

“Development of a concept for the EU-wide migration to a digital automatic coupling system (DAC) for rail freight transportation”

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Disclaimer

In this technical report, the generic masculine form is used to aid readability. Female and other gender identities are expressly included in this context, insofar as this is necessary for the statement.

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Summary

An analysis of worldwide rail freight transport (RFT) activities shows that no comparable approaches exist for the introduction of a digital automatic coupling (DAC). The couplings currently used in RFT (Janney and SA3) only create the mechanical connection between the wagons automatically. The complexity of automating systems above and beyond this mechanical interface is one of the reasons why no further advances in automation have been achieved in the sector.

It is proposed that the European rail freight sector make the direct leap from a screw coupling (SC) to a DAC Type 4. A DAC Type 4 permits automatic coupling of compressed air, electrical power, and data lines, in addition to the mechanical connection. The direct introduction of a fully automatic DAC Type 5, which can also be (automatically) decoupled remotely, is not recommended at this stage. This is to allow the migration to the DAC, and the possible resulting digitisation of RFT, to take place within a realistic time frame.

This report compares the properties of established RFT coupling systems with four new developments. Within the framework of the “Shift2Rail” research project “FR8RAIL”, the manufacturer CAF is currently developing a DAC based on the “SA3” coupling that has been used in RFT for many years. The other development projects are based on couplings for rail passenger transport. The manufacturers Voith and Dellner are developing couplings with the Scharfenberg Type 10 profile, familiar from European high-speed trains. The fourth coupling is being developed by Wabtec and is based on the Schwab profile, which is used extensively in regional transport, especially in Switzerland. Before the selection of a coupling type can proceed, the future operating concept must be defined, and the fundamentals of the design updated. This applies, in particular, to the strength and design of the shock absorber.

A theoretical evaluation of different AC types conducted in the aforementioned project “FR8RAIL” leads to very similar assessments of modern coupling types. This is positive in so far as all coupling types have a great potential for success despite their different characteristics. During the evaluation, it became clear that a coupling profile would have to be selected independently of the shock absorber. It may also be sensible to combine similar coupling profiles with different shock absorbers, as seen in various applications worldwide. Future tests comparing DACs should therefore consider possibilities for combining different suspension and coupling profile designs. In addition, due to the extremely high reliability requirements, exhaustive testing in carefully designed scenarios is required before the coupling can be selected.

An analysis of the legal situation shows that the European legislation is essential for obtaining approval of the DAC. The DAC can be implemented in conformity with TSI. The DAC should be approved independently of the vehicle and already cover the requirements for new interfaces and electrical equipment. According to current plans of the European Union Agency for Railways (ERA), the DAC should be specified as an interoperability constituent within the framework of the TSI revision in 2022. The tasks/costs involved in the registration of new vehicles with DACs will then be identical to those for vehicles with screw couplings (SCs). According to EU regulations, existing vehicles will require a new authorisation for placing in service (APS) after they have been converted. However, this must be avoided as a matter of urgency, as registration documents, especially for older models, are often no longer available or have not been prepared in the detail required today. Intensive clarifications with the ERA and national safety authorities will be necessary to find a solution that ensures the success of the migration to the DAC and the continuing safety of RFT.

1. Introduction

This report is part of the study for the “Development of a concept for the EU-wide migration of a Digital Automatic Coupling System (DAC) for rail freight transportation”, commissioned and financed by the German Federal Ministry of Transport and Digital Infrastructure (BMVI). The study comprehensively analyses and highlights the technical, operational, organisational, and financial challenges of the migration to the DAC.

This report is dedicated to the technical and operational challenges in the run-up to a DAC migration and also analyses the legal framework.

Chapter 2 investigates and analyses the use of automatic couplings (AC) around the world. Chapter 3 presents the state of the art in the world of DAC technology. Among other things, it describes established ACs and new DAC developments in RFT and compares their properties. The focus is on DACs, which are potentially suitable for European RFT. This section also spotlights the situation regarding the installation of DACs in European vehicles.

Chapter 4 outlines the principal technical and operational challenges involved in the development of a standard DAC for Europe.

Chapter 5 offers insights into the latest research relating to the DAC. Furthermore, it describes the situation regarding the registration of existing and new vehicles with DACs (see Chapter 6).

Clearly, the use of freight trains with (D)ACs equipped with different levels of automation (e.g. freight wagons with AC Type 2 and DAC Type 4 in one freight train) will create challenges in railway operations. It is also necessary to consider the requirements for a DAC Type 4 in terms of possible upward compatibility with a DAC Type 5 that incorporates a remote-controlled decoupling function. Chapter 7 presents the main aspects relating to this issue.

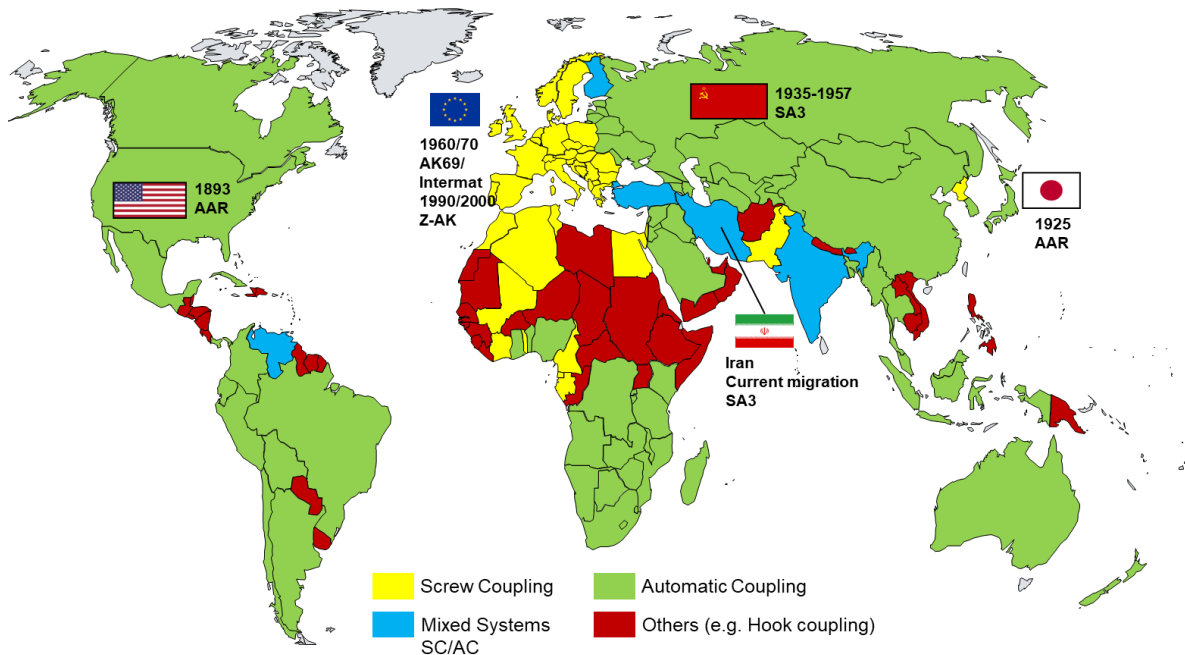
Finally, Chapter 8 draws conclusions based on the facts presented in this report.

2. Automatic couplings in RFT around the world

Globally, ACs are the dominant technology in rail freight traffic – the SC is essentially an outdated European solution.

The global map of coupling systems (see Fig. 1) clearly shows that the SC with buffer is only used in Europe¹, while ACs are used in large parts of Asia, Africa, and Australia as well as North and South America.

Fig. 1: Worldwide distribution of coupling systems



Source: hwh according to [1]

From this world map, it is noticeable that ACs are mainly used in states with large territorial areas. However, other countries, such as Malaysia, South Korea, and Japan, also use ACs, which is why they are presented separately in the following sections. A characteristic feature of many AC transports is that they operate over long distances and in uniform economic areas. In addition, these trains are characterised by high load weights and lengths of more than one kilometre, as they often transport heavy goods, such as coal and steel products.

Numerous ACs have been developed in the history of the railways. A more detailed overview is provided in [2]. A key distinguishing feature is the coupling profile, also called the coupling head. While many different coupling profiles are used in rail passenger transport (RPT), two dominant types have established themselves in RFT. Couplings with the Janney profile are by far the most common, e.g. in the USA, China, Australia and even South Africa. Couplings based on the Willison profile are the second most widely used ACs. This design is mainly used in the former CIS states and their neighbouring countries. Although the Janney, Willison and SC are not compatible without adapters, a few countries do also operate mixed systems that use different types of couplings.

¹ In states with significant RFT volumes.

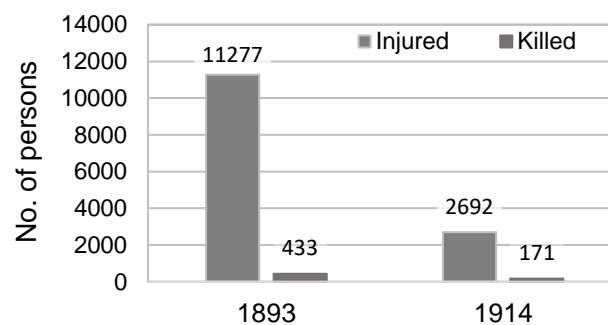
2.1 National experiences with migration and conversion to the AC

The conversion from manual coupling systems to the AC began over 100 years ago. At that time, RFT was often state-organised and unrivalled in terms of its performance compared with other modes of transport. Consequently, the only way to transport goods effectively overland was by rail.

The first conversion programme began in the USA in 1893. It took a total of seven years and could only be introduced across state borders by federal laws aimed at ensuring greater occupational safety in the rail sector. In 1957, the conversion to the AC was successfully completed in Russia. The process took more than 20 years due to World War II. [3]

One of the main drivers behind these changes was the industry's extremely poor safety record for shunting personnel. Fig. 2 shows the reduction in injuries and deaths among shunting personnel in the USA due to the introduction of the AC. In 1893, 11,277 people were injured and 433 killed in shunting operations. By 1914, however, this figure had fallen to "only" 2,692 injured and 171 dead, despite a significant increase in transport performance.

Fig. 2: Improvement in safety due to the introduction of the AC in the USA



Source: [4]

The following sections describe RFT activities relating to the AC in selected countries.

2.1.1 Turkey

Two types of couplings are used in Turkey – the SC and SA3 coupling (AC Type 1).² As no information about a comprehensive conversion to a AC is available, it can be assumed that two types of couplings will be used in Turkey for the foreseeable future. The locomotives are usually equipped with hybrid couplers and side buffers and can therefore be used universally. There are also freight wagons with coupling hybrids. According to research and information provided by the Turkish railway sector, the SC is the primary coupling in use. The AC is mainly used for ore and mineral oil transports. There is little mixed traffic.

2.1.2 Japan

The Janney coupling has been used in Japan since 1925. The conversion from SC to AC took place simultaneously for all wagons and locomotives within just a few days in that year (see Fig. 3). Seven years of preparation were needed for this successful conversion. The conversion was enforced by imperial decree in 1918.

² For more information on the AC types/degrees of automation, see Chapter 3.1.1.

Fig. 3: Conversion of a Japanese locomotive from SC to “Janney” AC



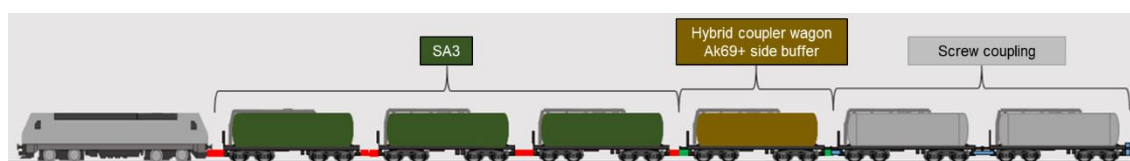
Source: Kyoto Railway Museum 2018

Today, RFT accounts for only a small share of the Japanese modal split, which is dominated by ferry traffic along the coasts. This is mainly due to Japan's topography and population distribution.

2.1.3 Iran

Iran is another country that uses two coupling systems in parallel. Both ACs (SA3 coupling and “AK69”) and conventional SCs with side buffers are in operation. In contrast to Turkey, Iran is actively switching from the SC to the SA3 coupling. The conversion process started approx. 15 years ago. In August 2019, 98.3 percent of its wagons had been converted, with the result that only about 400 wagons are still equipped with the SC. The conversion is essentially being carried out fleet by fleet within the framework of natural maintenance intervals. The operational management system is based on a “separate traffic” strategy and the use of coupler wagons. In the separate management of AC and SC traffic, it is sometimes necessary to wait for compatible wagons and simply accept the associated delays. Coupler wagons are used for “mixed traffic” (see Fig. 4). Some of these are equipped with the “AK69” and side buffers. It is not known why this coupling type was chosen. Ores, crude oil, and natural gas are the main products transported – usually in strictly separated fleets, e.g. belonging to mine operators or oil producers. Approx. 23,000 to 24,000 wagons are in operation in Iran.³

Fig. 4: Procedure for mixed traffic in Iran



Source: TU Berlin

2.1.4 Europe

The conventional SC with side buffers is the predominant system used in Europe. Some traffic, esp. in countries that use the Russian broad gauge and thus have significant economic relations with Russia, uses an AC (see Fig. 5). This is the case, e.g. in the Baltic States and Finland.

³ Information provided by the Iran University of Science and Technology.

Fig. 5: Overview of the use of AC in Europe



Source: TU Berlin, based on Openstreetmaps

2.1.4.1 Broad gauge network in Europe

As previously mentioned, the “SA3” is used in the Baltic States and Finland. The focus at this point is on Finland. This is because both the “SA3” and SC are used in Finland, which is a unique situation in Europe and of particular interest for the migration phase to a European AC. Some of the Russian AC wagons are included in SC trains. This requires the use of both coupler wagons and hybrid couplings with side buffers that combine both coupling systems. The hybrid couplings here are SA3 couplings with an SC adapter which can be hooked into the AC and into the draw hook of the SC wagon, if required (see Fig. 6, orange component). Conversely, it is also possible to hook the coupling head of the SC wagon into a corresponding horn belonging to the SA3 coupling. The SC can then be tightened as usual. During operation, however, the AC is inclined.

Fig. 6: From left to right: SA3 coupling with shunting adapter for SC folded up and engaged in the draw hook of the SC, “SA3” with attached SC adapter and “SA3” with additional horn (circled in red) on the left side for attaching the SC as a draw hook replacement.



Source: TU Berlin

Locomotives in Finland are always equipped with both types of coupling. Additional adapters for shunting engines are available for handling shunting operations. These have an SC adapter on the AC, which can be attached to the draw hook remotely from the driver's cab (see Fig. 6, left), known as a VAPITI coupling.

2.1.4.2 Standard gauge network in Europe

On the European standard gauge network, the use of ACs in freight traffic is almost exclusively limited to the coal and steel industry. The reason for this is that the AC permits comparatively high wagon loads and thus the operation of long and, above all, heavy trains. European AC traffic is usually strongly delimited and is presented in the following section.

Norway/Sweden

MTAB IORE runs ore trains weighing 8,600 t between Kiruna and Narvik. These wagon loads are possible due to the use of the Russian SA3 coupling.

Germany/Netherlands

In Germany, the “AK69” is used for iron ore transports between Hamburg and Salzgitter. This traffic comprises around 400 wagon units operated by DB Cargo. The “C-AKv”, on the other hand, is used in ore trains running from Rotterdam to Dillingen. As of 2011, 55 wagons were in service on this route with 49 further wagon units planned. [5] The “C-AKv” is also used in lignite transports between Wühlitz and Buna. [6]

Great Britain

The Janney coupling has been used in coal transports in Great Britain. These services are operated by DB Cargo UK. In addition, a few wagons with a rotating Janney coupling are used in “rotary dumpers”. A rotary dumper or “wagon tippler” is a device used in open freight wagons with bulk materials. During the unloading process, the whole wagon is turned upside down by rotating it around its longitudinal axis. One prerequisite for effective use of a rotary dumper is a coupling that can be rotated around its longitudinal axis, as this means that the wagon does not have to be decoupled from the train prior to unloading.

Switzerland

SBB Cargo has been operating ACs in domestic combined transports (CT) in Switzerland since May 2019 – the only known exception outside the coal and steel industry. These couplings are based on the Scharfenberg (SchaKu) Type 10 coupling.⁴ At present, approx. 100 freight wagons and 25 locomotives have been equipped with the coupling and there are plans to convert further wagons in the near future.

2.1.5 Other nations

Malaysia

Malaysia, an emerging market of growing economic importance, uses the Janney coupling. The advantages of the AC, in terms of wagon loads, are particularly useful for the transportation of heavy goods, such as ore, steel, iron, granite, cement and wood. However, the railways frequently transport both ISO containers and domestic containers for foodstuffs and pallets as well. Like Japan, RFT has a comparatively small share of the modal split in Malaysia and generally only covers hinterland traffic with the major ports. [7]

South Korea

At this point, it is worth mentioning South Korea, which is a driving force in the digitisation of RFT. In 2017, the Korea Railroad Research Institute (KRRRI) and Hyundai Rotem jointly tested a radio-based traction and brake control system for remote control of locomotives. The first

⁴ More information about the Scharfenberg coupling can be found in Chapter 3.2.3.

locomotive is controlled by the driver, who can operate the second locomotive via radio. [8] This proprietary development corresponds to the US ECP system from Wabtec and New York Airbrake (see Chapter 3.4.3). The Janney coupling is also used in South Korea. RFT has a comparatively small share in the modal split, due in part to the unfavourable geographical and political situation.

3. State of the art

This chapter provides an overview of the current state of the art regarding AC in RFT.

The first section describes the basic principles of automatic couplings. This is followed by a presentation of the state of the art regarding the necessary automation of RFT, using selected coupling types as examples. The characteristics of the various couplings are summarised below. Couplings used in passenger transportation are not covered, due to the significantly lower quantities and much higher prices.

Since the automation of RFT is inextricably linked to the provision of electrical power and data communication in freight wagons, this chapter also gives an overview of previous activities in Europe as well as existing electrical equipment systems for use in the sector.

3.1 Principles of automatic couplings

3.1.1 Degrees of automation in automatic couplings

RFT couplings traditionally distinguish between three degrees of automation: manual, semi-automatic and fully automatic. In the case of manual couplings, the vehicles are coupled and decoupled by hand. All media must also be connected manually. Semi-automatic couplings offer automatic coupling of the mechanical connection between the wagons but must still be decoupled manually. The air lines are also coupled manually. A fully automatic coupling can couple and decouple both the mechanical and air line connections automatically.

The traditional classification approach focuses on the automation of the mechanical coupling. It ignores the type and number of coupled media. Consequently, the Technical Innovation Circle for Rail Freight Transport (TIS)⁵, decided to undertake a reclassification of the AC for RFT. It defined five levels of automation (Types 1 to 5). These differ primarily in terms of their number of automatically coupling interfaces (see Fig. 7).

Type 1 incorporates automatic coupling of the mechanical connection, i.e. it is similar to the semi-automatic coupling. Type 2 additionally couples the main brake pipe (MBP) automatically. An AC Type 3 also provides automatic connection of electrical power lines while Type 4 includes connection of data lines. Only a Type 4 or higher can be described as a DAC since only these types offer automatic connection of power and data lines. According to the traditional classification system, Types 1 to 4 are semi-automatic couplings while a Type 5 coupling is a fully automatic coupling. A DAC Type 5 provides fully automatic coupling and decoupling.

Fig. 7: TIS nomenclature for the classification of AC automation levels

Automation level	Type 1	Type 2	Type 3	Type 4	Type 5
Mechanical connection	✓	✓	✓	✓	✓
Main brake pipe		✓	✓	✓	✓
Power line			✓	✓	✓
Data connection				✓	✓
Automatic decoupling					✓

Source: TU Berlin based on TIS

⁵ TIS: Technical Innovation Circle for Rail Freight Transport, see Chapter 5.2.1.

3.1.2 Basic construction of an automatic coupling

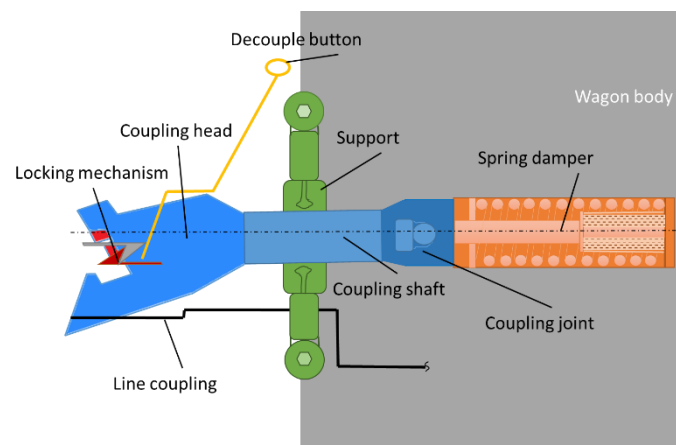
An AC essentially comprises the following six main assemblies:

- Coupling body
- Locking mechanism
- Actuator
- Support
- Spring damper
- Line coupling.

These assemblies are briefly described here and shown in Fig. 8. The coupling body (shown in blue in Fig. 8) comprises the coupling head, coupling shaft and coupling joint and thus forms the heart of the AC. Common types are listed below. The locking mechanism (red) on the coupling head connects the coupling with the partner coupling as closely as possible. The locking mechanism can be released by pressing the decouple button (yellow). A support (green) is required to guide the coupling body principally in the vertical direction. This can be designed in various ways and is described in more detail in Chapter 3.3.2. There is also a line coupling (black). This can include air, electricity, and data. The entire coupling device is attached to the wagon body.

To minimise longitudinal reactions within the train, and forces in the event of collisions, a spring damper is connected to the coupling body (orange). This functions essentially in the same way as variants used in SCs.

Fig. 8: Basic components of an AC



Source: TU Berlin

Spring damper

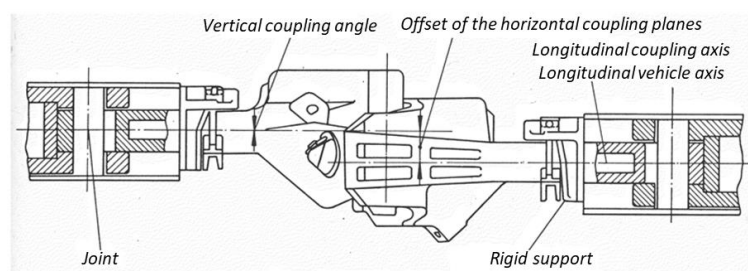
Regardless of the AC type or design, the spring damper is a component of every AC. Its main task is to minimise longitudinal reactions within the train while setting off and braking, as well as during the journey. The spring damper also helps to keep the forces during impacts by other wagons as low as possible. However, the requirements result in conflicting objectives. On the one hand, in terms of longitudinal dynamics, the coupling must minimise relative movement between the freight wagons in the train. A pre-loaded, stiff coupling spring with degressive spring characteristics is helpful here. To absorb impacts, however, a progressive spring characteristic – starting as softly as possible and not pre-loaded – is advantageous.

A variety of spring dampers are already used in RFT today. For side buffers, there are four standardised categories in Europe (EN 15551), including a special long stroke buffer. It may also be necessary to develop several spring categories for the spring damper used in the DAC. This need not be based on current characteristics⁶.

3.1.3 Rigid and non-rigid couplings

In principle, there are two basic variants of the AC. These differ in terms of the mechanism for the compensation of height offset between two wagons along the vehicles' longitudinal axes. The simpler of the two variants, in terms of the height of the coupling heads, is the non-rigid version. Examples of this design include the standard versions of the Janney or Willison couplings. The height offset between two wagons results in vertical displacement between the wagons' coupling heads, while the longitudinal coupling axis is parallel in height to the longitudinal axis of the wagon on which it is mounted. The advantages of this principle are the simple design and low-cost manufacturing processes for the spring damper bearing. The disadvantages lie in the significant wear to bearings while in motion and greater difficulties in terms of automation. Automatic coupling of lines is not possible. An example of a non-rigid coupling is shown in Fig. 9, in this case an SA3 coupling. [4]

Fig. 9: Non-rigid AC using the example of an SA3 coupling



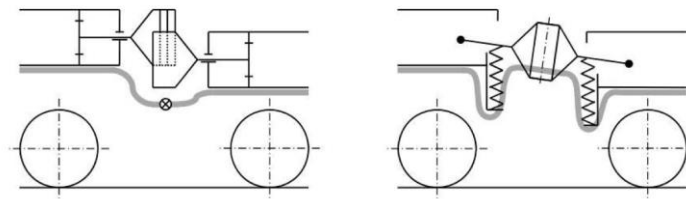
Source: [4]

Automatic coupling of electrical power, air or data lines – a requirement for AC Type 2 and higher – is not possible with a non-rigid AC. As with the SC, these lines must be handled separately, making non-rigid ACs unsuitable for use as a DAC.

In addition to the non-rigid AC, there is a second coupling type – the rigid AC. Familiar examples of these designs include the UIC/OSSHD couplings “AK69” and “Intermat”, the SchaKu, the compact coupling (“C-AKv”) and the Schwab coupling. With the rigid coupling, the height offset between the wagons (longitudinal axis of the vehicle), and thus also the longitudinal axis of the coupling, is compensated by an angle setting between the two longitudinal axes of the coupling. The longitudinal axes of the coupling and the vehicle are therefore not parallel, and there is no offset between the horizontal planes of the coupling, as is the case with the non-rigid variant. A key advantage of the rigid solution is that there is only minimal movement (friction) between the coupling heads, which results in low wear and clearly defined relative positions. This allows the lines to be coupled automatically. Fig. 10 again shows the difference between the two coupling types.

⁶ For further details see Chapter 4.4.

Fig. 10: Non-rigid (left) and rigid coupling (right)



Source: [3]

Fig. 10 shows that the coupling shaft in the rigid version must be mounted so it can rotate about the transverse axis. However, it must also be supported to centre it when in the uncoupled state. This is usually implemented using a support with a vertical spring. The rigid version of the coupling bearing must thus have two degrees of freedom: rotation around the vertical axis and rotation around the transverse axis.

3.2 Automatic coupling systems in RFT

This section examines the state of the art of automatic couplings for RFT. As already shown in Chapter 2, two main types of AC are used in RFT. The first type are couplings based on the Janney profile. These are the dominant type of coupling in use worldwide. The second type is the SA3 coupling based on the Willison profile. This is particularly widespread in the former CIS states. This chapter examines both these coupling types as well as two innovative couplings adapted from rail passenger transport (RPT). These are currently the subject of much discussion. A table comparing their characteristics is also provided.

3.2.1 Janney

In principle, the Janney coupling is not suitable, or only of limited suitability, for use in European freight trains. This is due, among other things, to its limited ability to couple in bends. For the present study, the coupling's operational handling is of particular interest.

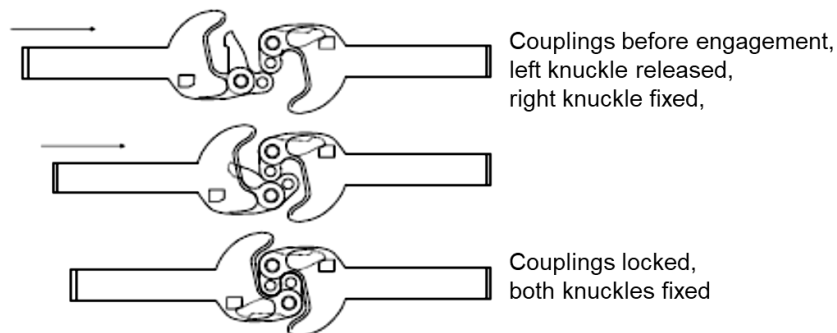
History

The Janney coupling was invented around 1870. It first entered service on freight railways in the USA at the end of the 19th century and has been continuously developed ever since. These technical refinements have resulted in four relevant application-specific derivatives of the Janney coupling. Types E and E/F have been the standard RFT couplings in North America, China, Japan, Australia, South Africa, and Brazil since 1932. In North America, the Types F [9] and H have been in service since 1947. [2]

Operating principle

All derivatives of the Janney coupling are based on the same principle and, except for a few details, also have an identical design. The tensile forces are transmitted via a movable hinge joint, known as the "knuckle". In addition, the knuckle, or the lock behind it, prevents the coupling heads from sliding apart once they have engaged. Initially, during the coupling process, one knuckle is locked and other movable. Once the two joints are interlocked, the second knuckle is also locked, connecting the two wagons (see Fig. 11).

Fig. 11: Operating principle of the Janney coupling



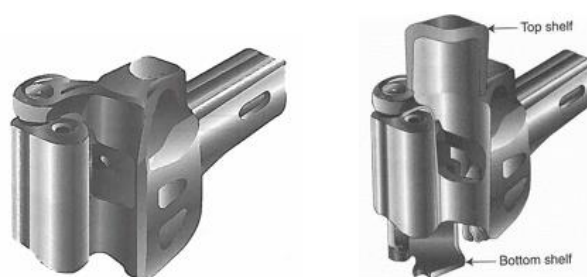
Source: [3]

Janney couplings are usually rigidly mounted on the wagon body. The coupling must provide a great deal of slack because the rotational movement around the vertical axis when entering and exiting bends takes place at the connection point of the coupling jaws.

Versions

The “Type E” is essentially the basic version of the coupling. The “Type E/F” is designed for use with particularly long freight wagons with a large overhang and ensures that they are able to travel through tight bends. For this purpose, the coupling profile has been widened and the shaft lengthened. In addition to the unlimited vertical slack, both versions are characterised by a high degree of longitudinal slack (approx. 20 mm [2]). In the event of a derailment, the lack of a vertical stop is particularly critical, as the coupling heads have the potential to drift apart and then act as a spike on tank wagon floors. For this reason, additional lower and upper stops (“top shelf” and “bottom shelf”, see Fig. 12, right and Fig. 12, left) are mandatory for hazardous goods transports in the USA. The lower stop is also helpful when removing the coupling, as it cannot fall down as long as it is engaged and can then simply be pulled out of the guide. The combination of stops provides an additional level of safety. If the forces become too great, the coupling heads become wedged and the couplings are sheared off whole. This prevents the couplings from penetrating the floors of tank wagons. [9]

Fig. 12: Standard version of Type E Janney coupling (left) and version with “top shelf” and “bottom shelf” stops for transportation of hazardous goods (right)



Source: [9]

The “Type F” turns the height-adjustable coupling into a rigid coupling and reduces the slack in the coupling head to approx. ten millimetres[2]. This reduction is achieved by the use of additional guide elements. The coupling profile of the “Type E” has been extended laterally by a guided arm nose and a corresponding interlocking wing pocket (see Fig. 13, centre). This arrangement makes the “Type F” compatible with the “Type E” and “Type E/F”. All Janney

couplings are intercompatible.[9] In 2008, a fully automatic version (DAC Type 5⁷) of the “Type F” coupling was tested in the USA. For reasons unknown, this was not developed beyond the prototype stage.[2] In Great Britain, the Buckeye coupling, a fully automated derivative of the Janney coupling, is used in RPT (see Fig. 13, right).

Fig. 13: Janney coupling with buffer override protection (left), fully automatic Type F (middle) and Buckeye coupling from England (right)



Source: TU Berlin

The “Type H” (Tightlock) is another derivative of the Janney coupling – in this case a rigid version. Due to its low coupling slack of two millimetres, the Type H is suitable for automatic connection of power, data and air lines. The Type H is only used in RPT. [2]

Wear behaviour

Due to the high level of coupling slack, the coupling is exposed to significant dynamic forces when in motion and is therefore subject to a considerable level of wear. Coupling takes place via the movable knuckles. Consequently, the knuckles are also subject to high wear during the coupling process.

Handling

When decoupling, it is sufficient to unlock one of the two couplings. There are operating elements for this purpose on the front sides of the freight wagons. In some places, these are not used, e.g. in China. In this case, shunting personnel use special “decoupling forks”. These unlock the coupling heads directly on the coupling head. The employee operates the unlocking mechanism with the “decoupling fork” without stepping between the vehicles. In the USA, however, shunting personnel use the controls directly on the freight wagon.

One major challenge is that the Janney coupling is difficult to decouple under tension. On the other hand, as long as the couplings are still engaged, it is possible to re-lock them if an operating error has occurred, e.g. if the disconnection point has been mixed up in the marshalling yard.

For European requirements, the gathering range of Janney couplings is low. Due to the lack of centring, the coupling must first be aligned manually when connecting the wagons in a bend, if this is possible with the derivative.

In the USA, the air couplings are connected manually and disconnected automatically by moving the wagons apart. The hoses are guided by thin coil springs to prevent them from swinging out too far.

⁷ cf. Chapter 3.1.1.

Automation potential

All Janney couplings are semi-automatic. Essentially, the traditional Janney coupling types “E”, “E/F” and “F” used in RFT only offer limited automation potential due to the high level of longitudinal slack. With the “Type E”, the vertical slack prevents the coupling of lines. The “Type H” can be automated but is subject to high wear during (de)coupling. The “Type H” has not yet been used in RFT and, here too, there is the problem of the relatively small gathering range.

Other features

All Janney couplings are weatherproof, have a simple design and comparatively low procurement costs.

3.2.2 Willison

History

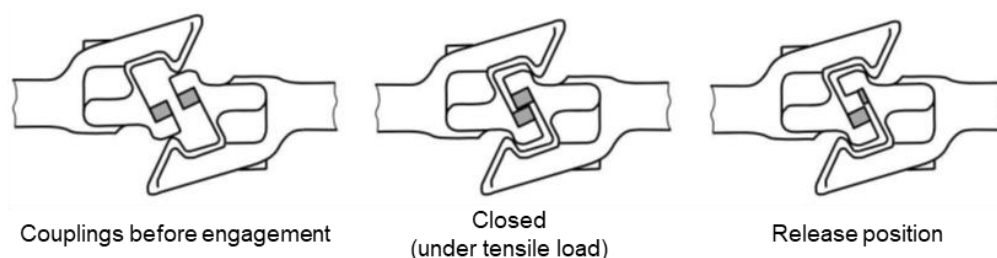
The Willison coupling is an AC that was developed in the USA in 1916 due to the deficits of the Janney coupling. Today, it is available in a wide range of variants. Between 1935 and 1957, it was introduced in the USSR as the “SA3” – a more developed version of the basic Willison coupling.

In the 1960s and 1970s, the “AK69”/“Intermat”, based on the Willison principle, was developed as a European AC. This was compatible with the SA3. However, for mixed operation of the “SA3” and “AK69”/“Intermat”, since the non-rigid design of the “SA3” means it cannot automatically couple any media. However, the designs of the air coupling heads in Russian RFT and the “AK69”/“Intermat” are identical.

Operating principle

Coupling takes place via rigid and movable elements. Fig. 14 shows the mechanism. The two couplings first slide into each other and are then locked in their end position. The tensile and compressive forces are transmitted via the solid coupling head. The lines are generally (dis)connected manually, e.g. in Russia. The coupling connection offers slack in both the longitudinal and vertical directions.

Fig. 14: Coupling mechanism for Willison couplings



Source: [3]

Design variants

The following design variants resulted from the attempts to establish an AC in Europe.

The “AK69” and “Intermat” are identical except for a few details. They can automatically couple two air lines and up to six electrical lines. Due to the significant mechanical slack, the line couplings are highly complex and mounted on soft springs to compensate for the slack.

The “Z-AK” was developed in the 1990s. With this coupling, the main brake pipe (MBP) can be coupled automatically, but side buffers are necessary because only tensile forces are transmitted via the coupling. Consequently, the coupling is very heavy, expensive and irrelevant for the purposes of this study. [10]

The “C-AKv”, developed between 1994 and 2002, allows two lines to be coupled automatically [2, 11]. The modular SA3 coupling from Voith is a further refinement of the Willison profile. However, this has not yet found an application (see Fig. 15) [2]. The “AK69” and “C-AKv” are only occasionally used in heavy goods traffic (see Chapter 2.1.4). The following illustrations show examples of these couplings.⁸

A DAC Type 4 based on the Willison principle is currently being developed as part of the Shift2Rail project “FR8RAIL II”.⁹ This coupling is expected to meet the technical and operational requirements of the relevant UIC leaflets. At the time this study was prepared, no further technical details relating to this coupling were available.

Fig. 15: “AK69” (top left), “Modular SA3” from Voith (top right), “Z-AK” (bottom left), “C-AKv” (bottom right)



Source: top left TU Berlin, top right Voith, bottom left [10], bottom right [6]

Automation potential

The SA3 coupling is a non-rigid derivative of the Willison coupling. In order to connect lines automatically via the coupling head, the slack between the coupling heads must be eliminated. As a result, complex centring and fixing solutions are required. This is the case with the “AK69”/“Intermat” derivatives, the “C-AKv” and the “modular SA3 coupling”.¹⁰ Due to the remaining slack of several millimetres in the coupling head, the automatic line coupling process is very complex.

⁸ Further information and graphics on the distribution of the couplings are provided in Chapter 4.5.

⁹ For more information on “FR8RAIL”, see Chapter 5.2.4.

¹⁰ Similar design approaches are expected for the newly developed Willison coupling from CAF.

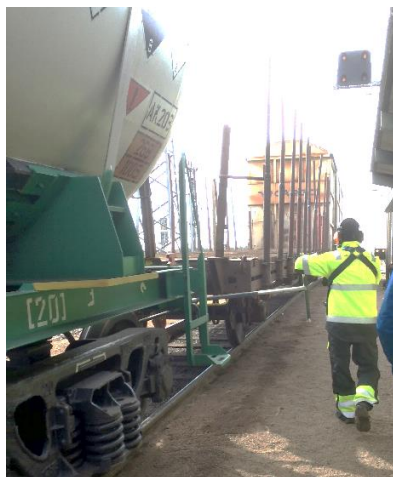
Maintenance costs

Willison couplings are very robust, as most of the load is transmitted via the rigid “nose” when under traction and only a comparatively small proportion via the movable locking wedge. During operation, the couplings are subject to wear due to the longitudinal and transverse slack. [4] However, due to their very high wear reserves, Willison couplings are generally low maintenance.

Handling

A key advantage of this coupling is its operational handling. The coupling can be in one of four positions: “Unlocked”, “Ready for coupling” (uncoupled), “Buffer position” and “Coupled”. The operating handles provided are generally not used. Instead, “decoupling forks” are used to operate the coupling head directly. Fig. 16 shows one such tool in use in Finland.

Fig. 16: Employee in Finland decouples freight wagons with SA3 couplings directly at the coupling head using a “decoupling fork”



Source: TU Berlin

In addition to the above-mentioned operating positions, this coupling also permits reversal of an unintentional release. This is particularly advantageous in marshalling yards.

The couplings can be unlocked under tension. In the case of the “SA3” this is possible up to a tensile force of 7.5 kN, for the “C-AKv” up to 20 kN [6] and for the “AK69” up to 40 kN. [4]

A certain, but unspecified, degree of tensile separating force is required to disconnect unlocked couplings with a Willison profile. This is because, even in the unlocked state, the couplings are still hooked together. During tests with the “Z-AK”, it became clear that this must be taken into account during processes at the hump. Compared to the SC, wagons running down the hump must first be given enough momentum to enable the couplings to unhook. Light wagons unhook comparatively late and thus roll down at a significantly reduced speed. If the following wagon is heavier in comparison and unhooks early, it will run down the hill faster and the distance between the wagon groups will be shorter. These shorter distances between wagon groups mean that points are required to switch much faster after the hump. This effect is particularly strong in smaller hump yards. [10]

The tests with the “Z-AK” were carried out approx. 20 years ago. It is possible that technology in the hump yards has already been upgraded. The extent to which this aspect is still relevant for interlocking technology in hump yards today is therefore unclear. Since tests on the hump

are essential anyway, additional observations of the behaviour of particularly light wagons should be made as they run down the hump. [10]

The gathering range of Willison couplings is type-dependent and, compared to the Janney coupling, exceptionally large for all derivatives. The “SA3” or “AK69”/“Intermat” permit coupling up to a height offset of ± 140 mm and a transverse offset of ± 160 mm or ± 220 mm in the case of the “AK69”/“Intermat”.¹¹ The “Z-AK” has a gathering range of ± 120 mm vertically and ± 190 mm horizontally.¹² The gathering range spans a rectangular area.

A minimum coupling speed for the “Z-AK” is known to be 0.6 km/h. It is assumed that a higher speed is required for the coupling of light vehicles. The “AK69”/“Intermat” are designed for a coupling speed of 1.5 km/h. [4]

Weather resistance

Based on experience in Russia, it is assumed that the coupling’s weather resistance is generally excellent. The “AK69” and “C-AKv” have been used successfully for years. Information on weather-related failures is not known.

Other

A disadvantage of this coupling design is its comparatively high weight. The maximum tolerable forces for Willison couplings sometimes vary widely. In the case of the “AK69”/“Intermat” [4] and “C-AKv”, these values are 2000 kN for compressive and 1000 kN for tensile forces[6]. In its basic form, the SA3 coupling is designed for tensile and compressive forces of up to 2500 kN. [4]

There are many experienced manufacturers and large quantities of the “SA3” coupling already in existence. Mixed operation with the SC is also possible and has been tested. However, this requires side buffers and adapters.¹³

3.2.3 Scharfenberg

History

The Scharfenberg coupling (SchaKu) was developed between 1904 and 1907. It was first introduced in 1925 – in the Berlin and Hamburg suburban railway networks – and has been in use worldwide ever since. In 2002, the Type 10 became the standard coupling for high-speed rail transport in Europe and was standardised in accordance with EN 16019. [2]

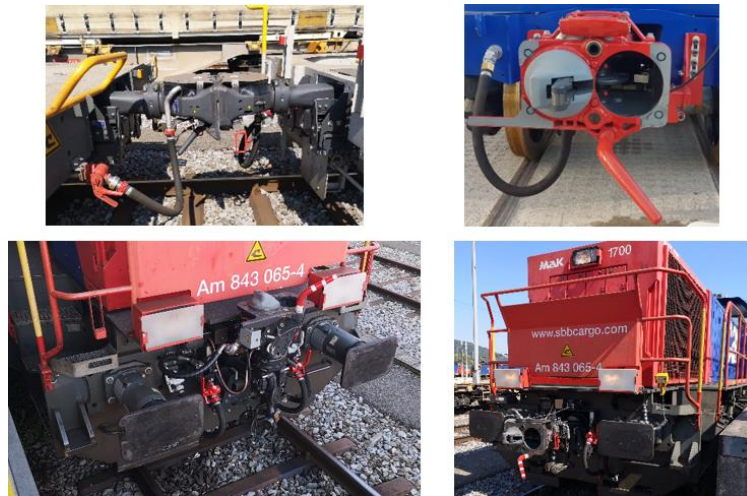
Versions of the SchaKu specifically for use in RFT have been developed in the past – including one as early as 1927. However, they were never adopted.

¹¹ Similar values are assumed for the “C-AKv” and “modular SA3”.

¹² This coupling is used as an example of the spread of the gathering range. The coupling is relatively new and was developed for European RFT in the 1990s.

¹³ For further information, see Chapter 2.1.4.1.

Fig. 17: SchaKu from Voith in Limmattal 2019 (left), DAC Type 4 prototype at the “transport logistic” trade fair in 2019 (top right), hybrid couplings folded up (bottom left) and ready for coupling (bottom right)

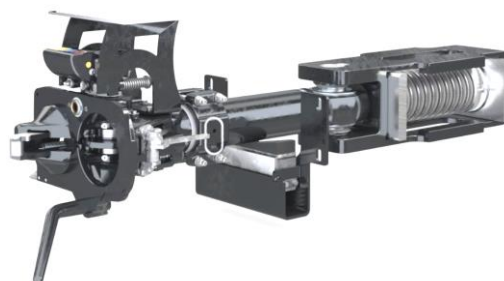


Source: TU Berlin

Within the framework of the BMVI’s “Innovative Freight Wagon” research project, a SchaKu made by Voith was used in field tests over 150,000 km.¹⁴ Development activity began to increase around 2014, when SBB Cargo began its comprehensive innovation programme. As part of this programme, a new Type 10 SchaKu from Voith for RFT has been undergoing tests in the “5L” demonstrator train since 2017. Most recently, a DAC Type 4 SchaKu was presented at the *transport logistic* trade fair in 2019 under the product name “CargoFlex Type Scharfenberg”.

In 2019, the first commercial use of this SchaKu began in Swiss domestic CTs with approx. 100 container wagons. Hybrid couplings for 25 locomotives are also used within the scope of this project. Fig. 17 shows Voith’s current developments for the SchaKu in Swiss domestic CT and the DAC Type 4 prototype. In addition to Voith, the coupling manufacturer Dellner has also been actively developing a SchaKu for RFT since Q3 2019. Its coupling is also based on the Type 10 profile. Fig. 18 shows a design for the coupling. At the time this study was prepared, only a few details about the coupling were known. The following information on the SchaKu is therefore primarily based on the SchaKu from Voith.

Fig. 18: Design of the RFT-SchaKu from Dellner



Source: Dellner

¹⁴ For further information, see Chapter 5.2.4.

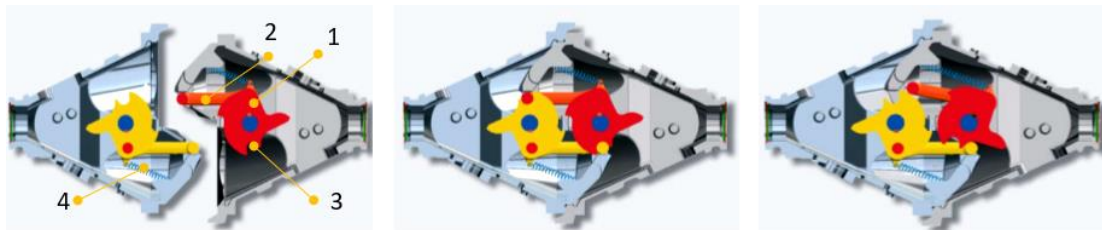
Operating principle

All SchaKu designs feature a characteristic cone and cup in the coupling profile. These are positioned next to each other at the same height. During coupling, the cone is guided and centred in the cup of the other coupling. Each coupling head contains a rotating metal disc (1) (see Fig. 19). Attached to one side of this is a “hoop” (2). On the other side there is a “notch” (3). The metal disc is held in position by a spring (4).

During coupling, as soon as the hoop presses against the metal disc of the opposite coupling, its own metal disc rotates until the hoop engages with the notch. The metal disc then springs back into its home position. The coupling process is now complete and the couplings are securely connected. The hoops are in the parallelogram position. This ensures that only half the tensile force is transmitted via each hoop and that the coupling does not release by itself.

When the coupling is released, one of the metal discs is turned (against the spring) until the hoop of the corresponding coupling slides out of the notch. Since the other coupling must follow the movement, actuating the release mechanism on one coupling unlocks both coupling heads. Fig. 19 show this process in a simplified form. [12]

Fig. 19: SchaKu mechanism



Source: [3]

Maintenance costs

The compressive forces are transmitted via the solid front face of the coupling. In contrast, the tensile forces are transmitted via comparatively small areas. Wear is thus primarily expected on the locking mechanism. When maintenance is required, it is necessary to access the inside of the coupling.

Voith has adapted the maintenance of the coupling to existing maintenance intervals in RFT. Major inspections of the coupling, especially those to check the locking mechanism, are therefore scheduled every six to eight years. However, this applies to very intensive use with five coupling operations per day. The coupling (the locking device) must be re-lubricated around every three years together with the outer sealing rings.

Handling

The following operational positions are possible: buffer position¹⁵, unlocked, ready for coupling and locked. The buffer position must always be set in pairs.¹⁵

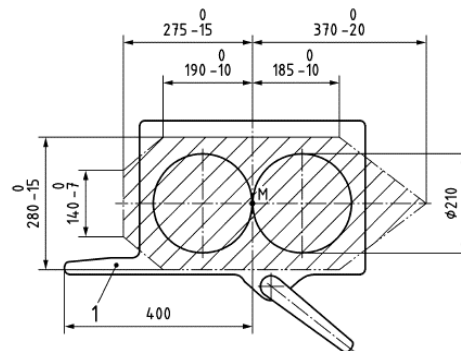
To disconnect two Scharfenberg type couplings, it is sufficient to unlock one coupling. The “CargoFlex” currently uses Bowden cables as the actuating devices. If an operating error occurs – releasing the coupling – this can only be reversed directly on the coupling head. To do this, the operator must step between the cars and lock both couplings manually.¹⁵ It is therefore only possible in exceptional cases.

¹⁵ Specifications of the coupling manufacturer Voith for the “CargoFlex Type Scharfenberg” coupling

Due to the operating principle, it is not possible to decouple Scharfenberg type couplings under tensile force.¹⁶

The gathering ranges of the Voith and Dellner couplings are identical. These are ± 140 mm vertically and between $+ 275$ and $- 370$ mm horizontally. [13] [14] The gathering range does not form a rectangle, as can be seen from the hatched area in Fig. 20. Consequently, the gathering range does not cover the entire area. As can be seen from the wear on buffer plates, the vertical and lateral extremes almost never overlap in practice.

Fig. 20: Gathering range of the SchaKu Type 10 according to EN 16019:2014



Source: EN 16019:2014

The minimum coupling speed of both couplings is almost identical. This is 0.5 km/h in the case of the Dellner coupling and 0.6 km/h for the "CargoFlex". Voith recommends a speed of approx. 1.0 to 1.2 km/h for light vehicles. This speed is also assumed for the Dellner coupling.

Weather resistance

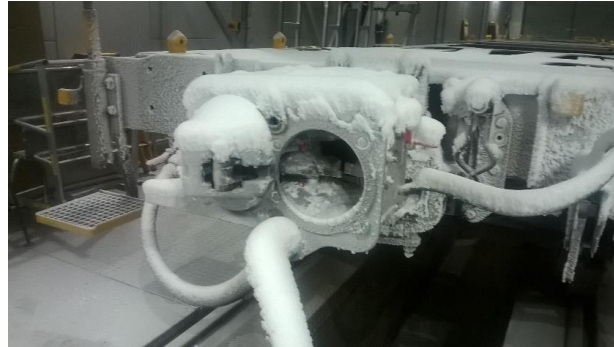
One reservation frequently expressed against the use of a SchaKu in RFT¹⁷ is that this type of coupling is sensitive to icing and dirt due to the openings for the locking mechanism on the coupling head. However, a climate chamber test successfully proved the weather resistance of the "CargoFlex" (see Fig. 21). Additional proof of the SchaKu's resistance to dirt and weather is provided by the coal transports that used SchaKu freight wagons in the 1940s .[15]

The opening for the MBP in the "CargoFlex" is open. However, the opening on the locomotive has a protective membrane. It is useful to point out a key distinction here – there is always a free coupling on the front of the locomotive, and this is directly exposed to the wind. The wagon couplings are usually coupled and the last one (open) points against the direction of travel. In terms of sealing, the situation is comparable to that of the current air coupling of the MBP. Regular cleaning with compressed air is still used to free the opening from dirt today.

¹⁶ To unlock the coupling, the metal disc must be rotated. To do this, any tensile force being applied must be counteracted with approximately the same amount of force.

¹⁷ This information is based on numerous discussions with representatives of the sector.

Fig. 21: Climate chamber test of the CargoFlex in Olten



Source: Voith

Automation

The locking mechanism provides a mechanical connection of the couplings with low slack (max. 0.8 mm according to EN 16019:2014) and is therefore a highly suitable candidate for the automation of connections for other media, such as compressed air, electrical power and data lines. The SchaKu is already 100 % automated and tested in the RPT sector.

Other information

A further advantage is that the SchaKu is tried, tested, and made by many manufacturers. Consequently, there is considerable experience of the coupling available in the sector. Its widespread use in European passenger transport increases the availability of towing vehicles in the event of an accident. The coupling is also lighter than traditional RFT couplings.

SchaKus are capable of tolerating compressive forces of 2000 kN and tensile forces of 1000 kN. The brake is guaranteed to be activated automatically in the event of an unintentional train separation due to a failure of the locking mechanism in accordance with EN 16019:2014.

3.2.4 Schwab

As with the couplings already presented, this section examines only the coupling head of the Schwab coupling. The Schwab spring damper and suspension are presented separately in Chapter 3.3.2.

Fig. 22: Schwab couplings: RFT version in the 2018 “5L” demonstrator in MuttENZ, in coupled (left) and uncoupled states (centre), as well as in the mainline version (right)



Source: TU Berlin

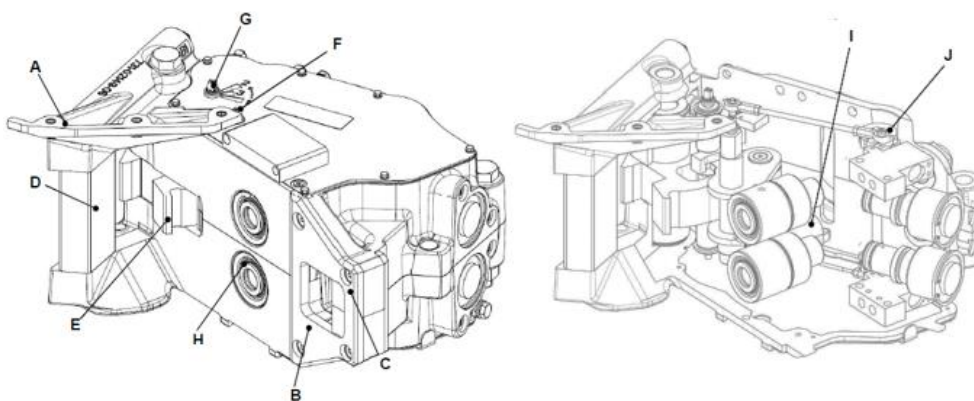
History

The fully automatic coupling type “Schwab FK” was developed in 2000. It is used in regional rail passenger transport, primarily in Switzerland. As a result of the cooperation with SBB Cargo, intensive efforts are underway to develop an RFT-compatible Schwab coupling, similar to the SchaKu. Currently, only one manufacturer (Wabtec) produces the Schwab coupling.

This is due to a patent which, according to the manufacturer, expired in 2019. Within the framework of the BMVI's "Innovative Freight Wagon" project, the Schwab coupling was used in a field test over 150,000 km.¹⁸ The Schwab coupling has also been undergoing tests in RFT with SBB Cargo's "5L" demonstrator train since 2017. A DAC Type 4 was presented at the *transport logistic* trade fair in 2019. Development of a hybrid coupling for locomotives is planned from 2020. Fig. 22 shows the Schwab coupling in RFT – (left and middle) and in the mainline version for RPT (right).

Fig. 23 shows detailed exterior and interior views of the Schwab coupling head. The version shown here is an RPT version of a DAC Type 5. This has an additional unlocking motor (designation "I" in Fig. 23), which enables automatic decoupling.

Fig. 23: Coupling head of the Schwab coupling



Source: Wabtec

Operating principle

The height is centred by the guide vane¹⁹ (A) and by the joint surface (B). During coupling, the connection is horizontally centred by the inclined faces of the coupling heads. The coupling heads slide past each other so that each of the flanges (C) enters the "opening" between the jaw (D) and the bolt (E) of the opposite coupling. During coupling, the flanges press against the stops of the bolts. This turns the bolts and causes them to engage in the recess of the joint surfaces. The couplings are now double locked via the bolts of both couplings.

The entire locking mechanism, except for the bolt, is housed inside the coupling head. Inside the head, the roller lever (F) secures the bolt in both coupled and decoupled states. The cam lever (G) located next to it, in turn, secures the roller lever and controls the air coupling (H) or the valve. The valve is connected to the cam lever via the actuator gear/disc (J). To disengage, the cam lever pushes the roller lever open. The cam lever can be driven by an unlocking motor (I) or operated manually.

Transmission of forces in the Schwab DAC is exclusively via rigid, non-moving components. Compressive forces are transmitted via the joint surfaces. Tensile forces are transmitted via the inner surfaces of the "jaw" (1) and its counterpart on the back of the flange (2) (see Fig. 24, right).

¹⁸ For more information on these research projects and field tests, see Chapter 5.2.

¹⁹ The guide vane in the RFT version is considerably larger in order to extend the vertical gathering range (see Fig. 23 and Fig. 24)

Fig. 24: DAC Type 4 Schwab coupling (left), Schwab head with wear plates marked in red (right)



Source: Wabtec

Maintenance costs

The couplings centre themselves during the coupling process by sliding along the end faces. To avoid unnecessary wear and to realise the coupling process with as little friction as possible, the coupling head of the Schwab coupling must be re-lubricated approx. every six months. The transmission of forces over a number of surfaces and rigid components has a positive effect on wear and maintenance – reducing both the frequency and intensity of maintenance work. It is not necessary to reach inside the coupling during servicing. It is sufficient to replace the external wear plates and sealing rings. This involves just a few simple steps (see Fig. 24, right).

Handling

Decoupling can only be performed by unlocking both coupling heads. This provides additional protection against separation of the train, since just one coupling lock is capable of sustaining the locking effect of a pair of couplings. However, it also increases the workload for shunting personnel when decoupling the wagons. Further detailed studies are required to determine whether this leads to restrictions in shunting operations.

In the event of the coupling being operated incorrectly, an unlocked coupling can be closed again without further work. In the current design, this must be done directly on the coupling head. Moving this process to the front side is technically possible. Decoupling is possible up to a tensile force of 300 kN.

The gathering range of the coupling in its current version is ± 290 mm in the horizontal and ± 120 mm in the vertical direction. The vertical gathering range meets gathering range requirements according to UIC 522. To the top and bottom, this is 20 mm less than that of the “AK69”/“Intermat” and the SchaKu, which are based on the vertical gathering range according to UIC 530-1. In contrast, the horizontal gathering range is 70 mm larger in both directions than that of the “AK69”/“Intermat”.²⁰ The gathering range of the Schwab coupling is rectangular, so that the entire clamped area is available as gathering range.

Automation potential

The Schwab coupling, like the SchaKu, is a fully automated coupling that has been tested in RPT. As mentioned at the beginning of this section, a Schwab DAC Type 4 has already been presented at the *transport logistic* trade fair in 2019. The DAC Type 4 presented there has already been prepared for the DAC Type 5. Fig. 25 shows this DAC Type 4 coupling. In the image, a blue box with a switch is visible on the left side of the wagon body. This can be used

²⁰ For more information on the applicability of the gathering range, see Chapter 4.3.4.

to unlock the coupling. Since this switch can be remote controlled, the coupling is also described as “Type 5 - Ready”.

Fig. 25: Prototype DAC Type 4, “Type 5 - Ready” exhibited at the *transport logistic* trade fair in Munich in 2019



Source: TU Berlin

Weather resistance

The Schwab coupling has an internal locking mechanism. This has a positive effect on weather resistance. During coupling, the coupling bodies also slide past each other so that dirt and ice are scraped off the coupling head. As the valve for sealing the MBP is located inside the coupling body, it is protected against impacts during shunting and dynamic loads. This carries the theoretical risk of a build-up of dirt and ice. This situation is comparable to that of the current air coupling.²¹ In practice, according to information provided by the manufacturer, this has not yet occurred in the area of RPT and the coupling also functioned perfectly in the winter/climate chamber tests conducted by SBB Cargo (see Fig. 26).

Fig. 26: Schwab head in the climate chamber in Olten



Source: Wabtec

Other information

Capable of handling tensile forces of 1500 kN and compressive forces of 2000 kN, the Schwab-coupling is one of the strongest couplings ever designed for European use. This is particularly relevant for heavy goods traffic.

Like the SchaKu, the Schwab coupling is also being adapted to the requirements of RFT while undergoing constant modification. Current developments provide for an implementation of the

²¹ For further information, see Chapter 3.2.3. on the SchaKu. The same problem arises with this coupling.

indirect action of the MBP as²² well as the buffer position. The latter is being done at the request of SBB Cargo,²³ in particular.

3.2.5 Summary

To compare the coupling systems and evaluate their suitability for a European DAC, it is essential to define selection criteria. The most important criteria for the selection of the coupling head is its capacity for the automation of the mechanical, pneumatic, and electrical power/data connections. These are the primary motivations for the introduction of a DAC. Consequently, the rigid Janney and “SA3” couplings, that are established in RFT, are not suitable for use as a European DAC.

In terms of usability (operating positions, gathering range, etc.), the DAC must cover a large spectrum of operating situations and associated functionalities. These require critical consideration. To keep costs and weight low, the objective is always to strike the right balance between actual requirements and desirable but non-essential functions.

Table 1 provides a comparison of the properties of the ACs. It shows that the couplings differ in terms of the range of their functions (e.g. decoupling under tensile force) and their characteristics (e.g. load capacity). It must again be noted that the Schwab coupling and SchaKu are undergoing continuous development. Regarding the Willison couplings, it should be mentioned that CAF is currently developing a DAC based on this principle. This was not taken into account in the study due to the lack of available information. The actual suitability of a DAC for European use can only be proven by extensive testing.

Table 1: Comparison of the functionalities of automatic couplings for RFT

	Janney		Willison			SchaKu ²⁴	Schwab
	E, E/F	H	SA3	AK69e/ Intermat	C-AKv		
Experience RFT	Yes	No	Yes	Yes	Yes	Partly	Pilot
Load capacity (push/pull) [kN]	1750/2900		2500/2500	1000/2000		1000/2000	1500/2000
Gathering range [mm]	V ± 30 H ± 60		V ± 140 H ± 160	V ± 140 H ± 220	V ± 120 H ± 190	V ± 140 H +370/-275	V ± 120 H ± 290
Deflection	Yes	Yes	Yes	Yes	Yes	Yes	
Decoupling under traction [kN]	No		≤ 7.5	≤ 40	≤ 20	No	≤ 300
Buffer position	Yes		Yes			Possible	
Re-locking	Yes		Yes			Possible, with restrictions	Yes

²² The Schwab coupling was originally developed for RPT. In RPT, an EP brake is used so the indirect action of the brake is released independently of the MBP.

²³ The need for the buffer position is discussed in Chapter 4.3.2.

²⁴ The couplings manufactured by Voith and Dellner are listed together due to their similarity.

Reliability		Good, prone to wear		Good		Good	Good	
Automatic operation of the brake		Yes		Yes		Yes		
Coupling speed		-		-	Similar to SchaKu, Schwab	~0.5 - 8 km/h	0.5 - 8 km/h	
Wear	Running	High		High, but wear-tolerant	-	Insignificant		
	Coupling			Insignificant			Low	Insignificant
Maintenance costs		Medium		Insignificant	Low	Low	Low	Very low
Pneum. connection		No	Yes	No	Yes	Yes		
Power/Data								
Coupling time S+D²⁵		-	Simultaneous	-	Simultaneous	Simultaneous, but cushioned	Delayed	
Dirt/Winter resistance		Very good	-	Very good	Good - Very good	Good	Very good	
Weight		Very low	Low	High	Very high	Low	Low	

Source: TU Berlin

3.3 Installation conditions and support

This section first discusses the degree of freight wagon preparation required for the installation of the AC. It then presents possible variants of the coupling support and their characteristics.

At this point it should be noted that the shaft, the support (including the suspension) and the necessary components for mounting the coupling to the body are responsible for:

- approx. 2/3 of the coupling weight,
- the deflectability of the coupling,
- the dynamics of the train in terms of derailment protection, and
- the crash protection concept of the vehicles, especially the locomotives.

²⁵ This refers to the time of connection of the power and data lines. This can take place simultaneously with the mechanical coupling or with a delay.

3.3.1 UIC installation space for the AC

Most European freight wagons today are prepared for the installation of automatic couplings. The international railway associations UIC and OSJD made this type of convertibility a requirement when UIC leaflet (MB) 530-1 came into force on 01.01.1974. At that time, the leaflet was binding for all European members of the UIC/OSShD.²⁶ It sets out the requirements for new freight wagons that are designed to be used with automatic couplings. The contents of the leaflet are briefly presented below, as they explain the level of detail with which today's freight wagons are prepared for the AC. Furthermore, the above-mentioned requirements can be used for (verification) testing the suitability of existing freight wagons for use with the AC.

UIC MB 530-1 regulates the following:

1. Conditions for ensuring coupling capability (see Chapter 4.3.4).
2. Strength and design requirements for the underframe (installation space).
3. Conditions for running safety.
4. Design installation conditions for the coupling and accessories.

3.3.1.1 Strength and design requirements for the underframe

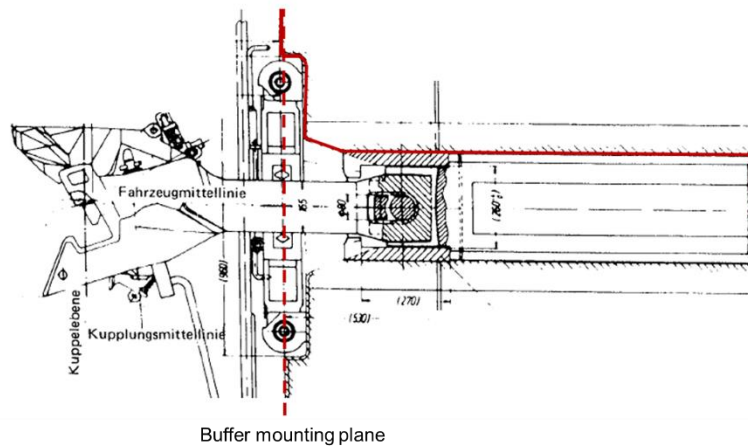
UIC MB 530-1 describes the strength requirements for freight wagons with an AC. Accordingly, the underframe and the installation space must be designed for static compressive forces of 2000 kN and tensile forces of 1500 kN in order to be AC-compatible. However, the strength requirements are not mandatory for newly built freight wagons. The requirements need only be implemented when the coupling is installed.

With the introduction of the test specifications “ERRI B12 RP17” in the 1980s and EN 12663 in the 2000s, it became necessary for freight wagons to meet the AC strength requirements ex works in order to be approved.

Furthermore, the leaflet requires that the installation space for the AC and supports be kept free in all new freight wagons ex works. There are two versions of the installation space, depending on the type of support used. The installation space in Western European freight wagons has been optimised for the crossbeam support, while the installation space in Eastern European freight cars is optimised for suspension strut support. The installation space differs on the level of the buffer mounting. The UIC-compliant crossbeam support requires an extended recess in this area (for comparison, see Fig. 27 and Fig. 28). Further differences are not known.

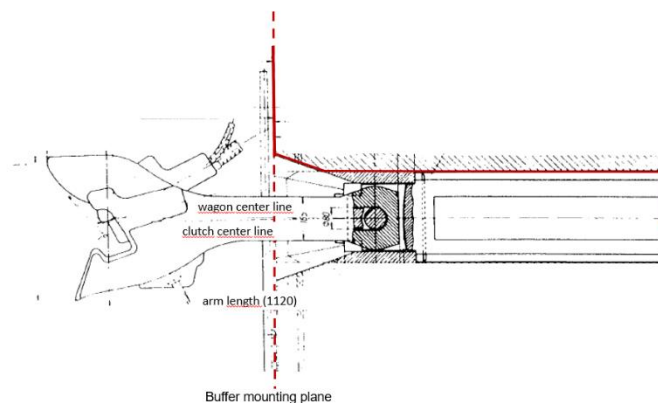
²⁶ The UIC leaflets have lost their importance since the introduction of the TSI. For further information, see Chapter 4.5.

Fig. 27: UIC installation space for the “AK69” with crossbeam support



Source: [16]

Fig. 28: UIC installation space for the “Intermat” with suspension strut support



Source: [16]

Consequently, the installation space is available in the majority of freight wagons (see Final Report [Hagenlocher et. al. 2020]). However, the introduction of TSI WAG in 2006 made it mandatory to equip freight wagons with an SC. Since then, it has been unnecessary to apply UIC-MB 530-1. As a result, the installation space for a central buffer coupler has been dispensed with, especially in the case of newer freight wagons (since 2006).

However, the existence of an installation space is not a clear indication that an SC can “simply” be replaced with an AC, especially for vehicles from the 1980s or older. The decisive factor is whether the vehicle has already been designed for the installation of the AC, or whether additional modification is required. Verification of strength is required for vehicle underframes in the area of the UIC installation space.

3.3.1.2 Conditions for running safety

MB 530-1 and 530-2 require that all new freight wagons that are AC-compatible must be able to withstand longitudinal compressive forces (LCF) of at least 500 kN without derailing. A value of over 600 kN is also recommended.

It is not known whether the higher value has been implemented or whether the implementation of these requirements has continued since the introduction of TSI WAG in 2006. Thus, it may

be necessary to verify the tolerable LCF separately. To determine the maximum tolerable LCF, UIC MB 530-2 refers to the ERRI reports B125/RP5 and RP6 and to the UIC website. The reports include a calculation method, while the UIC website²⁷ also presents diagrams for determining the tolerable LCF. It has not yet been determined whether these costly and complex tests can actually be avoided, as the calculations are based on the “AK69”/“Intermat”.

Background

For the “running safety” of freight wagons with and without an AC, the “tolerable “LCF” is an important measure in reducing the risk of derailment, e.g. in S-bends. Several design features of the freight wagon influence the maximum tolerable LCF, such as the torsional stiffness of the wagon body and the distance between the wheelsets.

3.3.1.3 Design installation conditions for the coupling and accessories

Various requirements are stated regarding design installation conditions for the coupling and its accessories, incl. those for the traction and compression stops, and the support. Like the strength requirements, the implementation of these requirements is not mandatory ex works, but only upon conversion to the AC. Statements provided by SBB Cargo and coupling manufacturers have made it clear that compression stops are not being used in some wagons. These must be retrofitted. The traction stops are available, as these are already used by the current SC.

3.3.2 Support

The support must be designed in such a way that the coupling can be easily lifted but lowered only with difficulty in order to compensate for the vertical offset of the longitudinal axes of the coupling. For this purpose, the UIC coupling supports are fitted with two springs of different stiffnesses (a softer one to make lifting easier and a harder one to prevent the coupling from lowering). In addition, the support must not restrict the horizontal movement and centring of the coupling. [4]

There are three main types of support:

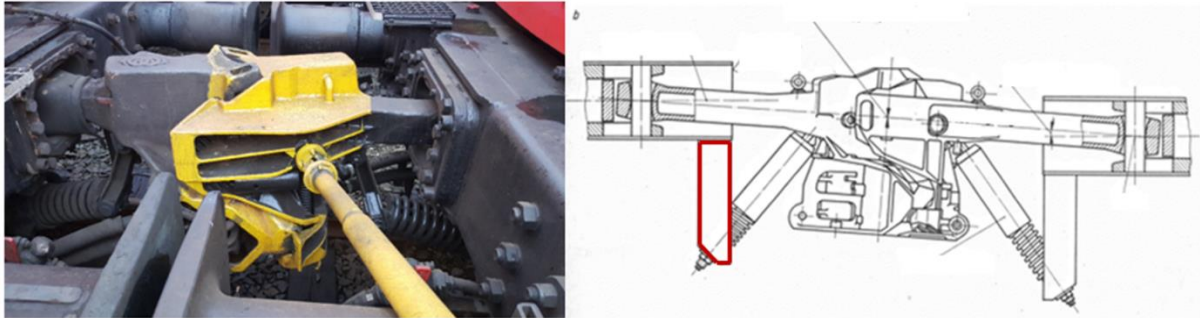
1. Crossbeam support known as UIC/OSShD Variant 1, UIC MB 530-1,
2. Suspension strut support, known as UIC/OSShD Variant 2, UIC MB 530-1 and
3. Horizontal support, a new approach developed by Wabtec.

The crossbeam and suspension strut supports were developed for the “AK69” and the “Intermat” for the introduction of the AC in the 1970/80s. These were standardised in UIC MB 530-1.

There is also a third variant with a horizontal support. The horizontal support was developed by Wabtec during its refinement of the Schwab coupling for RFT.

²⁷ See <http://www.uic.org>.

Fig. 29: Suspension strut support on a locomotive with “AK69” (left) and outlined using the example of the Intermat coupling (right)



Source: left TU Berlin, right [4]

Suspension strut support

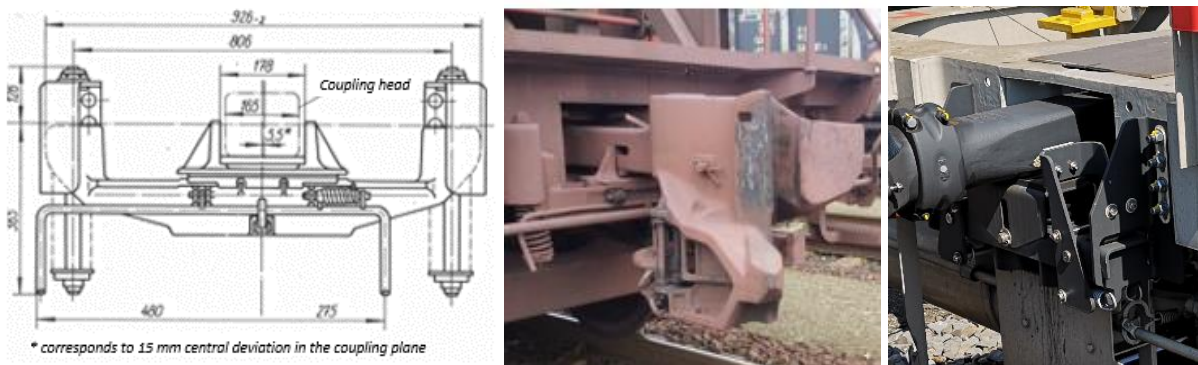
The suspension strut support is/was mainly used with the “Intermat” in Eastern Europe. In Germany, an adapted variant of the suspension strut support is used in combination with the “AK69” for locomotives in ore traffic from and to Hamburg (see Fig. 29, left).

The suspension strut support (see Fig. 29, right) horizontally centres the coupling by means of two tilting points fixed on balls. Inside the spring there is a pre-tensioned traction device. This ensures that a coupling, which has been deflected horizontally from the central position, returns to the central position.

The maximum deviation from the centre is two millimetres. On long wagons, the support mounted on the headstock of the wagon can be released by means of a notching device. This allows the coupling to be swung forward manually by at least eight degrees[16] – providing the ability to couple even under adverse conditions. The inclined spring compensates for the vertical offset between the two coupling heads. [4]

To mount the inclined spring, two additional plates must be attached to the headstock below the UIC installation space for the AC (see red marking in Fig. 29, right). The installation space provided for the suspension strut support does not require an extended recess in the buffer mounting plane and needs less horizontal installation space than the crossbeam support.

Fig. 30: Diagram of the crossbeam support (left), using the example of the “AK69” (centre) and in a domestic CT in Switzerland with the SchaKu



Source: left [4], centre and right TU Berlin

Crossbeam support

The crossbeam support is normally used in combination with the “AK69”, the “C-AKv” and, more recently, also with the newly developed RFT derivatives of the SchaKu. With the crossbeam support, the coupling is guided on a crossbeam. In the vertical direction, adjustments are performed by two vertical pairs of springs that support the beam. In the horizontal direction, a horizontally mounted spring moves the beam and ensures it is centred with an accuracy of 20 mm. The UIC-compliant crossbeam support is also mounted in the area of the headstock, in the extended UIC installation space for the AC. Remedial action must be taken if the recess in the UIC installation space is missing. The freight wagons used in AK69 ore transports in Germany – where the fastening elements of the support were welded to the front of the wagons (see Fig. 30, centre) – are an example of this.

As with the suspension strut support, the UIC-compliant version has a notching device with which the coupling can be swung forward manually by at least eight degrees [16]. [4]

A simplified version of the crossbeam support is used in domestic CTs in Switzerland (see Fig. 30, right). This dispenses with the notching device. The coupling can still be deflected manually and is held in position solely by the friction on the crossbeam. In this case, the coupling’s deflectability is reduced to plus or minus three degrees. The reduced deflectability is compensated by the comparatively large gathering range of the SchaKu.²⁸

Fig. 31: Horizontal suspension of Schwab DAC without (left) and with UIC insert (centre), derived from a conventional, rigid, fixed freight wagon coupling (right)



Source: Wabtec

²⁸ According to the manufacturer Voith.

Horizontal support

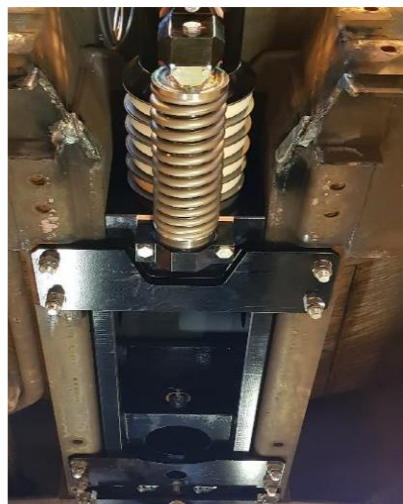
As part of its development of the Schwab DAC, Wabtec has redesigned both the support and its integration into the wagon body as well as the positioning of the suspension system as a whole. This design is based on a conventional, rigid freight wagon coupling for the inseparable connection of two wagons under operating conditions. It is therefore proven and comparatively inexpensive to manufacture (see Fig. 31, right). Unlike other coupling types, the forces are not transmitted by means of a stabilising joint at the end of the coupling shaft but directly via the longitudinal suspension. The suspension is essentially reduced to two large springs and one smaller (lower) spring, which are mounted directly on the coupling shaft (see Fig. 31, left and centre).

Centring is ensured by pre-loading both springs. The compressive forces are transmitted by loading the front main spring and relieving the rear spring. For tensile forces it is the other way round. The vertical support is supported by the lower spring, which is positioned in parallel in the horizontal direction under the front main spring (see Fig. 31, left and centre).

No further support is required at the headstock of the freight wagon, which means that the horizontal support requires little installation space. With existing wagons, it is mounted on the underframe using a separate insert for the UIC installation space (see Fig. 31, centre, and Fig. 32). This is attached directly to the coupling. A plate must be removed from the front part of the UIC installation space to make room for the spring assembly (see Fig. 32).

For future pure AC wagons, the UIC installation space and the corresponding insert are no longer required. The coupling and its horizontal support can be attached directly to the underframe from the outside.

Fig. 32: View from below of a mounted AC with horizontal support in the UIC installation space



Source: Wabtec/Schwab

The advantages of the horizontal support are its significantly lower weight, compact design and expected low life cycle costs (LCC) compared to previous suspension and spring designs. This effect will be even greater for the pure AC wagons of the future, since the UIC installation space is not required and the support can be installed from the front in just a few steps.

However, the implementation of this variant requires more detailed analysis in some areas. Firstly, it is essential to check the running safety, especially in the case of two-axle freight

wagons, due to the absence of the stabilising joint.²⁹ Secondly, it is necessary to check the extent to which the transverse forces occurring with this variant can be absorbed by the wagon body structure and whether it is acceptable to remove a plate in the installation space. It is assumed that the removal of the plate and the altered transmission of forces will have no negative effects on the strength of the underframe.

The currently developed version (see Fig. 32 and Fig. 31, left and centre) does not provide for any deflection. However, it is possible to implement the deflection. Clarification of the need for the deflection is a higher priority, independently of the coupling type and the suspension.³⁰

3.4 Electrical power and data lines in RFT

Most freight trains around the world operate without a power and data connection between the locomotive and the freight wagons. In the 1990s and early 2000s, two European projects aimed to establish electrical power and data transmission in European freight trains. However, their innovative approach was unable to establish itself in real-world applications at that time. In the BMVI research project "Innovative Freight Wagon"³¹, a power and data line using 110 V DC and CAN bus technology was tested between 2016 and 2019. This line was used to control a simplified electro-pneumatic (EP) brake valve.

In the USA, Canada and Australia, power and data lines have been widely adopted for use with EP brake systems. These systems and the European projects are presented below.

3.4.1 Project EBAS

The EBAS (electronic brake monitoring and control system) project, led by Deutsche Bahn, aimed to reduce train formation and handling times. Between 1994 and 1996, this project developed an accelerated brake test, a brake diagnostics system, an electrical brake control system and a simplified wagon identification system. A 9-pole power and communication line was specially developed for 900 m long trains with 64 vehicles. The power and communication line included a CAN bus system and an electro-pneumatic brake. The system was used on 20 container wagons and in CargoSprinters (freight trains with a control cab). The latter use the technology in combination with a control cab to achieve faster speeds in RFT.

3.4.2 FEBIS brake control system

FEBIS stands for "*Freight Electronic Brake and Information System*". Companies involved in the project included DB, SNCF, SAB Wabco, Alstom, and others. From 1999 to 2001, the project developed an open on-board communication system to serve as the basis for intelligent freight trains in Europe. FEBIS developed both wired and wireless solutions. The wired solution was based on LON Powerline technology, which permits data and electrical power to be transmitted via one cable. The system voltage is 230 V DC and the data transmission rate is limited to 3.5 Kbit/s. The radio-based solution included a train-talk protocol with a frequency of 5.8 GHz and a range of 100 m. The power supply for the radio link was provided by wheelset generators. For emergencies, each wagon still had a battery for the brake electronics and the UIC brake as a fallback level. [17]

3.4.3 EP brakes in international RFT

Among other things, the provision of an electrical power and data line fulfils a key requirement for the introduction of an EP brake. An EP brake provides smoother and more effective braking

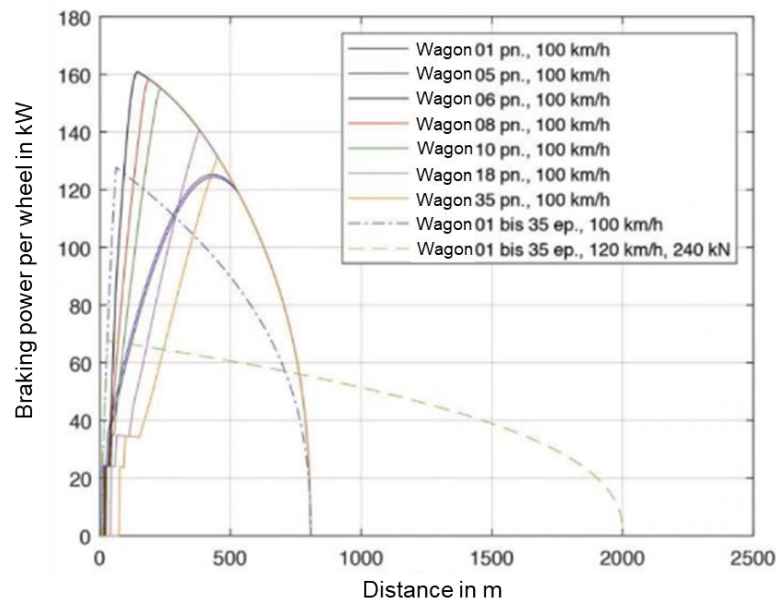
²⁹ The stabilising joint reduces the entry of lateral forces into the freight wagon and thus also the probability of derailment.

³⁰ For further information, see Chapter 4.3.4.

³¹ For further information, see Chapter 5.2.1.

and thus has many advantages for RFT. The use of EP brakes offers increased energy recuperation and higher running speeds. It also harmonises energy input to the wheels throughout the train during braking. This significantly reduces maximum loads (see Fig. 33) and reduces the risk of wheel breakage and wheelset wear. This is particularly relevant since wheelset requirements have increased significantly over the last 100 years – with the higher payloads and running speeds as well as the transition from cast iron to composite tyres. [18]

Fig. 33: Visualisation of even energy input into the wheelsets via the use of the EP brake in freight trains



Source: [18]

The introduction of the EP brake in certain RFT services has led power and data line technology to become established in the sector. Wabtec and New York Airbrake (NYAB)³² are the main suppliers and market their EP brake systems under the names “ECP” and “EP60” respectively. Both systems use a direct EP brake with a standardised LON Powerline for power and data transmission. The power supply uses standard voltages, such as 230 V DC. The pneumatic braking system is used as a fallback level. The system already includes the automatic brake test and digital generation of the wagon list or registration of the wagon order.

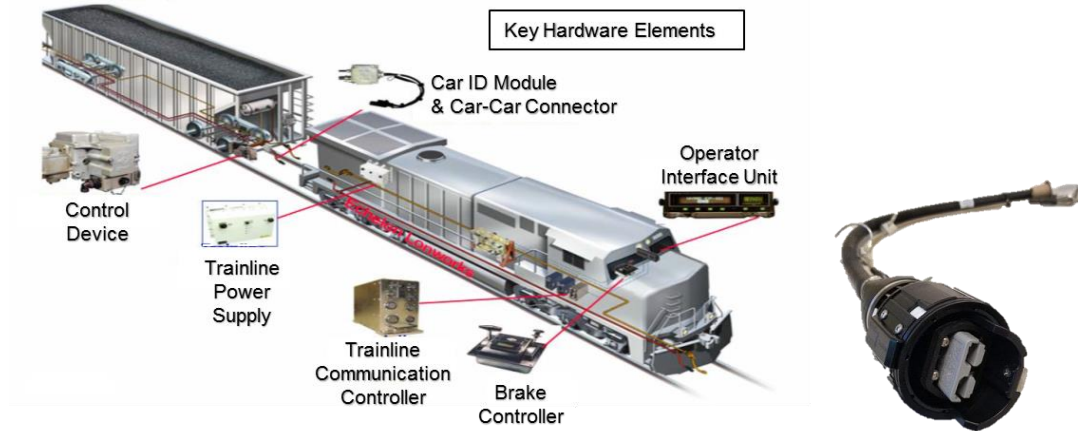
Fig. 34 (below) shows the functional diagram of this brake. The driver's cab is equipped with an operator interface unit as well as train and brake controllers. There is also a power line that runs through the entire train via connections between the individual wagons. [19]

ECP braking systems are used worldwide in AAR railways, but only in isolated cases. The system is particularly widespread in Australia. Approx. 230 locomotives and 13,000 wagons have been equipped with the system for the ore mines run by “Rio Tinto”. With the introduction of this and other systems in 2013, the operator laid the foundation for today's fully automated, driverless rail traffic. [20] However, despite the full automation of rail traffic, the power and data lines and the MBP are still coupled manually.

³² NYAB is a company of the Knorr-Bremse Group.

Fig. 34: ECP brake from NYAB (left), plug-in connection for ECP brake (right)

Key locomotive and freight car components of an ECP brake technology system



Source: left [19], right Wabtec

The following brief digression describes power and data connections in passenger traffic. These connections can then be transferred to freight traffic.

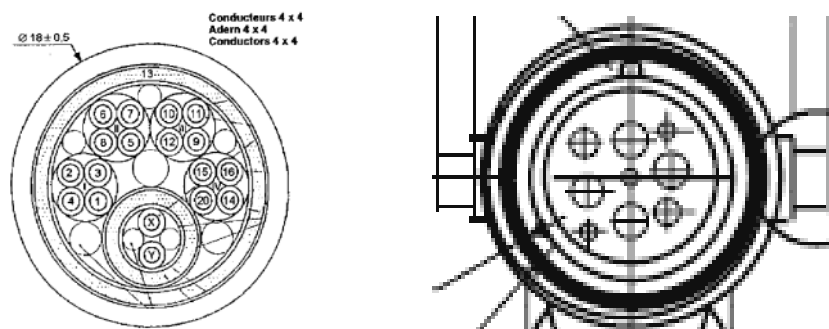
3.4.3.1 UIC control line/EP cable

Power line

In RPT, the power and data lines are designed in accordance with UIC guidelines. These include both the UIC control line in accordance with UIC MB 558, and the UIC “EP cable” for the EP brake in accordance with UIC MB 541-5/6.

The UIC control line is a redundant design incorporating connectors and sockets at the wagon transition. It consists of an 18-pole cable with an operating voltage of 24 V. Due to their rather small cross-section, the cores can only carry a low level of current (see Fig. 35, left).

Fig. 35: left: Connectors for the UIC control line in accordance with UIC MB 558, right: Connectors for the EP brake cable in accordance with UIC MB 541-5



Source: UIC

The UIC standard plug connection for the EP brake consists of a 9-pin connector for signal transmission with a redundant design. Electrical power is supplied to consumers via the wires A and B at 230 V AC 50 Hz. Two channels are reserved for the data bus line. Due to the larger cable cross-section, these can handle higher loads. The nominal control voltage is 72 V or 110 V DC and is supplied from a battery or converter. Fig. 35 shows the plug connections in accordance with UIC MB 541-5.

A preliminary investigation has shown that outputs of over ten watts per wagon are possible in cable cross-sections of 1.5 mm² for 50 wagons at a supply voltage of 230 V. This line could also operate an EP brake. Lower voltages of 48 V can only be used to supply shorter trains with small cable cross-sections due to the voltage drop at the connection points and the length of the cable. [21]

Data line

For data communication, a distinction must be made between the train (bus) and vehicle (bus) levels. On the vehicle level, the number of participants remains constant and changes to the structure are not expected during operation. The individual vehicle thus remains a closed system. On the train level, on the other hand, the number of participants changes continuously due to coupling and decoupling. The system must be able to respond to these dynamic changes. In practice, a hierarchically structured system of two fieldbuses, which combine to form a train communication network (TCN), has proven itself. This architecture and its detailed requirements are standardised in EN 61375. UIC MB 556 requires a data rate of at least 1.5 MBit/s for the vehicle bus. Table 2 provides an overview of the technical parameters for all the bus systems. [21]

Table 2: Technical parameters for selected vehicle and train bus systems

Bus type	Name	Poles	Voltage	Number of nodes per segment	Requirements
Train bus	WTB	2	0...+3.5 V	32(256)	Twisted pair, Impedance 120 Ohm
Vehicle bus	MVB	2	-7...+12 V	110	Twisted pair
Vehicle bus	CAN(open)	2	-7...+12 V	110	Twisted pair, Impedance 120 Ohm
Train bus Vehicle bus	LON	2	---	2 ⁴⁸	Power supply cable or twisted pair
Train bus Vehicle bus	Ethernet	8	-2.5...+2.5 V	1024	Four twisted pairs

Source: [21]

4. Challenges in the development of a European DAC

The introduction of a DAC brings with it a multitude of technical and operational challenges, because the DAC will have a key influence on the future design of railway operations and vehicle technologies and vice versa. The coupling type will define future train formation processes as well as the design of the vehicle structure. On the one hand, the future DAC and its properties must fit into the railway system. On the other hand, the railway system must also adapt to the DAC and take advantage of the opportunities offered by its introduction.

The previous chapter on the state of the art clearly showed that:

- There are several degrees of AC automation;
- There are four potential coupling types and three support options with different ranges of functions and installation requirements;
- The requirements relating to ACs can be traced back to historical UIC leaflets.

This chapter presents the fundamental technical and operational challenges facing the development of a European DAC in more detail. For the most part, these must be overcome before the selection of a suitable coupling type is made – so that the decision is based on solid foundations. Action and/or uniform definitions are required in the following areas:

- Degree of automation of the DAC
- Guarantee of reliability for the DAC
- Operating concept for the DAC
 - Handling of the couplings
 - Necessity of the buffer position
 - Necessity of an unlock cancellation feature
 - Gathering range and deflectability
- Current applicability of the design principles
- Wagon body integration of the DAC
- Degree of standardisation of the DAC.

4.1 Degree of automation of the DAC

A DAC Type 5³³ would bring with it by far the greatest leap in efficiency for RFT. However, there are still some obstacles to the introduction of a DAC Type 5, which need to be overcome at European level. The introduction of a DAC Type 5 is not recommended at this time, above all due to the unknown time horizon for finding solutions to these problems. The DAC Type 4 is a more suitable candidate for introduction in the near future. In terms of its functionality, the Type 4 is a good compromise, as all the essential interfaces for a Type 5 are already coupled automatically. Compared to the change from the SC to an AC, the change from Type 4 to Type 5 is comparatively simple. The Type 4 coupling can be created with an “upgradeable” design. This is also recommended.

³³ For more information on automation types for automatic couplings, see Chapter 3.1.1.

Challenges of a DAC Type 5

One of the central challenges facing a Type 5 is the definition of a uniform European operating standard. This must define all operation-relevant functions or behaviours of the coupling. These include, e.g. the handling of decoupled sections of the train, mixed operation, the automatic application of the brake during remote decoupling and the status of the MBP in train or shunting mode. Above all, the safety and security requirements for remote decoupling must be defined for a Type 5. Currently, this can only be controlled from the locomotive, even in RPT. Remote triggering by the infrastructure would be particularly advantageous in marshalling yard and sidings.³⁴

Reliability and availability must be very high. Software must not restrict interoperability. Downward compatibility of the software and the coupling must be guaranteed. Finally, it is essential that cyber-attacks can be detected and repelled, so that e.g. due to a fault a separated train is not detected. This must be avoided.

4.2 Guarantee of reliability

A high degree of reliability is essential for the DAC for two principal reasons: firstly, the failure of a single coupling usually prevents the departure of an entire train formation, with inevitable consequences for rail operations, infrastructure and, ultimately, the customer. Secondly, the DAC does not have the redundancy of the SC, where two couplings are always available. To avoid delays and failures, all elements, especially the interfaces between the freight wagons, must be weatherproof and robust, i.e. suitable for railway use. The critical need for a high level of reliability is highlighted by the fact that a reliability of 98 percent per coupling would result in an overall reliability of just 40 percent for a train of 45 wagons. Thus, the reliability per coupling must be significantly higher than 98 percent.

4.3 Operating concept for the DAC

The definition of a European operating concept for the DAC is a significant challenge. The concept has a decisive influence on the choice of coupling type. It is therefore important to develop operational objectives with corresponding technical requirements and to compare and balance these with each other. One important example here is the future design of the operating procedures in train formation facilities. The operating concept has a decisive influence on the complexity of the DAC in terms of the coupling/operating positions of the coupling. The complexity of the coupling increases with the number of operating positions. This is accompanied by corresponding increases in the areas of price, weight and maintenance. Other important aspects, some of which have far-reaching effects on the mechanical design of the coupling, are the ability to cancel the unlocking of two coupled wagons (without having to move them apart), the ability to decouple under tensile force and the behaviour of the MBP during intentional decoupling.

The following sections provide a brief overview of important operational issues concerning the DAC.

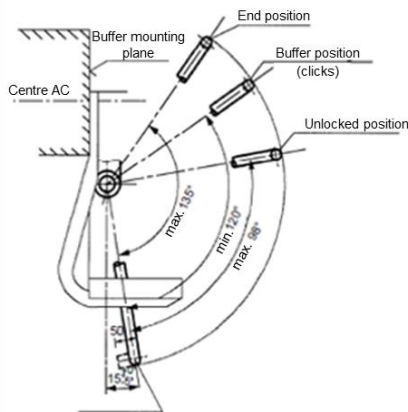
4.3.1 Operating elements and handling

The coupling must be easy and safe to handle. The physical effort required to operate the coupling must always be within an acceptable range for personnel. The operating controls must be clearly visible.

³⁴ For more information on the challenges of a DAC Type 5, see Chapter 7.

The operating controls should also have a uniform design, regardless of the manufacturer. Standardisation of the operating controls ensures that shunting personnel quickly become familiar with the new work routines and are thus more effective. Role models in this respect are the “AK69e” and the “Intermat”, which have uniform designs defined by UIC MB 535-2 (see Fig. 36). This also applies to the Janney coupling.

Fig. 36: Operating controls in accordance with UIC MB 535-2 incl. positions (left), coupled “AK69” with clearly visible operating control (yellow) in the basic position as well as separately available end cocks with red handles (right)



Source: left UIC, right TU Berlin

An essential requirement is that the controls must be located at the side of the vehicle. It must be possible to operate the coupling point from either side of the wagon. With the exception of the Schwab DAC, it is sufficient to mount the control in a diagonally offset position.³⁵ The controls must be positioned in such a way that personnel do not have to step between the wagons. This also applies to any end cock that may be required (see Fig. 36), and which is present with the “AK69”, for example. [12]

Other important issues include the required behaviour of the MBP in the unlocked position, and the option for releasing compressed air from the MBP. This is necessary because the MBP is closed in the decoupled state.

4.3.2 Necessity of the buffer/joint position

Until now, the following four positions have been provided in European RFT on the “AK69”/“Intermat”, “C-AKv” and “SA3” coupling.³⁶

1. Decoupled and ready for coupling.
2. Buffer position: decoupled and not ready for coupling.
3. Coupled and locked.
4. Coupled and unlocked.

The most important ACs used in RFT around the world³⁷ can assume all these positions. However, the SchaKu and Schwab ACs, which are being adapted from RPT, are currently only able to do so with restrictions regarding the buffer position.

³⁵ For further information, see Chapter 3.2.4

³⁶ Based on UIC MB 535-2.

³⁷ Janney, SA3, AK69/Intermat according to [12].

The buffer position is always advantageous if direct re-locking of the couplings is not desired. There are numerous views on the necessity of the buffer position. According to the authors' own estimates, this depends solely on whether the train is broken up in push-off or hump operations. The buffer position is advantageous in traditional push-off operations [12] and usually not in hump operations.

The following section briefly explains push-off und hump operations and thus provides a deeper insight into the problem.

Hump operations are mainly used in large marshalling yards with a hump and are considered to save energy and resources. In hump operation, as with the SC, the wagon connection is only finally released at a hump – in the case of the AC, the coupling is unlocked. The AC should now immediately return to the state “ready for coupling” because only in this way can the wagons be pushed together and automatically coupled in the sorting sidings without additional work by personnel. Productivity effects therefore arise in the course of the renewed train formation process.

Push-off operations are mainly used in smaller yards without a hump. This method uses the inertia of the wagons instead of gravity by braking a previously accelerated (pushed) train and allowing an uncoupled group of wagons at the head of the train to continue rolling. The detached wagon group is then sorted into the corresponding sorting sidings in the subsequent ladder track. The couplings must then be switched back to the state “ready for coupling” and pushed together by a shunting locomotive. This procedure must be repeated for each group of wagons. [22] The buffer position is required because when accelerating before the push-off procedure, it may be necessary to recouple the wagons. This shunting procedure is highly intensive in terms of personnel, technology and energy.

It is assumed that push-off operations are no longer an up-to-date shunting method, as the situations in which they can be implemented economically are very limited – due to their intensive use of personnel, shunting locomotives and energy. According to the authors' own estimates, there is no longer an urgent need for the buffer position. However, as RFT in Europe is a very diverse sector, no final conclusions about need for the buffer position can be drawn at this point. A more in-depth investigation is therefore recommended.

4.3.3 Necessity of an unlock cancellation feature

Sometimes, when a train is being broken up, it is possible to mix up the coupling points with the result that, e.g. a group of wagons is unlocked/disconnected at the wrong point. It is thus advantageous if the unlocking process can be cancelled directly. If this is not possible, the wagons/couplings must first be completely separated before being coupled again. The unlock cancellation feature avoids the need for what can be a considerable amount of additional work, e.g. in the siding. The lack of such a feature would also have a significant impact on productivity at the hump and slow down the sometimes highly automated processes.

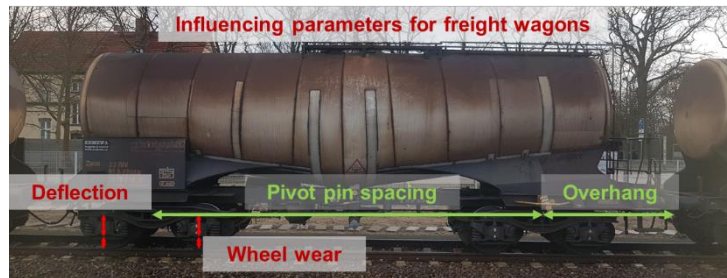
The unlocking process can be cancelled with the “SA3” and “AK69”, for example. [12] It is also possible with the Janney coupling. Since this application is not used in RPT, this is not the case with the SchaKu and Schwab DAC.

4.3.4 Gathering range and deflectability

The gathering range of an AC describes the max. permissible vertical and transverse offset of the coupling heads for automatic coupling. The actual gathering range depends on the infrastructure and the vehicle. In the area of infrastructure, the height deviation and the bend

radius of the track are the decisive factors. In the area of the wagon geometry, the overhang and the wheelset/pivot spacing determine the wagon's ability to couple automatically. [16] Fig. 37 shows the parameters that influence the gathering range using a freight wagon as an example.

Fig. 37: Overview of the parameters that influence the gathering range of an AC using the example of a freight wagon



Source: TU Berlin

The UIC has defined the gathering range of automatic couplings in several leaflets.

In UIC MB 522, a lateral gathering range of ± 190 mm and a horizontal height offset of 120 mm were defined as the general minimum requirement for an AC. In UIC MB 530-1/-2, which includes the requirements for the "Intermat" and the "AK69", the gathering range has been set at 140 mm in the vertical direction and ± 220 mm in the horizontal direction. The limiting conditions have changed since then, in some cases significantly. For example, the UIC standard wagon used as the basis for designs at that time has been completely withdrawn from service since 2007 (see Fig. 38, left). Modern freight wagons for the transportation of heavy goods have become shorter to promote effective utilisation of train length and axle load (see Fig. 38, centre). Freight wagons for the transportation of volume goods have become considerably longer (see Fig. 38, right). While shorter wagons can be automatically coupled effectively coupling in tight bends, the opposite is true for longer wagons. With regard to the infrastructure conditions, the development of the "AK69"/"Intermat" required the ability to couple automatically in the transition from the straight track to a bend with a radius of 135 m. [16]³⁸ Such conditions are usually rare and more typical of sidings. As many sidings have been dismantled, it is quite possible that the requirements in this area have decreased.

Fig. 38: UIC standard wagon as the basis for determining the gathering range (left), new freight wagons from the "Innovative Freight Wagon" project (centre, right)



Source: left dybas, right www.innovativer-gueterwagen.de

The development of the "Z-AK" and the "C-AKv" used the gathering range and infrastructure conditions stated in UIC 522. [23] The gathering range of the "C-AKv" is therefore smaller than

³⁸ An overview of the infrastructure requirements with regard to automatic coupling ability is contained in UIC MB 522 and 522-2.

that of the “AK69”. Both couplings are actively used³⁹ in Germany and it is not known whether there are any restrictions in this respect. It is assumed that very few freight wagons are coupled in tightly curved sidings and/or 150 m bends. Even today, freight wagons with SCs and side buffers can only be coupled in tight bends to a limited extent. As soon as the bend is so tight that the buffers touch each other on one side, coupling is no longer possible without unreasonable effort.

Manual deflection

One method to assist with coupling in the bend transition is to allow the coupling to be deflected. To do this, the centring device for the coupling is removed and swung out to the appropriate side before coupling takes place. After coupling has been completed, the coupling centres itself automatically.⁴⁰ The deflection depends exclusively on the type of support. An overview of AC support types is provided in Chapter 3.3.2.

The couplings currently under development have different gathering ranges. A sensible gathering range must be selected. The guides required for the realisation or extension of the gathering range have a direct influence on the weight and price of the coupling. The gathering range must therefore be kept reasonably small. For this purpose, an analysis of wagon fleets, infrastructure and operations should be conducted to find out where coupling usually takes place and for which wagon type.

Another possibility is to adopt an additional DAC variant with a larger gathering range and optional deflectability for selected types of freight wagons. This approach was followed, for example, in the USA with the introduction of the “Type E/F” Janney coupling.

4.4 Current applicability of the design principles

Virtually no information about today’s real-world operating requirements for freight wagons and couplings is available anywhere in the sector. Thus, nobody knows how often trains are braked and accelerated, or how strong the forces are in these cases. The same applies to processes on the hump. This means that the ORE/ERRI test reports and UIC leaflets are the only sources of information with regard to the coupling design. These reports and leaflets were produced for the planned introduction of an AC in Europe in the 1960s/70s, or the development of the “Z-AK” in the 1990s. For many reasons, they no longer reflect the state of the art. Firstly, today’s level of computer technology was not available at that time. This enables operators to calculate countless train combinations with a reasonable amount of effort.

Secondly, the characteristics of railway operations have changed over the last 50 to 60 years. For example, speeds and axle loads have increased, new brake blocks have been introduced, significantly fewer two-axle freight wagons are in use, and the annual mileage of freight wagons has increased many times over. These changes mean that a design based on historical precedents could force the coupling to be incorrectly dimensioned or prevent the development of innovative train designs.

Moreover, the aforementioned documents barely differentiate between existing conditions, but instead often contain assumptions based on worst-case scenarios. Thus, there is also a risk of over-dimensioning the coupling design. As a result, the sector is currently divided in its opinions on the design of the coupling and its associated spring damper and whether there is a need to differentiate between freight wagons, e.g. two-axle and four-axle. In particular, it is

³⁹ see Chapter 2.1.4.2.

⁴⁰ An overview of deflectable couplings is provided in Chapter 3.3.2.

still unclear whether there is a need for the stabilising joint to prevent derailment. To create a coupling for Europe that is both durable and economical, it is recommended that the DAC design requirements be redefined.

4.5 Wagon body integration

The interface between the coupling and the wagon body was standardised by the UIC when the installation space for the AC in UIC MB 530-1 came into force.⁴¹ From 1 January 1974, all freight wagons had to reserve an installation space for the AC. This is simply an insertion slot on the front side of the wagon. With the introduction of the first TSI WAG on 28 July 2006, the provision of installation space was indirectly abolished by the mandatory adoption of the SC at that time. As a result, since 2006, a growing number of wagons with no installation space – for cost reasons – have been coming onto the market. A solution must also be found for these wagons. This is particularly important as these are comparatively new wagons.

Even if the installation space for the coupling is available, this is still no “plug and play” situation. For economic reasons, some of the stops required to transmit the longitudinal forces have been eliminated.⁴² Furthermore, the UIC installation space is not necessarily designed for compressive forces in terms of strength. This applies primarily to vehicles built before the 1990s. The result is increased installation and conversion work (e.g. strength) during retrofitting.

The interaction with the spring damper is another more important point in the design. The structure of the wagon body must be capable of absorbing the coupling forces throughout its service life. Depending on the design of the spring damper, transverse forces may be introduced into the wagon body structure or intervention in the UIC installation space may be necessary. In these cases, it is essential to check whether this is permissible for the wagon body.⁴³

4.6 Degree of standardisation

Standardisation is essential to ensure smooth and effective operation in complex systems with many protagonists, as is the case with RFT. Here, it is necessary to distinguish between elements that must be standardised and those for which standardisation is recommended. Connection dimensions and measurements as well as the power and data specifications must certainly be standardised. Load requirements and weight limits should also be standardised.

The following AC components should be standardised:

- **Profile of the coupling head and line coupling:**

The profiles of the coupling head and the line coupling must be 100 percent compatible. Deviations would lead to incorrect or improper functioning or make it impossible to couple the wagons. Standardisation is essential to ensure that couplings from different manufacturers can be coupled.

⁴¹ There are two versions of the installation space: one for Western European railways and one for Eastern European railways; for more information see Chapter 3.3.1.

⁴² Not mandatory under UIC; for more information, see Chapter 3.3.1.

⁴³ For further information, see Chapter 3.3.2.

- **Operating controls:**

Standardisation of operating controls is not necessary for operation itself. However, a uniform design would be useful to simplify operations, accelerate processes and avoid operating errors.

- **Interface between the coupling body and spring/damping device:**

A common interface makes sense as separating the production of springs or dampers from pure metal working processes would mean that more suppliers could be considered for the production of coupling components.

In addition, the standardisation of other AC components would be helpful, e.g. the locking mechanism, shaft, joint, connectors, such as sleeves or similar, and wearing parts.

In general, the advantages of extensive standardisation can be summarised as follows:

- **Cost reduction:**

Defined standards offer the potential for achieving cost reductions, especially through greater competition and lower development costs.

- **Increase in component availability:**

The potentially higher number of suppliers, competition between these suppliers and the reduction in component diversity should lead to improved component availability.

- **Improved quality:**

Recognised standards in the supply chain and attractive market access for specialised manufacturers could raise the overall quality level.

The Janney coupling, which is highly standardised and therefore relatively inexpensive, is worthy of mention as a role model for this process. This applies, for example, to the “knuckle” which is the most common wearing part (see Chapter 3.2.1.). In addition, the different design variants can be coupled with each other, e.g. the non-rigid Type E with the rigid Type H.

Several versions of the DAC are required. Even today's system with the SC and side buffers includes a variety of designs. For example, the SC is available in versions with different maximum tensile loads. There are also several buffer categories and special crash buffers for the transportation of hazardous goods. The coupling head interfaces must, of course, be identical for all DAC designs in order to permit unrestricted, free movement of the freight wagons around the network. Depending on the application, the spring damper, shaft or other components must be adapted to the specific requirements. For example, existing side buffer categories, in accordance with EN 15551, must be reflected in the design variants of the AC spring damper. The derivatives of the DAC should also be standardised. This can be done by creating separate standards for subassemblies, e.g. for the spring damper. In this case, too, the Janney coupling can be taken as a role model.

4.7 Reduction of distances between vehicles

The introduction of a DAC enables the distance between vehicles to be reduced. Not only does this increase the available capacity per unit length of the train, it also offers an opportunity to improve the aerodynamics of freight trains. Air resistance is by far the most important parameter influencing driving resistance and thus traction energy requirements. General preliminary studies have shown that a 20 percent reduction in air resistance reduces energy requirements by between five and seven percent. [24]

5. State of the research – DAC

The following chapter provides an overview of the scientific literature relating to the AC in RFT. It also evaluates current research and development activities and presents the latest developments achieved by the European railway industry. For further information on previous research activities in the railway sector, please refer to the BMVI database “Forschungsüberblick zur Eisenbahnforschung” (*Overview of Railway Research*).⁴⁴

5.1 Literature

5.1.1 Sünderhauf: The automatic central buffer coupling

In 2009, B. Sünderhauf published “The automatic central buffer coupling (ACBC), a prerequisite for the automation of rail freight transport in Europe”. In it, Sünderhauf carries out a cost-benefit analysis for the use of an AC in European RFT. The analysis is based on the AC “C-AKv”. A timeframe of five years is assumed for the conversion of the freight wagons. The study shows that the operational and economic advantages clearly outweigh the investment costs, although it does not consider positive effects for control and security technology. The business aspects of the study essentially relate to the increase in transport performance (longer, heavier and faster trains), higher circulation speeds, reduced wheel/rail wear and the longer service life of the AC compared to the SC. The economic criteria primarily result from the shift of transportation from road to rail.

The study is optimistic, particularly with regard to its assessment of benefits relating to wear reduction. This is because it assumes the savings in the area of wear to wheels and rails to be in the region of 20 to 30 percent per year, although no reliable studies exist on this subject. The assumed increase in transport performance of 30 percent due to the AC is also extremely optimistic. Furthermore, the target service life of the AC is an ambitious 30 years. With regard to costs for the transfer of wagons to the workshops, the study refers to existing time spent in workshops and maintenance intervals. The study assumes that the wagons are converted successively during regular workshop visits, i.e. the migration is not coordinated and takes place for all sectors simultaneously.

In the area of financing, Sünderhauf proposes the agreement of leasing contracts for the couplings, at least during the migration period. This offers a way to limit the investment volume. [1]

5.1.2 Stuhr: Investigation of application scenarios for an automatic central buffer coupling

“Investigation of application scenarios for an automatic central buffer coupling” is a paper published by H. Stuhr in 2013. It deals with the development of an evaluation procedure for the benefits of an AC and considers transports on behalf of basic industries (mining, chemical and automotive industry) as well as combined transports (CT). The study examines technical equipment levels for seven scenarios. Starting with a purely mechanical AC (Type 1), it also considers the combination of this with an EP brake, train bus, automatic brake test, extended condition inspections and, finally, a DAC Type 5. The last of these is only considered in combination with the other technologies mentioned, here referred to as an AC Type 5+ (see Fig. 39).

The assessment of the overall benefits weighs the advantages of the technologies for transport against expected resistance to their introduction. The study determines that the balance

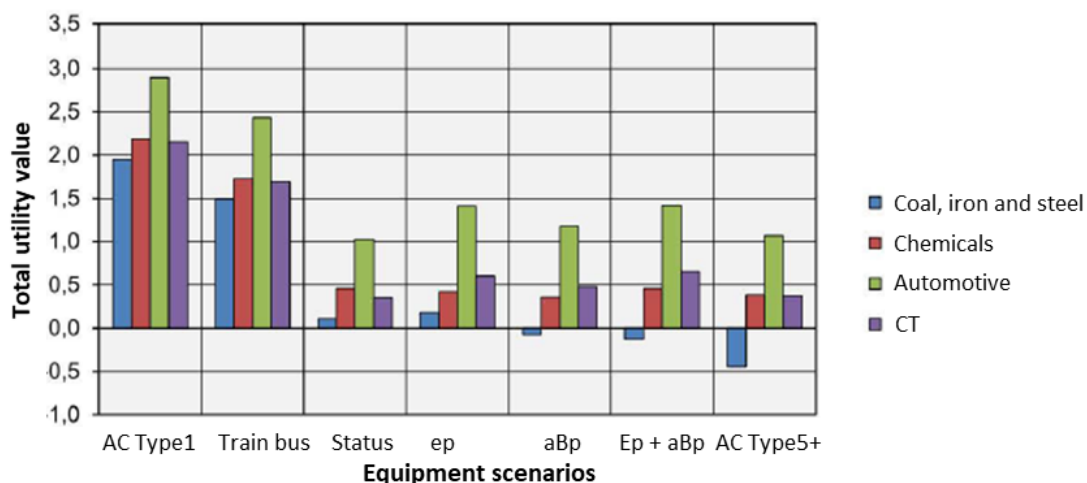
⁴⁴ Website: <https://www.bmvi.de/SharedDocs/DE/Artikel/E/forschungsueberblick-eisenbahnforschung.html>.

favours the resistance. This is understandable due to the unsuccessful record of attempts to migrate to an AC in European RFT. The study therefore considers overall benefits for single wagon traffic (SWT) to be poor. The situation in SWT is exacerbated by Stuhr's assumption of long-term mixed operation of SC and AC wagons. The benefits of technologies requiring 100 percent of the freight train to be equipped (brake test, EP brake, AC Type 5) are not taken into account in dynamic fleets. This applies to the coal, iron and steel and chemical industries. According to this assessment, block train services in the automotive industry and CT profit although they benefit less from these technologies than SWT.

This approach leads Stuhr to a more conservative conclusion than Sünderhauf. The study's core finding is that a Type 1 AC is useful in all sectors. Nevertheless, due to resistance, it considers the conversion of all freight wagons in Europe to be unrealistic. According to its investigations, the automotive industry stands to benefit most. The greatest advantages, but also the greatest resistance, are expected in the coal, iron and steel and chemical industries. For this reason, a lower overall benefit is attributed to these sectors by the evaluation model.

According to Stuhr, the long-term goal is to create an AC with a wide range of functions (use of EP brake etc.), which leads to increases in capacity. As a final comment, Stuhr states that the effects of an AC on network capacity must be studied.

Fig. 39: Suitability of AC and additive technologies for selected industrial sectors



Source: [3]

5.1.3 Martin, von Molo, Ji, Körner, Podolskiy: Comprehensive introduction of the central buffer coupling

Another source in the literature is the “Comprehensive introduction of the central buffer coupling – perspectives for railway infrastructure companies” published by U. Martin, C. von Molo, K. Ji, M. Körner and I. Podolskiy in 2015. This study considers an AC with an electrical power supply and data connection in the same way as [3], as an upgraded central buffer coupling (“CBC+”) that does not yet exist. Among other things, it examines the potential of train integrity testing, train setup, automatic brake testing and the automated provision of information about speed and braking performance that can be achieved through the introduction of a CBC+.

Unlike other studies, this study deals with the effects of an AC on control and safety technology (CST) in connection with the introduction of ETCS Level 3. It takes account of the business and economic benefits, the migration process and interoperability.

The study found a clearly positive cost/benefit ratio and therefore recommends the introduction of a CBC+. However, the economic effects of the “CBC+” require a differentiated view. One example is the elimination of track-side control and safety technology (CST) in the case of ETCS Level 3, which is attributed to the economic benefits of the CBC+. Another optimistic expectation is the anticipated 35 percent increase in the performance of RFT due to longer and heavier trains and the acceleration of transport processes through automatic coupling. [25]

5.1.4 Fumasoli: The automatic coupling in single wagonload traffic in Switzerland

This study by T. Fumasoli, published in 2010, deals with “The automatic coupling in single wagonload traffic in Switzerland”. It examines the use of the AC in this area and assesses the relationship between conversion costs and benefits. However, it only evaluates the benefits relating to personnel savings and occupational safety. Fumasoli concludes that the semi-automatic coupling with automatic line coupling (AC Type 2) is probably the most economically feasible. [26]

5.1.5 Bruckmann, Fumasoli, Mancera: Innovations in transalpine transport

The study “Innovations in transalpine transport – Study commissioned by the Federal Office of Transport” by D. Bruckmann, T. Fumasoli, A. Mancera was published in 2014 and investigates strategies for making RFT more competitive. Among other things, it assesses the introduction of an AC as a new vehicle innovation. The AC is classified as an option that is certainly possible. With longer trains and greater masses, in particular, it concludes that the AC could lead to an increase in productivity in transalpine traffic.

The findings are expressed very cautiously and draw no certain conclusions. Furthermore, the study does not deal with implementation and only discusses this as a theoretical possibility. [27]

5.1.6 Chatterjee, Besch: Improvement of safety in rail freight transport through the use of the simplified compact automatic central buffer coupling

In 1999, B. Chatterjee and J. Besch were already working on the “Improvement of safety in rail freight transport through the use of the simplified compact automatic central buffer coupling”. They looked at the effects of the “C-AKv” and examined the transmission of forces in the coupling. Ultimately, they conclude that higher longitudinal compressive forces can be tolerated using the “C-AKv”, which ensures greater safety. This study does not focus on the introduction of the AC, but on the effects and transmission of forces with the “C-AKv”. [28] Consequently, it is not a rich source of information for the introduction of a DAC.

5.2 Research and development activities

5.2.1 Research project “Construction and testing of innovative freight wagons”

The research project “Construction and testing of innovative freight wagons” included the construction and testing of twelve innovative freight wagons in the period between September 2016 and April 2019 (see Fig. 40). DB Cargo AG and VTG AG were responsible for the overall

project management. The project was financed by the BMVI⁴⁵ and involved various project partners.

The project originated from a previous survey carried out by the BMVI on the state of research and development in noise and environmental protection in RFT. This found that although various research and development projects were being carried out, particularly in the area of noise, the approaches were not being implemented due to the costs. The “Innovative Freight Wagon” project was thus commissioned to develop and test new and innovative freight wagons using existing components and technologies. The expectation was that this would accelerate the introduction of innovative freight wagons.

Fig. 40: Overview of the newly developed freight wagons from the “Innovative Freight Wagon” project



Source: www.innovativer-gueterwagen.de

The project had three objectives. Firstly, to reduce noise emissions from freight wagons by three to six decibels(A) compared to the current limits stated in TSI Rolling Stock – Noise. Secondly, to reduce traction energy by three to eight percent by reducing the weight of the wagons and using innovative bogies with radially adjustable axles. Thirdly, to improve economic efficiency through lower life cycle costs using innovative components. The innovative components were selected on the basis of a comprehensive technology screening.

A demonstrator train was developed for the study and equipped with four innovative types of freight wagon (three wagons of each type), the corresponding conventional types as reference vehicles (also three wagons per type), and two stock freight wagons. One wagon was empty, one full and one partially loaded. Thus, in total, the train consisted of twelve innovative freight wagons, eight reference wagons and three stock freight wagons, the last of which were fitted with an AC. A total of 23 freight cars were therefore tested over a distance of approx. 150,000 kilometres (see Fig. 41).

⁴⁵ For more information see <https://www.bmvi.de/SharedDocs/DE/Artikel/E/forschungsprojekt-innovativer-gueterwagen.html> .

Fig. 41: Composition of the demonstrator train for the Innovative Freight Wagon project



Source: www.innovativer-gueterwagen.de

The innovative freight wagons were equipped with innovative bogies, disc brakes and wheelsets as well as telematics/sensor systems, power/data bus lines, a digital brake indicator and an EP brake. The three stock freight wagons in the first field (see Fig. 41) were equipped with the Voith “CargoFlex” AC and Schwab couplings.

5.2.2 Technical Innovation Circle for Rail Freight Transport (TIS)

The Technical Innovation Circle for Rail Freight Transport (TIS) produced the white paper “Innovative Rail Freight Wagon 2030 - The 5L Future Initiative” in 2012.⁴⁶

The aim of the TIS is to identify and promote basic innovations for freight wagons that meet the “5L” criteria - Low Noise, Lightweight, Logistics-enabled, Long-running and LCC-oriented. These are to be achieved in several stages. Innovative freight wagons must first be combined to form an intelligent freight train, resulting in a competitive rail freight system with the associated growth opportunities. To this end, TIS published the white paper “Intelligent Freight Train” in 2019.⁴⁷

The core of the intelligent freight train is a digital AC with electrical power and data lines, i.e. a DAC Type 4, which lays the foundations for the digitisation and automation of RFT.

According to TIS, the freight wagon of the future will have innovative bogies, wheelsets and braking systems, which primarily means lightweight, low noise and low wear. The wagon design is characterised by a modular construction and lightweight concepts. The freight wagon of the future will also be equipped with telematics. Together, these measures will result in increased efficiency and lower life cycle costs.

Other focal points for intelligent freight trains include automated operating procedures, power and data management and an electro-pneumatic brake. Furthermore, TIS expressly points out that only an integrated approach, which takes account of the vehicle, infrastructure incl. CST, and the general (political) conditions, e.g. suitable funding measures, will lead to the desired success – namely more growth on the railways.

The ideas were taken up and implemented in three major projects: the “5L” demonstrator train run developed by SBB Cargo (see Chapter 5.2.2.), the innovative freight wagon developed by DB Cargo AG and VTG AG (see Chapter 5.2.1.) and the innovative tank container concept from BASF SE.

5.2.3 “5L” demonstrator train – SBB Cargo

SBB Cargo is currently developing and testing the “5L” demonstrator train with TIS and other partners, with the aim of achieving the “5L” targets.⁴⁸ The project began in April 2016 and is scheduled to continue until August 2021. Trials of the train started in summer 2017 and will run until August 2021 – these were initially restricted to Switzerland but have been taking place

⁴⁶ see website TIS; <http://www.tis.ag>.

⁴⁷ For more information see <https://www.bmvi.de/SharedDocs/DE/Artikel/E/forschungsprojekt-innovativer-gueterwagen.html>

⁴⁸ Innovative freight wagons that are low noise, lightweight, logistics-enabled, long-running and LCC-oriented (5L).

throughout Europe since mid-2019. The trials aim to cover at least 400,000 km. The “5L” demonstrator is embedded in the synonymous “5L” initiative, which aims to increase efficiency both in marshalling yards and on the tracks. This is to be achieved through the introduction of single-handed operation and automation of shunting processes, incl. an automatic brake test. New components being used in the project include the new ACs from Voith (SchaKu) and Wabtec (Schwab). Innovative bogies with low-maintenance, radially adjustable and innovative wheel sets, disc brakes, noise damping measures, telematics and sensor technologies, such as RFID chips, will also be installed. The wagon design is also optimised with a tanker concept and lightweight construction.

The “5L” demonstrator train consists of 16 container wagons, which have been equipped with various combinations of the innovations mentioned above (see Fig. 42).

Fig. 42: Innovations in the 5L demonstrator: disc brake and wheel noise absorber (top left), Voith AC (top right), Faiveley AC (bottom left) and sensor technology (bottom right)



Source: TU Berlin

The data gathered so far show that good results can be achieved with existing technology and minor adjustments. This applies to the individual effects of the components and the interactions between them. Noise emissions have been reduced by more than five decibels and economic efficiency has been increased. Thus, it has been shown that promoting innovation and replacing old standards makes good financial sense. It was found that the AC reduces wear on both the wagons and the infrastructure and can generate savings in traction energy.⁴⁹

5.2.4 Shift2Rail IP5 - FR8RAIL I+II

“FR8RAIL” is a recently completed Shift2Rail project from the innovation programme (IP) 5. Coordinated by Trafikverket and various stakeholders, such as CAF, it pursued the following very general project objective: “Development of Functional Requirements for Sustainable and Attractive European Rail Freight”. The project ran from 1 September 2016 to 31 August 2019 and was designed to provide the basis for the development of an AC. For this purpose, it assessed several AC types to determine their suitability for rail freight transport.

The following evaluation categories were defined: interoperability, gathering range, weather resistance, reliability, coupling capability for pneumatic and electrical connections, wear,

⁴⁹ For more information about the project, see the SBB Cargo Blog: <https://blog.sbbcargo.com/32342/5/>

dynamics, load capacity and price. These criteria were considered in the overall ranking and assigned different weighting factors.

The overall evaluation shows that Willison-based couplings are the most suitable for the development of a European AC, followed by the BSI coupling and the SchaKu. The Willison couplings were rated as the best couplings in five differently weighted evaluation models. It should be noted, however, that when assessing the coupling types, greater emphasis was placed on interoperability, reliability, wear and price and less on automation. The automatic connection of pneumatic and electrical lines always had the lowest weighting factor of one out of five. Yet automation is currently one of the key drivers of efforts to introduce an AC. [29]

The overall assessment in favour of the Willison coupling must be viewed somewhat cautiously, as almost all the couplings were awarded very similar totals of ranking points. Depending on the weightings, the three coupling types mentioned here are sometimes separated by only five points in the evaluation – which at 123 (Willison), 122 (BSI) or 121 (SchaKu) out of 175 points is not a very significant difference. The difference between the best and the worst rated couplings is also quite small at just 18 points. The use of other weighting factors and evaluation methods could therefore easily lead to different results, especially if the latest developments for the SchaKu and Schwab couplings were included in a new calculation, e.g. the extension of the gathering range and increased load limits for the Schwab coupling.⁵⁰

Looking past Shift2Rail's evaluation of the ranking points, the more important conclusion is that all the couplings could be adapted to European RFT with greater or lesser modifications. Based on the findings of the previous project, FR8RAIL II is currently developing a Type 4 Willison coupling in accordance with UIC requirements.⁵¹

⁵⁰ For more information, see Chapter 3.2.4.

⁵¹ For more information, see the FR8RAIL website.

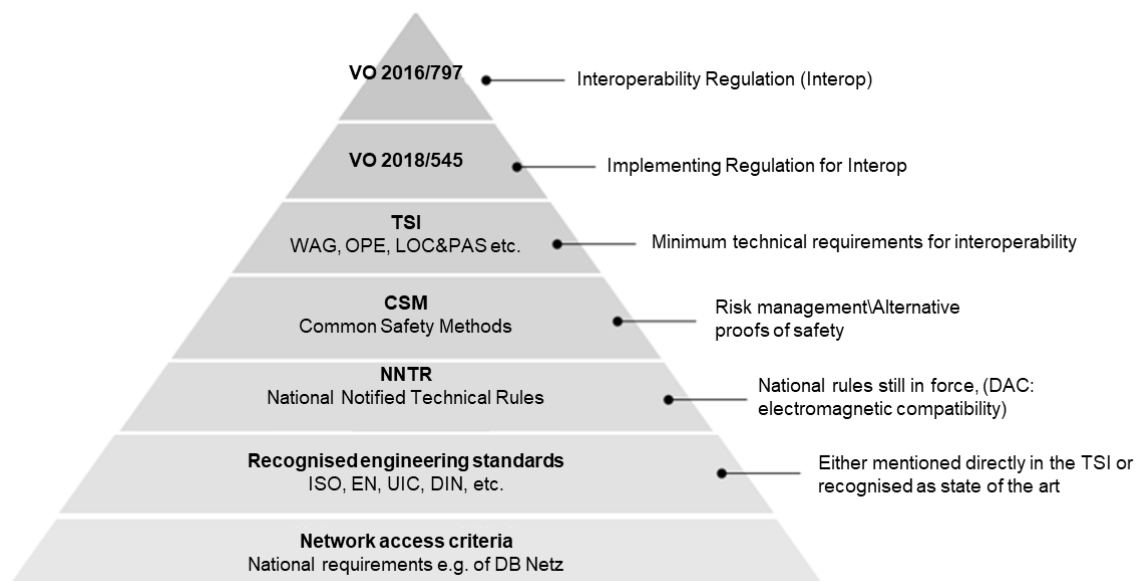
6. Legal framework

This chapter first identifies the legal framework conditions and classifies them hierarchically in the European context. It then looks at the aspects that are relevant to the DAC in greater detail and discusses the registration situation for new and existing vehicles.

6.1 General situation in Europe

Fig. 43 shows the legal situation in Europe in the form of a hierarchical pyramid. The top four levels of the hierarchy are all EU regulations, which are legislative in nature.

Fig. 43: Pyramid of rules and regulations for international European rail transport including comments relevant to the DAC

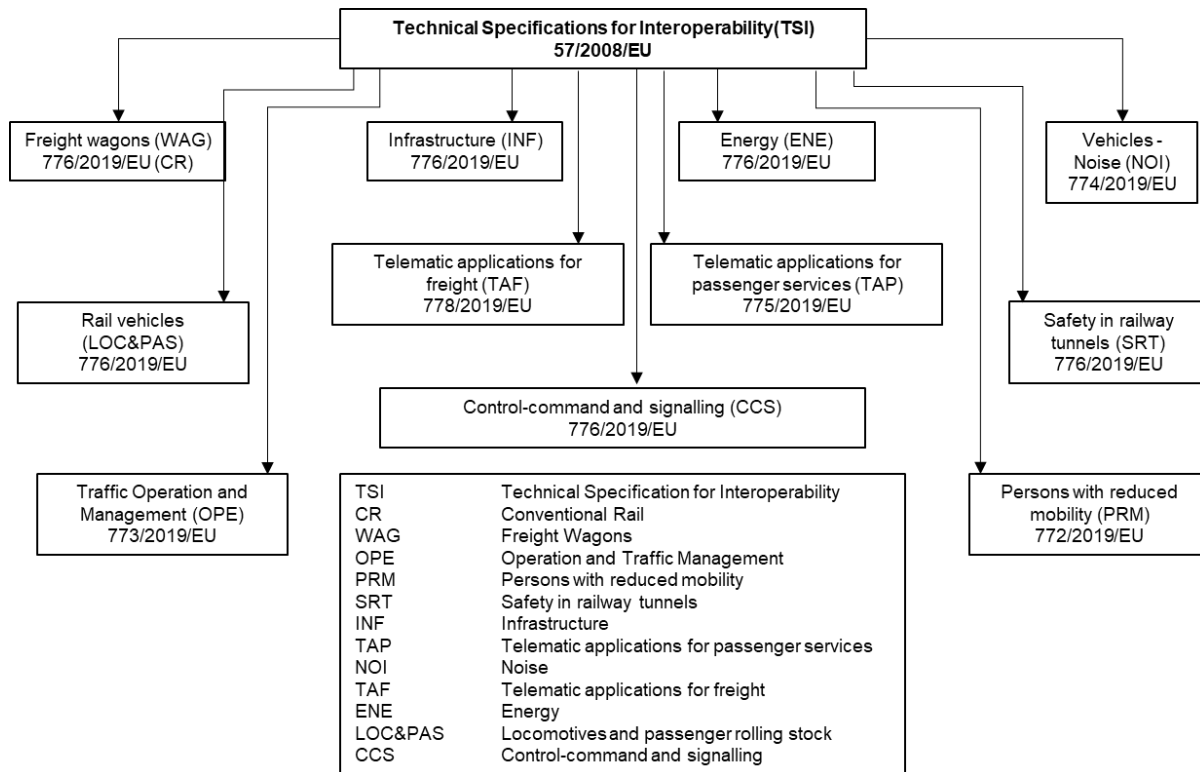


Source: TU Berlin

The top two levels are the Interoperability Regulation (Interop) and the Implementing Regulation (EU) 2018/545. Interop defines the general conditions for the implementation of interoperability in European rail transport and the procedures for placing rolling stock in service. The Implementing Regulation explains the practical arrangements for the placing in service of rolling stock, based on Interop.

One level below this are the Technical Specifications for Interoperability (TSI). These cover all relevant sub-areas of rail transport and regulate the basis for the provision of European transport by rail with as few barriers as possible. The TSIs are mainly used to derive technical and safety requirements. Fig. 44 provides an overview of all currently valid TSIs. TSI LOC&PAS, TSI WAG and TSI OPE are particularly relevant for the DAC.

Fig. 44: Overview of TSIs



Source: TU Berlin

The TSIs include CSM Regulation 402/2013, which allows alternative proofs of safety to be provided by means of explicit risk analyses. This is particularly useful when an innovation contradicts a TSI or supplements it on a specific point, making the legal situation difficult to assess. Provided that the innovation does not reduce the overall safety level, the alternative proof of safety is a route to gaining approval.

One level further down are the Notified National Technical Rules (NNTR). NNTRs contain national guidelines, which must be complied with in addition to the TSIs. For example, electromagnetic compatibility (EMC) is one area that is relevant to the DAC. Since electromagnetic effects can influence control and safety technology (CST) and CST will not be standardised in the foreseeable future, this topic will always remain important.

Recognised engineering standards follow on the second lowest level. These can include ISO, EN and DE standards as well as UIC leaflets. All of these are generally not binding, but nevertheless help to significantly reduce the workload involved in obtaining approval. As soon as standards or UIC leaflets are referenced in a TSI, they gain a legislative character. An overview can be found in Chapter 6.3.

At the lowest level are the network access criteria issued by the railway infrastructure undertakings (RIUs), which must be complied with by every railway undertaking (RU).

6.2 Legal requirements for the DAC

This section presents all the legal requirements that are considered relevant and evaluates them for potential conflicts. The focus here is particularly on European legislation due to the introduction of the 4th Railway Package and the associated shift of responsibility to the ERA.

First, this section considers the approval procedures for DACs as single components. It then examines the general approval modalities for new vehicles with DACs and existing vehicles with SCs that require conversion. The focus here is on existing vehicles, due to the necessity and complexity of the conversion process. For existing vehicles, it also investigates whether modifications to the coupling result in the requirement for a new authorisation for placing in service (APS) and to what extent a “simplified” approval process may be possible.

6.2.1 Approval options

This section presents the approval options for DACs as individual components.

Intermediate statement of verification (ISV⁵²)

For the registration of DAC vehicles, it is desirable to keep the registration workload as low as possible. Put simply, the DAC must receive a test certificate that is independent of the vehicle in order to avoid the need for individual testing of every component for each vehicle/type. This is current practice, e.g. for side buffers, draw hooks and SCs, using an ISV.

An ISV is an inspection of selected components in a subsystem (e.g. TSI WAG). A manufacturer can have a component certified for compliance with the TSI – including selected sections – via a DeBo/NoBo⁵³. The manufacturer must also define the limiting conditions for the use of the components. [Annex IV 2016/797 Interop]

For the DAC, this means that the coupling manufacturer must prove that the DAC complies with the corresponding TSI. The more comprehensive the ISV, the less evidence is required for the vehicle APS. In the best case, the ISV should already include all the interfaces for the DAC Type 4, including the power and data line. The requirements/verifications for system protection (e.g. grounding) and vehicle/track interactions (e.g. EMC) are then already covered by the coupling.

Compared to interoperability constituents, the approval of the DAC by means of an ISV would be quick and unbureaucratic. It is likely that a DAC standard would significantly reduce the burden of proof for manufacturers.

Interoperability constituents (IC)

“Interoperability constituents’ means any elementary component, group of components, subassembly or complete assembly of equipment [...] incorporated into a subsystem, upon which the interoperability of the rail system depends directly or indirectly [...]” [Article 2 Directive (EU) 2016/797 Interop]

Another possibility for obtaining approval of the DAC is to register the DAC in TSI LOC&PAS and TSI WAG as an interoperability constituent. While the advantages are identical to those of the ISV⁵⁴, according to the authors’ own estimates, the requirements and workload involved are much higher. An IC, unlike an ISV, must fully comply with the relevant TSIs. In addition, the usability and maintainability of the IC must be guaranteed in each EU Member State. Appropriate certificates of conformity or suitability for use issued by one or more notified bodies are required as evidence. [Articles 8,9,10 Directive (EU) 2016/797 Interop]

⁵² Intermediate statement of verification

⁵³ Designated or notified body.

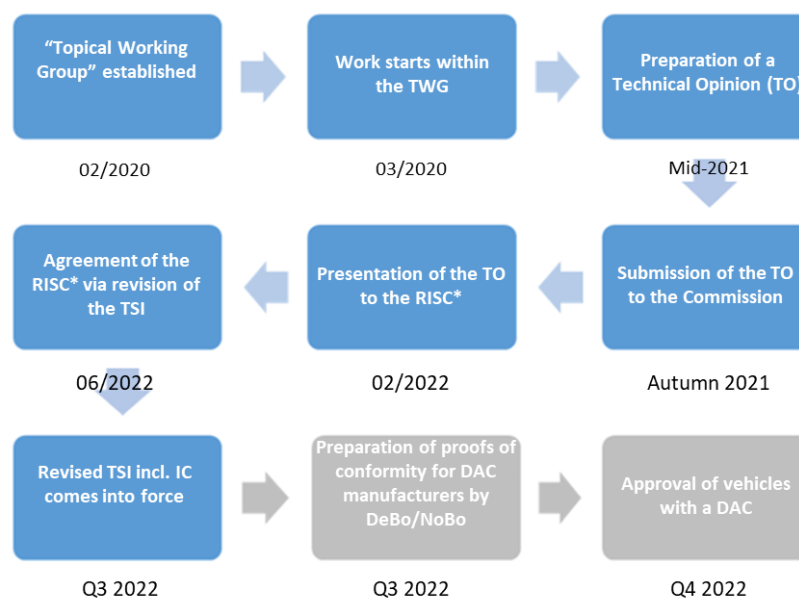
⁵⁴ A vehicle-independent test certificate can also be issued for the DAC.

Even though standardisation of the IC is not mandatory, this is recommended for the DAC. As soon as an IC is listed in the TSI, any manufacturer can have its products certified by a DeBo/NoBo.

The disadvantage is that an IC can only be introduced as part of a TSI revision (every five years). As a rule, this is a European agreement process that takes several years and is the responsibility of the ERA, which requires the approval of the Member States. The fact that the next TSI revision is scheduled for 2022 means there is an opportunity to complete the IC recognition process comparatively quickly. This process was initiated by the ERA earlier this year.

Fig. 45 outlines the ERA's agenda for the creation of the IC "DAC". The first step is to establish a "Topical Working Group" (TWG) to integrate the DAC into TSI LOC&PAS and TSI WAG. This can be requested, e.g. by the ERA or by the European railway sector associations, referred to as the "representative bodies". These include the UIC, UIP, CER and UNIFE. The representative bodies are also the members of the group. The task of the TWG is to prepare a technical opinion (TO). This contains the technical functions/mechanisms, requirements and many other limiting conditions and parameters. The "DAC Specifications" (see Annex 3 to the Final Report of this study) can form the basis for this technical opinion. Once completed, the TO will be presented to the Railway Interoperability and Safety Committee (RISC)⁵⁵. This committee consists of representatives of the European Commission from the respective Member States. The RISC must vote on the TO. If the TO is adopted, the EU Parliament and the EU Council will be formally involved and the revised TSI will be adopted as an IC, including the DAC. As soon as the DAC is specified as an IC in the TSI, it must also be approved as an IC. In the event that the DAC is not listed as an IC in the next TSI revision, the DAC can be approved via an ISV.

Fig. 45: Flow chart for the registration of an IC in the TSIs including the envisaged timetable



Source: Presentation by TU Berlin based on information from the ERA

⁵⁵ RISC: Railway Interoperability and Safety Committee

Innovative solution

The “innovative solution” is a special path. It is an available option for obtaining an approval even in the event of non-compliance with or additions to the TSI. The “innovative solution” route was introduced to allow innovations to be adopted in the rail sector at shorter notice, outside the five-year TSI revision intervals. However, it is unclear whether this is really possible as it will require intensive examination by the ERA and, most likely, a statement from the Member States or European associations. [Article 10a WAG TSI]

An innovative solution may be incorporated as an interoperability constituent in the course of revisions to the TSIs. This process is not recommended for the approval of the DAC.

6.2.2 Approval of vehicles with a DAC

As previously stated, almost all approvals for rail vehicles have to be issued by the ERA since the 4th Railway Package came into force. Each approved vehicle must be entered in the “European Register of Authorised Vehicle Types” (ERATV) as part of the process. ERATV distinguishes between vehicle types and versions. A vehicle type corresponds approximately to the traditional generic name. Several versions of a vehicle type can be entered in ERATV, e.g. one version with an SC and one with a DAC. For the registration of a new vehicle type, e.g. a new development, a comprehensive approval of the vehicle is required. Technical modifications to existing (registered) vehicle types may result in the creation of either a new vehicle version or a new vehicle type, depending on the modification. An “existing vehicle” is a vehicle already approved in ERATV. This can also be a new vehicle that conforms to a version of a vehicle type in ERATV or, put simply, is based on an existing vehicle.

The procedures and conditions for approval are described in Interop and the Implementing Regulation. Article 21 of Interop describes the procedure for the rolling stock APS. This covers the initial authorisation for placing in service (IAPS) and modifications to existing vehicles. As a rule, the following verifications or information are required:

- a. Areas of use
- b. Compliance with the relevant TSIs
- c. Compliance with the national rules (NNTR) of the area of use
- d. Terms of use and restrictions
- e. Maintenance of the overall safety level

(Risk assessment for DAC required at wagon and train level)

Modifications in the case of an existing vehicle.

For the IAPS of vehicles with a DAC, all these verifications must be enclosed with the vehicle dossier at the time of registration (EC test). The DAC of the corresponding manufacturer should be tested and approved in advance.⁵⁶ Compliance with the relevant limiting conditions for the installation of the DAC must “merely” be verified. For newly developed vehicles, the work involved is estimated to be low. The main reason for this is that the relevant verifications required for the use of the DAC are available. This is not necessarily the case for existing vehicles.

Points (b), (c) and (e) will be dealt with in the following sections.

⁵⁶ i.e. the EC declarations of the manufacturers or the corresponding ISVs are available for IC/innovative solution approaches.

6.2.2.1 Approval of existing rolling stock

At this point, the due date of a new APS cannot be clearly stated. According to the EU regulation, there are several arguments in favour of a new registration of existing vehicles. This section identifies the critical requirements. These aspects should be clarified together with the ERA to prevent disruption of the migration to the DAC and guarantee the safety of the overall system.

The EU regulations differentiate between whether a “modification to an already approved vehicle” results in a new vehicle type or a new vehicle version of an existing type. The creation of a new vehicle type has the same effect as a new APS. The vehicle must then be inspected in accordance with the applicable guidelines and a corresponding vehicle dossier with numerous verifications must be presented. If the creation of a new vehicle version of an existing vehicle type is required, the work involved is significantly lower. A new version of the vehicle type, e.g. with a DAC, is entered in ERATV. Only the verifications for the DAC and compliance with the limiting conditions for the installation are required.

Retrofitting existing vehicles presents a number of challenges. The first challenge arises with the use of the term “existing vehicles”. According to the EU regulations, this term only describes vehicles with an entry in ERATV. Currently, the majority of vehicles are only registered in the respective National Vehicle Registers. The vehicles being retrofitted must have an entry in ERATV so the ERA can agree to the conversion and thus create a new version of the vehicle with the DAC in ERATV in the first place. The procedure for the registration of existing vehicles in ERATV is unknown (even among sector experts) and may need to be defined.

Article 21 (12) Interop

Article 21 of Interop “Authorisation for placing in service of vehicles” is the most important text for clarifying the question of the registration of existing vehicles. Any modification to the vehicle must always ensure that this article remains unaffected. For existing vehicles, the applicability of a new APS depends on whether “[...]”

- a) the modification of the parameter according to the TSI or NNTR is relevant for checking the conformity of the vehicle with the area of use, (specified by the TSI)
- b) the overall safety level could be compromised,
- c) it is prescribed by the TSI when the parameter is modified. [...]” [Article 21 (12) 797/2016]

a) Specified by the TSI

This aspect concerns the functional and technical specifications of the subsystem and its interfaces to other subsystems (Sections 4.2 and 4.3). In short, this means TSI conformity according to WAG, LOC&PAS and OPE TSI. In all probability, the DAC will comply with the TSIs.⁵⁷

b) Overall safety level

This section is a critical because, according to Interop, even a potential impact on safety results in the requirement for a new APS. It is also unclear how an “overall safety level” can be

⁵⁷ Even if a safety assessment becomes necessary with regard to the essential modification of the MBP interfaces. For detailed information on TSI conformity, see Chapter 6.2.3.

quantified so precisely that it is possible to determine whether “authorisation requirement” or “no authorisation requirement” is the appropriate decision.

The fact that the coupling is per se a safety-relevant component, according to WAG TSI, suggests it will influence the safety level. Furthermore, according to Interop, electrical systems in the vehicle always imply changes in the safety situation. The same applies to the pneumatic connection of the MBP.⁵⁸ This represents a change to the braking system and requires a new safety assessment (according to WAG TSI Section 4.2.4.2).

Regarding the safety situation, an assessment in accordance with the CSM Regulation is required, irrespective of Article 21. On the one hand, it is assumed that the DAC may increase the overall level of safety. Among other things, it would reduce the risk for shunting staff, potentially improve derailment protection and also reduce the number of possible errors during train formation. On the other hand, the introduction of electrical power in freight wagons creates new safety issues.

Consultation with the ERA on this point is essential.

c) Specified by the TSI

The modification of the type of end coupling initially results (with the same level of safety) in a new version of the vehicle type which does not require a new approval (WAG TSI and LOC&PAS TSI Table 11a/17a).

According to WAG TSI Section 7.2.2.2., a new APS is required as soon as the MBP is included in the coupling process, thus removing compliance with TSI Annex C 9/14 (UIC brake).⁵⁹

After an initial consultation with the ERA, it emerged that this conflict could probably be resolved by means of a risk assessment in accordance with the CSM regulations and that a new APS was therefore not necessary.

Implementing Regulation

Articles 14, 15 and 16 of the Implementing Regulation are particularly relevant. These determine whether it is necessary to create a new vehicle type or a new version of a vehicle type. For the DAC, this depends on two main criteria. The first of these is the classification of the technical modification according to Article 15 (1). The second is the applicant or the relationship between the applicant and the holder of the vehicle type-approval [Article 15 (4)].

According to Article 15 (1), the modification of the coupling results in a new version of the vehicle, as long as it meets the requirements of Article 21 (12) Interop. Irrespective of the coupling, a new version of the vehicle can only be produced by a technical modification if the applicant is the same as the holder of the vehicle approval. If this is not the case, a new vehicle type must always be created and the APS must be renewed. According to the Implementing Regulation, the holder of a vehicle type approval is the person who applied for and obtained the type approval for a vehicle or their legal successor. This need not necessarily be the current owner. It may also be the original wagon manufacturer itself. This is presumably based on the assumption that the wagon manufacturer is best acquainted with the vehicle.

⁵⁸ Background: Table 1 of WAG TSI and LOC&PAS TSI refers to points 1.1.1, 1.1.3 and 2.4.1 of Annex III to Interop.

⁵⁹ For more information on conformity and the requirements of the relevant TSI, see Chapter 6.2.3.

6.2.3 TSI conformity

As already stated in the previous section, LOC& PAS, OPE and WAG are the most relevant TSIs for the DAC.

WAG TSI

The WAG TSI sets out the technical requirements for the freight wagon subsystem in relation to interoperability. These affect the vehicle structure, boundary lines, the braking system, environmental conditions, derailment protection, the coupling and system protection, etc. Many of these aspects, such as system protection and vehicle structure requirements, have an influence on the DAC and/or the suitability of the wagons. Compliance with the relevant standards and the limiting conditions for installation must be verified.

The focus of this section is primarily on the innovations that are associated with the DAC. These are principally the coupled media (electrical power, data, air). For the electrical power and data lines, the following aspects must be observed:

- Compatibility with train detection systems [Section 4.2.3.3]
This section refers to the mandatory requirements for electromagnetic compatibility with control and safety systems.⁶⁰
- Protection against risks from electric current [Section 4.2.6.2]
This section provides a reference to EN 50153:2014, which defines the requirements for grounding and against direct contact. This is extremely important here because an electricity supply in freight wagons is a relatively unknown application in RFT. In addition, on electrified lines, a small part of the reverse current of the locomotive flows back via the axle bearings and the wagon structure.
- Fire protection [Section 4.2.6.1.2.3 & 6.2.2.8.3]
The fire performance of installed cables must comply with the requirements of EN 50355:2013 and EN 50343:2014.

Regarding the pneumatic connection [Section 4.2.4.2], the TSI refers to the current standard. If this is not observed, a CSM assessment must therefore be carried out. The DAC is affected as follows:

- **Inner diameter (32 mm) of the MBP**
This is inspected in Germany using the ball test. During this test, a ball with a diameter of 20 mm is pushed through the MBP with compressed air from one end of the wagon to the other.⁶¹ This is a major challenge for the AC because the MBP can run at an angle in the head. In addition, seals and valves in the coupling head could obstruct the ball's progress.
- **The pneumatic energy of the braking system must not be used for any purpose other than braking.**
This point prevents the use of compressed air for potential actuators on the coupling head. In passenger traffic, the electrical power and data couplings are connected using compressed air from the supply line (ten bar), also known as the main air reservoir line. As coupling and decoupling are performed during shunting and not during train journeys, a

⁶⁰ For more information, see document: ERA/ERTMS/033281 rev. 4.0.

⁶¹ Brake testing of freight wagons within the scope of acceptance procedure in accordance with § 32 EBO.

special regulation for a Type 5 coupling could be achieved at best by using compressed air from the brake line (pressure range 3.5 to 5.0 bar).

- **Pneumatic coupling according to today's standard:**

WAG TSI currently requires the air coupling of the MBP to be operated manually.

In WAG TSI, the end coupling is listed as a “basic design feature of the vehicles”. The modification of the end coupling is also a factor in determining the applicability of an APS, with reference to Article 15(1) of the Implementing Regulation. Accordingly, modification of the type of end coupling (while maintaining the same level of safety and TSI conformity) will result in a new version of the vehicle type.

LOC&PAS TSI (1302/2014/EU)

This TSI applies to the subsystem “Vehicles – Locomotives and Passenger Rolling Stock”. The scope of this TSI is limited exclusively to locomotives/multiple units and wagons, which serve or support the transportation of persons in various ways (luggage wagons, car transport, etc.). As the LOC&PAS TSI already contains the AC “Scharfenberg Type 10” as an interoperability constituent, no conflicts could be identified for a new DAC for RFT.

Like the WAG TSI, the end coupling is a “basic design feature of the vehicles”, and its modification (while maintaining the same safety level and TSI conformity) results in a new version of the vehicle type.

OPE TSI (773/2019)

The OPE TSI “*Traffic Operation and Traffic Management*” describes the essential operational requirements for safe rail transport and often provides the interface between operations and the technical requirements of the subsystems.

For example, it regulates safety responsibilities and safety requirements for the formation/preparation/running of trains. This TSI is particularly relevant for the DAC because the DAC is the key element for train formation. It is essential to ensure that trains can be formed (safely). The RUs must therefore know the limiting conditions for the use of the DAC. A rescue concept for damaged vehicles must be developed. Consequently, rescue/towing couplings and appropriate vehicles are required (Section 4.2.3.6.3).

This TSI is particularly relevant for the digitisation applications that follow the migration to the DAC. This applies, e.g. to train end detection/signalling, wagon order, etc.

6.2.4 National laws in Germany

In Germany, there are many laws that regulate rail transport. One of the basic laws is the General Railway Act (AEG). It sets the legal framework for safe rail operations, the supervision and management of operating licences, and provides the basis for authorising further railway legislation.

The Railway Construction and Operating Regulations (EBO) are another key piece of legislation. This regulates the minimum requirements that ensure safety in railway operations. The following paragraphs concern the DAC:

- **§ 23 Brakes**

“A continuous brake is automatic if it is applied whenever the brake line is inadvertently interrupted.” This is an elementary requirement for a (D)AC Type ≥ 2 , irrespective of its legal character.

- **§ 24 Buffers and draw gear**

“Vehicles must normally be fitted with screw couplings and buffers in accordance with Annex 10; other buffers and draw gear are permitted on vehicles for special purposes.” The precise application of this paragraph must be clarified or its relevance checked after the introduction of a DAC. As some transports with automatic couplings already operate in Germany and Europe, no consequences are to be expected for the large-scale use of a DAC.

- **§ 25 Free spaces and components at the ends of the vehicle**

“The vehicles must be designed in such a way that coupling is possible without risk. The spaces required for this purpose (Annex 11) must be free from solid parts in vehicles with screw couplings and side buffers, [...]”

The free space at the end of the vehicle, the “Berne rectangle”, is essential for shunting personnel as they have to step between the vehicles to couple them. With the introduction of the DAC, this will become obsolete. During the migration phase, however, this is an important consideration for a hybrid coupling. A hybrid coupling makes it possible to couple both the DAC and the SC. Due to the dimensions of the coupling head, space in the Berne rectangle is limited and working conditions for shunting personnel become more difficult. Overall, this does not prevent the migration to the DAC, as a solution for the “C-AKv” already exists in Germany.

In addition to the EBO and AEG, the Railway Commissioning Authorisation Regulation (EIGV) regulates cases for the application of the European TSIs. The EIGV applies not only to new registrations, but also to retrofits on existing vehicles. According to the EIGV, freight wagons and locomotives almost always fall within the scope of the TSI. The TSI requirements are therefore critical for the installation of the DAC, or for the conversion from the SC to the DAC.

6.3 Important standards and regulations

Fig. 46 lists identified standards and regulations that are relevant to the DAC. Many of them are given legal status by being mentioned in the TSI. For others, there are no standards yet, only UIC leaflets.

Fig. 46: Overview of requirements and standards relevant to the DAC

Feature	Standards	Other
Energy absorption/Crash standards	EN 15227 EN 15551	UIC 524, UIC 530
Tensile/Compressive forces	EN 12663 EN 15551, EN 15566	UIC 524
Environmental conditions	EN 50125-1	
EMC		ERA/ERTMS/033281 rev. 4.0
Protection against electrical risks	EN 50153	
Insulation coordination	EN 50124-1	
Derailment protection	EN 15839	
Fire protection	EN 45545, EN 50355, EN 50343	
Operational handling	EN 16019*	UIC 522, UIC 535-2
Vehicle interface		UIC 530-1
Coupling speed	EN 12663**	
Air line diameter		TSI WAG Annex C
Deflection angle		UIC 530-1
Gathering range		UIC 522, 530-1/-2
Dangerous goods		RID, ATEX

Mandatory according to TSI	No TSI reference	* Only for Type 10	**Indirectly derived from the standard
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Source: TU Berlin

6.4 Requirements for dangerous goods

The transportation of dangerous goods is an important part of RFT. To ensure minimum safety levels along the entire transport chain, it is necessary to implement transport, product and operational safety measures.

The transport safety describes the safety of a dangerous goods transport between the starting point and the destination. Product and operating safety regulate the requirements for potentially explosive zones in companies and requirements for products that may be used in these zones.

In Germany, transport safety for the national and international transport of dangerous goods is regulated across all modes of transport by the “*Ordinance on the Transport of Dangerous Goods by Road, Rail and Inland Waterways*” (GGVSEB).

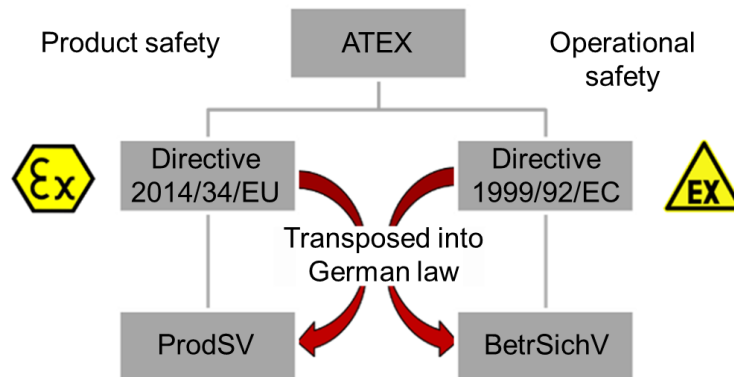
The GGVSEB is based on EU Directive 2018/217/EU. The GGVSEB refers to the following traffic-specific regulations:

- RID⁶²: Rail,
- ADR: Road,
- ADN: Inland waterways.

⁶² Regulation concerning the International Carriage of Dangerous Goods by Rail (RID)

The ATEX⁶³ directives⁶⁴ ensure product and operational safety. All matters relating to product safety are regulated in the European Directive 2014/34/EU. The national implementation of this directive for Germany is through the “*Equipment and Product Safety Act*” (ProdSV). Matters relating to operational safety are regulated by the EU Directive 1999/92/EC, which has been transposed into German law by the “*Ordinance on Safety and Health Protection at Workplaces*” also known as the “*Ordinance on Industrial Safety and Health*” (BetrSichV) (see Fig. 47).

Fig. 47: Overview of dangerous goods regulations in the EU for products and operational safety



Source: TU Berlin

The bodies responsible for the implementation and application of the ATEX directives in Germany include the Federal Institute for Materials Research and Testing (BAM), the Physikalisch-Technische Bundesanstalt (Germany’s national metrology institute) and, at EU level, the “European Committee for Standardization” (CEN).

These three sets of regulations form the legal framework for the transportation of dangerous goods in Europe and have a key role to play in determining the requirements of a DAC, if it is to be installed on wagons for the transport of dangerous goods.

RID

RID is the set of regulations concerning the International Carriage of Dangerous Goods by Rail. This defines the passive safety requirements for the protection of tanks or boilers. Different safety measures are prescribed depending on the hazard classes of the substances to be transported. Accidents, derailments and overrun impacts are mentioned as specific risks. Protective measures can include energy absorption elements, tank protection shields, the maintenance of safety distances between the headstock and the tank and, in particular, protection against the overriding of buffers. The aim of the protection against the overriding of buffers is to keep the underframes as level as possible and prevent the wagons from lifting off in the event of an accident. It is assumed that an AC will reduce the risk of wagons lifting off and thus have a positive effect on safety. The design of the AC must ensure that the AC shears off in the event of an accident to prevent it acting like a spike on the tank wagon. RID specifies the following measures for the AC on tank wagons:

⁶³ Atmosphères explosibles (explosive atmospheres)

⁶⁴ Product Safety RIL 2014/34/EU, Operational Safety RIL 1999/92/EC

- **Energy absorption of at least 70 kJ per wagon end**

This is a general minimum requirement and corresponds to the common energy absorption capacity of today's side buffers (see Section 6.8.3.1.6).

- **Energy absorption of at least 130 kJ per wagon end**

Requirement for tank wagons with an AC, which are intended for the transportation of liquids and gases (see RID special provision TE 22).

- **Anti-creep protection equipment/Shield at each end of the wagon**

In addition to special provision TE 22, the ACs must be fitted with anti-creep devices to prevent accidental disconnection of the couplings.⁶⁵ A protective shield is also required to protect the tank bottom (see RID special provision TE 25).

Energy absorption by plastic deformation must not occur under normal operating conditions but must be realised by reversible deflections.

As a benchmark for normal operating conditions, impact speeds of up to twelve kilometres per hour and individual buffer forces of up to 1500 kN are cited for today's system. The extent to which this is transferable to the AC requires further investigation.

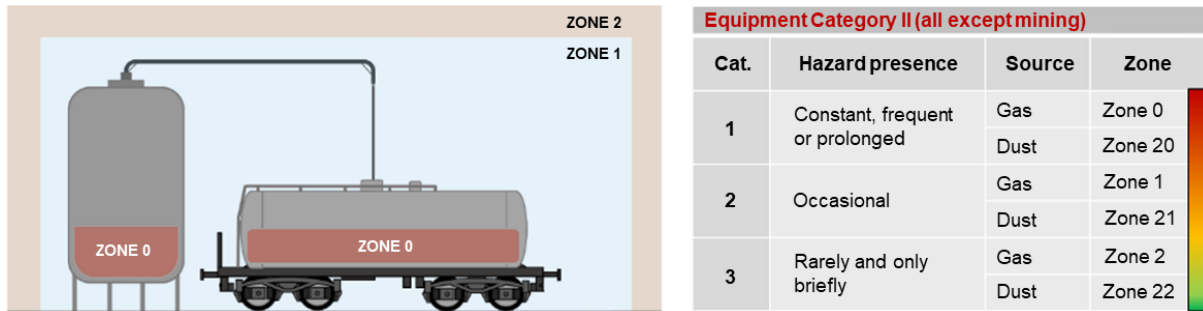
Electrical equipment on freight wagons for dangerous goods, in contrast to other modes of transport, is not yet taken into account in the RID. Together with the persons responsible for the regulations, it is necessary to clarify how to deal with a power line and electrical equipment and how the RID can be updated if necessary. The RID is re-issued every two years.

ATEX

The ATEX directives guarantee product and operational safety. In addition to the requirements for entering areas at risk of explosive atmospheres, they also include the definitions of the hazardous zones themselves. In addition, they define the equipment categories, which pool the equipment groups and safety classes according to the potential explosion hazard. The risks due to explosive atmospheres are differentiated according to the presence of dust or gas. Recognised and comprehensive "explosion protection" requirements for electrical components are listed in the IEC 60079 series of standards. These standards must be used when developing specifications for the DAC and other electrical components. Fig. 48 provides an example of hazardous zones relating to freight wagons carrying dangerous goods.

⁶⁵ Not specified in RID. This probably only applies to non-rigid couplings as these couplings can slide apart. For more information, see Chapter 3.2.1. on the Janney coupling ("bottom/top shelf").

Fig. 48: Hazard zones for freight wagons carrying dangerous goods using the example of filling a tank wagon



Source: ecom-ex.com, adapted

This example presents the filling process for a tank wagon in Equipment Category II. This category basically includes everything that is not mining. Equipment is classified in the Categories 1, 2 or 3 depending on the presence of the hazard, ranging from rare and short-term, through occasional, to permanent, frequent or prolonged. Category 1 – the most dangerous – corresponds to Zone 0 for gas or Zone 20 for dust as an explosive atmosphere. This zone is the space inside the boiler or storage tank for filling the wagon. Category 2 and Zone 1 or Zone 21 – where a hazard is occasionally present – include the area directly around the wagon and the loading facility. Finally, the wider environment is Category 3, Zone 2 or 22 with only a low hazard presence. These hazardous zones are relevant to the extent that a wagon, including the AC, must meet the prescribed conditions in order to enter them.

7. Ensuring compatibility between different AC types

Chapter 3.1.1. provided an overview of the ranges of functions offered by the different AC types. The degree of automation in the coupling process ranges from a single mechanical connection for Type 1, to automatic connection of the main brake pipe, electrical power line and data line for Type 4. A DAC Type 5 also permits automatic decoupling.

This chapter first presents conceivable mixed AC systems, the associated challenges and also measures for ensuring that the coupling and its dependent systems function correctly. Secondly, the chapter provides an overview of the complexity of mixed traffic. From an operational standpoint, the parallel use of different ACs must be avoided. This is also important for the barrier-free use of digitisation applications.

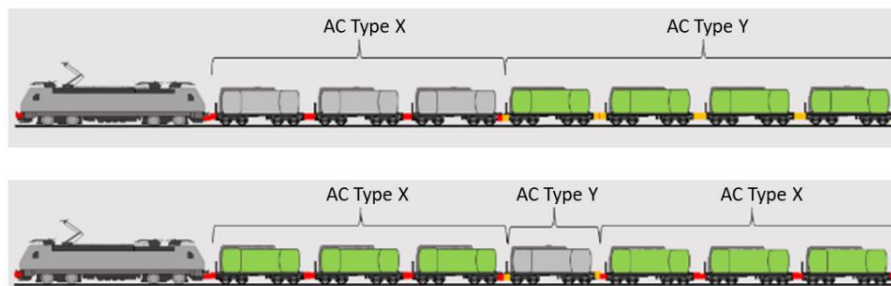
7.1 Possible variants of mixed operation in Europe

In principle it is conceivable that automatic couplings of all types will become established in Europe. Nevertheless, in the study, it is assumed that the Type 1 will rarely be adopted due to the remaining work involved in coupling the obligatory MBP. The following AC types were included in the study of mixed operation:

- Type 2: Mechanical (M) + Pneumatic (P);
- Type 3: M + P + Electrical power line (E);
- Type 4: M + P + E + Data line (D);
- Type 5: M + P + E + D + Automatic decoupling.

A train could then be formed as shown in Fig. 49.

Fig. 49: Example for freight trains with different AC types



Source: TU Berlin

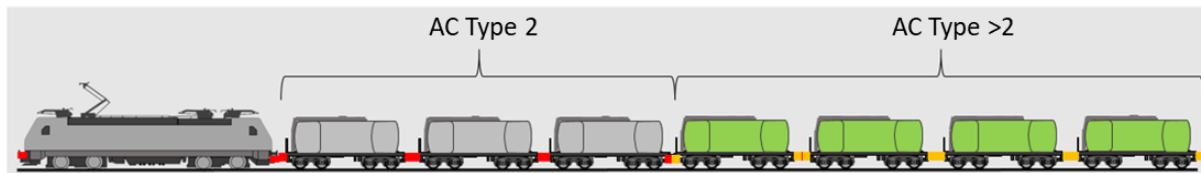
For this reason, the requirements for mixed operation must be defined with regard to the compatibility between the various AC types. First and foremost, train formation, i.e. the mechanical and pneumatic connection, must be possible without restriction and irrespective of the degree of automation. Mixed operation will inevitably be accompanied by certain restrictions on the usability of automation functions. These are unavoidable and must therefore be accepted as a fact of life for mixed operation, i.e. the functionality is reduced to that of the simplest (D)AC type.

Furthermore, fallback levels must be taken into account. Additional technical or operational measures for mixed operation should be avoided whenever possible, i.e. special measures should only be considered if safety-relevant functions in the wagons require an electrical power line or data connection, since the coupling itself does not depend on such a connection to fulfil its function. Technical measures could include, e.g. an autonomous power supply or radio

solution. Operational measures could be used, e.g. to skip a certain wagon or split the train. The procedures for specific cases must be laid down in the operating regulations. The following two examples illustrate possible procedures.

Mixed operation example 1: front section of train with lower AC type

Fig. 50: Mixed operation example 1

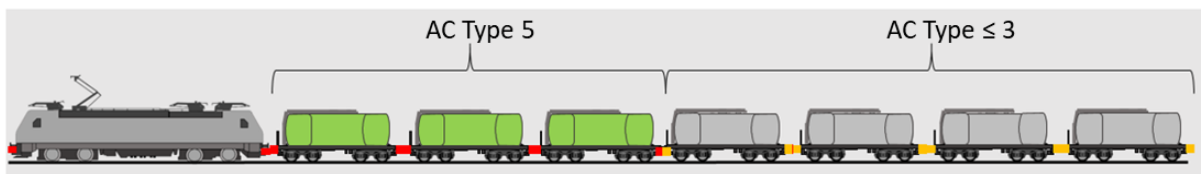


Source: TU Berlin

In this example, the front section of the train has a lower AC type than the rear section. No part of the train is connected to the electrical power and/or data line (see Fig. 50). As a result, the wagon group with the higher degree of automation cannot benefit from its potential. Thus, either alternative measures are necessary or the fallback level in “Type 2” mode must be used. In its fallback level, the train is operationally an “AC Type 2 train”.

Mixed operation example 2: rear section of train with lower AC type

Fig. 51: Mixed operation example 2



Source: TU Berlin

In this example, the front section has a higher AC type than the rear section. The wagons in the front group could use their automation functions but could potentially produce incorrect information (see Fig. 51). This becomes critical if, for example, the wagon list is created digitally. In this case, the last digital coupling (here behind the third green wagon) does not correspond to the last wagon in the train. Actually, the DAC should also check the mechanical connections, but the rear wagons with purely mechanically connections do not provide the necessary signal. This leads to the assumption that this type of mixed operation is not permissible. Further checks are required to see whether permissible exceptions exist.

7.2 Case distinctions for mixed operation without corrective measures

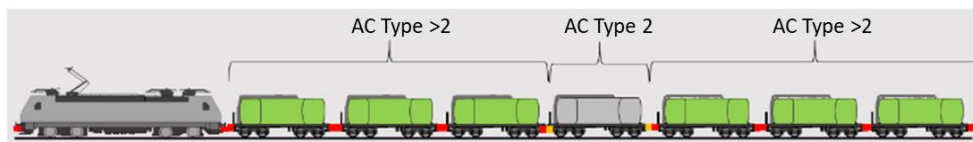
The two examples above clearly show that it is not just the combination of AC Types 2 to 5 within a train formation that is important, but also the positioning of the wagon(s) with a lower AC type. This section presents the consequences of mixed operations in terms of functionality. In this case, Type 2, Type 3 or Type 4 ACs interrupt the transmission of data, electricity and/or remote control signals of ACs of a higher type. Although the following application cases relate to freight wagons, they can be equally applied to locomotives.

7.2.1 Case 1: Combination of AC Type 3/4/5 + AC Type 2

In this case, at least one wagon with an AC Type 2 is positioned in the train between wagons with a higher AC type (see Fig. 52).

As a result, the electrical power and data connection (if Type 4/5) is interrupted. The train runs as an “AC Type 2 train”. This means that the electrical power line must be switched off and the data connection deactivated. Remote control of an AC Type 5 is not possible.

Fig. 52: Case 1: Combination of AC Type 3/4/5 + AC Type 2



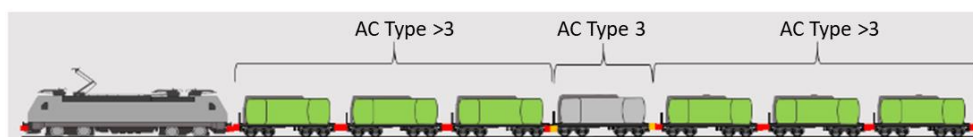
Source: TU Berlin

7.2.2 Case 2: Combination of AC Type 4/5 + AC Type 3

In this case, at least one wagon with an AC Type 3 is positioned in the train between wagons with a higher AC type (see Fig. 53).

As a result, the data connection is interrupted. The train runs as an “AC Type 3 train”. This means the data connection must be deactivated. Remote control of an AC Type 5 is not possible.

Fig. 53: Case 2: Combination of AC Type 4/5 + AC Type 3

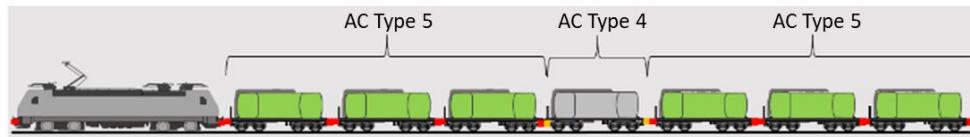


Source: TU Berlin

7.2.3 Case 3: Combination of AC Type 5 + AC Type 4

In this case, at least one wagon with an AC Type 4 is positioned in the train between wagons with an AC Type 5 (see Fig. 54).

Fig. 54: Case 3: Combination of AC Type 5 + AC Type 4



Source: TU Berlin

In theory, the consequences of this are relatively minor. At all coupling points with at least one AC Type 5, selective uncoupling of the wagon or group of wagons in question is possible.⁶⁶ The train could run as a mixed train with Type 4 and Type 5 wagon groups. Here, the operating regulations must clearly describe how to deal with this situation.

7.3 Technical conditions

To ensure compatibility between different AC types, and to minimise any additional measures required for mixed operation, the following four points are essential:

- **Downward compatibility**

Each DAC must be an AC Type 2 as a fall-back level, i.e. primarily ensure a mechanical and pneumatic connection with manual operation from the outside. The coupling status should be visible from the outside.

- **Independence of the (physical) interfaces**

The interfaces must be defined independently and be generally applicable to all types and for all connections relevant to the AC. This applies to the mechanical and pneumatic connections for the Type 2, the additional power connection for the Type 3, the additional data connection for Type 4 and higher, and the protocol for Type 5.

- **Standardisation and high quality standards**

It is important to avoid incompatibilities between manufacturers and the same DAC types. Therefore, standardisation that ensures high quality standards is absolutely necessary. All mechanical, pneumatic, electrical and data connections (M+P+E+D) must comply with uniform standards.

- **Software dependencies**

In the case of planned software updates, the first question to be answered is for what reason an update is to take place and whether it is really required before it is installed. If it is necessary, higher software versions must be downwardly compatible.

⁶⁶ Depending on the future coupling, with the exception of the Schwab AC, see Chapter 3.2.4.

7.4 Operating conditions

In addition to the technical conditions, it is also vital to examine the handling of mixed traffic from an operational point of view and to define appropriate standards:

- **Information flow**

The locomotive driver must know whether the train is in mixed operation or not. This requires appropriate documentation of the coupling types in the train, e.g. in the wagon list or indicated on the wagon. In addition, the continuity of the electrical power and data lines must be displayed at all times by means of status information in the driver's cab.

- **Uniform regulations for mixed operation**

The procedures for mixed operation, and also for fallback levels, must be clearly laid down in the regulations. If remedial action is required, the applicable measures depend on the degree of automation of the wagon concerned (e.g. EP brake, end of train) and the operational environment (e.g. brake test, wagon technical inspection).

7.5 Type 5 – Readiness

The digital automatic coupling system for rail freight traffic is based on the principle of a basic coupling, which can be upgraded in stages with five degrees of automation (Type 1 to Type 5). For this purpose, a number of requirements must be met.

The installation space and interfaces required for the actuators must be provided.

It is also essential to guarantee the electrical power or compressed air supply to the actuators for the decoupling function. This is a particular challenge in the case of parked freight wagons, since these – unlike locomotives – often stand for long periods of time without an external supply.

The development of routines/rights for (de)coupling authorisation is another key requirement. Clarification of remote access procedures by the infrastructure and, ultimately the definition of cybersecurity requirements will be vital.

8. Conclusion

The description of the current state of the art discussed the worldwide distribution of automatic coupling systems and the history of their introduction. The examples of the USA, Japan and Australia make it clear that a migration to an AC required a great deal of human and financial effort on the part of the sector. Generally, the introduction of an AC was required – and thus promoted – by the state via binding laws.

The nomenclature of the TIS with five degrees of automation (from Type 1 with a purely mechanical connection to Type 5 with coupling of electrical power and data lines and remote unlocking) was taken up and placed in an international context. An analysis of the AC for RFT showed that no comparable approaches exist for the introduction of a DAC. The existing Janney and SA3 couplings systems provide only the mechanical connection (Type 1). Even in Australia, where more than 10,000 wagons are equipped with an electro-pneumatic brake, the electrical power/data line and the MBP are still coupled manually. This is because the task of automating these systems is complex and costly – mainly for mechanical reasons (wear and slack).

A direct leap from the SC to a DAC Type 4 (automatic mechanical + MBP + electrical power + data link) was proposed to enable the digitisation of RFT to be completed within a realistic timeframe. It was considered that the development of a DAC Type 5 would take too long.

In parallel to the established RFT couplings, the Scharfenberg and Schwab couplings were presented and compared due to the potential they offer in the areas of automation and weight savings. These are currently being modified for European RFT and being considered as an option for Europe. A major challenge in the run-up to the selection of a coupling profile is the definition of requirements. These have not yet been precisely defined. This applies principally to the operating concept in terms of the gathering range, deflectability, buffer position and behaviour of the MBP during the unlocking process.

It is recommended that the design principles regarding the strength and design of the spring damper be adapted to today's requirements. So far, these are based on experience gathered in the 1960s/70s.

These questions should be answered before standardisation takes place so that a tailor-made coupling can be developed or selected for Europe. It is clear, that a coupling profile must be selected independently of the spring damper. This should be considered in future tests. In addition, due to the extremely high reliability requirements, exhaustive testing in carefully designed scenarios (currently being planned) is required before the coupling can be selected. Commercial pilot services under real conditions, similar to SBB Cargo's domestic CTs, are also recommended in order to achieve possible improvements.

For the transportation of dangerous goods, it is proposed that the 2021 revision of the RID includes the DAC and potential electrical consumers. The requirements for the electrical consumers can already be derived from the ATEX directives.

EU legislation applies to the approval of vehicles with a DAC and the DAC itself. The DAC as a component is basically in accordance with the relevant TSIs (LOC&PAS, OPE, WAG). The most practicable route is to approve the DAC independently of the vehicle, analogous to today's side buffers and draw hooks. One option for obtaining approval is to establish the DAC as an interoperability constituent (IC) in the TSI. This process has already been started by the ERA as part of the 2022 TSI revision. It is recommended that the development of the IC covers not only the interfaces but also the electrical requirements, so this does not have to be

completed again for each vehicle type. The approval of new vehicles with DACs would then work in the same way as for SC vehicles. According to EU regulations, existing vehicles must be re-approved. This must be avoided at all costs due to the additional work and expense involved. It can be assumed that a large number of verifications for existing wagons are no longer available or have not been documented. Intensive discussions with the ERA and national safety authorities will be necessary to find a solution that ensures the success of the migration to the DAC.

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List of abbreviations

AAR	Association of American Railroads
AEG	General Railway Act
ACBC	Automatic Central Buffer Coupling
AC	Automatic Coupling
AK69	UIC coupling with Willison profile developed for Western Europe
ATEX	Explosive Atmospheres, European directives for operational and product safety in potentially explosive atmospheres
BMVI	Federal Ministry of Transport and Digital Infrastructure
C-AKv	Compact Automatic Coupling, simplified
CSM	Common Safety Method for Risk Evaluation and Assessment
DAC	Digital Automatic Coupling
DeBo	Designated Body
EBAS	Electronic Brake Monitoring and Control System
EBO	Railway Construction and Operating Regulations
ECP	Electronically Controlled Pneumatic Brakes
EIGV	Railway Commissioning Authorisation Regulation
RIU	Railway Infrastructure Undertaking
EP	Electro-pneumatic
ERA	European Railway Agency
ERATV	European register of authorised types of railway vehicles
ERRI	European Rail Research Institute
ETCS	European Train Control System
EU	European Union
RU	Railway Undertaking
SWT	Single Wagon Traffic
EP-brake	Electro-Pneumatic Brake
FEBIS	Freight Electronic Brake and Information System
GGVSEB	Ordinance on the Transport of Dangerous Goods by Road, Rail and Inland Waterways
GHz	Gigahertz
CIS	Commonwealth of Independent States
MBP	Main Brake Pipe
APS	Authorisation for Placing in Service
IC	Interoperability Constituent

IP	Innovation Programme within Shift ² Rail
ISO containers	Standardised large-capacity steel containers
ISV	Intermediate Statement of Certification
CT	Combined Transport
KRRI	Korea Railroad Research Institute
LCC	Life Cycle Cost
LDF	Longitudinal Compressive Force
LOC&PAS TSI	EU Interoperability Directive for Locomotives and Passenger Trains
LON	Local Operator Network
CST	Control and Safety Technology
MB	Leaflet
CBC	Central Buffer Coupling
NoBo	Notified Body
OPE TSI	EU Interoperability Directive for Railway Operations
OSShD	Organisation for Cooperation of Railways (Eastern Europe)
RID	Regulation concerning the International Carriage of Dangerous Goods by Rail
RISC	Railway Interoperability and Safety Committee
SA3	Automatic coupling for RFT, mainly used in the Russian sector
RFT	Rail Freight Traffic
SC	Screw Coupling
RPT	Rail Passenger Transport
TCN	Train Communication Network
Loco	Locomotive
TIS	Technical Innovation Circle for Rail Freight Transport
TO	Technical Opinion
TSI	Technical Specifications for Interoperability
TWG	Topical Working Group
UIC	International Union of Railways
VDC	Volt, Direct Current
VO	Regulation
WAG TSI	EU Interoperability Directive for Freight Wagons
Z-AK	Automatic (Draw Only) Coupling