AUTOMATED RAIL CARGO CONSORTIUM:

DEVELOPMENT OF FUNCTIONAL REQUIREMENTS FOR SUSTAINABLE AND ATTRACTIVE EUROPEAN RAIL FREIGHT

WP 1 – Deliverable 1.3 – Automated Brake Test

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Leader/Responsible of this Deliverable:
Dr. Gerhard Troche – KTH Railway Group

Authors:
Dr. Gerhard Troche – KTH Railway Group
Dr. Carlos Casanueva Perez – KTH Railway Group

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REPORT CONTRIBUTORS

Name	Company	Details of Contribution
Dr. Gerhard Troche	KTH Railway Group	Initial Draft and Revisions
Dr. Gerhard Troche, Dr. Carlos Casanueva Perez	KTH Railway Group	Second Draft
Dr. Gerhard Troche	KTH Railway Group	Final Version

EXECUTIVE SUMMARY

This deliverable is related to the Shift2Rail-project ARCC WP 1, “Automated Train Operation”, sub-task 1.1.4 regarding the automation of brake tests for freight trains. It provides concepts and requirements for fully and partially automated brake tests primarily with a view on reducing time and costs associated to the execution of brake tests on freight trains.

The first part of the document contains an analysis of current procedures for carrying out brake tests on freight trains, identifies the shortcomings and justifies the need for improvements through automation, taking into account automation of procedures in the rail freight production system in a broader perspective.

This analysis is followed by proposals for two solutions for automated brake testing, one for a partial automation, one for full automation of the brake test. In the first solution, partial automation, any extra equipment required onboard the rolling stock is concentrated to the locomotive and the provision of certain lineside equipment – i.e. no modification of wagons is needed. This solution aims at low implementation barriers and short introduction times, thus being able to deliver “quick wins” to the rail freight industry; it is partly based on innovative solutions to brake testing recently implemented in freight train operations in Canada.

The second solution, full automation, eliminates entirely any manual interaction along the train. It reduces the time-consumption for brake testing even further and does not require any lineside equipment. At the same time, it requires in addition to an onboard-unit on the locomotive the equipment of all wagons in a train with sensors, electric power for the sensors and data transmission, and either the use of automated couplers with an integrated data transmission cable or wireless data transmission to the locomotive; the system must have the capability to identify the order of wagons in a train. It requires also that certain other tasks, which are not part of the brake-test as such, but which today are carried out in the context of the manual brake-testing procedures, can be automated. Thus, migration barriers for this solution are higher, while at the same time certain other innovations required for its implementation – such as a train-bus for data transmission

along the train, electric power supply on the wagons and possibly automatic couplers – also deliver other important benefits beyond the automation of the brake test.

The last part of the document contains recommendations for next steps, covering both aspects of testing and demonstrating the proposed solutions under real-world conditions, as well as identifying needs for further development, in particular with a view on fulfilling pre-conditions for full automation of the brake test.

Contents

1. INTRODUCTION

1.1 Background

The digitalization of rail freight is creating huge opportunities for rail to increase the efficiency and quality of its production processes, to raise asset productivity and to improve existing and create new value-added services to customers. Digitalization paves the way for automating production processes in rail freight traffic. One important element in the automation of rail freight concerns train preparation processes. Several railway companies in Europe are addressing this aspect.

This report focuses on the automation of *brake testing*, which is a central process in the train preparation. At the moment, brake tests have to be carried out manually by employees checking for each newly formed train (and whenever required by operational rules) the functioning of the brakes – in the case of a full brake test on every wagon – before departure. This is a time-consuming and therefore costly process. Since the manual brake test has to be performed outdoor under sometimes harsh working conditions it is also an increasingly less attractive job and railway undertakings might face challenges to recruit staff for this activity in the future; there are also issues of (work) safety in the context of brake tests. Further, with the time needed for carrying out brake tests today, the current manual processes can also make it increasingly difficult to meet market requirements by shippers with regard to transport time and may be a hinder for introduction of new production methods in rail freight – e.g. train-coupling and –sharing operations, where several freight trains are running coupled over certain line sections.

Against this background the railway sector have a strong impetus to exploit possibilities to partially and eventually fully automate brake testing processes.

1.2 Objective

The objective of the present report is to investigate and propose possible solutions to automate the brake testing process for freight trains.

The overall objective is to make rail more attractive on a highly competitive transport market by generating benefits to customers through more market-oriented transport services and to society by promoting modal shift to rail, which continues to be the most energy-efficient and environmentally friendly mode of transport.

With regard to the needs of the railway sector more specific objectives are to reduce costs and time needed for brake testing of freight trains and to increase the attractiveness of railway jobs as well as to ensure high work safety and comfort.

One important condition has been to include in a new approach to brake testing solutions with low implementation barriers which could be implemented relatively quickly – e.g. within a timeframe of circa two years. For this reason a solution based on a *partial* automation has been included as a possible first step, which, while not delivering the full benefits of a fully automated brake test, could be implemented at low cost and already deliver tangible benefits to railway undertakings as well as employees in a relatively short time frame.

At the same time a solution should be proposed which would allow for a full automation of the brake test.

Since it has not been possible nor been an objective to test the proposed solutions within the framework of the project, a further objective has been to identify the need for and suggest next steps addressing open questions, for testing and for possible subsequent implementation of the proposed solutions and to clarify the pre-conditions – e.g. with regard to implementation of other technical innovations – and possible limitations for the implementation of both the solution for a partial automation and the solution for a fully automation of the brake test.

1.3 Methodology

The elaboration of the approach and solutions for brake testing presented in this report are mainly based on a combination of three different methods:

-Literature review and internet research (focused on ongoing activities in the field, mostly in Europe and North America)

-Information gathering through contacts and meetings with railway undertakings, suppliers and researchers involved in rail freight automation projects

-"Brainstorming" among experts at KTH Railway Group (Division of Transportation and Logistics and Division of Rail Vehicles)

The combination of these approaches, together with the experience of the authors, gave a good understanding of the market needs, the current processes and the possibilities and feasibility of (partial and full) automation of brake testing of freight trains.

The results and proposed solutions have also been discussed with experts from the railway sector – in particular brake experts from railway undertakings – in order to achieve an independent preliminary assessment.

It should be emphasized, however, that the project did not involve any prototyping and thus any testing of the solutions proposed. Thus they should be seen as solutions which by experts are considered as appropriate and very likely feasible, but there is a need to follow up the current project with testing, in laboratory and ultimately in operations under real-world conditions; also, there is a need to address certain open issues before the full benefits of an automation of the brake testing process can be reaped (at least in the case of full automation). Concerning the scope of implementation of partially automatized brake testing even certain further analysis of i.a. infrastructure concerned will be necessary.

2. CURRENT BRAKE TESTING PROCEDURES AND EQUIPMENT

2.1 PRINCIPLE DESIGN OF AIR BRAKES

The operation of freight trains relies today, almost world-wide, upon a fail-safe air brake system which is based on a design patented by George Westinghouse in 1868. Even most passenger trains rely basically on the same system but may be complemented by additional brake systems.The Westinghouse-brake was further developed by various companies around the world, but the basic principle is maintained.

The in Europe widely spread **Kunze-Knorr brake** (*Kunze-Knorr-Bremse* or *KK-Bremse*) was the first graduated brake for freight trains in Europe. It is also used on passenger trains. When introduced after the First World War freight train brakes switched from manual operation to air-brake operation in several European countries. The German State Railways (Deutsche Reichsbahn) put the cost of equipping practically the entire German freight wagon fleet with Kunze-Knorr brakes within a ten-year period between 1918 and 1927 at 478.4 million Reichsmark. Thus, it was a substantial investment; however, the savings in operating costs stemming from faster freight services and having fewer brakemen was estimated by the German State Railways to be almost 96.3 million Reichsmark annually.

The air brake system uses air pressure to charge air reservoirs on each wagon. (Only) with full air pressure in the brake pipe the brakes of each wagon are released. A reduction or loss of air pressure signals each wagon to apply its brakes, using the force of compressed air in its reservoirs (compare fig.1).

The control valve is also called triple valve since it performs three functions:

1) charging air into an air reservoir,
2) applying the brakes, and
3) releasing them

When the train driver applies the brake by operating the locomotive brake control valve, the pressurized air in the brake pipe is released into the atmosphere at a controlled rate, reducing the brake pipe pressure and in turn triggering the triple valve on each car to feed air into its brake cylinder, which presses the brake blocks against the running surface of the wheels. In order to release the brake, the train driver closes the drivers control valve on the locomotive, allowing the brake pipe to be recharged by the compressor of the locomotive. The subsequent increase of brake pipe pressure causes the triple valves on each wagon to discharge the contents of the brake cylinder to the atmosphere, releasing the brakes and recharging the reservoirs.

The system is thus fail-safe, since any failure in the brake pipe, including the case of (unintentional) separation of the train, will cause a loss of train line pressure (in case of a train separation in both parts of the train), causing the brakes to be applied and bringing the train to a stop, thus preventing a runaway train.

Modern air brake systems serve two functions:

- The **service brake**, which applies and releases the brakes during normal operations
- The **emergency brake**, which applies the brakes rapidly in the event of a brake pipe failure or an emergency application by the train driver (or in case of passenger trains, any person pulling the emergency brake handle on any of the wagons/coaches, thereby opening the air brake pipe, releasing the pressurized air to the atmosphere)

During normal operations, the train driver makes a "service application" or a "service rate reduction", which means that the brake pipe pressure is reduced at a controlled rate to a controlled level of air pressure in the brake pipe. It takes several seconds for the brake pipe pressure to reduce and consequently takes certain time for the brakes to apply throughout the train. The longer the train is, the longer is the time span between application of the brakes on the first wagon and application of the brakes on the last wagon. The same applies to releasing of the brakes. In the event the train needs to make an emergency stop, the train driver can make an "emergency application" which immediately and rapidly vents all of the brake pipe pressure to atmosphere, resulting in a more rapid application of the train's brakes. An emergency application also results when the brake pipe becomes separated – e.g. in case of derailments or breaking couplers – or otherwise fails, as all air will also be immediately vented to atmosphere.

An emergency application brings in an additional component of each wagon's air brake system: the emergency portion. Normal service applications transfer air pressure from the service portion to the brake cylinder, while emergency applications cause the triple valve to direct all air in both the service portion and the emergency portion of the dual-compartment reservoir to the brake cylinder, resulting in a stronger application (ca. 20-30%).

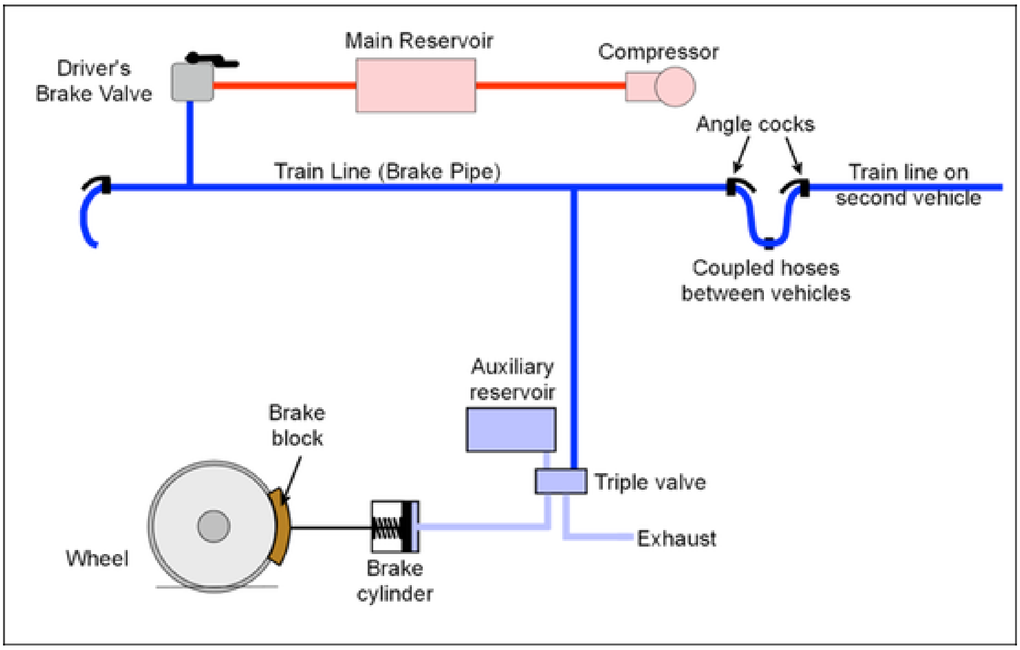

Figure 1: Schematic illustration of a freight train air brake system (Source: www.railway-technical.com (retrieved 2017-10-20)

The use of distributed power mitigates somewhat the time-lag problem with long trains, because a (radio) signal from the train driver in the front locomotive commands the distant units – which can be other locomotives in the middle or at the end of the train or devices on (all or some of the) wagons or (temporarily) mounted devices, such as end-of-train (EOT)-devices – to initiate brake pressure reductions that propagate quickly through adjacent wagons.

Limitations

The Westinghouse air brake system is very reliable, but not infallible. There are several reasons for problems which may occur in certain situations and under specific circumstances:

One is that the wagon reservoirs will only be recharged if the brake pipe pressure is higher than the reservoir pressure; also the pressure in the wagon reservoirs will rise at maximum only to the same level as in the brake pipe. Full recharging of the reservoirs on a long train can take considerable time, up to several minutes.

When the brakes must be applied before recharging of the wagon reservoirs has been completed, a bigger reduction of the brake pipe pressure will be necessary in order to achieve a certain amount of braking effort. Thus, in a situation where many successive brake pipe pressure reductions are made in short time, a point may be reached where wagon reservoir pressure will be severely depleted, resulting in a substantial reduction of the brake force, causing the brakes to brake insufficiently or in worst case not at all; this is a problem particularly on long descending gradients, such as on the descending sections of railway lines across mountain passes.

Solutions

There are several solutions to tackle the above-mentioned problems:

One solution is operational, i.e. to halt the train on long descending grades in good time in order to recharge the wagon reservoirs.

Another solution is to use so-called dynamic (rheostatic) braking where the locomotive(s) assist in retarding the train. Often, mixed braking, i.e. the simultaneous application of dynamic and train brakes, is used to maintain a safe speed. Also in the case of electric traction and in order to allow regenerative braking, i.e. the generation of electricity fed back into the overhead line, braking with the locomotive is used as much as possible. However, the brake effort from the locomotives alone would not be sufficient to bring a train safely to a complete halt within the signal distances used today.

A third, technical solution to the loss of brake pressure is the so-called two-pipe system, fitted on most modern passenger stock and nowadays even freight wagons. In addition to the traditional brake pipe, this improvement includes an additional main reservoir pipe, which is continuously charged with air directly from the locomotive's main reservoir. The main reservoir is where the locomotive's air compressor output is stored. Thus, the two functions (a) controlling the brakes and (b) supplying air to the wagon reservoirs are using separate pipes in this solution; the wagon reservoirs can be charged independently of the brake pipe. This solution helps to reduce the above-mentioned pressure loss problems, and also reduces the time needed for the brakes to release, since the brake pipe only has to recharge itself.

The air brake system here briefly described allows a safe operation of trains. However, the safety provided by the air brake system can only be guaranteed, if the brake system functions properly. In this context it is has to be particularly taken into account that the brake pipe of a train is regularly becoming disintegrated and formed again each time the train composition is changed. Against the background of the importance of a properly functioning brake for the safety of railway operations testing of the brakes is necessary and regulatory required. Below the cases when a brake test is required and the main forms of brake tests – the full brake test and the simplified brake test – are described.

2.2 The Full Brake Test

In this chapter the cases in which a full brake test has to be carried out and the principal process is described on the basis of the rules applied by German Railways (Deutsche Bahn). The rules and processes of other railway undertakings in Europe are largely identical, though differences in detail cannot be excluded. The basic principles of a manual brake test process are often similar even in many non-European countries. It should also be mentioned that the intention is not to address the brake test rules in each detail, especially not rules which usually are not relevant for freight train operations (such as brake tests of fixed train compositions (multiple units), which normally are not used in freight traffic) or which apply to very specific cases. Readers interested in these details are asked to consult the relevant brake test rules issued by the railway companies concerned.

A full brake test has to be carried out in the following cases[1]:

a) When a train composition has been newly formed, earliest 24 hours before departure (composition consisting of single wagons or wagon groups with more than two coupling locations)

b) When a train has been parked for more than 24 hours

c) At trains with unchanged composition once per day, usually before the first departure (usually not relevant for freight trains)

d) In case of irregularities

e) Before certain (longer) descending gradients

For completeness it should be mentioned that in Europe in many cases a full brake test is even required at borders (respectively in the border stations) since brake tests carried out in another country (by another railway undertaking) are not necessarily recognized across borders. This is one of the reasons for long dwell times for freight trains at border stations. However, at certain borders agreements have been reached accepting brake test carried out by other railway undertakings (so-called “trusted trains”).

[1] DB AG: *Richtlinie 915.01 Bremsen im Betrieb bedienen und Prüfen*. Modul 915.0103 Seite 1

The brake testing process itself – including preparation and the so-called pre-inspection walk – is as follows:

The locomotive driver (or an authorized person, the brake test authorized) fills the main brake pipe with 5 bar pressure. This is done from the locomotive in case it is already attached to the train, or, if not, from stationary trackside air cranes. In the latter case an additional simplified brake test (see next chapter) has to be carried out when the locomotive becomes attached to the train.

Now the pre-inspection walk begins. The brake test authorized carries out the following checks:

- That all brakes are released
- That all parking brakes are released
- The condition of the brake components (in particular that brake blocks are in place and that the thickness of the brake blocks is within permitted margins)
- That brakes are turned on (except brakes, which are marked to be non-operational)
- The correct setting of the braking regime
- The correct setting of the load change
- The correct coupling of the wagons, including the brake pipe

After the pre-inspection walk, the driver or the brake test authorized carries out a tightness-control. The reduction of air pressure inside the main brake pipe must not exceed 0,5 bar within one minute (0,3 bar for passenger trains). If this condition is fulfilled the brake pipe is considered as tight.

After these preparatory checks the brake test itself begins. The driver respectively brake test authorized fills the main brake pipe again to 5 bar pressure bringing the brakes in the release-position. Then the brakes are applied by releasing air from the main brake pipe until a pressure of 4.2 bar is reached. The test authorized walks now along the train and checks at each axle whether the brakes are applied. This is done by visually inspecting the brakes respectively by knocking with a metal hammer against the brake blocks; from the sound he or she can conclude whether a brake is applied or not.

As the next step in the brake test the driver respectively the brake test authorized releases the brakes by raising the air pressure in the main brake pipe again to 5 bar. The brake test authorized walks again along the train and checks whether the brakes are released.

Finally, the results of the brake tests are documented on a brake test form, finalizing the brake test procedure.[2]

Figure 2 illustrates the brake test process described above, including preparation and pre-inspection. As can be seen from it the brake test authorized has to walk six times along the entire length of the train (three times out and return), which, in case of a train of 700 m length, adds up to a total of more than four kilometers; during this entire time a person must even be on the locomotive in order to open/close the drivers brake valve and to monitor the brake pipe pressure. This explains the high time-consumption and personnel-intensity of the brake test procedure.

[2] For trains equipped with magnet brakes, further checks are required; however, magnet brakes are not used in freight traffic, thus, these steps are not relevant in the context of this report.

Typically ca. 45-60 minutes must be allocated for a full freight train brake test; only for very short trains the time can be shorter.

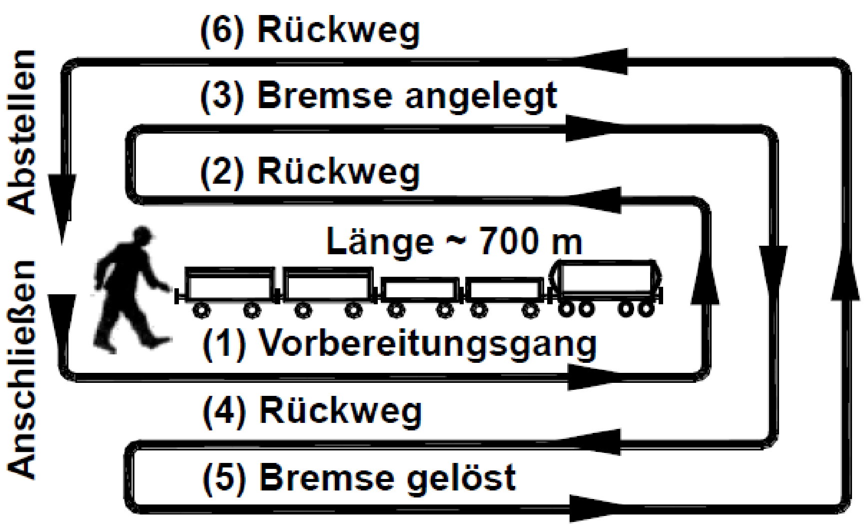

Figure 2: Illustration of the brake test procedure (Source: Hecht, 2001)

Processes associated to the brake-test

As could already been seen in the previous paragraph, there are certain processes or tasks carried out in the context of the brake test, which are not directly linked to the control of the functioning of the application and release of brakes as such. To keep this in mind is important when developing and assessing solutions for an automation of the brake test, as we will still see later.

The following tasks/processes must be mentioned here:

- Control of the condition of the brake components (in particular that brake blocks are in place and that the thickness of the brake blocks is within permitted margins)
- Turning on brakes, which are turned off and which are not marked
- Setting of the braking regime
- Setting of the load change
- Control of the correct coupling of the wagons, including (but not limited to) the brake pipe
- Control of the load, in particular concerning load displacements and leakages

2.3 The Simiplified Brake Test

The simplified brake test has to be carried out in the following cases:

a)When a full brake test has not been carried out from the locomotive, which will haul the train (e.g. if another locomotive or stationary air cranes were used for the brake test)

b)When wagons or wagon groups have been attached to a train

c)When the train has been temporarily separated d)When a train was parked for more than 1 hour

e)When a brake pipe end cock was opened

f)When the brake regime of one or several wagons was changed to R+Mg (usually only relevant for passenger trains)

g)When during shunting operations vehicles have been attached to the main brake pipe

h)Before certain descending gradients

The process of the simplified brake test is as follows:

In a first step the brake test authorized checks, usually at the last vehicle, whether the brake is released. Then he requests the driver to apply the brakes by reducing the air pressure in the brake pipe to 4,2 bar. The brake test authorized now checks the application of the brakes and requests the driver to lock the driver brake valve in center position, avoiding that air is supplied to the brake pipe.

Now the brake test authorized carries out a brake pipe integrity control by opening the brake pipe end cock at the last wagon for 15 seconds (or less in case the driver can communicate to him or her by radio that the brake pipe pressure is falling (by ate least 0,5 bar)).

Finally, the brake test authorized requests the driver to release the brakes. If this happens the brake test was successful and the test is finalized by communicating the result to the driver.

2.4 Shortcomings of the Current Process

The following shortcomings of the current manual brake test process, especially if a full brake test needs to be carried out, can be identified:

1)The process is time-consuming. SBB Cargo states for a 500 m long freight train a duration of 40 minutes for a full brake test.[3] Canadian Pacific mentions “typically 60-90 minutes” for a (longer) coal train (18.000 t loaded).[4] In production planning typical times allocated to a full brake test in Europe are at least 45-60 minutes for trains up to ca. 700m and rarely less than 30 minutes for shorter trains. Maintaining the current process, time consumption can be expected to increase even in Europe due to the trend towards longer trains.

2)Linked to the afore-mentioned aspect, the process is personnel-intensive, resulting in high labor costs. Usually two persons are needed during the test: The brake test authorized for the pre-inspection walk and the control of the correct application and release of the brakes at the wagons (application and release walks) and the train driver for opening/closing the drivers brake valve and monitoring the brake pipe pressure.

[3] SBB Cargo, 2017

[4] Jamieson, Aronian, 2011

3)Since the manual brake test by necessity involves several walks along the entire length of the train it results in long walking distances - in case of a full brake test on long trains (740m) more than 4 kilometres! Since brake tests have to be carried out even at night time and under adverse weather conditions (heat, cold, rain, snow), work safety and comfort are an issue, and consequently also the prospects for recruiting new staff for this task.

4)While the manual brake test certainly allows checking whether brakes are responding, they do not allow checking the force with which a brake is applied, i.e. the brake *effectiveness*.

3. MARKET NEEDS AND OPERATIONAL CONDITIONS FOR BRAKE TESTS ON FREIGHT TRAINS

3.1 POLICY CONTEXT, MARKET TRENDS AND CHALLENGES

Policy and strategic context

The European Commission has laid down key policy objectives for the transport sector in its White Paper on Transport. An overarching objective is to contribute to a reduction of Greenhouse Gas Emissions (GHG) by 60% until 2050 by strengthening the participation of rail and waterborne transport on the transport market. This is concretized in the objective to shift until 2030 30% of long-distance road freight to more energy-efficient modes of transport and increasing this figure until 2050 to 50%. In many cases this means a shift to rail and consequently rail freight ton-kilometers on the European network are expected to increase by 87% compared to 2007. This will also help to de-couple economic growth in Europe from pollution from the transport sector as a whole, reduce external costs of transport and contribute to a de-congestion of the road network. The objective of modal shift to rail exists even in many Member States.

An automation of the brake test for freight trains must be seen as one among several measures to help fulfilling this objective. Further, automatic brake tests pave the way for solutions in yard management allowing a better use of the existing infrastructure – e.g. through shorter train formation times and improved operational characteristics of freight trains (through better control of brake effectiveness).

Last, but not least, the introduction of automatic brake tests allows rail to better respond to and meet societal expectations and challenges. As a direct impact, automatic brake tests will result in better working conditions and work safety of staff involved in the formation and preparation of trains, and ultimately the attractiveness of jobs in rail freight operations. An (even partial) automation of rail freight operations – which includes brake testing – will help rail freight to meet the challenges stemming from an ageing population and high level of retirements.

The introduction of automatic brake tests must also be seen in the context of a much broader digitalization and automation of rail freight and the subsequent positive effects on service features, quality, reliability and efficiency of rail freight services as well as the positive effects on the ability of rail freight to become a fully integrated part of a modern digitalized intermodal transport system in Europe.

Market trends

Since 2000 rail's market share in European transport has decreased, from ca. 20% to ca. 17%, though patterns at national level show substantial differences between different countries. While the much more negative trends for rail, which were characteristic for the preceding decades, in most cases could be stopped, it has nonetheless to be noted that a broad and sustainable change towards a positive trend in rail freight market share has not yet happened.

This jeopardizes the achievement of key transport policy objectives on EU as well as in many cases even national level, and – as a consequence – also threatens the achievement of crucial environmental and climate policy objectives, in particular concerning the reduction of greenhouse gas emissions.

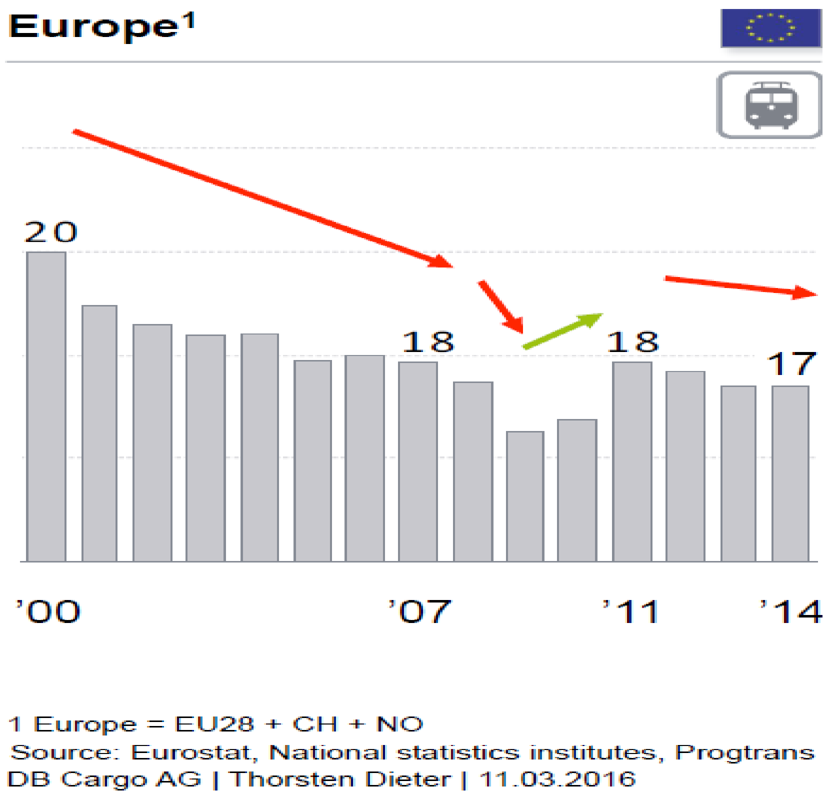

Figure 3: Development of rail freight market share in Europe since 2000. (Source: DB AG)

It should also be noted that in particular wagonload traffic is facing severe challenges and has already ceased in several countries. A further reduction might potentially lead to a loss of critical mass in the remaining wagonload system. The developments in the wagonload business deserve special attention since the characteristics of its production system mean that certain production processes – including brake test – are more frequently repeated in a wagonload transport chain than in other rail freight production systems (since a wagon a wagon group is moving in several different between its place of loading and its destination) – see even chapter 3.2. This makes this market segment particularly vulnerable for shortcomings in current methods for brake testing. Worth to mention, however, is that even in trainload and intermodal operations – in contrast to a wide-spread perception – brake tests (at least simplified brake tests) are often carried out not only once at the departing station, but even at intermediate stops, e.g. due to a change of locomotives, change of travelling direction and border crossings. Especially in trainload operations it has also to be taken into account that trains often have to be splitted into two or more sections for train movements of the first and/or last mile, since loading and/or unloading points cannot receive full-length trains.

Challenges for rail freight

European rail freight is facing a number of challenges:

The quality challenge – Improving reliability and punctuality

The cost challenge – Improving cost competitiveness by higher resource productivity, economies of scale and a more level playing field between modes

The service challenge – Adding new added-value service features allowing rail to (re-)enter into new / lost market segments

The political challenge – Securing societal and political acceptance and support of rail

The European challenge – Achieving a truly Single European Area, i.e. by eliminating borders for the users of the rail system

The automation of brake testing can contribute to meet in particular the cost challenge and the political (societal) challenge and to some extent the service challenge. Automation of this process can be expected to lead to reduced production costs, while at the same time to some extent having the potential to reduce transport times, thus helping to improve service to customers. For the railway sector further indirect cost saving effects can arise from reduced wheel wear due to the possibility to go from checking brake *application* to checking brake *effectiveness* on each individual wagon. Canadian Pacific Railway states that "brake systems (…) can have a direct influence on wheelset life through overheating of wheels and wheel sliding, account(ing) for (…) 20 percent of repair and maintenance costs" on freight cars, based on 2008 repair costs captured by the Association of American Railroads[5]. Wheelset replacement accounted for 51% of all freight car maintenance costs in 2008. Though the magnitude of the impact of automation of brake tests on freight wagon repair costs remains to be quantified, it is reasonable to assume that there is a positive impact (in terms of a reduction).

Automation of brake testing has also bearing on the political challenge to secure societal and political acceptance, taking into account that work comfort and safety become improved and jobs in the rail freight sector become more attractive.

The European challenge in the context of automation of brake testing is to find harmonized interoperable European-wide solutions both on the hardware-side and when it comes to adapting operational rules.

The table below lists potential benefits of an automation of brake tests in rail freight.

[5] Jamieson, 2014, p.1

Nature of advantage	Area		Comment
System advantage	Capacity	Line	-
		Train formation facilities	Reduced track occupation times
	Wear of public infrastructure		-
	Noise		-
Business economic advantage	Railway sector	Resource needs	Reduced personnel and time consumption, higher asset utilization
		Wear	Reduced wheel wear due to control of brake effectiveness
		Working comfort and safety	Improved work safety, due to reduced work “on the ground”
	Customer advantage	Transport time	Depending on whether reduced time for brake test can be translated into reduced transport time
		Flexibility	-
		Reliability	-
		Transport requirements	-

Table 1: Relative advantages of automatic brake tests (adapted and extended by the author from: Bruckmann, Fumasoli, Mancera, 2014, p.20, original in german)

3.2 Rail Freight Production Systems

In rail freight we can discern three major production systems, focused on different market segments and with different operational characteristics.

- ➔Trainload
- ➔Wagonload
- ➔Intermodal

These three systems are also differing with regard to the occurrence of train formation processes (and changes in the train formation) and thus the need for carrying out brake tests.

In the *trainload system* trains are in an ideal situation built at a point of loading and running without changing the train consist until a point of unloading. The train consist is in this case not changed, with exception of the change of locomotives at interoperability borders, the addition (and subsequent removal) of locomotives at the beginning and end of grade sections or the change of the locomotive position in case of a change of travelling directions. However, in reality even trainload operations are often more complex than in the above described ideal situation. One reason is that it is not always possible to handle full-length trains at the points of loading and unloading. This means that trains have to be moved splitted into two (or sometimes even more) for the first and/or last mile (which can sometimes be several tens of kilometers long). This increase the need for brake tests and therefore 6-8 brake tests during a roundtrip in a trainload operation are not unusual in national traffic; in international traffic the number can even be higher.

In the *wagonload system* a wagon or wagon group is conveyed in different trains between the point of loading and the point of unloading. The long-distance trains are usually not changed in their composition between the point of origin and point of destination, while local trains for collection and distribution of wagons/wagon-groups to different customers may change their composition (through attaching and detaching of wagon-groups) along their route. The wagonload system is certainly the most "brake-test-intensive" production system. In a typical wagonload operation the number of brake tests carried out on the trains in which a wagon or wagon-group is conveyed during a roundtrip can easily reach a two-digit number.

Production system	**Typical occurrences of brake test in a transport chain**	**Number of occurrences of brake tests in a transport chain**
Trainload	At point of origin (= point of loading) At handover points between IMs networks In special situations, e.g. -change of traction (simplified brake test) -change of travelling direction (simplified brake test) -certain descending gradients -when parking train between origin and destination	Medium
Wagonload	At point of origin of *each* train in the transport chain At intermediate stops during collection and distribution of wagons (simplified brake test) At all other points as under Trainload (see above)	High
Intermodal	At point of origin (= point of loading) At handover points between IMs networks In special situations, e.g. -change of traction (simplified brake test) -change of travelling direction (simplified brake test) -certain descending gradients	Medium

Table 2: Typical occurrences for brake testing and relative frequency in different production systems (G. Troche).

The *intermodal system* is production-wise to some extent similar to the trainload system. The splitting of trainsets is certainly less common over the first and last mile is certainly less common than in trainload operations, since terminals are usually able to handle full-length trains in the reception and departing tracks (not necessarily in the loading tracks), but at the same time intermodal train operations due to the competitive situation tend to be to a higher extent cross-border than trainload operations.

Table 2 lists typical occurrences of brake testing and the typical relative frequency in different production systems.

3.3 Requirement specification for automated brake testing in rail freight

Two key aspects have to be given particular attention when developing solutions for automation in rail freight:

1)**Interoperability** is an important aspect: 50% of European rail freight is cross-border (with a tendency to increase) and most of the freight rolling stock is regularly – in particular in the wagonload business) or at least seen over a longer (rolling stock life-time) period of time used in different traffic services, in different parts of Europe and sometimes even by different operators. Thus, interoperability is a central requirement from a business perspective and has also a strong legal backing.

As a consequence of this the rail freight sector needs to face a situation that, in case automation solutions require a modification of rolling stock,

a) as a general rule compatibility with non-equipped rolling stock needs to be ensured, and

b) in certain traffic operations and market segments automation may first be utilized fully and thus deliver benefits after having achieved high deployment rates.

2)**Low profit margins** are characterizing most commercial actors in rail freight. This is partly due to strong competitive pressure – both within the sector, but first and foremost from other modes of transport benefitting from the absence of a level playing field between modes. The consequence of this is that the ability to stem huge investments with long pay-back times usually is limited.

From the situation described above it can be concluded that an approach to automation in rail freight relying (exclusively) on a) a possibility to stem high initial investments, b) a need to achieve high deployment rates before being able to reap the benefits of automation and – as a consequence – c) long pay-back times for investments should be *avoided* (or would need to be accompanied by strong incentives and probably external financial support).

Thus, an approach to automation should – as far as possible – allow for a stepwise implementation, meaning that even partial automation should be considered, as an intermediate step, if this allows for faster implementation and quick wins for the parties involved.

At the same time, solutions for partial automation should not technically hinder a full automation at a later stage with a view on the potential benefits arising from full automation and the possible need for full automation with further changing market conditions in the medium to long term.

Thus, with regard to the concrete case of automation of the brake test process, the following flexible two-step approach can be formulated:

Step 1:

Objective: Fast implementation (→ quick wins) – low investment costs

- No need for hardware-modifications on wagons, modifications on locos only
- Limited manual activities acceptable
- Limited wayside-equipment acceptable
- Covering most brake test occurrences, but no full coverage required (coverage of major train formation facilities)

Step 2:

- Automation of all steps in the brake test process
- Full coverage of all brake test occurrences, in all places, or initial limitation to lines with isolated traffic operations
- Longer implementation period acceptable, or initial limitation to rolling stock fleets used in isolated traffic operations

Of course, it is possible to implement directly step 2 in such traffic operations, where it is feasible from an operating point of view (isolated operations) and where the higher investment costs are matched by quickly realizable benefits.

4. SOLUTIONS FOR AUTOMATION OF BRAKE TESTS ON FREIGHT TRAINS

4.1 SEMI-AUTOMATED BRAKE TEST

4.1.1Concept

The basic idea of this solution for a semi-automatic brake test is to avoid entirely the need for modification of freight wagons and to concentrate all extra equipment needed on the rolling stock-side to the locomotive. This substantially limits the number of vehicles subject to modifications.

The solution requires limited trackside equipment in form of hot-wheel detectors (also used as cold-wheel detectors), primarily on exit routes around major train formation facilities.

The concept is based i.a. on ideas by railway expert Hans Boysen at KTH and on key elements of a solution for automated brake tests at Canadian Pacific Railway.

The solution is semi-automatic in so far as it “only” eliminates two of the three out and return walks along the train, but keeps the preparation and pre-inspection walk. This walk is used to manually check the conditions of the brake components, to turn on or off brakes, as necessary, to set the brake regime and the load change, to control the correct coupling of the wagons (including the brake pipe) and to carry out the brake pipe continuity test. These are tasks which are not part of the control of the correct application and release of the brakes, but which are necessary in order to ensure a safe operation of the train brakes. It should also be emphasized that during this preparation and pre-inspection walk further tasks are carried out, which are not linked to the brake system, such as a control of the wagon conditions, including load displacements and leakages. It would therefore not be possible to replace this control walk without finding solutions for an automation of even these tasks. Under normal conditions the pre-inspection walk can be expected to still require two persons, the driver and the brake-test authorized, however, for a much shorter period of time. After the pre-inspection walk – which can be estimated to ca 20 minutes per train – the brake-test authorized can proceed to the next train; the remaining part of the brake test only requires the driver. In principle it is also possible that only one person (e.g. the driver) is involved in the pre-inspection walk, however, it might require the driver to walk two times along the train for the brake pipe continuity test, depending on whether the charging of the brake pipe with a (potentially) open pipe is accepted or not (with a “smart” (automatized) charging of the brake pipe – involving interruption of charging if the brake pipe is not closed – a one-person operation of the pre-inspection walk could be facilitated).

The brake application and the brake release as such are tested combining the following methods:

a)The brake application is tested after the train is formed by measuring with help of an on-board-unit on the locomotive (LOBU) the resistance of the train with brakes slightly applied. For this purpose the train driver must move the train a few meters (in order to ensure that the resistance is measured with all couplers stretched). If the LOBU registers a certain resistance (derived from the traction power to be applied by the locomotive) the train can be considered having sufficient brake force. Compared to today’s manual check of the brake application this solution does not check that individual brakes are applied, but that the brake force of the entire train is exceeding a pre-defined minimum value. The results of this stationary test are displayed to the driver on a screen and can be documented by the driver, or ideally by an automatically generated document.

b)The release of the brakes is tested with help of hot-wheel detectors shortly after leaving the departure location. Taking into account that the temperature of each wheel should not exceed a certain value if no brake application is taking place or has taken place recently, this method allows checking that each individual brake block is in released position respectively to identify individual axles where brakes are not released.

c)Finally, it is also necessary to check not only that the total brake force is sufficient, but also that individual brakes are applied. The same method as for the check of the released brake is used, only in the opposite way, i.e. with help of hot-wheel detectors “cold” wheels are identified. When passing a cold wheel detection site the train driver has to apply all brakes slightly in order to cause an increase in the wheel temperature which can be detected; thus, such a site should be located on a stretch of flat or slightly descending track.

In case of a non-successful test under b) or c) the lineside detector must be able to send (directly or indirectly) a message to the train in order to let the train driver take appropriate action (e.g. stopping the train immediately or reducing speed and stopping the train in the next suitable location).

The above-mentioned method under ‘a’ can be called the *stationary brake test*, while methods ‘b’ and ‘c’ form together the *rolling brake test*.

The method described under ‘b’ and ‘c’ has already been successfully implemented by Canadian Pacific Railway on its 2.400 km long Coal Loop in British Columbia, calling the solution ‘Automated Air Brake Effectiveness Test’. It has received approval by the Canadian railway safety authority for use on a permanent basis and is today replacing the manual brake test process for the coal trains in this traffic operation. The time required for brake-testing the trains has practically been reduced to 0 and the solution even opens for higher safety since the rolling brake test allows to check the brake effectiveness at several locations during a train run.

In the following, the hardware requirements and the processes for the proposed semi-automated brake test process are described in more detail.

4.1.2Hardware

The hardware used for the semi-automated brake test is relatively limited. It consists of:

1)A **locomotive on-board unit (LOBU)**, measuring the traction power to the traction motors; from this information in combination with information about the gross train weight the (braking) resistance can be derived during the stationary brake test (see point ‘a’ above). The LOBU has an interface allowing the driver to enter the train data (if not done automatically) and to see the results of the test on a screen.

2)A **hot-wheel detection site** located at certain distance after the point of departure on a flat or slightly ascending section of track where brakes usually do *not* need to be applied and consisting of a hot wheel detector; this hot-wheel detection site serves the function to identify hot wheels – indicating that a brake is not released.

3)A **cold-wheel detection site** located on a flat or slightly descending section of track consisting also of a hot wheel detector. When passing the detector brakes have to be applied slightly for the purpose of the test; this cold-wheel detection site serves the function to identify cold wheels – indicating that a brake is not applied.

Further it has to be ensured that an information link is provided between the hot-wheel and cold-wheel detection sites on the one side and the traffic control center respectively the train driver on the other side in order to ensure that a train can be stopped if necessary in case of malfunctioning of the brakes.

Figure 4 shows an example of a hot-wheel detector used by European railways.

Figure 4: Example of a hot-wheel detector (Photo: SST Signal- und Systemtechnik GmbH)

4.1.3Process

The semi-automated brake test is carried out in four steps:

Step 1: In a first step the pre-inspection walk is carried out. During this step the continuity of the brake pipe is checked manually by opening the air pipe shortly at the end of the train; further, all other tasks listed in chapter 2.2 for the preparation and pre-inspection walk are carried out as today.

Step 2: In a second step the automated stationary test is carried out using method 'a' described above (chapter 4.1). With this step it is checked that the train has a sufficient brake force. In this regard the solution represents a safety improvement compared to today's manual test procedure; today only the application of brakes is checked, but not the force with which they are applied – the proposed automated solution ensures that even the total brake force for the train is sufficient.

Step 3: In a third step the brake release check is carried out at a suitably located hot wheel detection site, shortly after leaving the point of departure. With this step it is checked that *all* brakes are released – i.e. no hot wheels must be detected at this site. In case a hot wheel is detected, information can be provided in connection with axle counters at the site about exactly which wagon respectively axle is concerned.

Step 4: In a fourth step the brake application check is carried out at a suitably located cold wheel detection site. This step completes step 2, i.e. the stationary test. While the stationary test already checked that the total brake force for the train is sufficient, this fourth step checks that all respectively a sufficient number of wagons and wagon individuals required to have brake force actually do so.

The steps 3 and 4 are in principle identical to the so-called Automated Air Brake Effectiveness Test introduced in 2010 by Canadian Pacific on its British Columbia Coal Loop, there replacing the manual brake test procedure (in that case no stationary test corresponding to step 2 above is required).

Figure 5 and Table 3 illustrate the Automated Air Brake Effectiveness Test as used in Canada.

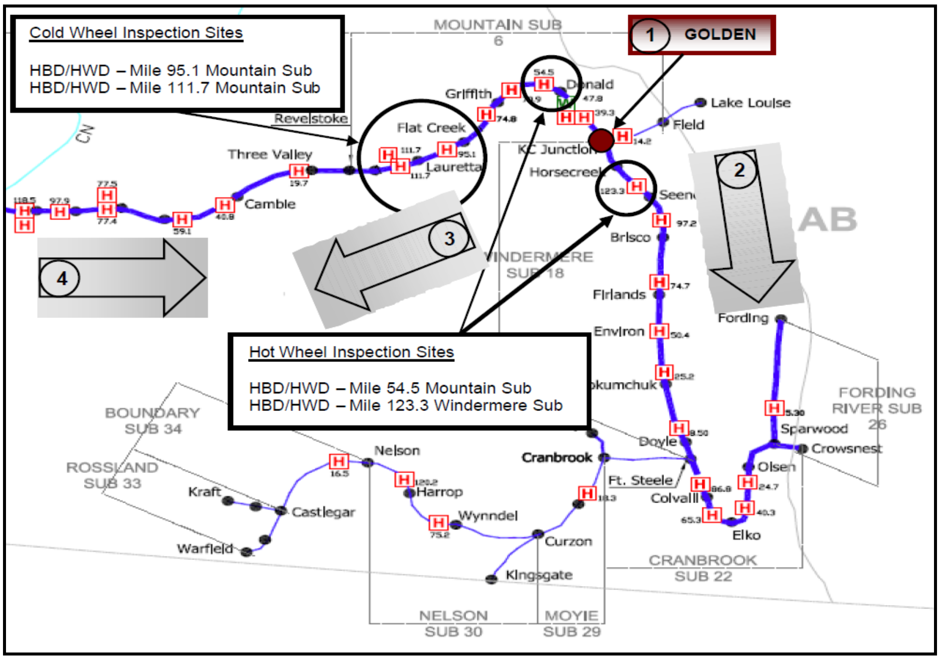

Figure 5: Map of Canadian Pacific´s British Columbia Coal Loop on which the Automated Air Brake Effectiveness Test has replaced manual brake tests. (Source: Jamieson, Aronian, 2011)

1.Empty Train at Golden Mechanical Facility ➔Train undergoes Safety & Maintenance Inspection ➔Removal of any bad order cars from train; replacement with pre-brake -tested spare cars
2.Empty Train travels South to Coal Mines ➔Train passes <u>Hot Wheel Inspection Site</u> – Mile 123.3 Windermere Sub ➔EHMS publishes any alarms, which are transmitted to the train crew via rail traffic controller (RTC) ➔If the train crew is notified of hot wheel alarms, they will stop the train to inspect for sticking brakes, or a left-on hand brake ➔If the problem cannot be rectified, the train crew will have air brakes cut out on the problem car for remainder of cycle; the train crew will update brake status paperwork
3.Loaded Train travels West to Pacific Coast ➔Train passes <u>Hot Wheel Inspection Site</u> – Mile 54.5 Mountain Sub ➔Same process followed as described for hot wheels in section 2. ➔Train passes <u>Cold Wheel Inspection Sites</u> – Mile 95.1 and Mile 111.7 Mountain Sub ➔EHMS publishes any alarms, which are transmitted to the train crew via RTC ➔If the train crew is notified of cold wheel alarms, they will note the cars on the brake status paper work, and ensure compliance with Train Brake Rules regarding distribution and quantity of inoperative brakes within

the train ➔In the event the train is no longer in compliance with the Train Brake Rules regarding operative brakes, the train crew will set off or remarshall cars in order to be in compliance
4.Empty Train travels East to Golden Mechanical Facility ➔Prior to the empty train arrival at Golden Mechanical Facility, a TDTI report will be compiled by EHMS and published with either: a)A list of all highlighted cars on the train with hot and cold wheel alarms, or b)A message indicating no alarms found on the train, or c)A message indicating EHMS could not retrieve any successful test results from the database, and a No.1 Brake Test is therefore required in Golden ➔In the event a train arriving empty into Golden has not been preceded by a TDTI report, Golden will perform the full No.1 Brake Test on the train

Table 3: Process for the Automated Air Brake Effectiveness Test of Canadian Pacific on the British Columbia Coal Loop, replacing manual brake testing. (Source: Jamieson, Aronian, 2011)

4.2 Fully Automated Brake Testing

4.2.1Concept

The ambition with a fully automated brake test has been to eliminate entirely manual processes for carrying out the brake test (except entering train data in the locomotive on-board unit – if not done automatically – and monitoring the results)

In order to allow for full automation it has to be accepted that a modification of locomotives and wagons - *all* wagons in a train consist, on which a fully automated brake test should be applied – is necessary.

The modification of wagons comprises the installation

a) of sensors indicating the position of the brake valves (and thus whether brakes are applied or released)

b) of a wagon on-board unit (WOBU) which controls the sensors and devices of each wagon and which communicates with the locomotive on-board unit (LOBU).

c) of energy supply equipment

The modification of locomotives comprises the installation of a locomotive on-board unit (LOBU), which communicates with the WOBUs in the train and a server on the ground and which includes a man-machine interface for the train driver (can be eliminated in case of driverless automatic train operation).

Figure 6 illustrates the communication links between the different components of a system for a fully automated brake test.

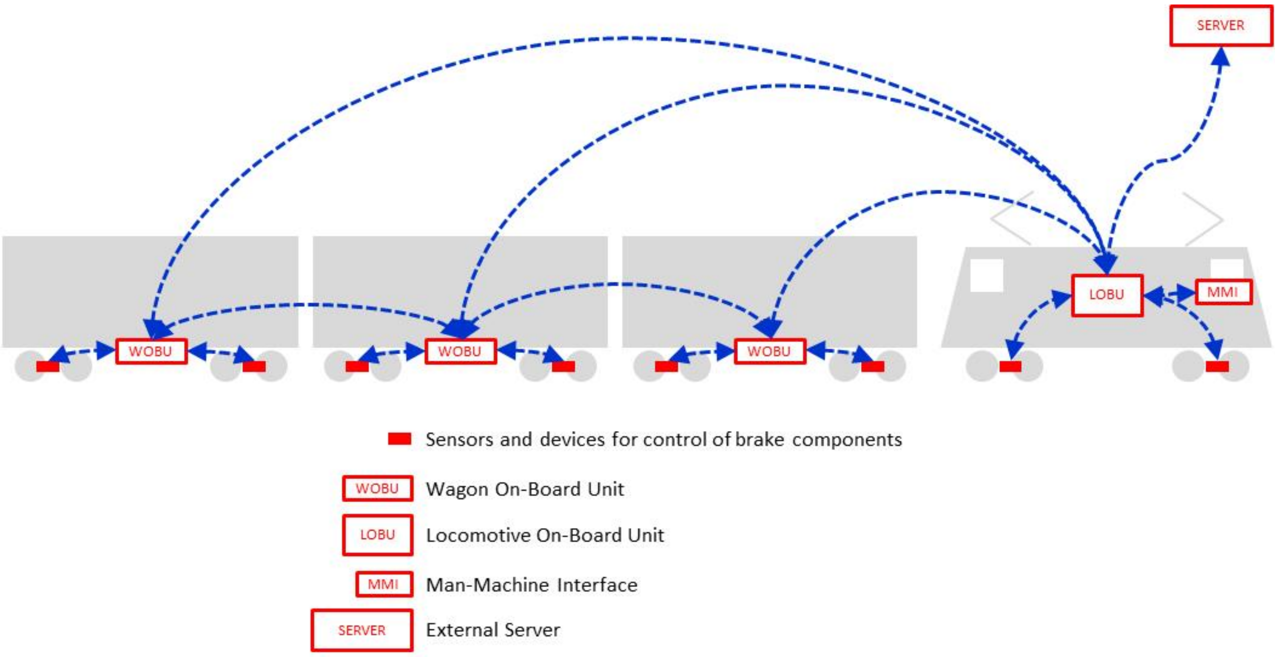

Figure 6: Communication links in a system for a fully automated brake test (G.Troche)

It should be emphasized that the solution presented here is limited to the automation of the functional check of the application and the release of the brakes. It does not automate certain other tasks carried out during the preparation and pre-inspection walk, such as the control of the brake components (that the brake blocks are in place and that their thickness is within permitted margins), the control of couplers and the control of the load regarding i.a. load displacements and leakages.

The automation of the setting of the brake regime and the load change should be relatively easy with help of remote-controlled devices (however increasing the energy demand) and could thus optionally be foreseen in the solution. However, the automation of the other above-mentioned tasks is more challenging and remains an open issue (see even chapter 5.2).

4.2.2Hardware

The hardware required for a fully automated brake test consists at a minimum of

-sensors on the wagons placed at the brake valve measuring the position of the piston (if checking only whether brakes are applied or not; if in addition the brake force should be measured, the sensors even have to measure the force in the brake piston – alternatively, the effectiveness of the brake can be measured independently with the help of the Rolling Test described under chapte 4.1.1 b and c),

-WOBUs communicating with the sensors, with adjacent WOBUs and with the LOBU,

-A LOBU communicating with the WOBUs and externally with a server, and comprising a man-machine interface for information of the train driver (obsolete in case of driverless automated train operation)

-An external server for storage of information from the brake test; information from this server could be accessible for traffic management purposes and vehicle service and maintenance purposes

Optional hardware comprises

-devices on the wagons for setting of the braking regime and the load change

-sensors for measuring the air pressure in the wagon reservoirs in each wagon

In principle the communication links can be radio-based or cable-based or a combination of both. A cable-based solution for communication along the train (“train-bus”) would strongly benefit from – if not be dependent on – the introduction of Automatic Couplers with integrated data transmission. Automatic Couplers with integrated energy transmission would facilitate the provision of electricity for the operation of the sensors and WOBUs. In particular in case wagons will also be equipped with remote-controlled devices for the setting of the brake regime and the load change with their higher power demand a train-based energy supply becomes even more advised.

An important aspect affecting the cost-benefit-ratio of a system for fully automated brake tests is that the communication links to be established and the components required (with limited additional features) could be used not only for the brake test, but also for a continuous (remote) control of the brakes during train movements (electro-pneumatic braking). This would create additional benefits in form of a remarkably better braking performance, opening for higher speeds for freight trains and reduced longitudinal forces.

4.2.3Process

After filling the brake pipe with air the fully automated brake test is carried out in two steps:

Step 1: In a first step the correct application of brakes is checked. The train driver reduces the air pressure in the brake pipe. Sensors measure the movement of the brake piston indicating the application of the brakes. Since all axles are equipped with sensors even the continuity of the brake pipe is automatically checked in this step.

Step 2: In a second step the correct release of brakes is checked. The train driver increases again the air pressure in the brake pipe, releasing the brakes. The same sensors as used in step 1 measure the movement of the brake piston now indicating the release of the brakes. Since all axles are equipped with sensors even the continuity of the brake pipe is automatically checked in this step.

After this test information on the results of the brake test is via the LOBU saved to an external server.

In case the wagons are equipped with devices for remote-controlled setting of the braking regime and the load change the above-mentioned steps are foregone by using this system function. Further, additional checks can be carried out in connection with the above-mentioned steps, e.g. measuring the air pressure in the wagon reservoirs.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Choice of solution

In the aforementioned chapter two solutions were presented for an automation of the brake test for freight trains, a semi-automated solution and a fully automated solution.

The fully automated solution delivers the biggest benefits in terms of time savings, reduction of staff needs and improvement of work safety and comfort. However, it also becomes clear that its implementation in depending on a number of pre-conditions. In particular a large-scale modification of wagons and locomotives is required, mostly consisting of equipment of wagons with sensors and of wagons and locomotives with on-board units. For a full brake tests all vehicles of a train must be equipped.

Thus, a quick introduction of fully automated brake tests is likely to be limited to certain train operations using isolated wagon (and locomotive) fleets. Further, the full benefits of a fully automated brake test can first be reaped when there are solutions for automation of tasks and processes, which are not part of the brake test as such, but which are today carried out in the context of the brake test (as part of the pre-inspection walk), see chapter 2.2. As long as no solutions are developed for these tasks they will still have to be carried out manually; the pre-inspection walk cannot be eliminated before not automated solutions are in place for the entirety of these tasks.

The recommendation is therefore:

1) to introduce on a broader front a semi-automated brake test based on the principles described under 4.2.

2) to introduce a fully automated brake test in pilot applications where and if they can deliver a positive cost-benefit ratio (even with keeping the pre-inspection walk to carry out tasks not yet automatable)

3) to develop – even in the up-coming work within the Shift2Rail-initiative – solutions for automation of the tasks carried out in the context of the pre-inspection walk (see even chapter 5.2), but not being part of the brake test itself, in order to pave the way for a full automation of the brake test in the longer term

The semi-automated brake test can be expected to deliver “quick wins” and implementation barriers are relatively low, in particular since no modification of wagons is needed; all additional equipment on the rolling stock side is concentrated to the locomotive, keeping the number of units affected low. Certain lineside equipment is needed, however, with relatively few sites equipped (= limited investments) the major train formation facilities (marshalling yards and terminals) could be covered. The geographical concentration of train formation to fewer facilities during past years is of advantage in this context. Further, the lineside equipment needed is consisting of well-proven technology (hot-wheel detectors), thus technical risks are low.

In both cases, the fully automated brake test and the partially automated brake test, an adaptation of the regulatory framework is needed. In the case of the partially automated brake test it might be an advantage that certain key elements of the proposed solution are based on a solution implemented in Canada and already having received regulatory approval by the Canadian authorities; operational conditions are certainly not identical between Canada and Europe and the solution proposed in this report is more comprehensive, nonetheless, the experience gained in Canada should be taken into account.

5.2 Next steps

As has been pointed out in the introduction, the current project did not allow any prototyping and consequently no testing of any of the proposed solutions. Therefore it is unavoidable that certain questions remain open and further steps are needed before any roll-out of solutions can happen.

Below, next steps are proposed, both for the semi-automated brake test as well as for the fully automated brake test.

Proposed next steps for the semi-automated brake test

The following steps are proposed; several of them can be carried out in parallel or be overlapping in time.

1) Development of a Locomotive On-Board-Unit (LOBU) and equipment of a locomotive

2) Testing under real-world conditions, in particular

    a. definition of minimum track length required for the stationary part of the semi-automatic brake test

    b. identification of minimum/maximum distance between point of departure and hot-wheel detector (for control of released brake)

    c. confirmation of general operational feasibility

3) Inventarisation of train formation facilities with regard to the possibility to introduce semi-automatic brake test (important aspects here: track lengths/train lengths and identification of places for hot-wheel/cold-wheel detectors)

4) Investigation of wheel temperature development of wagons, in particular dependency on (gross) weight, in order to define limit values for hot wheel-/cold-wheel-inspection respectively scope of application with regard to type of train compositions (unit trains versus mixed trains)

5) Revision of regulatory framework for brake tests in order to accommodate semi-automated brake testing

For a test/demonstration under real-world conditions (points 1 and 2 above) involvement of different parties is necessary, in particular:

- A locomotive manufacturer (possibly together with a component manufacturer)
- A railway undertaking (freight train operator)
- A railway infrastructure manager
- An R&D-unit (such as KTH Railway Group) to plan, monitor and evaluate the test

In addition, involvement of the competent rail regulatory body is advised, in particular in the context of point 5 above.

Proposed next steps for the fully automated brake test

The following steps are proposed; several of them can be carried out in parallel or be overlapping in time.

1) Development of automated solutions for tasks carried out as part of the pre-inspection walk not being part of the brake test itself:

    a. Control of the condition of the brake components (in particular that brake blocks are in place and the thickness of the brake blocks is within permitted margins)
    b. Turning on brakes, which are turned off and which are not marked
    c. Setting of the braking regime
    d. Setting of the load change
    e. Control of the correct coupling of the wagons, including (but not limited to) the brake pipe
    f. Control of the load, in particular concerning load displacements and leakages

2) Investigation of need for and form of solution for operation in degraded mode

3) Development of wagon sensors, a Wagon On-Board Unit (WOBU) and Locomotive On-Board Unit (LOBU), including communication links

4) Equipment and operation of a test train under real-world conditions, in particular aiming at

    a. Long-term testing of sensors and system architecture, i.a. with regard to reliability

    b. Confirmation of general operational feasibility, including solution for degraded mode operation

5) Revision of regulatory framework for brake tests in order to accommodate fully automated brake testing

For a test/demonstration under real-world conditions (points 3 and 4 above) involvement of different parties is necessary, in particular:

- A locomotive manufacturer (possibly together with a component manufacturer)
- A wagon keeper (together with a component manufacturer)
- A railway undertaking (freight train operator)
- A railway infrastructure manager
- An R&D-unit (such as KTH Railway Group) to plan, monitor and evaluate the test

In addition, involvement of the competent rail regulatory body is advised, in particular in the contest of point 5 above.

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