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Transforming
Europe's Rail Freight

Running safety under longitudinal compressive forces (Derailment)

Test scenario

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Abbreviations & Acronyms

Abbreviation / Acronym	Description
AAR	Association of American Railroads
BP	Brake Pipe
DAC	Digital automatic coupler
DBC	DB Cargo AG
DBST	DB Systemtechnik GmbH
DC	Dellner Couplers
DMS	Strain gauge (ger.: DehnungsMessStreifen)
e-coupler	Electrical coupler
eLCF	Endurable Longitudinal Compressive Forces
ERJU	Europe's Rail Joint Undertaking
FDFT	Full Digital Freight Train
FP5	Flagship Project 5 of the ERJU project
FT	Faively Transport - Wabtec
HBK	Hottinger Brüel & Kjaer GmbH
KB	Knorr-Bremse AG
LCF	Longitudinal Compressive Forces
oLCF	occurring Longitudinal Compressive Forces
P/F	Pass / Fail - criteria
ToR	Top of rail
TRL	Technology Readiness Level
TTL	Train Test Lab
VT	Voith GmbH & Co. KGaA
WP4	Working Package 4 of the FP5 – Authorisation requirements
WP13	Working Package 13 of the FP5 – Test management
WP14	Working Package 14 of the FP5 – Train Test Lab

1 Project description

The TRANS4M-R consortium within Flagship Project 5 (FP5) of the ERJU project aims to develop and validate the Full Digital Freight Train (FDFT). A main component of the FDFT is the digital automatic coupler (DAC). Couplers are produced by various suppliers and sent to testing in accordance with the V-model process for validation.

The tests are coordinated by the test management (WP13) within TRANS4M-R and distributed across several test instances. This test scenario covers the tests that were executed by TRANS4M-R WP14 in the Train Test Lab. The objective of the tests within WP14 is to validate technical enablers in a safe, closed test environment (TRL 5 to TRL6). The systems under test must have been previously tested on test rigs and the corresponding verifications described in Quality Gate 1 must be available. The purpose of the tests in the Train Test Lab is to generate further evidence for quality gate 2 for operating demonstrator trains on public infrastructure (TRL 6 to TRL 7). [DEL13.2]

The test scenario described here involves tests that are to be used as verification for further trains and the general operation of vehicles on public infrastructure.

2 Test objective

The objective of tests described in this document is to demonstrate that selected vehicles with a DAC meet derailment safety requirements. The basis for this is the EU regulation concerning the technical specification for interoperability relating to the subsystem 'rolling stock – freight wagons' of the rail system in the European Union [TSI-WAG]. Section 4.2.3.5 of this regulation requires proof of safe running behavior of freight wagons. In sections 6.2.2.2 and 6.2.2.3, testing in accordance with EN 14363:2016 is required here. In EN 14363:2016, section 6.1.1 presents three methods for determining proof of derailment safety [EN14363]. In this process, the wheel lift and the wheel contact forces when running through a curve are measured. A method that is currently frequently used is described in EN 15839:2012+A1:2015 [EN15839].

However, all the documents presented assume vehicles with side buffers. The test procedure specified here is therefore based on the known procedures, but has been adapted for use with center buffer couplings. The specific requirements for the derailment safety of vehicles with a DAC are described in [DEL5.2] and relevant test procedures are described in [DEL5.3]. Further test procedures that have been implemented so far were realised in the DAC4EU project and are described in [DAC4EU01].

Another objective is to validate the methodology described in TRANS4M-R WP4 task 3 for a possible simulative verification of vehicles with a DAC with regard to derailment safety under longitudinal compressive forces [DEL4.3].

3 Fundamentals, definitions and technical principles

The aim of this section is to explain the technical mechanisms involved in derailment of vehicles with center buffer couplings and to clarify the differences compared to vehicles with side buffers. This results in a need to adapt the test criteria described in the standards, which will be discussed together with the new requirements for vehicles with center buffer couplings.

In [DEL4.3], Jobstfinke describes the mechanisms of train dynamics, in which relative movements of vehicles within a train can lead to longitudinal forces. These represent a risk for running safety of trains. The following sections are extracted from [DEL4.3].

3.1 Occurring Longitudinal Compressive Forces (oLCF)

Traction and brake forces inevitably lead to longitudinal dynamics when operating freight trains. The reason for this is that there is no evenly acceleration/deceleration acting on all vehicles, neither during the acceleration phase nor during brake application.

The acceleration phase of a freight train is a simple example of these relationships: the traction forces are not evenly distributed across the train. They only act at the positions of the locomotives - very often only at the head of the train. Forces therefore arise between the vehicles: tensile forces behind pulling locomotives and compressive forces in front of pushing locomotives. When a freight train accelerates with a locomotive at the head of the train, the highest tensile forces typically occur at the first coupling point behind the locomotive. The interrelationships during air brake applications are much more complex but are also particularly relevant in the context of the present task. Although the standard air brake used on the railway usually acts on all vehicles in the train, it does not act on all vehicles at the same time, nor does it act with equal decelerations. The brake is applied by venting the brake pipe (BP) from the front of the train. The air in the BP must flow along the entire length of the train to the venting point. There is a relatively rapid drop in pressure in the brake pipe close to the venting point at the front of the train. However, as the distance from the venting point increases, the time required for the pressure drop increases. [DEL4.3]

As the pressure in the BP decreases, the pressure in the vehicle's brake cylinders increases and so does the effective brake force. The front part of the train therefore begins to decelerate earlier than the rear part. As a result, the rear section of the train runs onto the front section due to its inertia. Excessive longitudinal compressive forces can therefore occur approximately in the center of the train. Figure 1 illustrates the above relationships. [DEL4.3]

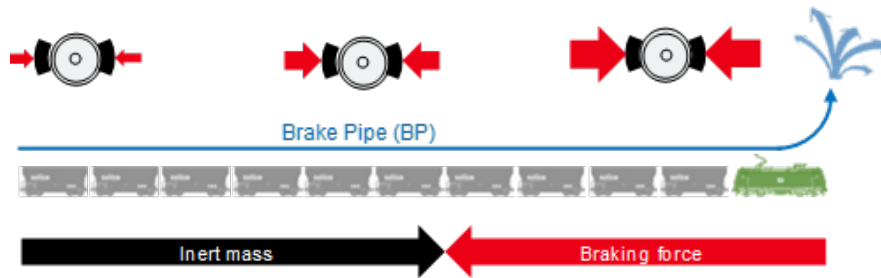


Figure 1: Principle of occurring longitudinal compressive forces during brake application [DEL4.3]

The level of *occurring longitudinal compressive forces (oLCF)* depends on a number of parameters. Some of the most influential ones are [DEL4.3]:

- Type of brake application (service brake or emergency brake)
- Train mass and length
- Mass distribution
- Brake position
- Characteristics of the buff and draw gear
- Characteristics of the brake's friction elements

3.2 Endurable Longitudinal Compressive Forces (eLCF)

The previous section shows that the operation of freight trains inevitably leads to *occurring longitudinal compressive forces (oLCF)*. The level of these forces depends on a number of boundary conditions. [DEL4.3]

Excessive *oLCF* can pose a safety risk for railway operations. At this point, however, it is important to note that this is not about the direct effects of compressive forces on the vehicle structure (strength)¹. Instead, we are talking about potential derailments that can be caused by vertical and lateral forces resulting from the *oLCF* (Figure 2). *oLCF* lead to vertical and/or lateral forces if the longitudinal axis of the couplers between two vehicles runs at an angle to the longitudinal axis of the vehicles during the occurrence of the LCF. [DEL4.3]

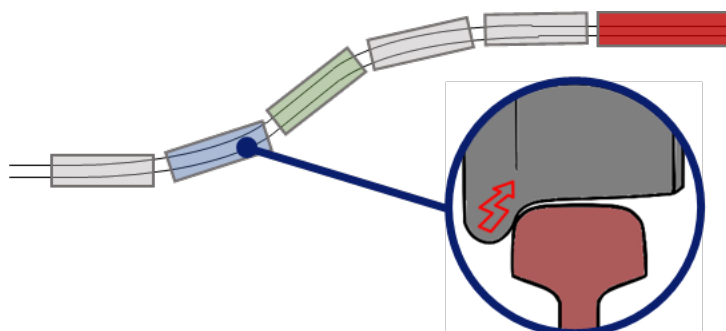


Figure 2: Derailment risk due to oLCF. Source: DB Systemtechnik

When the train travels through a curve, an angle occurs in the horizontal plane, so that lateral forces arise from oLCF (Figure 3). Differences in height (e.g. due to load differences) lead to an angled coupler axis in the vertical plane. This results in vertical forces (Figure 4). [DEL4.3]

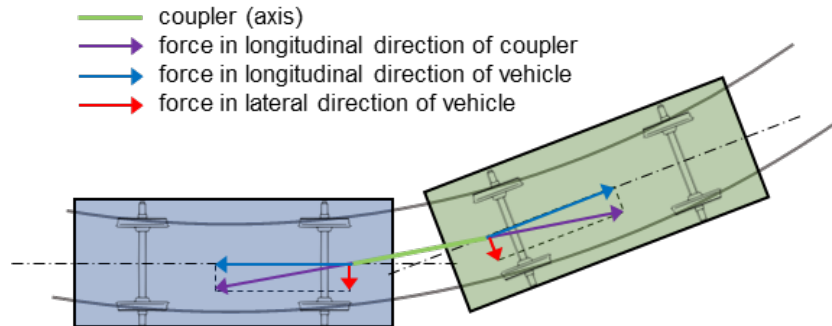


Figure 3: Appearance of lateral forces from oLCF during curve transition. Source: DB Systemtechnik

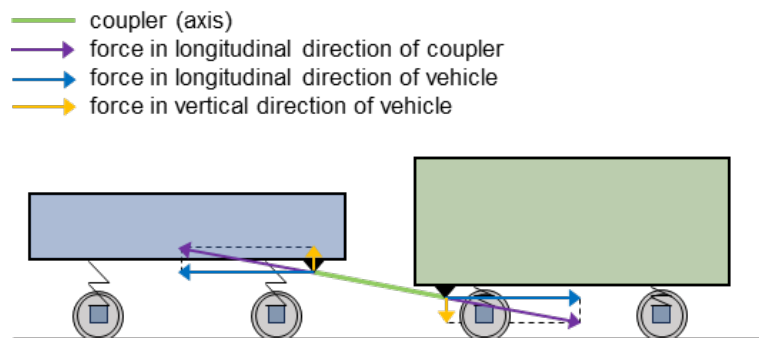


Figure 4: Appearance of vertical forces from oLCF due to different (coupler) heights. Source: DB Systemtechnik

It can be deduced from the above explanations that the level of lateral and vertical forces that can arise from oLCF is not only dependent on a vehicle and its coupler system. Instead, the infrastructure and the two neighbouring vehicles also play a significant role. This also means that the risk of derailment of a freight wagon due to oLCF cannot be determined solely by looking at the wagon in question. In principle, there are again a large number of possible combinations. [DEL4.3]

For this reason, a scenario that includes various unfavourable conditions was defined in the past [EN15839]. This serves as a reference scenario for determining the *endurable longitudinal compressive force (eLCF)*. It is characterised in particular by the simultaneous occurrence of lateral and vertical forces. This is achieved using the following boundary conditions, among others:

- narrow S-shaped curve (150 m) → large coupler angles in the horizontal plane → large lateral forces
- wagons in front of and behind the wagon under test (so-called flanking wagons) with specific dimensions → large coupler angles in the horizontal plane → large lateral forces
- flanking wagons are loaded, wagon under test is empty → large coupler angles in vertical plane → large vertical forces

A constant longitudinal compressive force at which the wagon under test runs over the test track without derailing and without exceeding limit values is referred to as the *endurable longitudinal compressive force (eLCF)* of the wagon under test. [DEL4.3]

This definition of the *eLCF* represents a standardised procedure for determining it. Furthermore, it is possible to compare different vehicles in this way. However, the *eLCF* determined in this way is not an absolute limit value that must never be exceeded. This is discussed further in the following section. [DEL4.3]

3.3 Relationship between eLCF, oLCF and Railway Operation

For the safe operation of railways, it is necessary for *eLCF* to reach at least a minimum value and for *oLCF* not to exceed a maximum value. The lower the *eLCF*, the more measures to limit *oLCF* are necessary. Conversely, *oLCF* may become larger if the *eLCF* are high. For example, high *eLCF* and thus higher acceptable *oLCF* enable heavy freight trains to run in more effective braking positions and thus also higher maximum speeds for freight trains. High *eLCF* are therefore desirable from the point of view of railway undertakings. [DEL4.3]

The description of the above indirect correlations is simple. The derivation of direct quantitative correlations, however, is much more complex. This is because the *eLCF* represents a reference value, but not a generally applicable absolute limit value. If the *oLCF* acting on a wagon is greater than its *eLCF*, then there is only an increased risk of derailment if the same boundary conditions prevail as in the reference scenario. If less critical boundary conditions prevail, for example if the wagon is loaded instead of empty and/or is not in a tight curve, then the *oLCF* may exceed the *eLCF* without this posing a risk. [DEL4.3]

3.4 General Differences between Center Buffer Couplers and Side Buffers

There is a general difference between the vehicle reactions caused by *oLCF* in trains with center buffer couplers compared to trains with side buffers. This difference also exists on a straight track and is not limited to curves. With center buffer couplers, a rotation around the vertical axis of the wagon is caused by acting *oLCF* when there is a horizontal angle between vehicles and the couplers have a spherical joint on the wagon body. The rotation increases the angles occurring between the wagons, resulting in a self-reinforcing (unstable) process. In contrast, in the same situation with side buffers, a rotation occurs that reduces the occurring angles. In this way, the system stabilises in the nominal position. Figure 5 shows these relationships. [DEL4.3]

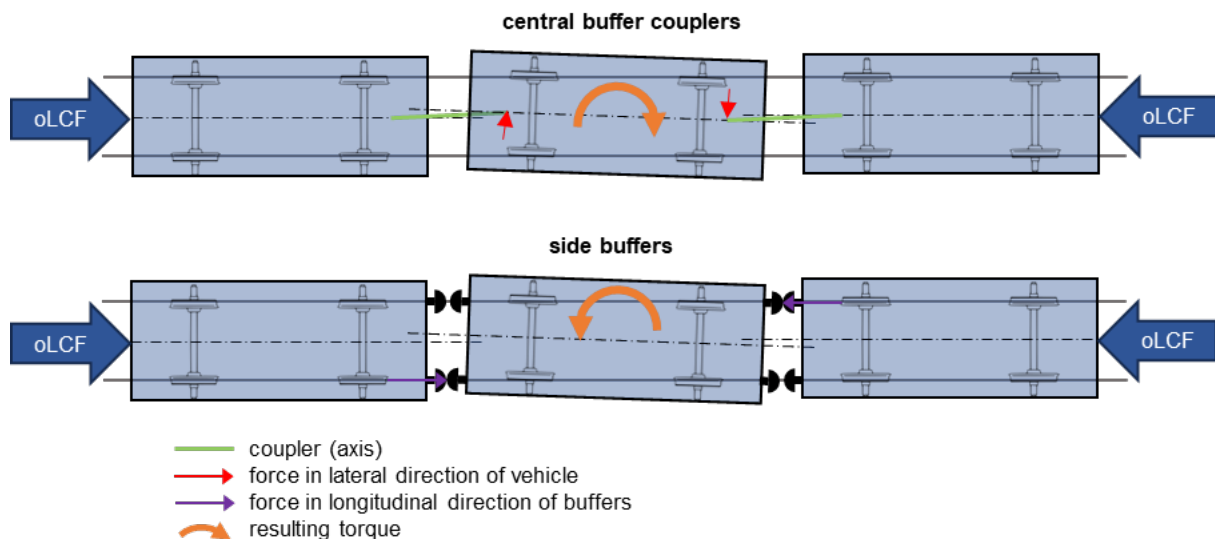


Figure 5: General differences between center buffer couplers and side buffers under *oLCF*. Source: DB Systemtechnik

As Figure 5 indicates, short (often two-axle) vehicles are more prone to take an angled position within the side play between the center lines of vehicle and track. An article about tests of the UIC center buffer coupler in the 1960s [Jahnke] reports that the Soviet railways conducted experiments where *oLCF* led to derailments of two-axle wagons. This subsequently led to further experiments conducted by the German railways. Here it was found that light two-axle freight wagons derailed under high values of *oLCF* on straight tracks. Wagons with side buffers did not derail in the same situation. This mechanism of derailment is referred to as “buckling” and “jackknifing” by North American railways. [DEL4.3]

The derailments in the 1960s led to ORE’s further work in this area that ultimately resulted in an ORE calculation scheme [ORE]. It should be noted that the work was carried out over a period of more than ten years. The ORE scheme considers the 150 m and 250 m full curves for the calculation of *eLCF* for wagons with center buffer couplers. However, the report on the calculation scheme also highlights the relevance of 150 m S-shaped curves

with 6 m intermediate straights for wagons with side buffers. This is explained with the high friction forces between the buffer plates that influence the kinematic movements of the wagons. [DEL4.3]

There is no such pronounced influence of frictional forces with the center buffer coupler. This means that the position of the wagons in curves and thus also the coupler angles responsible for the generation of lateral forces can be determined from geometric considerations. Analytic formulas for this can be found both in the report on the ORE calculation scheme [ORE] and in UIC Leaflet 530-1 [UIC530]. It is important to cover both the angular positions because of curving and the angular positions because of side plays between the center lines of vehicle and track, as shown in the beginning of this section. [DEL4.3]

3.5 Role of a Stabilising Joint

The results of the tests carried out in the 1960s led to extensive work on the development of special joints to connect the coupler arm to the draft gear and thus to the vehicle body. The aim of these developments was to create a joint that does not have an unstable effect as described in Figure 6 in section 3.4, but has a stabilising effect similar to the side buffers. The basic principle is visualised in Figure 6. [DEL4.3]

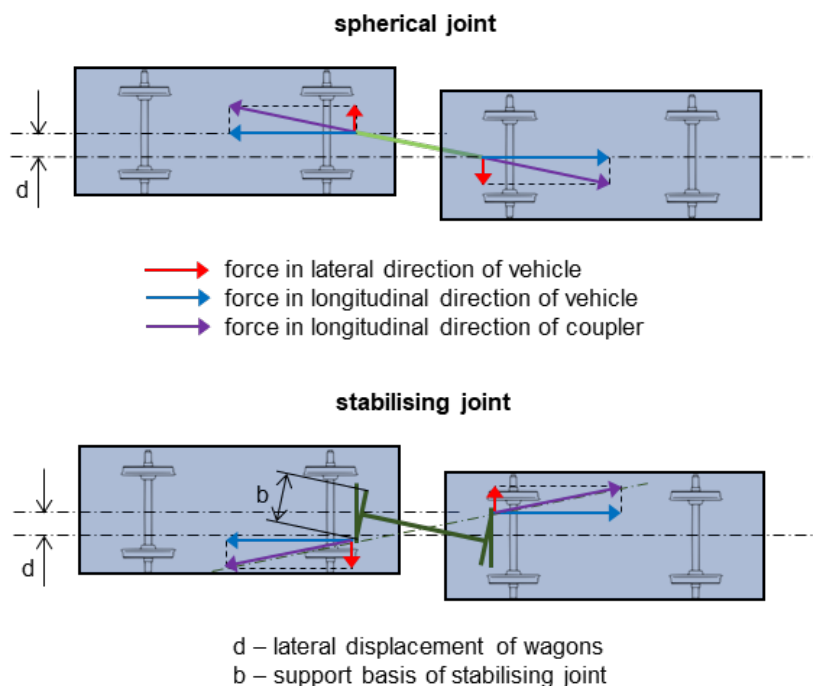


Figure 6: Principle of a stabilising joint [DEL4.3]

A parallel displacement of the longitudinal axes of the wagons leads to an unstable situation in an unstable joint as already shown in section 3.4. The resulting lateral forces lead to an increase in the lateral displacement. With stabilising joints, a lateral displacement of the wagon axes leads to a displacement of the contact points in the joint.

This creates a line of acting force that is inclined in the opposite direction to the coupler arms. The resulting forces at the contact points therefore aim to reduce the lateral displacement, i.e. have a stabilising effect. This effect is present as long as the lateral displacement is smaller than the so-called support base. Depending on the design of the joint, this stabilising effect can only act horizontally or horizontally and vertically. The latter joints are referred to as complete stabilising joints (stabilising on all sides). [DEL4.3]

Various tests were carried out to evaluate different designs of stabilising joints, which are documented in test reports [ORE2] [ORE3]. These tests included tests in which empty wagons were pushed between loaded wagons under constant longitudinal compressive force. The track used for this test was a passage from a straight into a 150 m full curve. The result of these tests was the finding that a complete stabilising joint is clearly superior to other designs. Furthermore, the need for such joints on two-axle wagons has been proven beyond doubt. Additionally, the tests showed that the stabilising effect of the joints is less efficient in reality than in a (simplified) theory. For this reason, efficiency levels for the stabilising effect were introduced on the basis of the test results. [DEL4.3]

During the development and testing of the stabilising joints, requirements and component tests were also defined for the joints. These requirements and tests ensure that different versions of the complete stabilising joints offer the required functionality. Details on this can be found in UIC Leaflet 524 [UIC524]. A detailed procedure for tests of positional deviations of the thrust plate under load are an example. [DEL4.3]

3.6 Procedure for AAR couplers

On railways that use the Association of American Railroads (AAR) standard, the Janney coupler is used as a center buffer coupler. The topics of oLCF and eLCF are also relevant here and have been addressed. For the past decades, there was and is a continuing trend towards longer and heavier trains on several AAR railways. In 1989, there were 2146 derailments in the USA alone, of which around 200 were due to longitudinal dynamics. For this reason, the AAR developed a new evaluation procedure for the curving behaviour under tensile and compressive forces. The development was based on tests with special test wagons as well as analyses and computer simulations and is described in a publication [El-Sibaie]. [DEL4.3]

With the special test wagon, lateral forces could be introduced into the wagon under test independently of oLCF and coupler angles. The test unit was pulled through a 175 m full curve with a constant lateral force. This test was repeated several times with successively increased lateral force values. Vertical and lateral forces in the wheel-rail contact were recorded via instrumented wheel sets. The wagons under test were in the critical empty state. The limit values in these tests were [DEL4.3]:

- wheel unloading of 90 % or more (wheel normal force less than 10 % of the static value)
- ratio of individual lateral wheel forces Y and individual vertical wheel forces $Q > 1$ ($Y/Q > 1$)

To be able to determine lateral forces arising from oLCF in real situations, the coupler angles must be known. A simulation programme was developed for this purpose and validated using real tests. The AAR Manual of Standards and Recommended Practices Part C-II [AAR] (Section 2.1.6) defines a test to verify the safety of light wagons against derailment under longitudinal forces. The wagon under test is pulled through a 175 m curve under a force of 890 kN (200,000 pounds of force), whereby it is connected on both sides to wagons that have a length of approx. 12.8 m between the coupler arm supports (strikers). This test aims at the effect of wagons overturning under longitudinal forces. This can happen in both buff and draw direction. A tensile force leads to overturning towards the inside of the curve, a compressive force towards the outside of the curve. This latter case is illustrated in Figure 7. [DEL4.3]

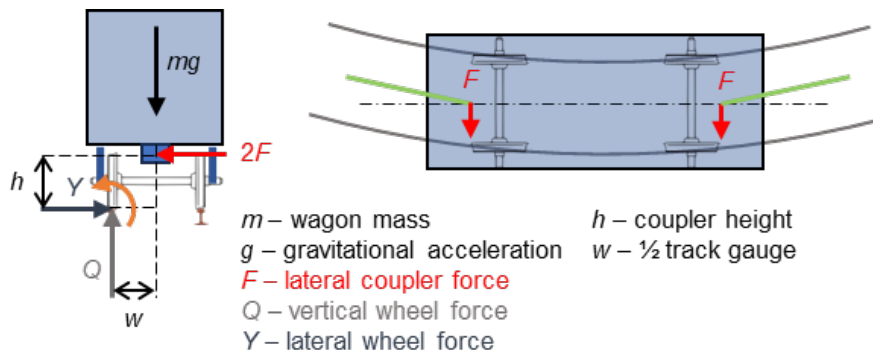


Figure 7: Static equilibrium at 100 % wheel unloading of one wagon side. Source: DB Systemtechnik

The limiting case (complete wheel unloading on one wagon side) can be determined statically [El-Sibaie]. There is no torque in this situation if the following equation holds:

$$Y/Q = w/h$$

For the AAR railways, h equals to 876,3 mm (34.5 in) and w equals to $\frac{1}{2} \times 1435$ mm, resulting in $Y/Q = 0.82$. Both Y and Q refer to the sum in the bogie in this case [AAR]. This is consequently defined as the limit value for this test. [DEL4.3]

Despite having this test defined, there was again an increase in derailments that were related to longitudinal dynamics in Northern America the 2000s [FRA] [NRC]. Investigations found that further increasing train lengths and masses had an influence on these derailments. Furthermore, it was found that jackknifing of the wagons in curves leads to larger coupler angles which leads to increased lateral forces and that this effect was not covered by the test mentioned above [Chen]. The AAR identified additional Y/Q limit values, one of them being $Y/Q > 0.75$ where the risk of wheel climbing on worn rails arises [NRC]. [DEL4.3]

A report on oLCF-related derailments in Canada [NRC] lists some interesting statistics:

- All of the derailed trains were mixed goods trains. No empty or loaded unit trains were involved.
- Most of the first derailed wagons were empty except for two yard locomotives (without alignment control, see below).
- 64 % of the derailed trains were longer than 2.4 km (8,000 feet)
- The lightest of the derailed trains had a weight of 4,500 t, the heaviest 17,200 t.

A report of the US Federal Railroad Administration [FRA] identified “difficult” wagons. These are:

- Wagons with Jacob’s bogies; not because of these articulated bogies but because of the vehicle’s light tare weight
- Wagons without bogies because of their very low tare weight
- Long wagon-short wagon combinations on turnout combinations in sidings

The findings of the investigations led to further improvement of operational rules, especially rules regarding the make-up of trains. [DEL4.3]

Couplers for AAR wagons do not have stabilising joints. In contrast to that, modern AAR mainline locomotives are required to have couplers with so-called alignment control. This feature limits the coupler angles during curve negotiation. AAR locomotives without alignment control couplers might derail under high oLCF values [Chen]. The reasoning for locomotives needing this feature while the wagons do not is given in an alignment control coupler patent [Metzger]. Here it says that the different geometry of locomotives compared to freight wagons in connection with short coupler shanks can lead to misalignments of the couplers. [DEL4.3]

3.7 Existing Test Experience for Wagons with DACs

In 2020/21, the DAC4EU project carried out the first propelling tests with DAC wagons. In this phase of the project, the aim was to compare different basic types of DACs to create the basis for the selection of the future DAC type. The behaviour under longitudinal compressive forces was only one aspect of many. The various basic types of DACs were each tested in standardised three-wagon groups. The propelling tests are described in a published test report [DAC4EU01].

The tests were based on the procedure described in EN 15839 but deviated from it in some details. One major difference was the configuration of the test train. The same wagon types were used for this purpose as for all other DAC4EU tests in this phase. This resulted in the following DAC4EU test configuration:

- Eanos-x 059 (leading flanking wagon)
- Hbbins 306 (test wagon)
- Zags 119 (trailing flanking wagon)

With a wagon of the Hbbins 306 type, propelling tests with an UIC center buffer coupler and the EN 15839 wagon configuration were carried out in the 1990s. Here, eLCF of over 600 kN were determined. The locomotives used were unable to apply greater forces. In two publications, the authors state that based on the measured values, the eLCF could be extrapolated to at least 700 kN without exceeding the limit value. [DEL4.3]

3.8 Interim Conclusion

The above explanations show that there is currently no methodology that can be used without restriction to assess the running safety of wagons with DAC under longitudinal compressive forces. The reasons for this lie both in system-related differences between side buffers and center buffer couplers and in different system parameters within the group of center buffer couplers. However, it is also clear that a lot of work has already been carried out in this area in the past and that there is a large knowledge base. The critical case to be assessed is the same for all the methods presented [DEL4.3]:

- Wagon to be assessed in an empty state,
- in a curved situation, resulting in coupler angles,
- with flanking wagons that lead to particularly large coupler angles.

The assumed critical curve situation differs between the various sets of rules. Overall, empirical evidence (tests as well as dispensation based on experience), analytical calculation methods and numerical simulation methods are used for the assessment. Table 1 summarises this. [DEL4.3]

Table 1: Summary of methodologies for eLCF assessment. E = empirical, A = analytical, N = numerical.

Methodology	Area of Application	Context	Type of Infra.	Type of Methodology		
				E	A	N
Dispensation from further consideration if design criteria are met	wagons w. side buffers	EN 15839	-	x		
Propelling tests	wagons w. side buffers	EN 15839	150 m S curve	x		
Simulation of propelling tests if validated simulation model available	wagons w. side buffers	EN 15839	150 m S curve			x
Calculation scheme and result diagrams	wagons w. UIC AC	UIC 530-2	150 m, 250 m full curves	x	x	
Lateral force test	AAR Wagons	AAR	175 m full curve	x	x	x

4 Test procedure

On the basis of the principles presented so far, a test procedure according to EN15839 is proposed, which should, however, be adapted for the special case of the center buffer coupler.

4.1 Procedure according to EN 15839

For wagons whose properties do not lie within specific value ranges, EN 15839 defines a test procedure for determining the eLCF. These are referred to as propelling tests. [DEL4.3]

In this test, the wagon to be tested is pushed unloaded through an S-shaped curve with a radius of 150 m and a 6 m straight between the two curves (Figure 8). Within the train configuration, the wagon is placed between two exactly specified so-called flanking wagons (see Figure 9). The train is pushed by one or more locomotives and there are brake wagons at the opposite end of the train (Figure 9). The locomotive(s) push the train at approximately walking pace, with the brake force of the brake wagons acting against the traction force of the locomotive(s). This results in a longitudinal compressive force that must be kept as constant as possible for each test run. [DEL4.3]

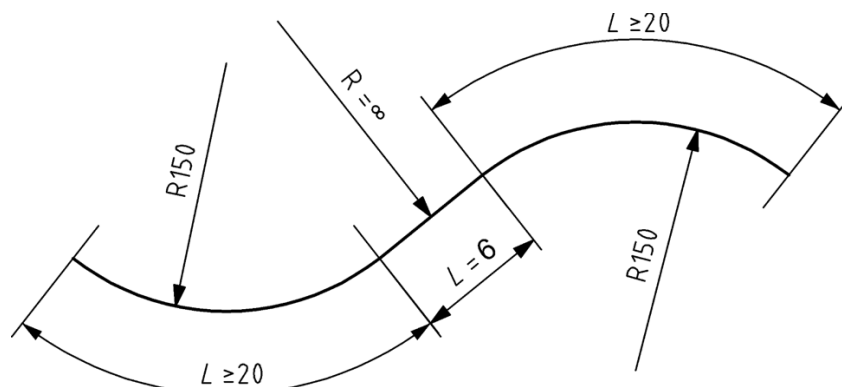


Figure 8: Test track according to EN 15839. Source: [EN15839] (modified)

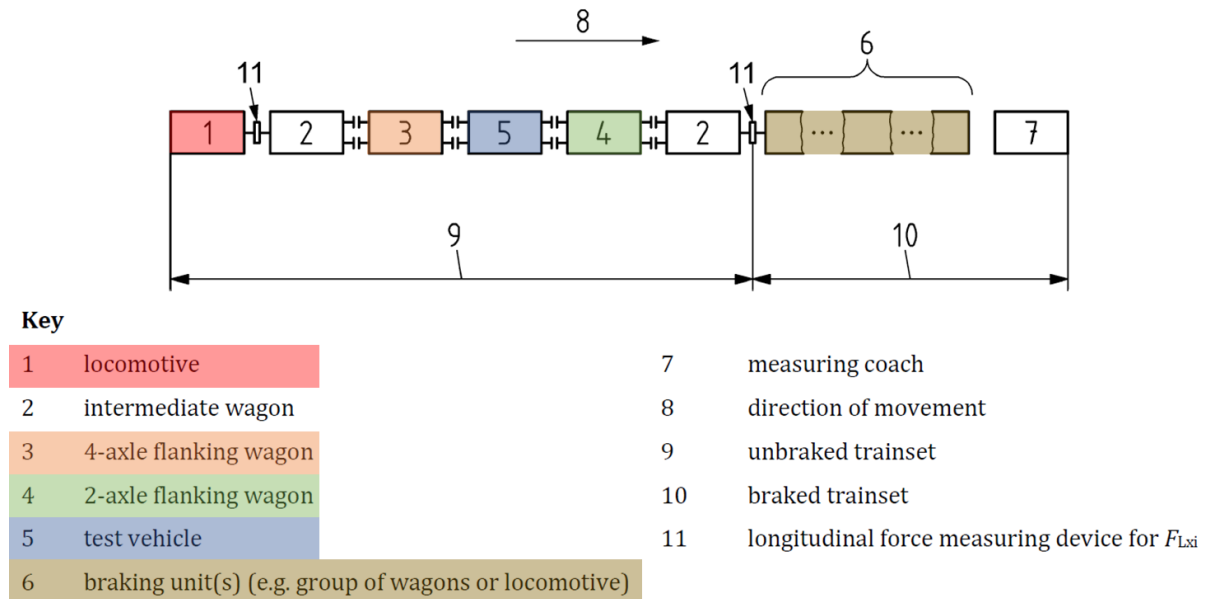


Figure 9: Test train configuration according to EN 15839. Source: [EN15839] (modified)

The following variables must be measured on the wagon under test:

- wheel lift
- lateral axle box force
- axle guard deformation (only for two-axle wagons)
- overlap of buffer plates

In addition, the longitudinal compressive force in the consist must be measured. For this purpose, special intermediate wagons with center buffer couplers are often used in tests with side buffer wagons. [DEL4.3]

The longitudinal compressive force must be successively increased from test run to test run until a limit value for the measured values is exceeded or a sufficiently high longitudinal compressive force is reached. There is a minimum number of required test runs, some of which must be above the eLCF to be verified. The values to be proven are the same as shown in the previous section: 200 kN for two-axle wagons, 240 kN for wagons with bogies.

The flanking wagon in front of the test wagon is a two-axle wagon with a wheelbase of 6 m and a length over buffers of 9.64 m. Typical types are Fcs and Tds wagons. The flanking wagon behind the test wagon is a bogie wagon with a length over buffers of 19.9 m and a bogie pivot distance of 13 m. A typical wagon with these dimensions is the Rs 680 type. [DEL4.3]

4.2 Adaptations for center buffer couplings

The previously described procedure is also suitable in principle for tests on vehicles with center buffer couplings. However, a few adaptations need to be applied in comparison to the standard, which are described in more detail below.

4.2.1 Limit values

The limit for the minimum eLCF that can be withstood by two-axle freight wagons with side buffers in the standard test according to EN 15839 is 200 kN. For freight wagons with a bogie, the value is 240 kN. This must be exceeded by 10 % in 10 tests. In general, the longitudinal compressive force does not increase further at a value of 280 kN. [EN15839]

An important use case of the DAC is the operation of longer and heavier trains, which leads to an increase in the oLCF. To address this, the minimum value for the eLCF was increased to 500 kN in [DEL5.2]. According to the standard, 10 tests must therefore be withstood at an oLCF of at least 550 kN.

4.2.2 Infrastructure and setup

The track geometry should be the s-curve shown in Figure 8 of Section 4 in accordance with EN15839. This is available, for example, at the TÜV Süd site in Görlitz. As described in section 3.7 an s-curve is not absolutely necessary for testing the derailment behaviour of the DAC. For example a 150m curve could be sufficient. In order to achieve the highest possible level of compliance with the standard, the tests should nevertheless initially be carried out in the described s-curve. Whether this is necessary for further tests should be the subject of the test campaigns and taken into account in an extension of the standard.

The test set-up as described in Section 4 and shown in Figure 9 must be adapted due to the now higher oLCF. To achieve values above 500 kN, at least two 4-axle locomotives and additional brake wagons must be used. The adapted set-up is shown in Figure 10. The concept of intermediate and flanking wagons remains the same, but the force measuring point has been placed between the flanking and intermediate wagons. This simplifies coupling with locomotives and the brake wagon group. To derail the test wagon first, all the other wagons except for this one are loaded.

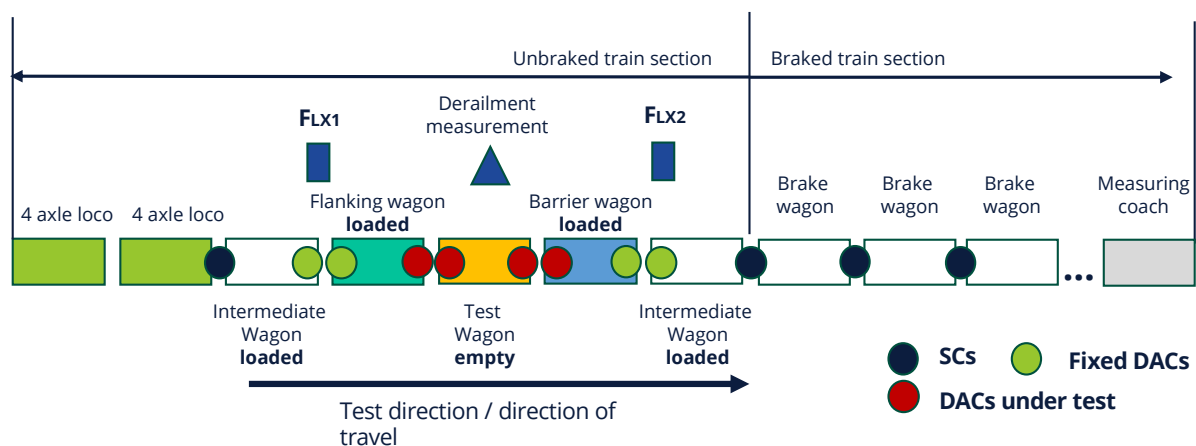


Figure 10: Test train configuration adjusted from EN 15839

The tests implemented in [DAC4EU1] describe a different derailment behaviour for the DAC compared to side buffers. As described in Section 3.4, the torsion of the wagons plays a minor role in the process. This means that a derailment does not occur as described by

the slow lifting of a wheel, but can happen quite suddenly. In order to detect this at an early stage, the wheel contact force should also be measured and the evaluation criteria in the standard adjusted. Suggestions for this are discussed in the following chapters.

4.2.3 Vehicles

The vehicle recommendations in accordance with EN15839 are shown in Table 2. The flanking wagons play a major role here.

Table 2: Wagon characteristics according to EN15839 (modified).

	Front flanking wagon	Test wagon	Rear flanking wagon
Examples	Fcs or Tds	-	Rs
Type	2-axle wagon	-	4-axle wagon
Length over buffers	9,64m	-	19,9m
Wheelbase	6m	-	
Distance between the pivot pins	-	-	13m
Axle load	Close to maximum load	Only dead weight	Close to maximum load
Overhang	1,82m		3,45m

It is important to implement the front flanking wagon as a short 2-axle wagon and the rear flanking wagon as a longer 4-axle wagon. In addition, it is important to ensure that both vehicles have the largest possible overhang. For a 2-axle wagon, this is calculated as follows:

$$\text{Overhang} = 0.5 (\text{Length over buffers} - \text{Wheelbase})$$

For four-axle wagons, the wheelbase is replaced by the Distance between pivot pins. The results are also shown in Table 2.

However, the wagon types described in the standard are now rather outdated, which means that they are in short supply and extremely difficult to obtain on the market. Furthermore, it is currently unclear to what extent the vehicles described are suitable for integrating a DAC. Table 3 therefore contains additional vehicles with similar characteristics. The test wagon proposed for DAC validation has also been included.

Major challenges were encountered in the search for a suitable short 2-axle front flanking wagon, similar to the Tds 930 described in the standard (see table 3). Short 2-axle wagons are not considered economical by wagon owners and have not been produced for several decades. In previous projects [DAC4EU1], a 4-axle Eanos-x 059 was used as the front flanking wagon. A large database is already available for this. If identical wagon types are used, this can serve as a comparison of the DAC properties, which is why these wagon types were also chosen for this test campaign to validate the DAC. The same applies to

the rear flanking wagon. Here, a Zags 119 was chosen instead of an Rs 680. However, the relevant wagon characteristics are almost identical in this case.

Table 3: Proposed wagon characteristics similar to EN15839.

	Front flanking wagon		Test wagon	Rear flanking wagon	
Examples	Eanos-x 059	Tds 930	Hbbins 306	Rs 680	Zags 119
Type	4-axle wagon	2-axle wagon	2-axle wagon	4-axle wagon	
Length over buffers	15,74m	9,64m	15,5m	19,9m	18.8m
Wheelbase		6m	9m		
Distance between pivot pins	10,7m	-	-	13m	12,1m
Axle load	Close to maximum load		15t	Close to maximum load	
Overhang	2,52m	1,82m	3,25m	3,45m	3,35m

The proposed test wagon is to be considered critically as a very light two-axle wagon with a large overhang and was also used in previous tests [DAC4EU1]. Thus, further comparable data sets are available to validate a DAC. In order to address the second objective of the tests, the validation of the simulation tool [DEL4.3], two further test vehicles are to be examined in the tests.

- A center-jointed wagon that is as long as possible (e.g. Sggrs 741)
- A long 2-axle wagon with a very long overhang outside the limit line in EN15839 (e.g. Hbbills 311)

For the tests with four different coupler suppliers, it is also easier to keep the wagon sets in stock in sufficient numbers. The vehicles required for the tests are summarised in Table 4. The wagons used are identical to the wagon types from previous test campaigns, which significantly increases the comparable data basis for validating the DAC.

Table 4: Selected wagons for tests.

Quantity	Wagon Type	Characteristics	Loading
2	Zags 119	Rear flanking wagon 4-axle, long, large overhang	Water
2	Eanos-x 059	Front flanking wagon 4-axle, medium length, large overhang	Concrete blocks
2	Hbbins 306	Test wagon Test data available in DAC4EU 2-axle, long, large overhang	unloaded
1	Sggrs 741	Test wagon	unloaded

		center-jointed wagon, long	
1	Hbbills 311	Test wagon 2-axle wagon with a very long overhang outside the limit line in EN15839	unloaded

4.2.4 Measurement values

According to the standard, the following values have to be measured at the measuring points shown in Figure 11.

1. longitudinal compressive force F_{LXi} in the test train
2. wheel lift d_{zij} of all wheels in the test wagon
3. lateral forces on the axle box H_i of all the test wagons axles
4. deformation of the axle brackets dy_{Aij} of all the test wagons wheels (only in freight wagons with axle brackets)
5. buffer displacements dy_{P1} , dy_{P2} between the frame and test wagons
6. recording of track marks
7. distance along the track (e.g. 1 m mark)

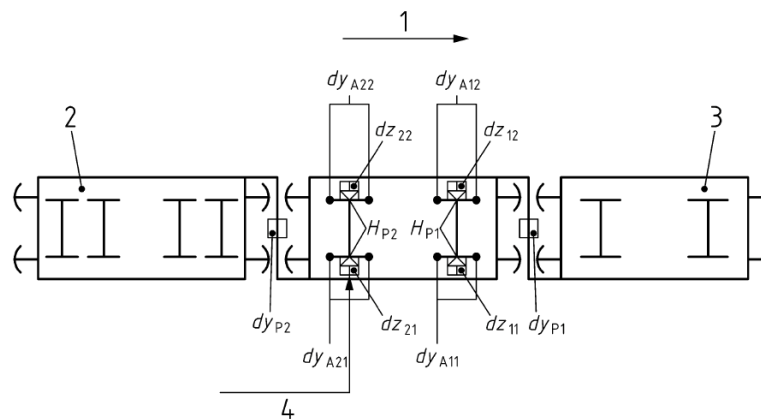


Figure 11: Arrangement of the measuring instruments during the test; 1 = Direction of travel; 2 = 4-axle flanking wagon; 3 = 2-axle flanking wagon; 4 = Recording of the track marks (example) – source: [EN15839]

Since a center buffer coupling is to be used instead of side buffers, measurement of 5. buffer displacements is not necessary. However, the issue of sudden derailment, as mentioned in section 4.2.2, should be addressed by measuring the wheel contact force at each wheel of the test wagon.

Overall, a measurement of the following variables is to be implemented. This includes not only all except the already mentioned point 5 of the measurement variables presented in EN15839, but significantly extends them. Reasons for the extended measurement equipment are, on the one hand, the data necessary for the validation of the simulation tool and, on the other hand, the possibility of a deeper error analysis in the event of failed attempts.

1. longitudinal compressive force F_{LXi} in the test train (oLCF)
2. wheel lift d_{zij} of all wheels in the test wagon
3. lateral forces of all wheel sets on rail Y_{ij}
4. deformation of the axle brackets dy_{Aij} of all the test wagons wheels (only in freight wagons with axle brackets)
5. wheel contact force Q_{ij} of all wheels in the test wagons
6. recording of track marks
7. distance along the track (e.g. 1 m mark)
8. deflection angle β_{aij} of the DAC on both sides of the test wagon
9. velocity v_x of the test wagon
10. Tilting angles γ_{aij} and β_{aij} of the thrust plates of both DAC's draft gears
11. Wagon body acceleration a_{xyz} of the test wagon (optional)
12. Wagon position lat, lon, alt, of the test wagon (optional)
13. Yaw angle of wheelsets of two axle-wagons

In addition, the rail profile, the wheelsets of the wagons and the track markers must be regularly checked and documented during the tests.

4.2.5 Hypotheses

In accordance with the test objectives defined in section 2, the derailment safety of freight wagons with a DAC is to be verified at longitudinal compressive forces of at least 500 kN. This fundamentally important correlation is formulated in hypothesis 1:

HYPOTHESIS-01:

Freight wagons with a DAC are in principle capable of running safely at a longitudinal compressive force of at least 500kN. This must be demonstrated in 10 tests at 550kN oLCF within the limit criteria.

These criteria limits are described in [EN15839] as follows:

- lifting of a non-leading wheel $dz_{ij,lim} = 50$ mm over a rolling path of ≥ 2 m;
- axle box holder deformation $dy_{Aij,lim} = 22$ mm, measured 380 mm from the lower edge of the longitudinal beam;
- wheel contact force Q_{ij} of all wheels in the test wagons
- minimum horizontal covering of the buffer heads $dy_{p,lim} = 25$ mm;
- climbing of the leading wheels $dz_{ij,lim} = 5$ mm;

The next objective is to determine a regression line in a diagram of dz (lifting of non-leading wheel) over FLX (oLCF).

In general, the evaluation criterion with the lowest value determines the permissible longitudinal compressive force (eLCF) for FLX . Due to the previously mentioned differences in the behaviour of wagons with central buffer couplings and the resulting spontaneous derailment of those vehicles, it is suspected that none of the criteria used is able to detect a subsequent derailment during the test procedure in time. Therefore, a further hypothesis is formulated.

HYPOTHESIS-02:

A vertical wheel force is a sufficiently precise limit criteria for tests with center buffers and can supplement the limit criteria in EN15839 regarding climbing of the leading wheels $dz_{ij,lim} = 5$ mm.

Another consideration that needs to be demonstrated relates to the variation of couplers from different suppliers. Currently, four companies supply DACs for the validation tests. The running safety must be demonstrated for each of the possible combinations. However, the simulations and theoretical considerations implemented so far in [DEL4.3] show that the DAC used in the flanking wagons has none to a negligible effect on the derailment safety of the test wagon. The third hypothesis therefore follows:

HYPOTHESIS-03:

The DAC system installed in the test wagon is responsible for the eLCF of the test wagon. The coupled DAC system installed in the test wagon does not play a significant role. The deviation of mixed DAC systems compared to in-house DAC systems is less than 5%.

Hypothesis 03 is to be confirmed or rejected by selection experiments. First, the eLCF of DAC systems from the same suppliers in the test wagon and the flanking wagons are to be determined. For example, in the case of the supplier Voith, all four coupling systems marked in red in Figure 10 are from Voith. After that, experiments with mixed coupling systems are implemented. In this case, the worst and best-rated DAC systems from the first tests should be combined. The hypothesis can be confirmed if the eLCF of the test wagon in the mixed case does not deviate by more than 5% from the eLCF of the test wagon in the non-mixed case.

Another hypothesis concerns the confirmation of the mechanical principles regarding the eLCF in the draft gear. It is assumed that the tilting angle of the draft gear's thrust plate has a major influence on the eLCF of vehicles. This has already been confirmed in test rig experiments and simulations, which is why further validation in vehicle experiments is optional. For validation in vehicle tests, a continuous measurement of the tilting angle of the thrust plate in the draft gear according to section 4.2.4 is foreseen.

HYPOTHESIS-04:

The eLCF of vehicles with a DAC is strongly related to the tilting stiffness of the DAC draft gear's thrust plate. The higher the tilting stiffness, the higher the eLCF of the test wagon. At an eLCF of 500kN, the measured tilting angle of the thrust plate is less than 2°.

The next hypothesis is used in particular to validate the simulation tool described in [DEL4.3]. This is intended to determine the eLCF of vehicles with DACs in a simulation. The focus of the hypotheses described above is to determine the influence of DACs on the eLCF of a test vehicle. However, the influence of different vehicle geometries is considered to be crucial for the eLCF. This is to be further validated by the investigation of different vehicle types. As already described in section 4.2.3, it is assumed that the vehicle length, the overhang and the dead weight have the greatest influence on the eLCF of vehicles. However, hypothesis-01 must also be confirmed for vehicles with unfavourable geometry. To illustrate this, it is clarified again in hypothesis-05.

HYPOTHESIS-05:

The eLCF of vehicles with a DAC is highly depending on the vehicles geometry. The main factors influencing this are the vehicle length, the overhang and the unladen weight of the vehicle. However, the eLCF of vehicles with a DAC is higher than the specified 500kN, even with difficult vehicle geometries.

The last hypothesis is based on the assumption that the s- curve specified in EN15839 is not necessary for validating the derailment safety of freight wagons with center buffer couplings. This is based on the spontaneous derailment behaviour of the above- mentioned vehicles observed in previous tests. A torsion of the vehicles similar to the case of vehicles with side buffers is only very slight and probably negligible. Accordingly, driving through the s- curve may not be necessary for future tests of vehicles with center buffer couplings. The corresponding hypothesis follows:

HYPOTHESIS-06:

Vehicles with center buffer couplings derail at high oLCF shortly after entering the 150m s-curve. For further tests, a 150m curve (e.g. half of the s-curve specified in EN 15839) is sufficient.

5 Test execution

5.1 Description of test case

In order to evaluate the hypotheses set out in section 4.2.5, various individual tests must be carried out (see Table 5). The influence of DAC systems from different suppliers on wagons with eLCF should be investigated first. The tests should initially be carried out with single-source DACs (all DACs from one supplier). After that, DACs from different manufacturers should be used to validate the influence of DAC mixing. Finally, the general suitability of the DAC systems should be analysed by testing vehicles with unfavorable geometry.

The following individual tests are to be executed:

Table 5: Overview of test cases.

Case	Test wagon	DAC test wagon	DAC flanking wagons	Amount
1xx	Hbbins 306	Only DACs from same supplier. Expection: The wagon group is pushed through the s-curve. In the process, the oLCF will be increased continuously. As soon as the required 550kN have been reached, the test will be repeated 10 times. Recommended oLCF values: 200kN, 300kN, 400kN, 450kN, 500kN, 550kN or more (10x), higher oLCF are possible (on request of the supplier)		
111	Hbbins 306	DEL	DEL	20
121	Hbbins 306	KB	KB	20
131	Hbbins 306	FT	FT	20
141	Hbbins 306	VT	VT	20
2xx	Hbbins 306	Mixed DACs from two suppliers. Expection: The wagon group is pushed through the s-curve. In the process, the oLCF will be increased continuously. As soon as the required 550kN have been reached, the test will be repeated 10 times. Recommended oLCF values: 200kN, 300kN, 400kN, 450kN, 500kN, 550kN (10x)		
211	Hbbins 306	VT	FT	20
221	Hbbins 306	FT	VT	20
231	Hbbins 306	VT	KB	20
241	Hbbins 306	VT	DEL	20
251	Hbbins 306	FT	DEL	20
261	Hbbins 306	FT	KB	20
3xx	Varies	Variation of wagons. Expection: The wagon group is pushed through the s-curve. In the process, the oLCF will be increased continuously. As soon as the required 550kN have been reached, the test will be repeated 10 times. Recommended oLCF values: 200kN, 300kN, 400kN, 450kN, 500kN, 550kN (10x)		
311	Sggrs 741 or Laes 559	To be chosen (e.g. DAC within spec, but critical)	To be chosen (e.g. DAC within spec, but critical)	20
321	Hbbills 311	To be chosen (e.g. DAC within spec, but critical)	To be chosen (e.g. DAC within spec, but critical)	20
331	BR 185 V2	To be chosen (e.g. DAC within spec, but critical)	To be chosen (e.g. DAC within spec, but critical)	20

Some of the criteria to be evaluated have already been discussed in section 4.2.4 and are summarised in Table 6.

Table 6: Evaluation – Criteria.

To evaluate	Criteria
Coupler	
Mechanical coupling	The couplers are mechanically coupled during each test
Pneumatical coupling	Brakes of test wagons are not in use
Electrical coupling	No influence on electrical coupling expected
Mechanical uncoupling	The couplers must not uncouple during each test
Derailment criteria	Derailment criteria (see below) are not exceeded with tests up to 550kN eLCF (see Hypothesis 1)
Critical damages	The coupler must stay functional and not be critically damaged during or after the tests
Wear and tear of coupler	The wear of parts should be noted. Remark: The wear should not lead to failure of the parts, considering the amount of tests
Dimensions of components	The dimensions of the DAC components must match the suppliers' drawings
Wagon	
Derailment criteria	Derailment criteria (see below) are not exceeded with tests up to 550kN eLCF (see Hypothesis 1)
Critical damages	The Wagons must stay functional and not be critically damaged during or after the tests
Position of derailment in s-curve	The exact position of a possible derailment within the s-curve needs to be evaluated
Dimensions of wagon geometry	The dimensions of wagon geometry must match the wagon keepers' drawings
Derailment criteria	
Wear and tear of coupler	The wear of parts should be noted Remark: The wear could lead to failure of the parts (e.g. wheelsets or axle bearings), considering the amount of tests
Lifting of wheels	lifting of a non-leading wheel $d_{zij,lim} < 50$ mm over a rolling path of ≥ 2 m and climbing of the leading wheels $d_{zij,lim} < 5$ mm
Axle box	axle box holder deformation $d_{yAij,lim} < 22$ mm, measured 380 mm from the lower edge of the longitudinal member
Wheel set	wheel contact force Q_{ij} of all wheels in the test wagons
Vertical wheel force	vertical wheel force ≥ 0 N (optional criteria -> to be validated in Hypothesis-02)
Tilting angle of draft gear's thrust plate	tilting angle of the draft gear's thrust plate $< 2^\circ$ -> to be validated in Hypothesis-04
Rails – track infrastructure	
Wear and tear of coupler	The wear of parts should be noted Remark: The wear could lead to failure of rails – ramps – geometry out of standard

5.2 Test procedure

In general, the test procedure was described in section 4. This chapter suggests a detailed step-by-step procedure during the tests.

5.2.1 Preparation and initial situation

ID	
1	Preparation
1.1	Measured parameters
1.1.1	Wheel lift d_{zij} of all wheels in the test wagon
1.1.2	Lateral forces on the axle box H_i of all the test wagons axles
1.1.3	Deformation of the axle brackets dy_{Aij} of all the test wagons wheels (only in freight wagons with axle brackets)
1.1.4	Wheel contact force F_{zAij} of all wheels in the test wagons
1.1.5	Recording of track marks
1.1.6	Distance along the track (e.g. 1 m mark)
1.1.7	Deflection angle β_{aij} of the DAC on both sides of the test wagon (if possible)
1.1.8	Velocity v_x of the test wagon
1.1.9	Tilting angle γ_{aij} and β_{aij} of the thrust plates of both DAC's draft gears (if possible)
1.1.10	Wagon body acceleration a_{xyz} of the test wagon (optional)
1.1.11	Wagon position lat, lon, alt, and UTC time of the test wagon (optional)
1.1.12	Rail geometry and condition, e.g. via 3D scan before tests (if possible)
1.2	To document
1.2.1	Vehicles – Vehicle number – Vehicle type – Direction – Loading condition – ...
1.2.2	Couplers – Supplier – DAC Type – ID / Serial Number – Subparts – ...
1.2.3	Weather conditions – Temperature – Rain / Snow – ...
1.2.4	Operator – For protection of data provacy an „operator-ID“ is sufficient
1.2.5	Infrastructure – Location

	– Geometry (e.g. rail geometry and condition)
1.2.6	Abnormalities and deviations from procedure
1.2.7	Time and date
2	Initial Situation
2.1	Description
2.1.1	Unbroken wagon group: – Brakes deactivated – Coupler centred – Coupler status „coupled“
2.1.2	Braked wagon group: – Brakes activated
2.1.3	Test wagon is unloaded, other wagons are loaded
2.1.4	Continuous communication between the train driver (in the locomotives) and the brakeman (in the brake wagon at the other end of the train) is ensured.
2.1.5	The test train is ready in front of the S-curve. The brake and traction tests have been carried out.
2.2	To document
2.2.1	-
2.3	To measure additionally to .1.1
2.3.1	Height difference of the couplers
2.3.2	Weight of test wagons and flanking wagons

5.2.2 Derailment test

3	Start pushing train set throw s-curve
3.1	Description
3.1.1	The locomotives start traction and begin to move the wagon group in the direction of the s-curve.
4	Setting up oLCF with brake wagons
4.1	Description
4.1.1	From a speed upwards of 6 km/h, the brakeman starts to apply the brakes on the brake wagons.
4.1.2	The locomotive driver and brakeman iterate traction and braking force until the desired oLCF has been measured. A speed of 4 to 6 km/h must be maintained.
5	Running through s-curve
5.1	Description
5.1.1	The group of wagons with the test wagon enters the s-curve at the set oLCF and at the given speed of 4 to 6 km/h.
5.1.2	The speed and oLCF are continuously maintained within the validity range. (oLCF = targeted +2%; Speed = 4 to 6kph)
5.1.3	The technical test manager checks the measured values to see if any of the limit criteria have been reached. In this case, the train driver is informed immediately and traction is stopped.
5.2	To document
5.2.1	Abnormalities -> limit criteria
5.2.2	Eventual derailment
6	Pull back watrain set to start location
6.1	Description
6.1.1	Releasing the brakes
6.1.2	Pull the train set back to start position
7	Check for valid execution
7.1	Description
7.1.1	The test execution of the impact is defined as valid in case of:
7.1.2	– Deviation of actual test wagon speed 4 to 6 kph
7.1.3	– oLCF is within targeted value to targeted value + 2%
7.1.4	– No relevant abnormalities and deviations from test procedure

5.2.3 Visual check

8	Visual check
8.1	Coupler
8.1.1	A visual check of the couplers and draft gear is done regularly. It is not to be executed after each test, but approx. every 5 th test or in case of derailment or abnormalities.
8.1.2	The following is to be checked in detail: – Draft gear pin – Screws – Wear – Draft gear position
8.2	Wagons
8.2.1	A visual check of the wagons is done regularly. It is not to be executed after each test, but approx. every 5 th test or in case of derailment or abnormalities.
8.2.2	The following is to be checked in detail: – Wheel sets – Axle bearings – brakes – Measurement system – Wear
8.3	Rails – track infrastructure
8.3.1	A visual check of the infrastructure is done regularly. It is not to be executed after each test, but approx. every 5 th test or in case of derailment or abnormalities.
8.3.2	The following is to be checked in detail: – Wear of rails – Track marks – Cameras
8.4	To document
8.4.1	Photo documentation
8.4.2	Abnormalities

5.3 Detailed overview of Measurement equipment

The required measurement values have already been discussed in Section 4.2.4. The aim of this section is to present the operating principles in detail, i.e. the sensors and I/O systems used, as well as their planned installation on the vehicle.

The overview of the measurement technology will be provided shortly.

5.4 Evaluation

The given criteria are evaluated the following way:

Table 7: Evaluation - Way of evaluation.

To evaluate	Way of evaluation
Coupler	
Mechanical coupling	→ Documentation of coupler status in protocol
Pneumatical coupling	→ Documentation of brake status in test wagons, flanking wagons and barrier wagons in protocol
Electrical coupling	→ Documentation of e-coupler status in test wagons, flanking wagons and barrier wagons in protocol
Mechanical uncoupling	→ Documentation of abnormalities in protocol → Photo documentation
Derailment criteria Coupler force - oLCF	Measurement of force on the coupler with on-wagon system: → Max. compression force during test evaluated → oLCF should be in range "targeted value to targeted value+2%"
Critical damages	→ Documentation of abnormalities in protocol → Photo documentation
Wear and tear of coupler	→ Documentation of abnormalities in protocol → Photo documentation
Dimensions of components	The dimensions of the DAC components must match the suppliers' drawings
Wagon	
Derailment criteria Wagon velocity	Measurement of velocity of the train group with on-wagon system: → velocity should be in range 4 to 6 kph
Critical damages	→ Documentation of abnormalities in protocol → Photo documentation
Dimensions of wagon geometry	→ Documentation of abnormalities in protocol → Photo documentation
Derailment criteria	
Wear and tear of coupler	→ Documentation of abnormalities in protocol → Photo documentation
Lifting of wheels	Measurement with on-wagon system: → lifting of a non-leading wheel $d_{zij,lim} < 50$ mm over a rolling path of ≥ 2 m and → climbing of the leading wheels $d_{zij,lim} < 5$ mm
Axle box	Measurement with on-wagon system: → axle box holder deformation $d_{yAij,lim} < 22$ mm, measured 380 mm from the lower edge of the longitudinal member
Wheel set	Measurement with on-wagon system: → wheel contact force Q_{ij} of all wheels in the test wagons
Vertical wheel force	Measurement with on-wagon system: → vertical wheel force ≥ 0 N (optional criteria -> to be validated in Hypothesis-02)
Tilting angle of draft gear thrust plate	Measurement with on-wagon system: → tilting angle of the draft gear's thrust plate $< 2^\circ$ -> to be validated in Hypothesis-04
Rails - track infrastructure	
Wear and tear of coupler	The wear of parts should be noted Remark: The wear could lead to failure of rails - ramps - geometry out of standard

6 References

Abbreviation	Document-Nr.	Title	Author	Date	Version
[DEL13.1]	-	TRANS4M-R - D13.1 System Integration Plan & Test Concept for DAC components	Anna Björkman	22.12.2022	1
[DEL13.2]	-	TRANS4M-R - D13.2 Consolidated full system integration plan, test concept & validation concept and plan	Anna Åkerman	11.04.2024	4
[DEL5.2]	-	TRANS4M-R - D5.2 Technical Specifications of Wagon and Locomotive DAC up to Level 5	Johan Ahman	20.12.2023	1
[DEL5.3]	-	TRANS4M-R - D5.3 Validation/Test Procedures of Wagon and Locomotive DAC up to Level 5	Andreas Schuhmacher	31.10.2023	4
[DEL4.3]	-	TRANS4M-R - D4.3 DAC Running Safety Assessment Tool	Daniel Jobstfinke	07.02.2025	1
[TSIWAG]	321/2013	TSI Wagon COMMISSION REGULATION (EU) No 321/2013 of 13 March 2013 concerning the technical specification for interoperability relating to the subsystem 'rolling stock - freight wagons' of the rail system in the European Union and repealing Decision 2006/861/EC (Text with EEA relevance)	European commission	13.03.2013	-
[EN14363]	EN 14363:2016 +A12028	Railway applications Testing and simulation for acceptance of running characteristics of railway vehicles – Running behaviour and stationary tests; German version EN 14363:2016+A1:2018	DIN-Normenausschuss - FSF	01.11.2019	-
[UIC530]	UIC 530-2	Railway applications – Freight wagons – Running safety – 5 th Edition	International Union of Railways (UIC)	01.12.2005	5
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7 Appendices

Annex	Vn.	Title	Content