Integrating on-board authorisation measurements with in-service measurements and risk assessment towards more effective running dynamics approval

Riccardo LICCIARDELLO[1], Gabriele MALAVASI[1], Luca RIZZETTO[1]

[1]SAPIENZA Universita' di Roma DICEA Dept. of Civil, Building and Environmental Engineering, Rome, Italy
Corresponding Author: Riccardo LICCIARDELLO (riccardo.licciardello@uniroma1.it)

Abstract

In-service wheel-rail contact force measurements are increasingly being performed with both on-board and wayside systems for various purposes, such as identifying problems on single vehicles (overloading and unbalance, wheel flats etc.) and enabling predictive maintenance of components. Such a wealth of measurements can be expected not only to fulfil their original purposes, but also to steadily fill in vehicle-track interaction knowledge gaps if properly exploited - e.g. with a big-data approach. One possible exploitation regards the authorisation to place rolling stock in service from the point of view of running dynamics. This issue is carefully addressed in European legislation and usually requires a significant extent of on-track testing. It is still widely considered a topic where significant cost reductions could be achieved without sacrificing safety, and a possible barrier to innovations such as active primary suspensions and steering. A number of research directions have been addressing this issue, first and foremost the use of virtual methods (Multi-Body Simulation) as a supplement to on-track testing. However, the process defined in the legislation opens the door to other possible improvements. It comprises as a key element "return of experience", and although still essentially rule-based, is open to risk-based approaches such as that defined in the European Common Safety Method for Risk Assessment (CSM RA).

Having developed both on-board and wayside wheel-rail contact force measurement systems, the authors consider that the "return of experience" element may further be specified by taking into account, for a given type of rolling stock, the lateral forces and wheel loads that are increasingly being measured in actual service.

Keywords: vehicle, authorisation, risk, wheel, load, measurement

1. Introduction

1.1 EU regulatory framework

In the European Union, rolling stock is defined as a "subsystem" of the EU rail system and similarly to the other subsystems it is placed on the market according to the the so-called "Interoperability Directive" [1], which is in line with the legislation for any other product. National legislation must conform with this document and locomotives and passenger vehicles must conform with the subsystems' "Loc&Pas" TSI Technical Specifications for Interoperability [2], which set out "essential requirements" for the products. Of interest for this paper is the TSI's clause §4.2.3.4 "Rolling stock dynamic behaviour", which is largely based on mandatory compliance with standard EN 14363 [3].

Authorisation for placing in service is considered by the authorities as a short period in time in which the design of the rolling stock type is validated, see Fig. 1 which was developed as a clarification for the previous Interoperability Directive. Safe integration of the vehicle into a network with given characteristics is a key part of the required assessment which may be performed according to another fundamental piece of legislation: the Safety Directive [4] which refers to the so-called Common Safety Method (CSM) for Risk Assessment (RA) [5].

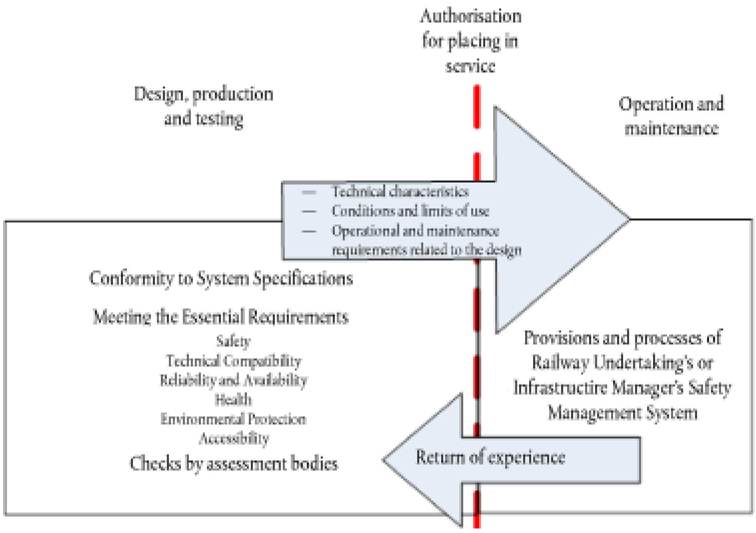

Fig. 1: Activities before and after an authorisation for placing in service according to European legislation (Commission Recommendation 2014/897/EU).

In the latest issue of the Interoperability Directive the focus of authorisation is shifted to placing on the market by the manufacturer. Following up on the concepts of the 2004 Safety Directive, the Railway Undertaking (RU) takes up the risk of placing in service an authorised type on a certain network. The RU must also cover the risk that the in-service characteristics of the vehicles deviate from those of the vehicle tested in the authorisation phase. For a RU, the introduction of the new vehicle type is considered as a “significant change” to the rail system for which safety risks must be assessed according to the CSM RA [5].

In summary, the EU legislation considers vehicle authorisation and risk management during operations as two distinct but strongly correlated aspects.

1.2 Technical background

From the technical point of view, the basis for authorisation tests regarding running dynamics are historically on-board measurements following EN 14363: wheel lateral and vertical loads (Y and Q) and accelerations. Recent years have seen efforts to expand the use of validated Multi Body Simulation models, already considered in the standard, which is a tool capable of comparable accuracy with the traditional experimental process (see e.g. [6] and [7] based on the results of the EU research project DynoTRAIN 2009-2013). MBS may be used for example to support authorisation through virtual testing of a given vehicle on a network with different characteristics from those tested experimentally or of vehicles with limited changes with respect to a previous design.

In-service measurements do not currently directly contribute to the authorisation phase, but they could contribute to the management of the associated risks and inform the design and authorisation phase as “return of experience” as envisaged in Fig. 1. Measurements that could be useful in this sense are:

- on-board contact force measurements (longitudinal, lateral and vertical wheel loads) as studied e.g. in the on-going RUN2Rail research project [8], which are still not widespread, and on-board acceleration measurements.
- wayside contact force measurements, which are nowadays increasingly abundant due to the spread of automatic wayside load checkpoints for vertical [9] but more recently also lateral loads [10].

In a broader sense this fits within a widely studied rail-sector problem: how to use the enormous amounts of data available for many different purposes (big-data approach to rail).

This paper intends to provide ideas for research on how to integrate in-service measurements and risk assessment into the processes of authorising vehicles and managing their risks. The overall goal is to provide direct output to regulatory and standardisation documents with a similar approach to that used in the DynoTRAIN project [11], in order to further reduce the burden of authorisation and risk management whilst maintaining, if not improving, the high levels of safety already achieved.

2. Characteristics of the available measurements

2.1 On-board contact load measurements

The Loc&Pas TSI is the highest-level document that points to which on-board measurements are needed for authorisation from the point of view of running dynamics behaviour (§4.2.3.4). In this regard it specifies limit values for running safety and track loading. For these two aspects it relies on EN 14363 which also addresses other aspects. The on-board measurements required by EN 14363:2005 are indicated in Fig. 2, along with a concise representation of the process to obtain them. Although a new version of the standard was issued in 2016, this is still not referenced in the TSI and therefore the older version still applies.

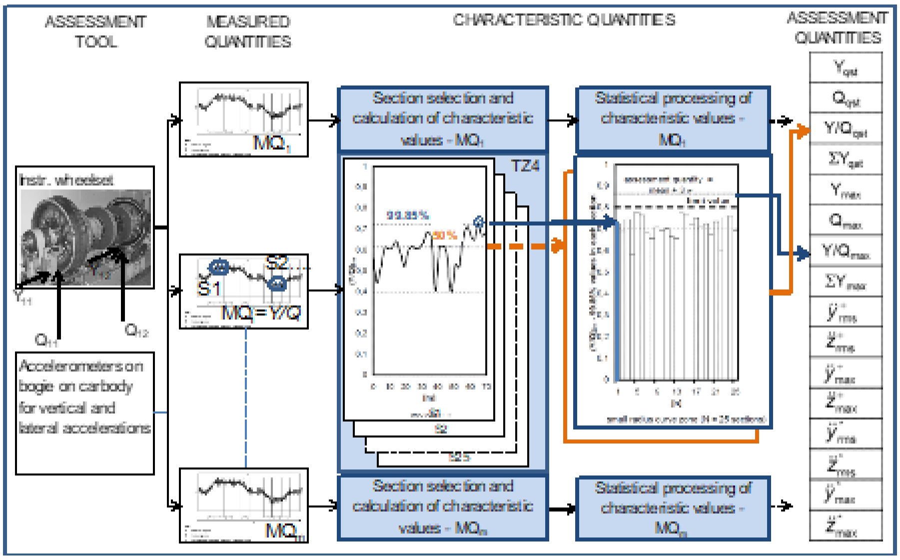

Fig. 2: Assessment quantities required by EN 14363:2015.

For a completely new design, the prototype train requires instrumentation comprising load-measuring wheelsets and accelerometers. After initial fixed-site tests, tests are performed in controlled conditions on lines otherwise open to service at speeds of up to 10% more than the allowed service speed. Track layout and irregularities, as well as running conditions (speed, cant deficiency etc.) are specified including the numerosity of required cases. For each measured quantity, characteristic quantities are drawn from the signals and put together to form a statistical sample. This means acquiring signals over a few tens of kilometers on representative railway lines (see e.g. Figure 3 which shows a line in Italy with several curves in the range required for the “very small curve radii” test zone TZ4, one of the four prescribed). The assessment quantity is a statistic (e.g. mean + 3 standard deviations for running-safety related quantities), representing e.g. an estimate of a quasi-worst situation. Examples of assessment quantities are the quasi-static lateral and vertical loads (Yqst, Qqst) for track loading (rail bending), the maximum sum of lateral loads (SYmax) for track shift, the maximum derailment ratio Y/Qmax. The assessment process is characterised by satisfactory accuracy as demonstrated by several applications and also theoretically in the research project DynoTRAIN [7].

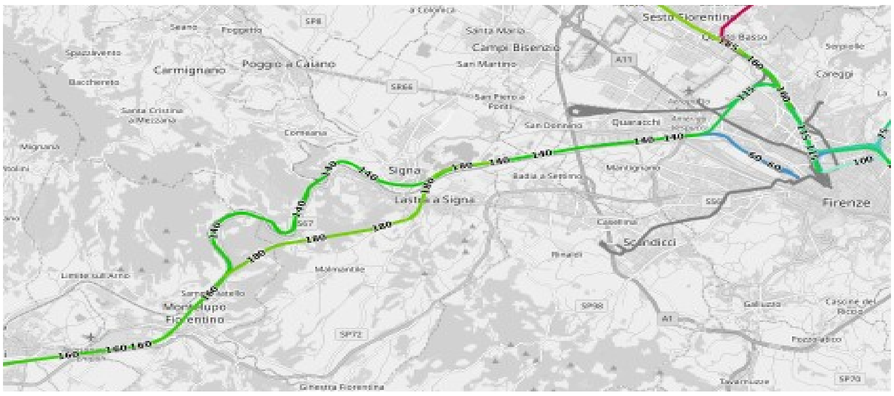

Fig. 3: Map of line with several curves of different radii suitable for the low-radius tests (TZ4) according to EN 14363.

2.2 Wayside contact load measurements

Wayside interaction force measurement systems are based on the measurement of rail strain or deflection caused by passing trains.

For example, by fitting strain gauges in specific points on the rail (foot and web), it is possible to quantify separately the vertical and lateral loads that cause the strains.

Vertical forces (Q) are present on every wheel both on straight and curved track. Lateral forces (Y) are generally much larger in curves than on straight track. The higher values occur on the leading axles of bogies and particularly on the so-called guiding wheel (leading outer wheel). The derailment ratio (Y/Q) is important particularly for the first wheelset of each vehicle.

Figure 4 shows an example of measured force components Q and Y for a train composed of a locomotive and three coaches passing over a load checkpoint.

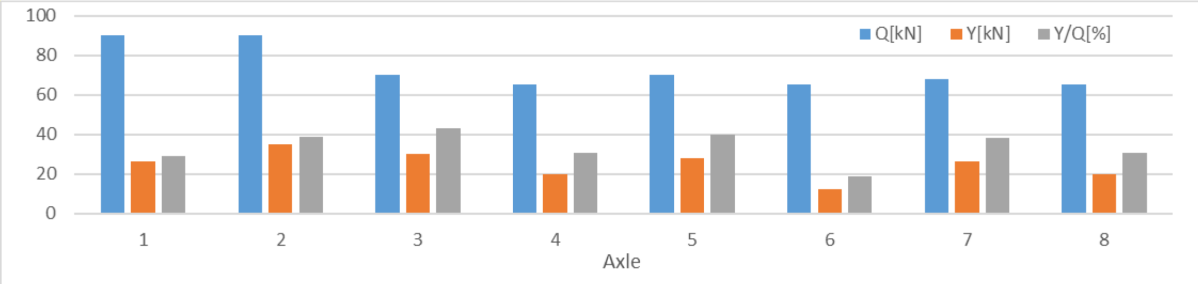

Fig. 4: Example of vertical and lateral forces Y and Q measured by a wayside system installed in a curve on the passing guiding wheels of each bogie of a train (composition: n. 1 2-bogie loco + n. 3 2-bogie coaches).

The following list exemplifies some important pieces of information that may be drawn for passing trains:

- vehicle load distribution on each wheel;
- distribution of vertical loads between two wheels of the same wheelset (effect of lateral curving forces);
- variation of vertical load on the same wheel as it passes over consecutive measurements sections of the same checkpoint;
- lateral forces acting on each wheel (adhesion forces, flange force);
- Y/Q ratio on each wheel.

All information can be recorded continuously for all trains passing over the load checkpoint. Automatic data processing can provide the most significant indicators and eventual alarms.

3. Safety risks and placing on the market

The CSM RA [4] states that the risk acceptability of a significant change such as the introduction of a new vehicle type should be evaluated by using one or more of the following risk acceptance principles (see Fig. 5):

- the application of codes of practice,
- a comparison with similar parts of the railway system,
- or an explicit risk estimation.

The CSM is an acceptable means to prove safe integration of a vehicle into the network for the purposes of placing it onto the market. As an established code of practice, EN 14363 covers the risks related to running dynamics (essentially derailment and clearance gauge infringement). However for innovative systems such as active steering there are no codes of practice for RA and the explicit risk estimation channel is very difficult because of the obvious lack of statistics related to the probability of system failure and currently under investigation (see [5]). This last problem could be partially covered by means of simulations (see 2016 version of EN 14363), but this would not completely close out the related risks.

Wayside measurements offer the great opportunity to exploit the reference system channel (formed by the set of measurements on all trains already in commercial service) to be used to assess innovative systems using the second risk acceptance principle. Sets of measurements on commercial trains could represent a better reference system than the thresholds currently indicated in the various standards referred to by the TSIs.

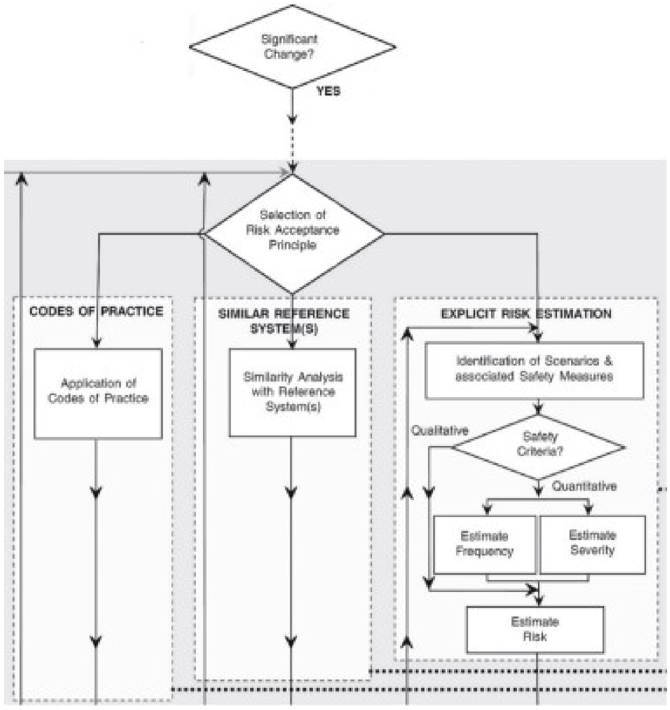

Fig. 5: CSM RA risk acceptance principles.

4. Knowledge contributed by wayside systems

Contact forces govern the stability of the wheel-rail system. Their values depend on operational / structural vehicle characteristics, on wheel-rail contact characteristics (e.g. profile wear, adhesion coefficient) and on running characteristics (speed, traction/braking).

The main operational/structural characteristics that may influence contact force distribution are shown in Table 1.

Table 1: Main operational/structural vehicle characteristics influencing contact loads.

Operational/structural vehicle characteristics	***Types***
Service	Urban, passenger Regional, passenger High-Speed, passenger Solid freight Liquid freight
Traction power	Concentrated Distributed
Composition	Blocked Variable
Suspension	Single-stage/double stage Passive/active secondary (e.g. tilting)
Payload	Fully laden Empty

Depending on their installation points on the network, load checkpoints can provide information on:

- a given vehicle (or vehicle type) passing on the same track at different times under different operational conditions (e.g. payload, speed etc.) or in different structural conditions (suspension state, wheel profiles etc.);
- vehicles with different operational/structural characteristics (Table 1) passing under the same track conditions.

The checkpoints are thus capable of a good actual picture of the interaction forces and constitute a significant terms of comparison for the on-board measurements. The key contact loads required for authorisation purposes for on-board systems are measurable. What is currently missing is the required variability of conditions which is expected to increase as the number of installed checkpoints increase. A careful choice of installation points would support the integration of on-board and wayside measurements. Railway Undertakings and Infrastructure Managers would also have a useful database for the management of the associated risks as required by the Safety Directive, but also for other aspects such as predictive vehicle and track maintenance.

Such and other valuable contributions to the knowledge of vehicle-track interaction phenomena and their evolution over time should provide an incentive to IMs and to the whole sector to extend their installation in critical network points thus contributing to a safer rail system.

5. Conclusions

The discussion above outlines a possible research theme that could deliver a process for rolling stock authorisation based on an optimal combination of on-board measurements according to today's current practice, integrated with in-service measurements, and proposed integrations to the legislative, regulatory and standardisation framework.

At the moment of writing, there is no news in Europe regarding the use of in-service data as proposed. The key objective of the research is to devise a strategy to use the wayside measurements of in-service trains as a reference system to assess the acceptability of the risks related to the integration of a new rolling stock type on a given network, and support the demonstration that it is a "safe integration" as required for its authorisation to be placed on the market. To this end it is important to know the current practices around the world, and thus international collaboration would be of great benefit. There is potential for implementation certainly in Europe. Potential for implementation in other countries would depend on their current practice, and actually something similar to the approach proposed might actually be already used. The impact on railway business is potentially quite high. The main benefits would be the reduction of authorisation costs with an unchanged or improved risk in terms of safe integration between rolling stock and network. The main cost of implementation would be the changes to the regulatory framework and the consequent administrative costs for companies. A favourable cost-benefit ratio would be expected.

Acknowledgment

The Authors wish to acknowledge the European Commission, the European Agency for Railways and the European Standardisation Committee CEN for their continued effort in clarifying the framework towards a safer and more efficient rail system.

References

[1] Directive (EU) 2016/797 of the European Parliament and of the Council of 11 May 2016 on the interoperability of the rail system within the European Union

[2] Commission Regulation (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union

[3] EN 14363:2016+A1:2018 Railway applications - Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behaviour and stationary tests

[4] Commission Implementing Regulation (EU) No 402/2013 of 30 April 2013 on the common safety method for risk evaluation and assessment

[5] Goodall, R., Hughes, P., Licciardello, R., & Stichel, S. (2019). An integrated, systems-based approach to authorisation of actively-controlled running dynamics. 12th World Congress on Railway Research, October 28 – November 1 2019, Tokyo, Japan.

[6] Götz, G., & Polach, O. (2018). The influence of varying input parameters on model validation results. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 232(2), 529-541.

[7] Licciardello, R., Funfschilling, C., & Malavasi, G. (2017). Accuracy of the experimental assessment of running dynamics characteristics quantified through an uncertainty framework. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 231(8), 945-960.

[8] DEMADONNA, A. 2018. Run2Rail: Innovative RUNning gear soluTiOns for new dependable, sustainable, intelligent and comfortable RAIL vehicles. In: UNIFE (ed.) Run2Rail.

[9] EN 15654 series, Railway applications - Measurement of vertical forces on wheels and wheelsets.

[10] Cortis, D., Bruner, M., Malavasi, G., Rossi, S., Catena, M., & Testa, M. (2017). Estimation of the wheel-rail lateral contact force through the analysis of the rail web bending strains. Measurement, 99, 23-35.

[11] Hanley, R., Licciardello, R., Martin, S., & Rose, K. (2014, April). TrioTRAIN: bringing research and standardisation closer together. In Transport Research Arena (TRA) 5th Conference.