its members have an 84% market share in Europe and supply 46% of the worldwide production of rail equipment and services. The mission of the association is to proactively foster an environment where its members can provide competitive railway systems for the growing demand for rail transport [18]. The UIC is a worldwide professional association whose mission is to promote railway transport around the world and to help its members to optimally meet all the current and future challenges of mobility and sustainable development. This association also proposes new ways to improve technical and environmental performance of rail transport, increase competitiveness and reduce costs. Another major challenge embraced by this body is the boost of the railway system's interoperability, particularly on an international scale. Additionally, UIC develops and facilitates all forms of international cooperation among members, and assists the sharing of best practices [20]. The PFP joins the end users, managers, industry, SMEs and academies to build critical mass with a common strategical agenda for medium and long term [21], aiming at:

- Developing technologies, products and services
- Increasing national competitiveness in the field of railways
- Obtaining public and private financial resources to feed innovation
- Changing the perception that railways is something antique
- Becoming recognized at an international level
- Creating added value for the country and for the regions

3. The EVO4Rail system

The project aims at designing and developing a wireless monitoring system for the weighing-in-motion (WIM) and defective wheels detection (DWD) in railway vehicles, with the purpose of optimizing the railway operation and maintenance processes, for which the following components are being developed:

- Monitoring Equipment *(Measuring nodes and sensing modules)*: sets of integrated hardware and firmware elements to be laterally installed on the track, for measuring a certain quantity (depending on the built-in sensor) and transmitting the digitized signals to a nearby gateway inside a wayside Local Station, so that the weight of the vehicle's wheels and their defects can be analysed;

- *Local Station / Aggregation and Data Processing Unit*: equipment that integrates hardware and software for aggregating and processing data from all monitoring equipment installed on site. Subsequently, the information of interest (e.g. KPIs) will be transmitted to the database of a central server;
- Management Software *and Central Database*: the *Central Database* should contain the information of all systems installed throughout the infrastructure, and should be endowed with applications capable of: a) presenting the data of interest to the operator according to its needs and requirements; b) serve as a direct interface to the local systems software for maintenance or raw data collection purposes; and c) serve as interface to other management or results visualisation software of the infrastructure manager as is the case of the Supervisory Control and Data Acquisition (SCADA) system.

The definition of the architecture is carried out in a comprehensive and modular way in order to anticipate/foresee the integration in the future of new devices, sensors and software, as well as the evolution of the system development, which is expected to occur in two phases:

- Phase *1* - All measuring nodes and sensing modules installed in the track will be powered and have communication through wired technologies. At this stage the main objective is to implement a wired connection in sequence for the several components (daisy-chain), thus enabling the use of a single cable for the whole installation;
- *Phase 2* - All measuring nodes and sensing modules deployed in the track will use wireless technology for communication and preferably also for power purposes. To this end, short range communications and WPT technologies should be implemented, making possible that a gateway radiates power to the monitoring equipment, which in turn will also send back the data wirelessly.

The architecture of the system is of the client-server type in which the Local Station (LS) acts as a client that sends the data automatically to the Central Server (CS). A different and unique client is also the Operations Control Station (OCS) where all the actions to perform in the system will take place.

The LSs will have the ability to provide real time measurements in order to enable the detection of any existing problem. All data generated at the wayside LSs is sent to a Remote Server (RS) for backup, which can be accomplished by a Cloud storage service, either through a web service API or applications using API (e.g. cloud desktop storage, a cloud storage gateway or web-based content management systems), or simply by implementing a co-located cloud computer service. The CS will send the significant data, such as the KPIs processed at the LSs and the alarms or notifications generated by the CS itself, to the servers of the infrastructure owner systems, namely the SCADA. It is also foreseen the possibility of the LSs receiving train related information directly from the CDS-ATT (Central Dispatch System – Automatic Train Tracking) for a clear identification of each log entry associated to an occurred event. Fig. 1 presents a schematic representation of the system general architecture and of the LS.

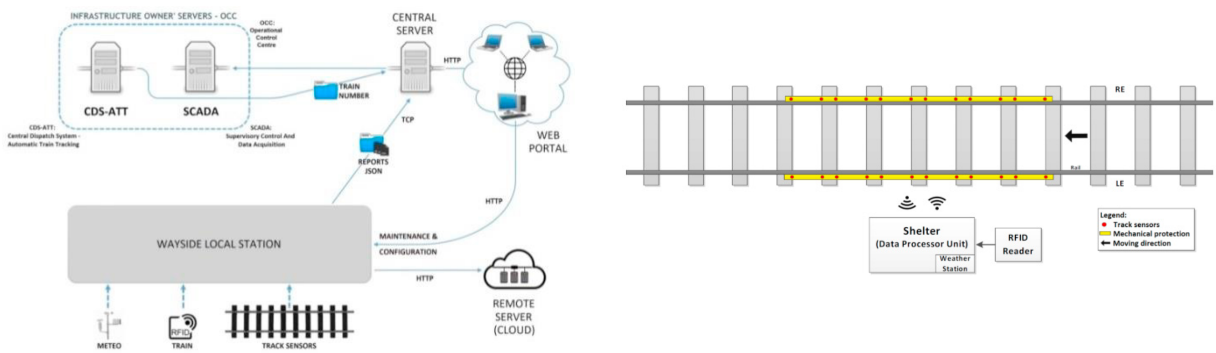

Fig. 1. Schematic representation: (left) System architecture; (right) Local Station.

4. Final considerations

The EVO4Rail project was presented briefly in this paper, which targets the design, development and implementation of a new wireless monitoring system for weighing in motion and wheel defect detection of trains. As the infrastructures' owners are increasingly demanding for technology based systems in order to assist the maintenance and management of their resources, this novel system may positively impact the railway market in getting key data concerning the vehicles' wheels condition, axle loads, cumulative operating load and travelling speeds. This information should promote an extension of the track service life by extending renewal cycles, therefore favoring a sustainable rail transport in the near future.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the European Regional Development Fund (ERDF) through the Operational Program for the Northern Region of Portugal (Norte2020) to the project EVO4Rail – Monitorização sem fios para ferrovia, NORTE-01-0247-FEDER-010957, under which a Post-Doctoral Fellowships was granted. The authors would also like to thank IP – Infraestrutras de Portugal, S.A. for their assistance and cooperation, as well as the partnership with FEUP (Faculty of Engineering of the University of Porto) in preceding projects.

References

[1] Eurostat (2015). "Sustainable development in the European Union – 2015 monitoring report of the EU Sustainable Development Strategy", Luxembourg.
[2] Schafer, A. (1998). "The global demand for motorized mobility." *Transportation Research Part A: Policy and Practice*, vol. 32, 6: 455-477.
[3] Steg, L. and Gifford, R. (2005). "Sustainable transportation and quality of life." *Journal of Transport Geography*, vol. 13: 59-69.
[4] Abdallah, K.B., Belloumi, M. and De Wolf, D. (2005). "Indicators for sustainable energy development: A multivariate cointegration and causality analysis from Tunisian road transport sector." *Renewable and Sustainable Energy Reviews*, vol. 25: 34-43.
[5] Proost, S. and Van Dender, K. (2012). "Energy and environment challenges in the transport sector." *Economics of Transportation*, vol. 1: 77-87.
[6] International Energy Agency (2011). "Key world energy statistics.", Paris, France.
[7] European Environment Agency (2009). "Transport at a crossroads – TERM 2008: indicators tracking transport and environment in the European Union", Copenhagen, Denmark.
[8] Banister, D. "Sustainable Transport and Public Policy." In *Transportation Engineering and Planning - Volume 2*. Eds. Kim, T. J. (2009).
[9] UIC-ETF (2015). "Rail Transport and environment – Facts & Figures", Paris, France.
[10] Dincer, I., Hogerwaard, J. and Zamfirescu, C. (2016) "Clean Rail Transportation Options.", Springer International Publishing, Switzerland.
[11] Popović, Z., Lazarević, L., Brajović, L. and Gladović, P. (2014). "Managing rail service life." *Metallurgy*, vol. 53, 4: 721-724.
[12] Andrews, J. (2013). "A modelling approach to railway track asset management." In *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, vol. 227, 1: 56-73.
[13] Antony, J.J.V. and Nasira, G.M. (2013). "Towards Predictive Maintenance and Management in Rail Sector: A Clustering Approach." In *Proceedings of the 2013 International Conference on Recent Trends in Information Technology (ICRTIT)*, Chennai, India.
[14] DGET (2008). "Modern rail modern Europe – Towards an integrated European railway area", Luxembourg.
[15] CER-UIC (2012). "Moving towards sustainable mobility – A strategy for 2030 and beyond for the European railway sector", Paris, France.
[16] Kettner, J. (2012). "Moving towards sustainable mobility." In *Proceedings of the 12th UIC Sustainability Conference*, Venice, Italy.
[17] Doll, C., Rothengatter, W. and Schade, W. (2015). "The Results and Efficiency of Railway Infrastructure Financing within the EU", Brussels, Belgium.
[18] UNIFE (n.d.). *UNIFE The European Rail Industry*. Retrieved June 30, 2017, from http://www.unife.org/.
[19] EC (n.d.). *The Voice of European Railways*. Retrieved June 30, 2017, from http://www.cer.be/.
[20] EC (n.d.). *UIC The Worldwide Railway Organisation*. Retrieved June 30, 2017, from http://www.uic.org.
[21] EC (n.d.). *PFP Portuguese Railway Platform*. Retrieved June 30, 2017, from http://www.ferrovia.pt/.