

# Development of Functional Requirements for Sustainable and Attractive European Rail Freight

## D5.1 – State of the Art on Automatic Couplers

Due date of deliverable: 28/02/2017

Actual submission date: 03/03/2017

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Reviewed: Y

Document status		
Revision	Date	Description
1	03/02/2017	First issue
2	03/03/2017	Final version after TMT approval

Project funded from the European Union's Horizon 2020 research and innovation programme		
Dissemination Level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

Start date of project: 01/09/2016

Duration: 36 months

## EXECUTIVE SUMMARY

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The attempts to introduce automatic couplers (AC) are almost as old as the railways are. Several different designs have been developed over time. Resulting from the specific situation in Europe sometimes quite sophisticated types of AC have been designed, but due to the fractured structure of the European Railway system no general decision for an introduction in a wider scale was taken and executed.

This delivery gives an overview of the history, the drivers of technical progress and examines different coupler designs. A strength and weakness analysis of the technical solutions is part of the documentation. Suggestions for further designs are included.

With a starting point in technical requirements, e.g. the forces, different automation levels and functionalities are defined and technical characteristics and features explained.

With this basis application cases are identified and the geographical spread of different types of AC the railway world is presented.

The main differences between AC and the standard UIC-coupler are regarded, followed by an examination of technical key performance indicators e.g. interoperability, transmitted forces, weight and potential data and power transmission.

A key factor for the choice of couplers is the price; from existing projects estimations for different types of AC have been derived.

Migration is also essential; the main aspects of two different approaches – “simultaneous migration” and “progressive migration” – are described.

A technical evaluation contains a FMECA (Failure Mode and Effects and Criticality Analysis) regarding the weaknesses of the existing designs. That leads to an in-depth analysis of the existing types and a trade-off of the different technical KPIs related to the examined coupler designs, resulting in weighted score numbers.

The conclusion chapter compares the technical and commercial KPIs and interprets the results of the trade off to generate some conclusions and statements for the further action in this WP and to describe the future research areas.

The analysis shows that the most competitive solution, according to the checked weighting scenarios, is the Willison type, followed by the BSI and Scharfenberg types. Thus, it is recommended to carry out design studies in first hand based on the known Willison couplers (mostly SA-3, AK69 and C-AKv). In second hand the BSI and Scharfenberg concepts might be examined. A key question to be dealt with is the establishment of a specification document also regarding questions of interoperability with existing types of couplers and migration scenarios. These issues will be dealt with more in-depth in other deliverables of the project.

**ABBREVIATIONS AND ACRONYMS**

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AAR	Association of American Railroads
AC	Automatic coupler
AK69	Automatic coupler designed by Unicoupler consortium, ordered from UIC
CIE	Coras Iompair Eirean – Irish Railways
DB	Deutsche Bundesbahn (German Federal State Railway; 1949 – 1993)
DR	Deutsche Reichsbahn (German Imperial Railway); 1921 – 1949; 1949 – 1990 in German Democratic Republic / 1990 – 1993 in Germany, federal states in the east of reunited Germany
ERRI	European Railway Research Institute
INTERMAT	Automatic coupler designed by united design office DR / SZD
OSJD	Organisazija sotrudnischestwa shelesnych dorog (Russ.): Organisation for Co-Operation between Railways (OSJD)
RIC	Regolamento Internazionale delle Carrozze (ital.) - International Coach Regulations
RIV	Regolamento Internazionale Veicoli (ital.) - International Wagon Regulations
SA-3	Автосцепка СА-3 (Russ.) - Automatic coupler introduced in the USSR in the 1930s
SZD	Советские железные дороги (СЖД) - Soviet State Railways
UIC	Union international de Chemin de Fer – International Union of Railways
VEB	Volkseigener Betrieb (germ.) – “people owned” (nationalized) company (German Democratic Republic)

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## 1. INTRODUCTION

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Objectives of the deliverables (with reference to the Technical Annex):

This documentation intends to give an overview of the state of the art on automatic couplers (AC). Not only the history and the drivers of technical progress and failures are examined, also a strength and weakness analysis of the technical solutions is part of the documentation. Suggestions for further designs are included.

Inputs (contributions from beneficiaries, other deliverables....)

Evaluation of several technical documents and studies is the base; contributions from railway operators and suppliers of railway equipment are an integral part of this deliverable.

Main results

From the beginning of railways in the 1820s there was the question how to couple the wagons with the locos and underneath. Parallel with the spreading of the railways in the different states of Europe (starting from England) and also other continents there has been a permanent progress of technical solutions. Interoperability was always a feature. Nether the less in the different systems different techniques of coupling have been introduced, following an incompatibility between the continents. But that is still a subject in all railway technology.

Driven from the political situation in Europe in the 19th and 20th century (small states and lots of borders) a technical standardization was achieved to enable interoperability, but – in case of coupling – on a very simple technical level: UIC-screw coupler and side buffers.

The actual parameters of this system have been fixed over 100 years ago; of course there has been some progress e.g. materials that allow stronger loads today, but the principle has been unaltered. Especially in question of automation there has been no concrete progress; only in special niches (e.g. high-speed, EMU/DMU, special freight traffic) there is now a high level of automation, but a general technical improvement was not realized due to the costs and political questions.

The different types of semi-automatic and automatic coupler are presented and analyzed in this study.

Possible links of results with other deliverables

All other deliverables of WP 5 are connected with this report; it describes the “state of the art” and evaluates the potential of the existing designs and directs the further steps.

## **2. DEFINITION OF AC, TECHNICAL REMARKS AND HISTORIC REVIEW**

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### **2.1 DEFINITION OF AUTOMATIC COUPLER (AC)**

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A general characteristic of the railway system is the joining of individual vehicles (mostly locomotives and wagons in the freight operation) to train sets. These vehicles are mechanically connected by use of couplers to allow safe operation.

An Automatic Coupler (AC) is any type of coupler, which is not fully hand operated (manual). It is easy visible by exclusion: e.g. screw coupler, link and pin coupler, hook coupler.

### **2.2 FORCES**

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One main subject is the transmission of forces: Most types of AC transmit tractive and also compressive forces; others transmit only tractive forces. This issue is related to the other task of an AC: it reduces the movement between the vehicles by use of springs with damping behaviour. Some tractive/compressive types (“middle buffer coupler”) transmit these forces and also reduce the relative movements between each of the vehicles but allow the necessary flexibility and provide some damping when the wagons are shunted e.g. in a marshalling yard when being humped. In the other group (tractive forces only) the longitudinal tractive forces only are handled by this coupler; but the compressive forces are handled by several means, normally the known side buffers.

### **2.3 AUTOMATION LEVELS**

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Different technical principles are possible and have been realized in the technical history and so are crucial to achieve the possible levels of automation:

#### **2.3.1 Manual coupler**

Coupling and uncoupling is done by hand: e.g. screw coupler or “link and pin” coupler. Operation when coupling: bring the buffers or couplers in contact, then fix and tighten the screw coupler or insert the pins into the coupling links.

#### **2.3.2 Semi-automatic coupler**

Coupling is executed automatically, when the vehicles are shunted in tight contact with a certain speed or force; this enables the latching mechanism to connect both couplers. Uncoupling is triggered by hand, in most cases by removing parts of the latching mechanism with a handle. Also manual coupling / uncoupling of the air pipe and electric connection for signals and power are specific for semiautomatic couplers. From that view all existing types of AC in freight operation are “semi-automatic”.

#### **2.3.3 Automatic coupler**

The coupling process here is almost the same as with the semi-automatic couplers: Automatic coupling, when wagons get in contact at a certain speed. Additionally in this process also the connections of brake pipes and, if equipped with such devices, connections for signals and electricity are executed. Uncoupling, when needed, is remote controlled. No manual interference at the couplers is necessary.

### 2.3.4 Level of Automation

The described technical principles are in a strong relation to the different levels of automation, which can be achieved:

- I       mechanic coupling
- II       pneumatic (brake)
- III       electric signals
- IV       electric powers
- V       automatic uncoupling

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## 2.4 LATCHING MECHANISMS

Regarding the different types of manual couplers, the means for the transmission of the tractive and, for systems without separate buffers, the compressive forces are chains, screw tighteners, links and/or bolts or pins. These have to be operated manually.

In AC these devices cannot be used unaltered; for the safe transmission of these forces and also for the locking of this systems (to prevent from unwilled uncoupling) different systems have been designed. They are related to the principle and type of the given AC, so descriptions can be found in 3.1 to 3.8 and also in the analysis in 8.2.1 to 8.2.8.

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## 2.5 BUFFING POSITION

The obvious functions of an AC are “coupling” and “uncoupling”, these functions are executed automatically or by manual operation of a handle at the coupler; mostly “uncoupling”.

For operation in the marshalling yard, especially for hump operation, it is useful that after uncoupling the coupler is blocked against undesired coupling. That is realized with a special “buffing” position; therefor the handle is fixed in a certain position, later it has to be moved in the base position enabling automatic coupling again.

This feature is not common with all AC designs.

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## 2.6 COUPLING TYPE: MOVABLE / RIGID

These options are connected with the coupler types: the shape of the coupler head and also the latching mechanism make the couplers movable or rigid:

Movable: the coupler heads profile allows vertical movement between both couplers when coupled that reduces the movement of the draw gear in the headstock of the wagon. By principle coupling of moveable couplers is easier than for rigid ones, especially in tight curves.

Rigid: can be realized with all mechanical latching mechanisms mentioned: when coupled there is no vertical movement between both couplers. This gives a fixed connection between both couplers; the relative movement between the vehicles has to be handled by the draw gear in the headstock in the wagon.

## 2.7 AUTOCENTERING JOINT

Transmission of compressive forces by means of a simple ball joint will result in lateral forces, which cause instability and increase wear of running gear and permanent way. A safe operation for wagons with two axles, which are prone for derailment following these forces, is not secured.

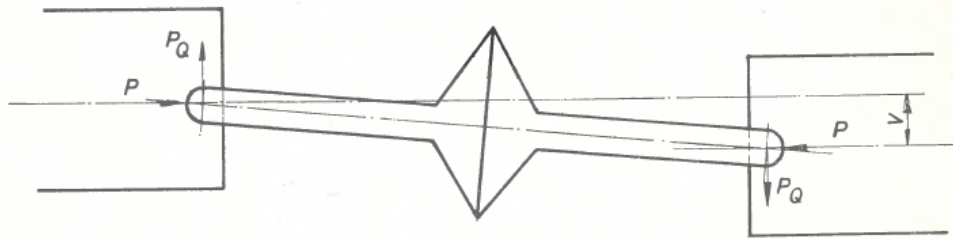


Figure 1: Lateral forces following compressive forces in ball joint (from /2/, Dr. Schelle, p.98)

The use of an autocentering joint (sometimes called “stabilizing end”) leads to a significant reduction of these lateral forces and so reducing the danger of derailment and also reducing the mentioned wear.

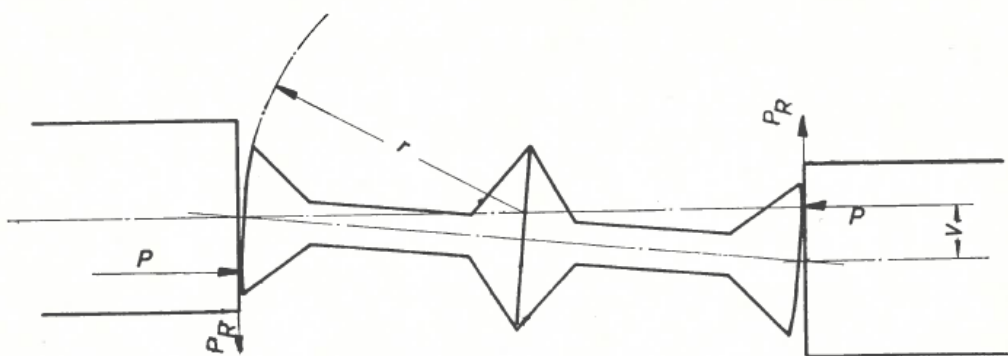


Figure 2: Principle of an autocentering joint (from /2/, Dr. Schelle, p.98)

## 2.8 ADDITIONAL FEATURES: AIR, DATA SIGNALS, ELECTRICITY

### 2.8.1 Air connections

Railway operation requires an air connection between the wagons for the operation of the UIC-brake (5 bar system). In some cases also an additional 8 – 10 bar hose connection is necessary, e.g. for tipping wagons or passenger wagons. This can be realized with connectors besides the coupler or by separate hoses, which require manual operation.

One of the objectives of the air brake is the automatic stopping of a train, if there is a division of a train. Therefore it is necessary, that in case of an undesired uncoupling the air pipes remain open, so that a release of the air pressure occurs.

Regarding the UIC brake system there are always air valves at the headstocks of the vehicles. There is no mechanic connection between these valves and the AC; resulting in the need of operating these valves manually even when the connection is part of the AC.

### 2.8.2 Data signals

Transmission of electrical data via cables is not in use in the freight business, but common in passenger traffic (UIC-cable). Data transmission offers a huge potential in automation and modernization. This can be realized with connectors besides the coupler or by separate cables, which require manual operation.

### 2.8.3 Electricity

Transmission of electrical energy via cables is not in use in the freight business, but common in passenger traffic (e.g. RIC-heating cable). Electric energy offers a potential e.g. in supply of reefer container or other devices to control the condition of freight during transport. This can be realized with connectors besides the coupler or by separate cables, which require manual operation.

## 2.9 HISTORIC REVIEW

Starting in the 1820s in England railway vehicles have been coupled with each other using hooks and chains; the tractive forces have been transmitted from the prolonged sole bars. Later these have been modified to the known side buffers, which were sprung by means of wood, rubber blocks or springs. The chain was later combined with a screw tightener to reduce slack; additional “emergency chains”, which have been introduced due to the unreliability of the coupler chains, have been later been relinquished (in the 1930s), also as a result of the introduction of the air brake in freight trains.

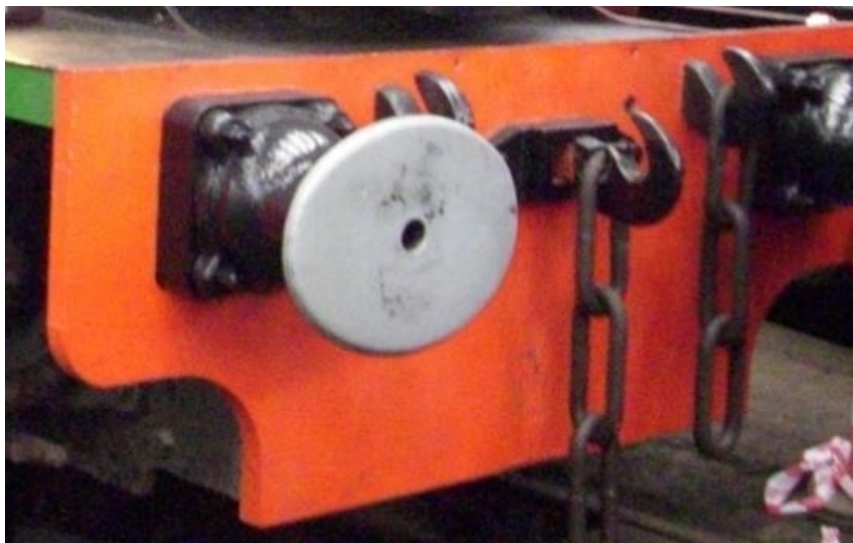
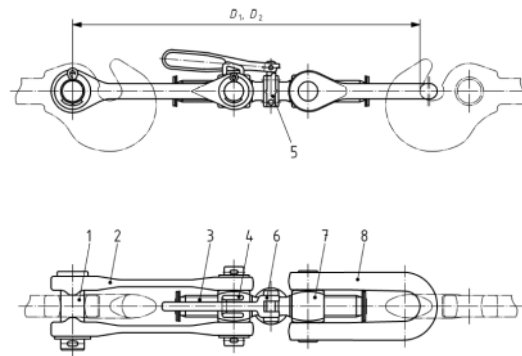


Figure 3: Chain coupler with side buffers (and emergency chains), UK in 2009

Contract No. H2020 – 730617



**Figure 4: UIC (screw) coupler (from EN 15566:2009)**

So for most European railways in the 1850s there has been a standardized system, which allowed interoperability in the joined railways. Some railways used different couplers, for example the railway of the German kingdom of Württemberg; their railway was inspired from American suppliers, so they used a central buffer with an integrated link – and pin coupler. Conversion to the European system was necessary as general requirement of interoperability.

In North America the railways mostly used the mentioned link and pin coupler: this was a good primary stage for the later introduction of the semi-automatic Janney coupler; this was introduced by American railways in the 1890s. The official reason was the number of workers accidents during the manual operation of the link and pin coupler; especially the coupling process of the insertion of the link into the central buffer was prone to personal hazard.

The coupler is named after the inventor Eli H. Janney (1831 – 1912).



**Figure 5: link & pin coupler, South Africa 2012**

The migration from screw couplers to Janney couplers was executed in Japan for freight wagons in only one day on the main network in July 1925 /8/.



**Figure 6: Janney Coupler, Spain 2012**

Russia resp. the Soviet Union used screw coupler with side buffers as their standard. Following modernization efforts semi-automatic coupler from Willison type was introduced, named “SA 3” (Cyrillic CA-3). Conversion started in 1935; due to the Second World War this was finished in the 1950s.



**Figure 7: SA-3, Bulgaria 2016**

European History:

Following the general introduction of the fully compatible screw coupler combined with side buffers some railway companies inspired from the American success asked the supply industry for suitable designs and started testing of AC; some examples from the 1920s are preserved in Berlin technical museum. Deutsche Reichsbahn (DR) in the 1920s operated some heavy coal trains with Scharfenberg couplers.



**Figure 8: Experimental AC from the 1920s**

About 1925 UIC set up a committee “Attelages Automatiques” /1/, but following the political situation in that period no results could be achieved. 1956 this committee was again established, later resulting in two parallel designs: “INTERMAT” from VEB Waggonbau Bautzen (GDR) favored by OSShD and “AK 69” from Unicoupler consortium (UIC). A common group UIC/OSShD worked in further standardization and optimization of the coupler; in parallel an UIC/OSShD leaflet 522 was written (actual version is from 1990!). Due to the political and financial situation in Europe in general and the railway sector in special there was no consent of an introduction of these ACs.



**Figure 9: Modell of a platform--wagon with UIC AK 69 coupler**

Starting in the 1980 another approach was considered: following an economical calculation “from the end” the maximum price of an AC was calculated; and a contract for such a design was signed. The partners have been DB and Knorr-Bremse; the coupler was from the “draw only” type. Test traffics have been started, but due to technical and financial issues there was no introduction in a larger scale.

Today in Europe there are only a few freight operations which use AC:

- Malmbanan (Iron Ore) Sweden/Norway with SA-3
- Ore and Coal traffic in Germany and also from the Netherlands and to Austria with AK69 and C-AKv
- Spanish narrow gauge with Janney coupler
- All trains on the East European (mostly Baltic) 1520 mm-gauged network with SA-3

### 3. REAL APPLICATION CASES, REGIONS OF USE

#### 3.1 KNUCKLE-COUPLER TYPE JANNEY

The semi-automatic couplers of the type „Janney“ spread over most parts of the world following economic relations with USA, mainly in North and South America, southern part of Africa, Australia, China, Japan and other Asian countries. It is the most resilient type of coupler. Two movable knuckles interact and are mechanically locked when coupled. The allowed tractive force is 1.750 kN; this allows the formation of the longest trains. The heaviest one was about 32.000 t.

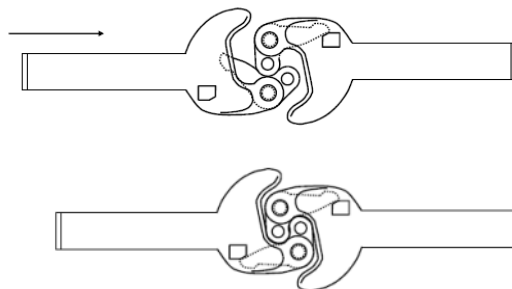
The tractive forces are transmitted via the movable knuckles. When two couplers are pressed to each other, the turning of the knuckles will lock both couplers, so that there is a rigid connection in the longitudinal direction of the couplers. The couplers are mounted in the headstock of the vehicles and supported by springs and so are movable in the vertical and also in lateral direction. By this means horizontal deviations caused by mistakes in the permanent way, inclination changes or different payload of the vehicles can be eliminated. Automatic connection of pneumatic hoses and electric cables is not possible with the basic versions and almost not used in freight operation.

Another disadvantage is the small “gathering range”, relevant when coupling in curves; that results in manual alignment of the drawheads when coupling. For European use this may be a problem; following this the International Railway Conference in Berne 1907 declared the Janney coupler as unsuitable for use in Europe /5, p.31/.

Manual pulling up of a link at the drawhead releases the knuckle so allowing uncoupling.



Couplers prior to connection; left knuckle is released, right one is fixed



Coupled, both knuckles are locked

**Figure 10: Scheme of the Janney-Coupler (from /5/, p. 30)**

Officially this coupler is called “AAR coupler” in the US. There are different versions; in freight traffic almost the movable type E is used. AAR type E and E/F have a horizontal play of ca. 20 mm. The gathering range is quite small.

AAR type F is a more rigid version of the types above; its vertical play is reduced to 10 mm. It is in use with tank wagons and also in passenger vehicles and is compatible to type E and E/F. The traction force is higher than 1.750 kN.

AAR coupler type H (Tightlock) is exclusively in use for passenger traffic and is also compatible with AAR Type E and F. There are fully automated versions of this type with automatic connectivity of pneumatic and electric modes. This coupler is from the rigid type with a vertical play of only 2 mm („Tightlock“).

Research object Fully Automated F-Type Tricoupler

In 2008 a prototype of a fully automated Janney-coupler was designed and tested by Sharma & Associates Inc. (US) /7/ No commercial operation is known. Coupling and uncoupling is executed automatic. The brake pipe with brake cocks and also an electric connection are automated. Operation is executed from external controls. The mechanical figures are the same as F-type.

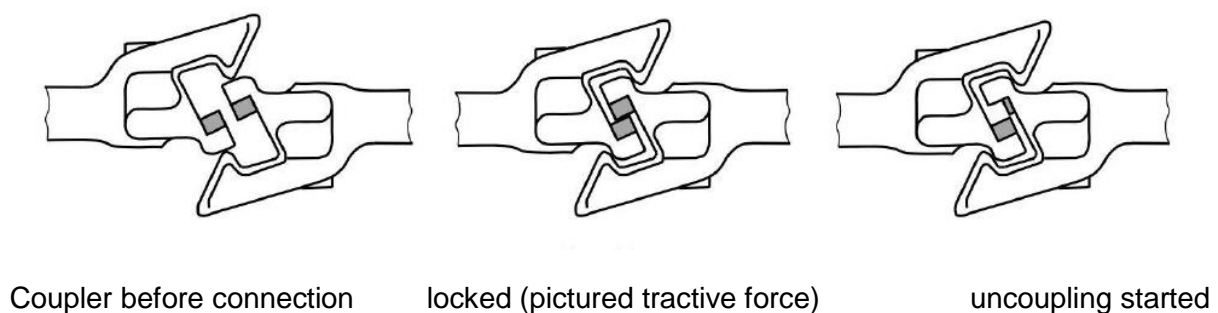
### 3.2 WILLISON

The other type of coupler widely used is type „Willison“, also a semi-automatic coupler, capable to transmit tractive and compressive forces. The design is simpler than the Janney coupler. In opposition to the Janney coupler the transmission of the tractive forces is executed by the fixed elements of the draw head, the latching mechanism only transmits a smaller portion of the given forces. When interlocking the locks are at first pushed back and after that due to their weight they are moved forward and so they block the coupler.

The Willison coupler in its basic version is from the movable type, there is high friction between the couplers surfaces. In this version pneumatic and electric connections have to be coupled manually. Vertical and horizontal sliding elements increase the gathering range and so help to couple in tight curves (Type AK69 down to 135 m radius).

For coupling in tracks with smaller radii the couplers have to be moved from the centre line of the wagon; for this purpose there are small ropes, which fix this manual movement. If the couplers move to the centre line, because the wagons are now in straight tracks, flexible devices release that ropes.

To start the uncoupling procedure the lock of one coupler is lifted via an external operation rod and the couplers can be segregated.



**Figure 11: Mode of operation of a Willison coupler (from /5/ p. 31. )**

There are different couplers based on the Willison principle. Widest spread is type SA-3, a design from the former Soviet Union, which has been adapted to the harsh Russian conditions. This type is the general standard in the states of the former Soviet Union, also in use in Finland, Turkey, Iran and Iraq and also at the “Malmbana” (Iron Ore Line) in Sweden and Norway. It is from the movable type, its lateral play is about 10 mm. Maximum tractive force is 1.320 kN. The latching mechanism works automatically; uncoupling requires manual action. No connection of the air hoses is integrated; this requires manual coupling of the air hoses sideward the draw head. Maximum tonnage of the trains is about 8.000 t.

Coupler type AK69e (Unicoupler), which was designed as a European standard coupler (particular: West European, driven by UIC), is in operation in our days for ore trains in Germany and also in Iranian freight trains. It is from the rigid type; the lateral play is a few mm. To achieve a vertical flexibility the draw head is supported by a sprung slide bar at the headstock of the wagon.

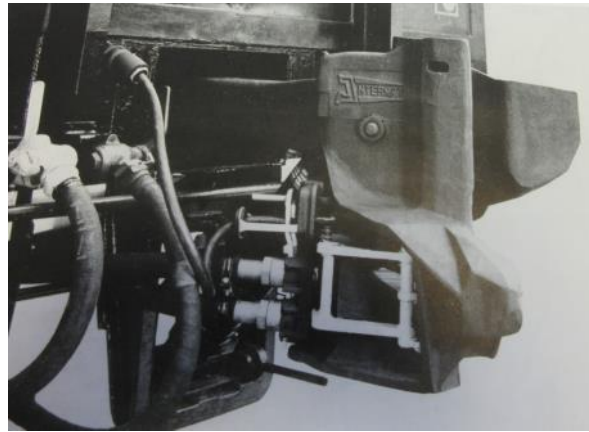
Integrated in the coupler are two air pipes, also addition of an electrical module for six connectors up to 220 V and 20A is possible. Maximum tractive force is 1.000 kN, the heaviest train operated is about 6.000 t. Uncoupling is a manual operation.

AK69e can be coupled with the Russian SA-3 type, because the mechanical parts are designed according the Willison principle. Connection of the air hoses has to done in the conventional manual way.



**Figure 12: AK 69e (DB Cargo)**

AK69e was designed following an initiative from the UIC; the East European OSJD had a similar initiative as agreed with UIC: a semi-automated rigid coupler INTERMAT was designed and tested in operation. It has almost the same features as AK69e; both types are fully compatible with each other and also (with the described restriction) with SA 3. For the vertical flexibility INTERMAT is supported from a “sprung leg”; that requires a different preparation of the wagon’s headstock.



**Figure 13: INTERMAT (from /10/)**

In later years a more modern version of AC was designed and put on the market; Transpact, later called C-AKv, has the same maximum tractive force of 1.000 kN and is compatible with AK69e, INTERMAT and also SA 3. Two air connections are integrated into the draw head. The latching mechanism works automatically when coupling; uncoupling requires manual action.



**Figure 14: C-AKv (DB Cargo)**

Z-AK (draw-only coupler):

Following the obvious failure of a general introduction of ACs „AK69” and “INTERMAT” in Europe a working group within UIC analysed the situation. The main objectives have been economical questions; so it was decided to start another approach: a significant reduction in cost of labour and wagons gave the maximum cost of the coupler. A value analysis gave some features for this coupler:

- Transmission of tractive forces only (draw - only coupler; UIC leaflet 522-2)
- Tractive forces in the range of the screw coupler (500 kN, fracture load 1.000 kN)
- Interoperability with screw coupler enables smooth migration.

The Z-AK was designed and delivered from Knorr Bremse, after successful testing an UIC - acceptance was achieved, but following test traffic with about 400 wagons in the years 1998 to 2001 there was no introduction in a wider scale due economic problems of the railway undertakings.



**Figure 15: Z-AK (draw only coupler) DB Cargo 1998**

### **3.3 SCHARFENBERG**

AC type „Scharfenberg“(German abbreviation „Schaku“) is almost used in passenger traffic. It was first designed in 1903; it is a rigid coupler and transmits tractive and compressive forces. Type 10 was included in the TSI as the standard type for high speed trains.

In difference to the Willison couplers the latching is not done by heavy latches. Transmission of the forces is via a system of movable links with eyes, which are connected to a revolving disc inside the draw head. When coupling each movable eye interfere with a hook at the discs of the opposite coupler; the discs turn and the eyes are caught by the structure of the draw head. The draw head at its front has a cone and a similar shaped cup; in coupled state these build up a rigid connection. Due to this system the tractive forces are transmitted from both eye links with their counterparts; the compressive forces are transmitted from the mentioned characteristic front structure. Due to the spring supported system of the discs and eye links there is no horizontal play in the couplers. Uncoupling is executed by turning one of the discs against the spring forces, the movable eye links are then out of the hooks of the discs and so uncoupled. The operation of this is done manually or electrical or pneumatic released from the drivers cab.

Some couplers have a gathering range of max. 370 mm horizontal and up to 140 mm vertical. This is enabled by sliding devices; the last step is the interference of both cones and cups; coupled there is almost no play.

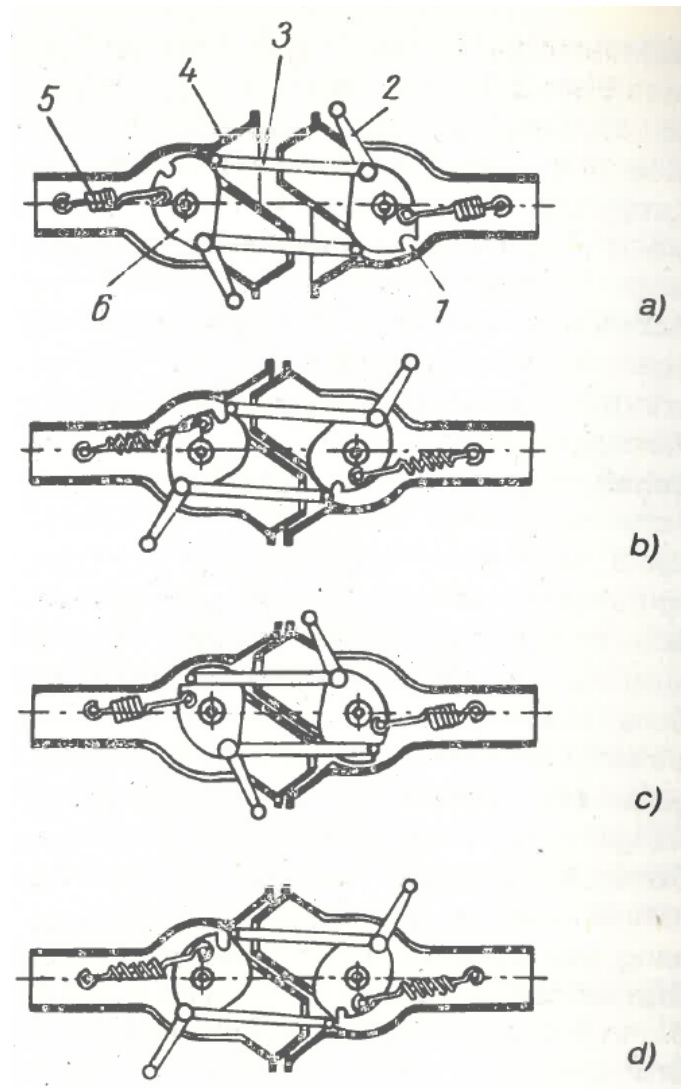
For the different areas of use following customers' demands there are different types of Scharfenberg couplers. There are a several versions of these couplers.

Type 10 is standard, used in German ICEs, French TGV, Spanish AVE. Variation exist in the arrangement of the modules for electric connection, the number of contacts etc. Max. tractive force is 1.000 kN; compressive force is 1.500 KN.

Other versions e.g. types 330 and 430 are in use for tramway vehicles and underground trains.

For freight trains type 140 is on the market; it is in use on some German industrial railways in rough environment. Max tractive force is 1.500 kN; compressive force is 2.500 kN.

One new product is type 11, it is offered for freight trains without maximum loads, max. tractive force is 1.000 kN, max. compressive force is 2.000 kN. SBB Cargo at the time of writing is preparing equipment of wagons for test operation.



**Figure 16: Scharfenberg-Coupler (from /9/, p. 606)**

a) initial position      b) during coupling      c) coupled      d) release position  
 1 hook   2 release arm   3 eye link   4 coupler head   5 spring   6 revolving disk

### 3.4 BSI

BSI (Bergische Stahl-Industrie; today part of Faiveley – Wabtec) in the 1950s designed their compact coupler.

The coupler has a prismatic cone and also an inverse shaped slot; these are in close contact when coupled. There are also inclined surfaces for vertical guidance. The latches are integrated in the prismatic cones. It is in use on several tramways in Germany (e.g. city of Bielefeld) and EMUs in UK (e.g. Metro Tyne & Wear Newcastle).



**Figure 17: BSI-Coupler, Metro Newcastle 2009**

### **3.5 TOMLINSON,**

This coupler is a standard automated coupler, which is widespread in the US for passenger service and mass transit (underground), not so often in general passenger traffic due to the lack of strength compared with the AAR types. Developed by Ohio Brass Company, it is now in the portfolio of WABCO (= Wabtec??). The principle of the latching mechanism can be found in 8.2.5.

### **3.6 WEDGELOCK**

The wedgelock coupler is in function quite similar to the Tomlinson /6/, but its appearance is different: it is much wider than high to fit to the low floor of underground vehicles. The latching mechanism consists of pneumatically operated wedges, which lock the tongues when they are positioned in the adverse throats of the opposite coupler /15/.

For transmission of compressive forces buffers are mounted above the coupler.

Main use is the London Underground.

### **3.7 GF FISCHER**

GF Fischer in Switzerland (company was in relation with Schwab) designed in the 1950s a number of different AC, Type "Vollbahn" ("Main Line") was designed following relations with the Irish Railway (Coras Iompair Eirean CIE), there also some tests have been executed /12/. Today's operation is mainly in Switzerland, the metregauged Zentralbahn / Brünigbahn has them in operation, but they can be found also in Belgian EMUs and Prague tramways.

### **3.8 SCHWAB**

Schwab couplers are a product of former Schwab Verkehrstechnik in Switzerland, today part of Faiveley. Today there are several types of the "FK"-line, which are in use in several in several operations, mostly in Switzerland. There are also versions only for tractive forces.



Schwab Vollbahn



Schwab Metro

**Figure 18: Schwab couplers (from /3/)**

SBB Cargo also intends to use a modified version in its demonstration – and test trains starting in 2017. /11/

#### **4. CENTRAL BUFFER COUPLERS VS SIDE BUFFER COUPLERS**

According to the existing bibliography and conclusions of previous projects (indicate references), the use of a Central Buffer Coupler is one of the main drivers, due to the great amount of advantages that provide. Operators like DB agree with these conclusions, and justify its use, on the basis of the following benefits:

1. Reduction of the wheel-rail contact forces and wear on the wheel and track. This will reduce the access fees to the tracks, if evidence for this can be achieved. There are some publications indicating this, but these are related to certain conditions e.g. tight curves. A general investigation has to be based on a comparison regarding a larger fleet of vehicles.
2. Higher tractive forces than the existing Screw Coupler (6.000 t compared with ca. 3.000 t)
3. More efficient shunting operations, because of the minimization of the human intervention during the coupling processes. In the years several cost benefit analyses and other surveys have been executed.
4. Rigid couplers (slide-free) minimize sliding, and thus, friction. Moreover, the reduction in the play benefits the vehicle dynamics with the reduction of continuous impacts.
5. Allows the use of pneumatic/electric contacts to connect vehicles.

## 5. IDENTIFICATION OF THE TECHNICAL KEY PERFORMANCE INDICATORS

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In this chapter, the most important parameters for freight couplers are identified. If good performance values are achieved, it means that the solution is more suitable for the present application.

In the following paragraphs, an analysis of each indicator one is done, justifying its importance in the overall performance of the coupler.

### 5.1 INTEROPERABILITY

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Interoperability is a key point when considering the design of the new coupler system. The system should be integrated in a complex network with different coupler types. Moreover, when considering a progressive migration plan, in which there is a transition period where more than one technical solution exist at the same time, it gets even more relevance.

The coupler type more extended in the EU freight corridors in the 1435 system is the Screw Coupler. For this reason, in case that a transition period is considered in the Migration Plan, compatibility with the Screw Coupler is important. Otherwise, there will be operational limitations and the need of adaptors will be necessary. The last ones are not desirable, because they will require additional manual operations and thus, delay the coupling/uncoupling times, together with a safety risk for the staff.

The difficult compatibility with the Screw Coupler has been one of the reasons why the UIC AK69 coupler has failed in the implantation. Therefore, this functionality is dependent on the proposed Migration Plan.

For all types of AC the “mixed coupler” to match the screw coupler is a feasible, but restricting device.

If the link to the draw hook of the proximate vehicle or any other device has to be operated, the shunter (the worker) has to work in the “Berne rectangle” between the buffers. The AC always fouls this space; so that there are administrative issues to be solved (e.g. in Germany a special acceptance is necessary for this).

So the migration phase makes the working conditions worse than operation with screw coupler only. That leads to the requirement of a short migration phase.

Type of AC	Compatibility of base version	Compatibility possible	example
Janney	no	yes	Indian Railway broad gauge or UK vehicles (hinged coupler)
SA 3	no	yes	USSR early versions (see Fig. x; SA3 Voith)
AK69e	no	no	adaptor (existing)
INTERMAT	no	no	adaptor (existing)
C-Akv	yes	yes	integrated
Z-AK	yes	yes	integrated
Scharfenberg	no	no	adaptor (existing)
BSI	no	no	adaptor (existing?)
Tomlinson	no	no	
Wedglock	no	?	?
GF Fischer	no	yes	CIE tests 1950s
Schwab	no	no	adaptor (existing?)
Remarks:			
to achieve compatibility also the vehicles with AC have to be equipped with buffers use of an adaptor without buffers only allows restricted loads and speeds			

**Table 1: Interoperability AC with screw coupler**

Interoperability with the AK69 is not so relevant, as there is a small fleet equipped with this type of coupler. Interoperability with the Russian SA-3 coupler has been widely studied. The final conclusion is that it is not a key point, because from a migration point of view, interoperability has to be considered, as the latter is used in Europe on the 1520 system; but in Turkey, Iran and Iraq SA-3-couplers are widespread and interoperability with such standard gauged RIV-wagons on the EU-network sometimes happens (e.g. TCDD Sgns-Wagons to Germany). The unique reason why SA-3 coupler or SA-3-based solution, could be adopted, is to minimize costs by producing higher coupler amounts. Mass scale production will help to drop down costs. However, this additional SA-3 compatibility functionality will make the system more complex and the limitations of the SA-3, such as the high longitudinal play will be inherited.

Interoperability with the American AAR Janney-type couplers is not necessary. It will make the mechanism too complex and there is no need for interoperability with the US, Pacific and Hong Kong. Moreover, gauge difference between Central Europe and China will generate 2 changes that make very difficult the interoperability.

## **5.2 TRACTIVE/COMPRESSIVE FORCES:**

The maximum admissible tractive and compressive forces limit the train lengths and the speed. Therefore, it has a direct impact in the operative limitations of the new railway system.

Due to the small tractive forces (<500 kN) that can withstand the existing Screw Coupler, which limit the maximum train length, it is a common agreement that this value should be increased. After conversations with operators like DB, a tentative maximum tractive/compressive limit has been reached. This value is initially set up to a maximum of 1.500 kN. This maximum tractive force will cover the composition of most of the rolling stocks in Europe. Compressive forces should be in the same range, around 1.500 kN.

Other operators like SBB Cargo consider lower limits for these values, down to 800 kN. These different requirements depend on the business case of each operator. However, the target of this S2R project covers the EU countries and therefore, should cover most of the cases within this area.

### 5.3 WEIGHT

As in all freight transportation weight of the equipment is important. The preparation of freight wagons for AC gives some extra weight to the tare wagon: For some types of AC a comparison was done of the weight of the screw coupler and also buffers to the AC with the draw gear needed for function.

The two last columns show the difference in weight for both cases: wagon only equipped with AC and wagon with AC and also buffers during migration phase.

	weight per piece	total weight	overweight to screw coupler	overweight to screw coupler; side buffers remain for compatibility with screw coupler
2 screw couplers	each 38 kg	76 kg		
2 x draw gear with tow hooks	each 117 kg	234 kg		
4 buffers	each 140 kg	560 kg		
weight of removed parts		-870 kg	0	-310 kg
draw gear type B412 (tensile/ compressive)	each 330 kg			
AC type AK 69e	each 440 kg	1.540 kg	670 kg	1.230 kg
AC type C-AKv	each 330 kg	1.320 kg	450 kg	1.010 kg
AC type SA 3 Voith (incl. draw gear)	each 650 kg	1.300 kg	430 kg	990 kg
AC type Scharfenberg 11 (incl. draw gear)	each 495 kg	990 kg	120 kg	no compatibility
AC type Schwab	?	?	?	no compatibility

**Table 2: Weights of the different types**

In short the pay load of each wagon will be reduced by 400 - 700 kg; with keeping the buffers (migration phase) that will be about 1.000 kg – 1.300 kg.

On the other hand a general introduction of AC lead to lighter designs of the underframe of the wagons; this resulting in a simpler distribution of the forces in the structure. There is less need for deviation of the compressive forces.

## **5.4 GATHERING RANGE**

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An increased gathering range allows coupling in smaller radius curves. This increases the operative performance of the new railway system. For this reason, special attention is paid to the elements used for this purpose, such as horns or special geometries.

## **5.5 WEAR**

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Wear reduces life of the coupler and increases the LCC of the system. For this reason, the new concept should consider minimizing wear and the number of components that suffer high wear rates. The main driver is to select special pairs of materials, and to minimize the number and friction areas. This also helps reducing the risk of jamming. Rotative motion is preferred in the latching mechanisms, over linear sliding elements, because it normally leads to simpler parts and better performance.

Another reason for using rigid couplers is the minimization of the sliding between coupler heads, and therefore, wear rates. This is also important to allow passing pneumatic and electric signals, without damaging the connection elements. One of the reasons for selecting a central buffer coupler, and removing the side buffers, has been the high wear rates that they suffer, due to a continuous contact in service.

## **5.6 AUTO CENTERING JOINT**

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One of the drawbacks of using a central buffer coupler is the derailment risk when braking under curve negotiation. Rigid central buffer couplers are provided with rotary joints that allow keeping the coupler heads connected, without relative motion. When compressive forces exist, together with small vertical offsets, the wheel-rail contact vertical force in rear axle of the forward vehicle is reduced, increasing the risk of derailment.

According to Nadal criteria:

$$\frac{Y}{Q} < 1.2$$

Where:

Y: Lateral force in the wheel

Q: Vertical force in the wheel

A common recommendation to assure that no derailment occurs is to keep the value Y/Q above 1.2. This not only depends on “Y” and “Q”, but in the flange angle and in the friction coefficient. Depending on this, different values from 1.2 are selected. However, the equation gives an overview of the importance of this effect in the vehicle stability.

In order to mitigate this problem, autocentering joints exist. These connection elements are designed in a way that generates autocentering bending moments, when working under compressive forces. These elements are very commonly used, and called anticlimbing. They are responsible for generating a counter-momentum that holds the wagons down. The resultant effect is that the joint tries to align the coupler draftgear with the travel direction, preventing Q value to drop. When the vehicle is negotiating a curve, while braking, the situation is even worse, because

higher lateral forces exist, and if no auto-centering joint is used, the “Y” value increases, leading to a higher Y/Q, and therefore, higher derailment risk.

## 5.7 WINTER CONDITIONS

Operation in winter is one of the most important conditions to consider, when designing a freight AC for Europe. Winter conditions are very common in many EU countries, during long periods of time.

Low temperatures combined with moisture, create ice in the mechanical cavities or friction elements, that can lead them to get stuck. For this reason, the number of mechanical guiding surfaces should be minimized, and specially designed to deal with this condition.

Another problem related to winter conditions is the snow deposition that will cover cavities and prevent the coupler head front surfaces to make contact. This has a direct impact in the geometry of the coupler head that has to be conceived in order to minimize the closed cavities that can lead to snow/ice packing. The most convenient geometries to mitigate this problem are open head profiles, such as the C-AKv or SA-3.

There are other problems related to the malfunction of specific subsystems, such as the uncoupling cylinders and the electric head connections, due to water penetration. However, at this early stage, this is not the most important issue and can be studied separately in the following stages of the project.

## 5.8 DATA AND POWER TRANSMISSION

Data transmission is important in order allow monitoring the payload condition, but also to track the vehicle conditions, for maintenance.

In the frame of FR8RAIL there are specific WPs that focus on these issues and one of the drivers is consider wireless techniques to transmit information between wagons. This consideration is of great importance in the current coupler design activity, because wire signal transmission requires tight mechanical plays, whereas wireless doesn't require these tight play levels.

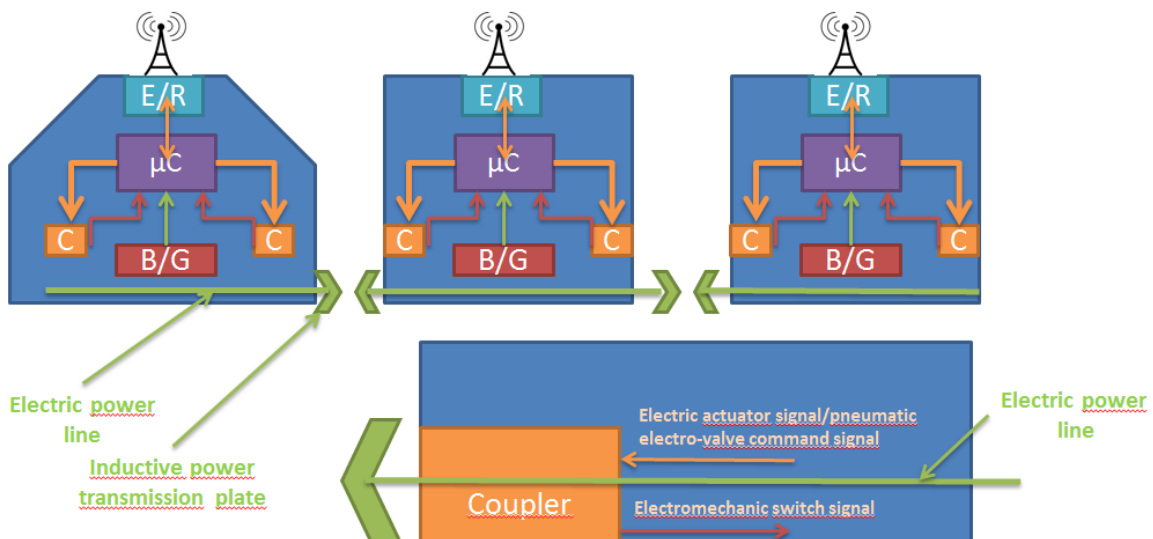


Figure 19: Scheme of possible signal transmission architecture

## 6. COMMERCIAL DATA

It is almost impossible to find reliable prices for the different couplers. Some of the European types are intellectual property of a certain supplier and so there have to be negotiations related to the number of couplers requested.

A type F AAR coupler is priced at about 500 \$ (470 EUR) in the US (/13/); bought from Chinese suppliers it may be a third of this.

	cost per wagon end	cost AC incl. Installation	extra cost to screw coupler	extra cost to screw coupler; buffers remain
one screw coupler	each 140 €			
one draw gear with tow hook	each 630 €			
two buffers	each 260 €			
cost of removed parts	1.300 €		0	0
AC type AK 69e with draw gear B412	each 5.000 € *		nil	nil
AC type C-AKv (incl. draw gear)	10.000€ (estim.)	11.000€ (estim.)	9.700 € (estim.)	10.220 € (estim.)
AC type SA 3 Voith (incl. draw gear)	10.000€ (estim.)	11.000€ (estim.)	9.700 € (estim.)	10.220 € (estim.)
AC type Scharfenberg 11 (incl. draw gear)	10.000€ (estim.)	11.000€ (estim.)	9.700 € (estim.)	no compatibility
AC type Schwab (incl. draw gear)	10.000€ (estim.)	11.000€ (estim.)	9.700 € (estim.)	no compatibility

**Table 3: Prices / costs per “wagon end”**

General remark: All costs estimated; these have to be dealt with suppliers!

\*: remark: internal price, not for procurement

## 7. MIGRATION

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There are two mayor approaches to realize a migration from screw coupler to AC:

Simultaneous migration:

(GT)The migration would be carried out during a rather short period of time, some days up to a few months. The Japanese railways migrated from their British-derived buffer and chain couplings to the American Janney coupling over a period of a few days in the early 1920s, after considerable preparation /8/. However, there are no examples of major networks of 'continental' dimensions where a simultaneous migration was carried out.

Advantages of a simultaneous migration are:

- Very short phase of co-existence of Automatic Couplers and Screw Couplers
- Maximum reduction of additional risks for shunting stuff during migration
- Quick realization of full benefits of Automatic Couplers

Disadvantages of a simultaneous migration are:

- Difficulty to agree among a high number of stakeholders on the date for migration
- Very high investment during a very short period of time
- Logistical and organizational challenge to execute the exchange of couplers
- Risk of major disruptions of freight services during and around the migration date

Progressive migration:

GT: The migration would happen over a longer period of time, typically several years. An example of progressive migration is the introduction of the SA-3 coupler in the former Soviet Union, which started in the beginning of the 1930-ies (the SA-3 coupler was invented in 1932) and was not finalized before 1957, when the entire fleet was equipped with Automatic Couplers. The migration to the Z-AK couplers in Europe was planned to happen over a period of 6 years, following the revision cycle of the wagons.

Advantages of a progressive migration are:

- Certain flexibility for market actors to choose suitable migration date for their fleet or parts of it
- Spreading out of investment over a longer period of time
- Less demanding organization and logistics for exchange of couplers

Disadvantages of a progressive migration are:

- Long period of co-existence of AC and SC delays the realization of full benefits of the target system with Automatic Couplers only

- Need to take mitigating measures to reduce risks for shunting stuff when building mixed trains AC+SC
- Train operations may need to be adapted to reduce mixed coupling AC+SC

UIC planned a mixed approach, combining simultaneous and progressive migration; to convert the conversion of the wagon fleet dedicated for international traffic was foreseen to be done within in a few days, the rest in the following four4 years (see /2/ p40).

GT The migration approach is crucial for a successful introduction of AC in Europe and is dealt with in more detail this issue will be regarded in deliverables D 5.6

## **8. TECHNICAL EVALUATION AND TRADE-OFF**

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This chapter aims to analyse the most extended solutions in the market, paying special attention to their weaknesses and strengths, for a freight application. For this reason, this analysis starts with a review, of all the incidences gathered, related to the most extended and feasible technical solutions. The information is classified and shown, using an FMECA table.

The next step is to perform an individual analysis, of each technical solution, according to the previously identified KPI. Special attention is paid to specific requirements, and their suitability for freight is addressed.

Finally, with all the previous gathered information and analysis, a comparative between the different coupler types is conducted, and each one is scored according to different KPIs. This technique allows selecting the most convenient or competitive solution for the current application.

### **8.1 FMECA ANALYSIS AND LESSONS LEARNT**

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An extended work and research has been done to investigate the performance of the different coupler types in service. Experiences from operators have been obtained. In order to gather all this information, a specific survey has been prepared and distributed to the operators, partners and stakeholders that can provide information on the matter. Table 4 shows an example of the survey format.

		Scharfenberg		BSI		C-Akv Faiveley Transpact		Faiveley Propact		AAR Janney (Tightlock)	
		Comments	Scoring	Comments	Scoring	Comments	Scoring	Comments	Scoring	Comments	Scoring
Technical performance evaluation	Maximum forces										
	Gathering range/alignment										
	Wear										
	Operation Compatibility/operative limitations										
	Integration in the existing wagons										
	Resistance to winter										
Purchasing costs											
Maintenance costs											
Additional features needed											
Additional comments											
	<b>TOTAL</b>		<b>0</b>		<b>0</b>		<b>0</b>		<b>0</b>		<b>0</b>

**Table 4: Survey sent to obtain experiences and lessons learnt**

The next step is to classify all the identified problems and weaknesses of each solution. The data is classified in an FMECA table (table 5).

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
Screw coupler	Limited tractive forces	Reduced train lengths	Weak screw link strength, to achieve a lightweight solution for an easier manual manipulation	Newest screw couplers have fracture load of 1.350 kN, already used in heavy trains.
	Manual coupling	Increased coupling time	Impossibility to automate screw coupling process	Roboter planned @DB Cargo
	Longitudinal play	Bad dynamics, undesired longitudinal forces that could lead to derailment. More critical in EU railways, for two-axle wagons.	Not properly tightening the screw, so that buffers are not really in contact. Common problem in operation when tightening in curves	
	Wear in buffers	Wear in buffers Reduced life Intensive maintenance	Contact between buffers lead to wear	
Janney	Wear in the knuckle	Unintentional uncoupling	Coupler head geometry allows horizontal and vertical relative sliding. It is higher or lower depending on the AAR coupler version	Knuckles are the components that suffer more wear. However, this element is more easily replaced, and thus not as expensive as the SA-3. Tightlock solution will reduce play and wear

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
Janney (c'd)	Longitudinal play	Bad dynamics, undesired longitudinal forces that could lead to derailment. More critical for two-axle wagons. In the US and Russia this solution is not so bad because the wagons are provided with bogies, so that the wheelsets have lower attack angle respect to the rail	Mechanical design that uses play between couplers to allow the curve inscription without the need to install a pivot	
	Limited pneumatic functionality		There is no Brake Pipe Valve installed, so in order to achieve the required safety operation modes, manual commutation of the valve should be done.	Installing a Brake Valve will be the solution and will allow the automatic functionality
	Gathering range	Limited gathering range, coupling not possible and need of manual intervention	Coupler head geometry, no coupling horn use	
SA-3	Wear in the head	Unintentional uncoupling	Coupler head geometry do not restrict vertical movements and therefore, vertical sliding appears.	Wear affects the main body casting (the whole coupler), so that it requires a complete replacement of the head. More expensive
	Wear in the coupler carrier, shank	Reduced life in the shank and pivot components	When two SA-3 couplers interact, they follow a zigzag path and move laterally in both directions as the cars come together	

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
SA-3 (c'd)	Gathering range	Limited gathering range	Coupler head geometry, no coupling horn and no planar contact surfaces leading to an autoalignment	
	Fail of the interlocking sections	Unintentional uncoupling	Longitudinal shock loads	This latching mechanism is more reliable than the Janney one, but more expensive to repair because in case of failure, it needs to replace the coupler castings
	Weight	Heavy component. Passenger architectures are lighter		
	Longitudinal play	Bad dynamics, undesired longitudinal forces that could lead to derailment. More critical for two-axle wagons. In the US and Russia this solution is not so bad because the wagons are provided with bogies, so that the wheelsets have lower attack angle respect to the rail	Common problem in AC, but necessary to couple and uncouple without adding excessive friction forces. These friction forces should be minimized to reduce the risk of jamming the latching mechanism	
	Limited pneumatic functionality		There is no Brake Pipe Valve installed, so in order to achieve the required safety operation modes, manual commutation of the valve should be done.	Installing a Brake Valve will be the solution and will allow the automatic functionality
C-Akv	Pneumatic incompatibility with AK69	Operative limitations/problems	Need of adaptor when coupling the brake pipe with the AK69	This was introduced by Ulrich F. Further details should be given, however, compatibility with AK69 is not a main driver – problem is

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
C-Akv(c'd)				still existing
	Gathering range	Limited gathering range	Geometry leads to smaller gathering ranges	
	Limited pneumatic functionality		There is no Brake Pipe Valve installed, so in order to achieve the required safety operation modes, manual commutation of the valve should be done.	Installing a Brake Valve will be the solution and will allow the automatic functionality
	Additional manual intervention	Risk for personnel and poor automation level	Need for additional manual operations to couple. Low automated level.	
	Electric signals	No electrification is possible	Higher play limits the use of electric signals to transmit signals	
	Cost	Was never extensively introduced	Purchasing costs higher than the maximum admissible	There are 65.0000 freight wagons in Europe. However, since 1965, all wagons are prepared to allocate a central buffer coupler. Estimated costs 8 k€ per unit.
	Wear	Reduced life	Wear appearance in the elastic elements of the yoke (interface with the headstock)	The new Faiveley version has this problem. Further details will be provided by UF in the D5.1 Wear in the draw gear, has to be redesigned.
AK 69/Intermat	Incompatibility with SK	Limited operability	Compatibility with SK was not considered a critical issue.	Interoperability requires buffers at the wagons (also with AC) and special adaptors.

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
AK 69 / INTERMAT (c'd)	Longitudinal play	Bad dynamics, undesired longitudinal forces that could lead to derailment. More critical in EU railways, for two-axle wagons.	Common problem in AC, but necessary to couple and uncouple and not adding excessive friction forces leading to a stuck of the latching mechanism	
	Limited pneumatic functionality		There is no Brake Pipe Valve installed, so in order to achieve the required safety operation modes, manual commutation of the valve should be done.	Installing a Brake Valve will be the solution and will allow the automatic functionality
	Economic reasons	Was never extensively introduced	Purchasing costs higher than the maximum admissible. Migration costs higher because of the incompatibility with screw coupler that leads to a complete upgrade of all the European wagons	Main problem for all Railway Undertakings: money, need of high investments in short time....
Z-AK	Wear	Wear in buffers- same as screw coupler Reduced life Intensive maintenance	Constant contact in buffers lead to wear	No experience due to short test life. Wear in buffer same as for screw coupler
	Compatibility	Not compatible with SA-3 nor AK69		Not possible due to the principle
	Longitudinal Play	Bad dynamics, undesired longitudinal forces that could lead to derailment. More critical in EU railways, for two-axle wagons.	Common problem in AC, but necessary to couple and uncouple without adding excessive friction forces leading to a stuck of the latching mechanism	study predicting derailments due to this problem: ERRI B177.5

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
Z-AK (c´d)	Limited pneumatic functionality		There is no Brake Pipe Valve installed, so in order to achieve the required safety operation modes, manual commutation of the valve should be done.	Installing a Brake Valve will be the solution and will allow the automatic functionality
	Reduced train length	Reduced train length. Not valid for all the EU business cases	Weak mechanical link strength	
Scharfenberg type	Resistance to winter cond.	-Electric contact failure -Coupling not possible	-Ice/snow deposition in the electric head -Coupler cavities/pocket covered with snow and ice	In Winter some problems seem to occur; no written evidence found
	Reduced train length	Reduced train length. Not valid for all the EU business cases	Limited maximum tractive forces (850 kN)	
	Economic reasons	Has never been introduced in freight	Purchasing costs higher than the maximum admissible	High number of parts, lead to high costs. More complex machining in the head, with guidance elements, hardstops, make the coupler head more expensive.
BSI	Resistance to winter cond.	Electric contact failure Coupling not possible	Ice/snow deposition in the electric head Coupler cavities/pocket covered with snow and ice	We don't have exact details about it, but due to the mechanical design of the coupler head, similar to the Scharfenberg one, ice/snow packing problems are prone to occur. However, the simpler latching mechanism, reduces the risk of failure (jamming, galling)

Affected coupler type/supplier	Failure/weakness	Effects	Cause	Comments
BSI (c'd)	Wear	Unintentional uncoupling	Wear in the plunger	The wear in the plunger, affects its shape and geometry. This could lead to an unintentional uncoupling. This point has been solved in a DELLNER alternative, provided with a second latching mechanism that prevents the spring from working under fatigue loads in service when coupled
	Broken spring	Unintentional uncoupling	Fatigue after some time in service	This point has been solved in a DELLNER alternative, provided with a second latching mechanism that prevents the spring from working under fatigue loads in service when coupled
	Fail in the uncoupling	No uncoupling is possible	Excessive friction forces in the latching mechanism, when working under tractive forces	When wear increases, this axial tractive force is reduced, and therefore, friction forces are smaller. Need to increase the uncoupling force in the cylinder
	Longitudinal Play	Reduced life	Wear appearance in the latching element due to continuous impacts during operation	

**Table 5: FMECA table with weaknesses failure modes of the existing coupler types**

## 8.2 TECHNICAL ANALYSIS OF EXISTING SOLUTIONS

After concluding the documentation work, an individual analysis of each configuration has been performed.

### 8.2.1 Janney Tightlock

AAR Janney is one of the worst heads in terms of alignment. It has the lowest gathering range and it does affect the operative performance, because requires manual alignment in small radius curves. There are some upgrades that include additional horns to increase it, but still need manual intervention in specific conditions. In order to increase the gathering range, it is recommended to keep the knuckles of the two couplers open. This can be done in some cases from cabin but others should be done manually.

Type H version has been selected, because is the one with the smallest transversal and longitudinal play. For this reason, it is included in the rigid coupler's group that allows for pneumatic and electric connections (figure 20).

It is provided with a horn that engages against a receptor surface, for vertical alignment. The AAR profile is modified to minimize the play. For this reason, this solution should be combined with articulated drawgears. Pneumatic connections are installed in external supports, separated from the coupler head.

This is a robust solution, that leads to high tractive forces, ranging the 1.750 kN and 2.900 kN compressive forces.

When coupling and uncoupling, the knuckle suffers high wear rates that reduce the life and induce sudden failures in service that lead to carbody separation. London's commuter suffered this type of failure modes in service.



**Figure 20: Automatic Tightlock coupler, provided with electric and pneumatic couplings**

The latching mechanism is very simple, and the release mechanism as well. This is positive to reduce price. However, it is more prone to suffer damage or breaks under shock loads.

When wear exist, it increases longitudinal play, and therefore, the derailment risk. This is even more critical for two axle wagons, which is the case of Europe.

The performance of this technology in winter is good. This is because of the mechanism's simplicity and robustness, reducing the number of components, but also due to the open head geometry, that minimizes the possibility of dust, snow or ice packing in cavities.

This coupler head is simple to produce because most of the components are produced from cast steel and there is no need to machine parts. The knuckle element should be periodically replaced because it is the one that suffers higher wear rates. In some cases, brass is used for this part, to minimize friction forces.

This type of coupler has been used in British Railways in the electrical multiple units, at cab ends.

### **8.2.2 Willison-based solutions (SA-3, AK69, C-AKv, Z-AK)**

In this group the SA-3, AK69, C-AKv and Z-AK solutions are included. All of them are based on the SA-3 concept that uses the Willison profile together with the same latching mechanism. Even though, not all of them are mechanically compatible.

The latch mechanism is robust, good for freight, and allows for 1.000 kN -1.500 kN tractive and 2.000 kN compressive force.

The main drawback of this solution is the high play, inherent to this latching concept. This play is necessary to allow the latching elements to rotate and release. If small gaps exist between movable parts, and high frictions occur, due to excessive dust, the latch release mechanism could get stuck, not being able to couple or uncouple the cars.

High plays induce a bad dynamic behaviour in the vehicle, increasing the derailment risk. This effect is even more important in case of two axle wagons.

Some upgrades limit lateral and longitudinal play down to 2 mm. The C-AKv solution includes a vertical guiding horn and conical receptor that limits the vertical play down to +/-4.5 mm, eliminating the risk of unintentional vertical disengagement. This is a similar solution to the Tightlock upgrade in the AAR Janney versions.

The SA-3 profile play also generates higher wear rates in the whole coupler head that lead to a full replacement of it. Wear is also detected in the new developed drawgear.

C-AKv solution, which is the most advanced available solution for freight, allows pneumatic and electric connections, but requires some specific floatable mountings that absorb the small displacements and makes the system more complex. C-AKv and also other couplers of the "semi-automatic" type require manual intervention for coupling. These operations are related to the brake pipe connection. Safety in railways requires a brake pipe valve that evacuates the brake pipe when there's an unintentional uncoupling. The C-AKv doesn't include this valve, therefore, manual pneumatic coupling should be done in order to comply with safety requirements. .

Some SA-3 commercial upgrades, like the VOITH solution, allow pneumatic connections and are compatible with screw couplers. However, they are heavy elements, not easy to operate.

The performance in winter is one of the strengths of this solution. It is an open-head geometry that minimizes closed cavities. The mechanism is simple with a limited number of movable parts and joints, which reduce the risk of jamming due to ice.

The price of the SA-3 is very low and affordable, because it is widely extended and optimized along the years. It is formed by cast steel parts and non-machined geometries, which minimize costs. Moreover, it has been mass produced, leading to low costs. Higher automation levels of the SA-3, such as the C-AKv have a medium cost, and this is the main reason why it has not been successful yet.

### 8.2.3 Scharfenberg

The alignment method uses a conical protrusion that helps the engagement, until the cylindrical base surface engages a circular receptor hole in the opposing coupler. This is a reliable fixation method that restricts vertical and lateral play below 1 mm (figure 21).



**Figure 21: CAF's T10 Automatic Coupler**

The latching mechanism is one of the most interesting ones, because it limits the longitudinal play to the minimum. However, there are more parts required, with complex geometries, and also requires some additional machining operations in the coupler head.

Special attention has been paid to try to simplify the number of parts of this solution, and achieve a low cost upgrade, but this reduction has not been possible.

The tractive force varies, depending on the Scharfenberg model type, but it starts from 600 kN and goes up to 1.000 kN. The compressive force goes from 800 to 2.000 kN.

Reduced longitudinal play is beneficial for the dynamics, and to reduce wear, as it limits the level of continuous impacts in operation.

This concept is widely used in Europe for passenger applications, and it allows the installation of pneumatic and electric heads.

Wear in the latching mechanism does not affect directly to the longitudinal play, because there is always a spring preload that mitigates this effect.

The performance of this type of coupler in winter depends on whether they are equipped with heating elements or not. Their closed-cavity geometry and the number of sliding surfaces generate operational problems. Heaters are not considered for a freight implementation; therefore, this point should penalize this concept, when comparing it with other open-head geometries, better for winter.

The price of this coupler type is in the high range, because of the number of parts and their complex geometry.

To conclude, this solution is interesting in terms of wear and dynamics, but the high cost makes it difficult to implement it in the freight market.

#### 8.2.4 BSI

BSI couplers use a closed-head typology, provided with a pair of teeth that engages one against the other (figure 22).



**Figure 22: Real BSI coupler**

When coupled, the teeth restrict vertical and lateral displacements, and provide a rigid coupler type. This is the final approach alignment technique, which allows for a good rigid fixation, minimizing play. However, transversal play will be higher than the Scharfenberg one, because the latter uses diameter adjustment, for a more rigid and tight alignment method.

The BSI's initial approach alignment method is based on the flat front plate of the head, which allows alignment when touching the heads, similar to the Scharfenberg one, together with a horn that helps with the vertical alignment, but also enhancing the lateral gathering range.

The latching system is based on two pins that engage one against the other, in a configuration similar to the ones used in common doors. This mechanism is one of the most simple and requires less number of parts. However, to be able to operate, it needs some longitudinal play, to allow the

release of the pins in the engagement process, and the retraction of the pins in the disengagement (figures 23 and 24).

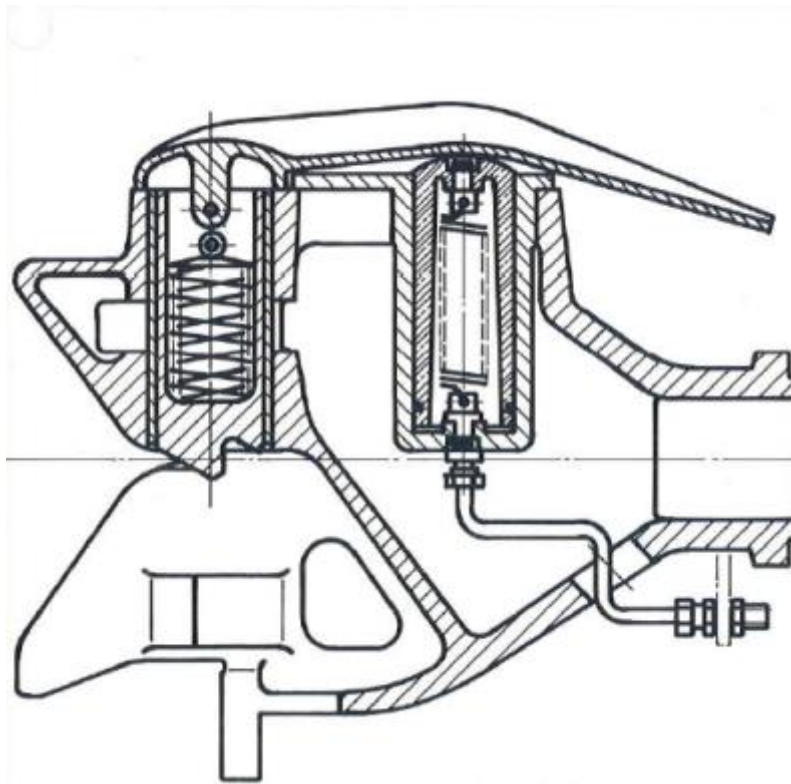
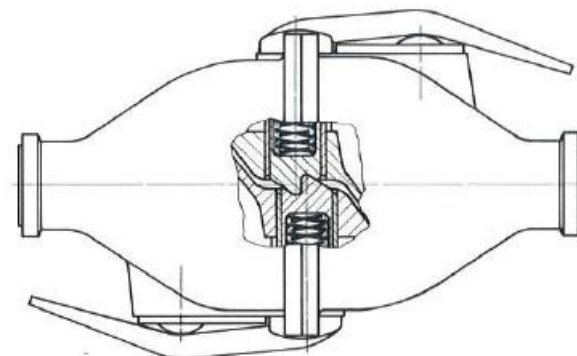
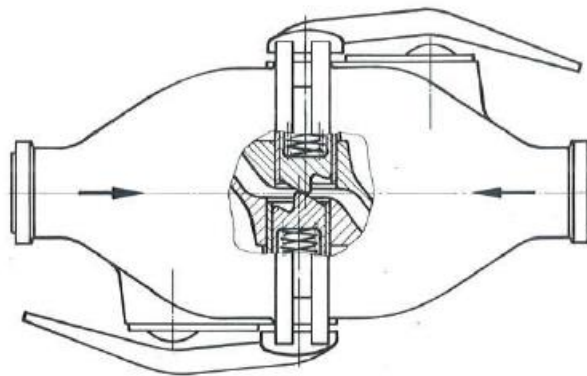
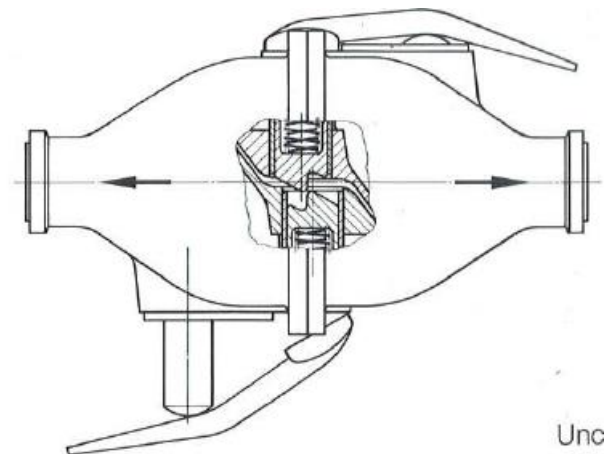


Figure 23: BSI coupler mechanic concept





**Figure 24: BSI coupling process**

Longitudinal play is very common in most of the existing latching mechanisms. The only ones that limits it to the minimum are the Scharfenberg and Schwab solutions, but no significant differences in dynamics exist.

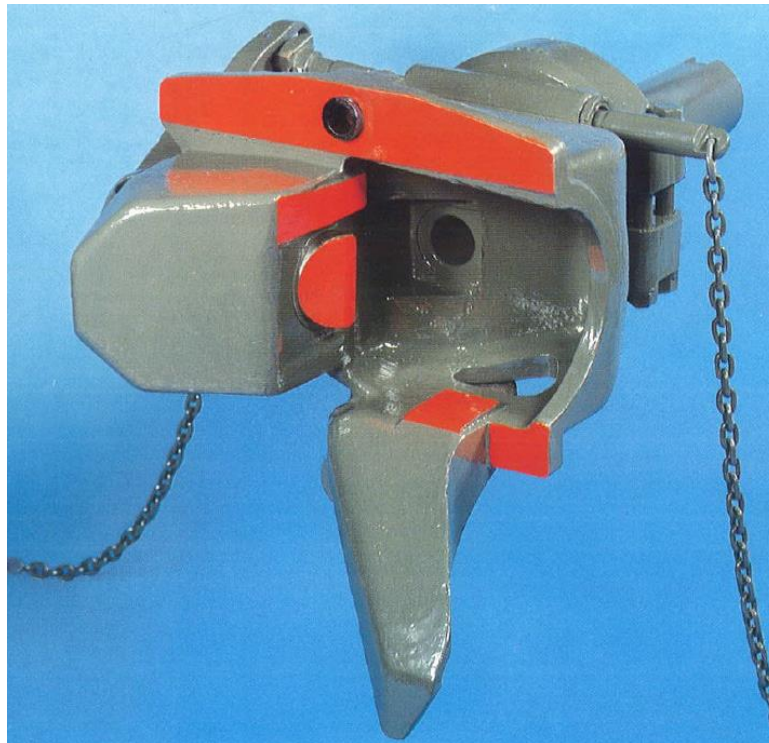
In the BSI, longitudinal play induces wear in the locking pin, and if not properly controlled, it could lead to a sudden disengagement. This play has also an impact in the life of the spring and other elements. For this reason, there is a patented upgrade that includes a second latching mechanism that prevents continuously alternate loading the spring.

Transversal play does exist and is higher than the Scharfenberg. However, it is expected to be smaller than open geometries, such as the C-AKv and SA-3-based ones.

The maximum tractive force is in the range of 1.500 kN, and the compressive in the 2.000 kN. These values are acceptable for freight applications.

BSI couplers are commonly used in passenger applications, because their limited transversal play, allows passing pneumatic and electric signals. Pneumatic signals are integrated in the head frame, but electric signals are mounted in an external holder, attached to the coupler head.

There are simpler solutions that only include pneumatic connections (figure 25).



**Figure 25: Simplified BSI version**

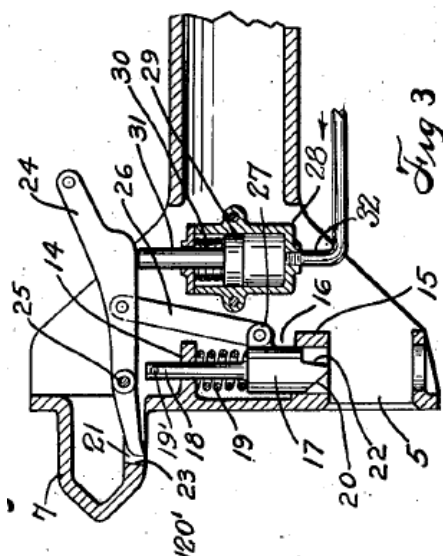
The performance of the BSI solution in winter conditions has to be addressed, but there are some improvement points to make it more reliable for these conditions. This is mainly to adapt the external head so that it has a more open geometry, leading to less closed cavities. If this first point is solved, the latching mechanism should not be problematic, because the number of parts and components, prone to get stuck due to ice is minimized.

The cost of a complete BSI head is in the same range as the Scharfenberg type, due to the head geometry. For this reason, special attention should be paid to the optimization of this part, in order to reduce costs. The latching mechanism uses a small number of parts, and it doesn't require too much machining operations in the head. This is positive to reduce costs.

The latching mechanism of the BSI solution is really interesting for the present project, because it provides a good solution in terms of gathering range, play, reliability of the mechanism, and forces, but also allows to minimize the number of components, thus, reducing the risk of failure. This is also beneficial for winter operation, because increases reliability and minimizes costs.

### **8.2.5 Tomlinson**

The alignment and head geometry is very similar to the BSI solution. The latching mechanism is similar, as well. However, the main difference is that the release mechanism allows the release of the two latches, at the same time (figure 26).



**Figure 26: Tomlinson coupler concept**

This latching solution is considered not as good as the BSI, in terms of force transmission, because there are two latches, and therefore, different forces are absorbed for each one. This makes the resultant force not to be aligned with the central plane, and induces bending moments.

When two couplers encounter, if they have different wear rates in their latching mechanisms, most of the tractive force will be transmitted through the latch which has lowest play.

Apart from this, the rest of the analysis brings out similar conclusions to the BSI.

### 8.2.6 Wedgelock



**Figure 27: Wedgelock coupler**

According /15/ the coupler is almost exclusively in use in UK underground trains; the latching mechanism is similar to BSI and Tomlinson. In the version provided the gathering range is quite small; manual alignment of the coupler is often necessary. Also the coupler is pneumatically operated.

### 8.2.7 GF Fischer

The external head geometry is very similar to the BSI and Tomlinson solutions, and thus, similar results in terms of signals transmission, and performance in winter are expected.

The latching mechanism is based on a plunger that works as the latching element, activated by means of a rod (figure 28). Decoupling is done by means of rotating a cam.

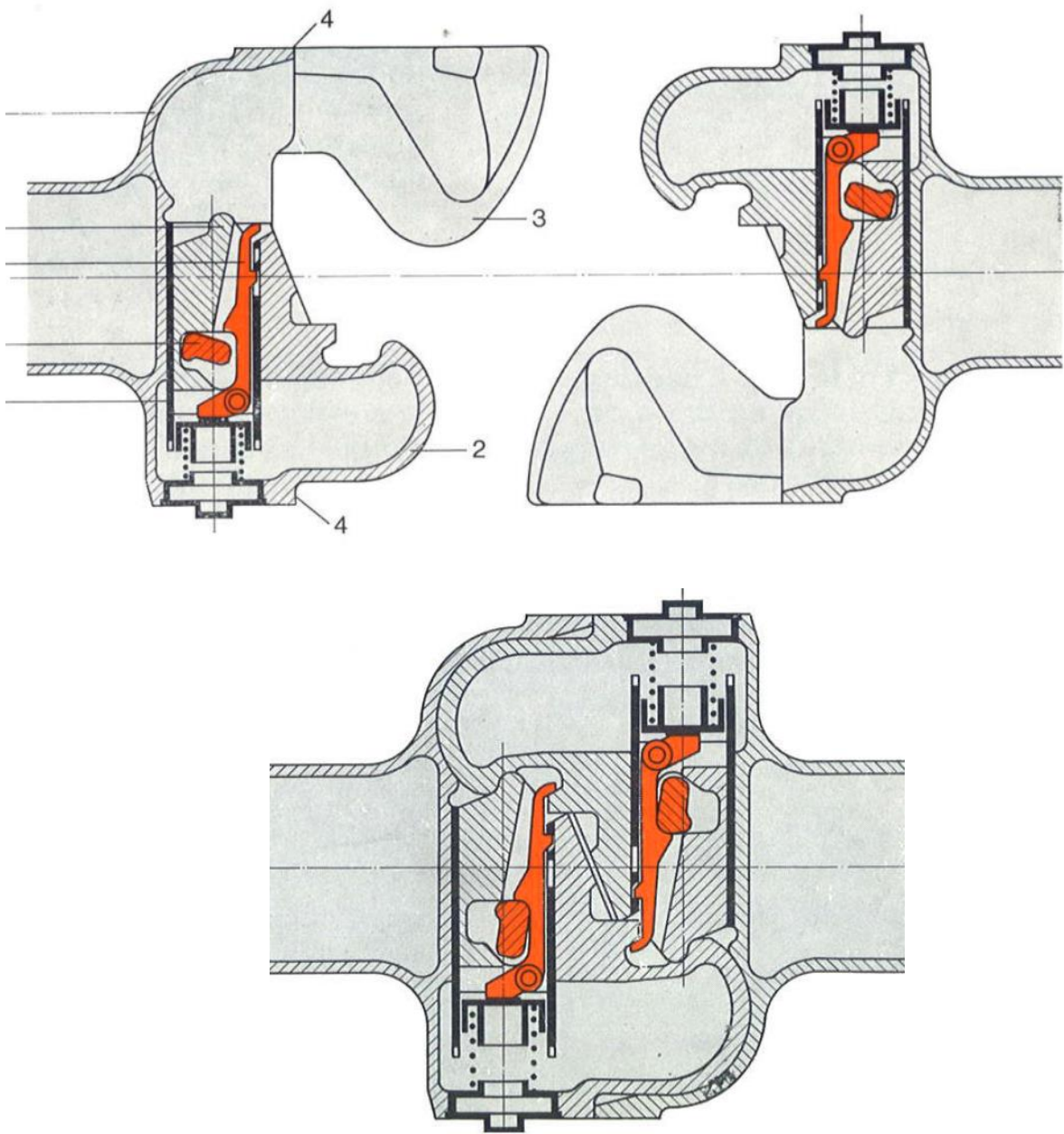


Figure 28: GF Fischer coupling mechanism

### 8.2.8 Schwab

This solution is based on an inclined surface, in which two latches engage one against the other. The latch consists on a lever that engages radially the protruded horn of the adjacent coupler. An intermediate lever is used to reduce the actuation force of the disengagement actuator.

The head geometry allows for a good vertical and lateral alignment, by means of the guiding vane and the jaw (figure 29). This has to be addressed, but it is expected to have similar performance as the BSI in terms of transversal play, because it allows mounting an external electric head. In order to assure engagement, the coupler heads should be initially shifted around the vertical axis, to generate a lateral offset that allows engaging. This means that for each coupling operation, some rotary motion is required in the pivot. In case that both couplers are aligned, coupling won't be

possible. This is a disadvantage because it may require manual intervention for a correct alignment.

This rotation around the pivot increases the wear rate in the pivot of the drawgear.



**Figure 29: Schwab real coupler**

The tractive force range starts from 600 to 1.000 kN, and 900 kN to 1.500 kN in compression.

One of the main advantages of this solution is that it minimizes friction forces that face the uncoupling actuator, when uncoupling under tractive forces.

Another positive point of this solution is that it eliminates or minimizes play, while assuring always a positive contact pressure. This reduces the shock levels in operation and improves dynamic performance. Wear is reduced thanks to this play minimization. The use of rotative elements, minimize friction and reduces the wear rates in parts.

Operation in winter should be further studied, because it is difficult to evaluate at this stage. Overall, the head geometry is open and doesn't lead to important cavities, which is positive. However, the latching mechanism should be tested. The latter is similar to the standard ski fixation elements. It is known that ski fixations fail when there is too much snow, but with a few impacts, the some part of the snow falls down and then the latch performs well.

No electric signals are provided in this configuration, but external electric heads can be mounted. The actuation mechanism is pneumatic, similar to pneumatic actuations in the standard passenger Scharfenberg and BSI solutions.

Head geometry is based on a cast iron part, divided in two halves that are mounted together. The front plate is an external plate. The latching elements require some accuracy, and therefore, should be machined. For this reason, price is expected to be in the same range as the Scharfenberg or BSI.

### **8.3 TRADE-OFF**

In this section, the conclusions of the previous analysis are grouped, and the different coupler configurations scored, according to specific KPI (table 6). The higher the total score number, the better the solution is for the current application.

The results are classified in a table format. In table 7, the numerical values are collected and multiplied, according to a weight factor, used to prioritize the KPI, according to its importance in freight application. Weighting the KPI is not an objective task, and depending on the different values given, one solution or other can be selected as the best choices. For this reason, different weighting scenarios have been considered (table 9), in order to check if the preferred solutions are common to most of the weighting scenarios.



	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
<p><b>Interoperability</b></p> <p>5: Compatibility with some of the EU existing couplers</p> <p>1: No interoperability with EU existing couplers</p>	Not a significant number of AAR couplers in freight		SA-3 is already in use in East Europe in 1435-networks, and also in countries like Turkey, Iran and Irak. Depending on the level of automation, high or low automation level-rolling stock can be exchanged with these networks, and this is an important issue		Not a significant number of Scharfenberg couplers in freight		Not a significant number of BSI couplers in freight		Not a significant number of Tomlinson couplers in freight		Not a significant number of GF Fischer couplers in freight		Not a significant number of Schwab couplers in freight	
		1		5		1		1		1		1		1

	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
<b>Gathering range</b>	Knuckle-based. Conical teeth and receptor to limit vertical relative motions. Worst alignment system. Many times it needs for a manual alignment. RSSB reports gathering limitations that require the two knuckles to be opened		Based on the Willison profile. Low gathering range Additional plates or conical surfaces are used for vertical engagement and to restrict vertical displacements. However, it will hardly restrict the transversal play, as much as the Scharfenberg or BSI coupler heads. It limits horizontal backlash to 2 mm, whereas the BSI/Scharfenberg limit it to 0,8-1 mm Wear in the head will lead to a complete replacement of the coupler head. The zigzag engagement profile leads to a higher wear rate in the shank and carrier The vertical play of the C-AKv is +/-4,5 mm		Alignment is done using a pair of conical surfaces. We achieve vertical and lateral fixation Robust alignment system that releases the coupling links from transversal forces		Alignment is done using a pair of protruded pyramid-shaped surfaces. Vertical and lateral fixation is achieved and transversal play, limited.		Smaller apertures. Pyramidal centering horns, like in the BSI Similar performance to the BSI, with small transversal backlash. Gathering range, similar to the BSI		Head very similar to the Scharfenberg, Tomlinson and Wedgelock solutions. Provided with a circular coupling surface and a receptor. The first alignment is done with a horn, so similar gathering ranges to the BSI and Scharfenberg are achieved. Transversal play is in the same range as the Scharfenberg and BSI		Vertical and lateral alignment method. Vertical expected clearance similar to C-AKv. Limited gathering range due to the need of coupling always attacking the opposed coupler from the right side	
		1		1	Vert: +/-140 mm Horiz: 370/-275 mm	5	Vert: +/-100 mm Hor: +200/-200 mm	4		5	Vert: +/-150 mm Horiz: 290/-290 mm	5		1



	Concept 1 AAR Janney Tightlock	Concept 2 Willison: SA-3, C-Akv AK69, Z-AK	Concept 3 Scharfenberg	Concept 4 BSI	Concept 5 Tomlinson	Concept 6 GF Fischer	Concept 7 Schwab
<p><b><u>Resistance to winter</u></b></p> <p>5: Good feedback reported in winter</p> <p>3: Problems reported in winter</p> <p>1: Prohibited in some regions in winter</p>	<p>Good results, open geometry and less cavities</p>	<p>Good results, open geometry and less cavities</p>	<p>Bad results, ice/snow packing in cavities. We didn't find evidence of the technical reasons for the T10 being prohibited in Finland</p>	<p>Expecting bad results, ice/snow packing in cavities of the coupler head. No heating elements are used currently. Some companies are testing a new version with heaters</p>	<p>Expecting bad results, ice/snow packing in cavities of the coupler head. Articulations are prone to get stuck.</p>	<p>Better results in winter than Scharfenberg. In Finland their use was authorized</p>	<p>Operation in winter should be addressed. For this, inputs coming from SBB Cargo early tests are welcome. However, no major problems with winter operation are expected. This is because the head design is open, without significant cavities and without many friction elements. The latching mechanism is similar to the standard ski fixation mechanism. Experience with this concept in snow.</p>
	5	5	3	3	1	3	5

	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
<p><b><u>Mechanism's reliability</u></b></p> <p>5: No major incidences reported in normal conditions. Tensile resultant force, centered.</p> <p>3: Some incidences reported in normal conditions; wear can lead to unintentional uncoupling. Tensile resultant force, uncentered.</p> <p>1: Lots of incidences reported. Prohibited in some regions; wear leads to unintentional uncoupling</p>	Reliable and robust mechanism, but unintentional uncoupling can occur when parts suffer wear. Reported incidents in London's commuter		Reliable and robust mechanism		Reliable mechanism, in normal conditions. Resist wear very well		Reliable mechanism if no wear exists. In case of wear, unintentional uncoupling can occur		Long rods form the coupler. Preferable to use smaller latching elements, more reliable under fatigue. Wear can lead to unintentional uncoupling		Long rods form the coupler. Preferable to use smaller latching elements, more reliable under fatigue. Wear can lead to unintentional uncoupling			
		3		5		5		5		3		3		5

	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
<p><b><u>Pneumatic coupling</u></b></p> <p>5: Small play, suitable for pneumatic couplings. No floatable nor retractable mechanism needed</p> <p>3: Higher play can be used with pneumatic couplings. Floatable or retractable mechanism needed</p> <p>1: High play, pneumatics not recommended"</p>	Higher plays, but this Tightlock version is widely used in the RSSB, together with pneumatic couplings		More complex automatic coupling elements because of the higher relative motion. Some commercial products have a floating and autocentering connector bracket that absorbs the existing offset and play.		Integrated pneumatic retractable connections, thanks to a limited relative motion. Better than BSI and Tightlock because transversal play is lower		Simple pneumatic retractable connections, thanks to a limited relative motion.		Simple pneumatic retractable connections, thanks to a limited relative motion.		Simple pneumatic retractable connections, thanks to a limited relative motion.		Deployable pneumatic coupler provided with a pneumatic actuator. This makes the system more complex and expensive. The best choice would be to use non-movable connectors.	



	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
<p><b><u>Electric connections</u></b></p> <p>5: Small play, suitable for electric connections</p> <p>3: Higher play, could lead to problems</p> <p>1: High play, electric connections not recommended. Need of floatable pinheads"</p>	Higher plays, but this Tightlock version is widely used in the RSSB, together with electric connections		No electric connections are available because of the high play. Even the newest commercial versions do not have these electric connections.		Electric pins mounted in a separate electric head that deploys after mechanical coupling has been completed. This is better, because protects the pinout from high impacts		The electric heads engage at the same time as the mechanic ones. This increases the risk of damaging the pins due to a high impact level. However, it is a cheaper solution than the ones using external moveable electric heads, but needs a floating bracket with some compliance for the final electric coupling. We could analyse in detail the electric connections in the C-AKv. The protection against ice/snow should be addressed.		Electric connections are done by means of separate electric heads. Specific alignment pins are provided, in order to reach to the final alignment when the heads are closer		The electric heads engage at the same time as the mechanic ones. This increases the risk of damaging the pins due to a high impact level. However, it is a cheaper solution than the ones using external moveable electric heads, but needs a floating bracket with some compliance for the final electric coupling. We could analyse in detail the electric connections in the C-AKv. The protection against ice/snow should be addressed.		Electric heads are mounted on a separate support	



	Concept 1 AAR Janney Tightlock	Concept 2 Willison: SA-3, C- Akv AK69, Z- AK	Concept 3 Scharfenberg	Concept 4 BSI	Concept 5 Tomlinson	Concept 6 GF Fischer	Concept 7 Schwab
<p><b>Wear</b></p> <p>5: Low wear in service. Low wear during coupling</p> <p>3: Higher play and wear in service. Higher wear during coupling</p> <p>1: Highest play and wear in service. Highest wear during coupling</p>	<p>Highest wear rates due to the continuous impacts and relative motions. The Tightlock solution mitigates these two problems, but there exist high wear rates during the coupling/uncoupling that have caused problems in London's Commuter</p>	<p>Higher wear rates because of the play and relative motion</p>	<p>Low transversal play, leads to low wear in the head. Reduced longitudinal play leads to low wear in the coupling links and mechanism. High wear rates during coupling/uncoupling. The latching mechanism withstands wear very well, because of the preloaded coupling solution.</p>	<p>Low transversal play, leads to low wear in the head. Higher wear rates in the coupling uncoupling. However, wear in the plunger has a direct impact in the longitudinal play. Longitudinal play leads to continuous impacts and wear in the latching elements/plunger. This also affects the life of the spring as it works under continuous alternate stresses</p>	<p>Low transversal play, leads to low wear in the head. However, wear in the plunger has a direct impact in the longitudinal play. Longitudinal play leads to continuous impacts and wear in the latching elements/plunger.</p>	<p>Low transversal play, leads to low wear in the head. However, wear in the plunger has a direct impact in the longitudinal play. Longitudinal play leads to continuous impacts and wear in the latching elements/plunger.</p>	<p>Expected wear in this solution is minimum, because relative motion is minimum. Moreover, there are no major friction forces during the engagement/disengagement.</p>
	3	3	5	5	5	5	5

	Concept 1 AAR Janney Tightlock	Concept 2 Willison: SA-3, C-Akv AK69, Z-AK	Concept 3 Scharfenberg	Concept 4 BSI	Concept 5 Tomlinson	Concept 6 GF Fischer	Concept 7 Schwab
<p><b>Dynamics</b></p> <p>5: &lt;2 mm. Low longitudinal play, good dynamics</p> <p>3: 2-5 mm. Higher longitudinal play</p> <p>1: &gt;5 mm. Highest longitudinal play, bad dynamics</p>	<p>Very high longitudinal play that leads to the highest derailment risk. This is mitigated in the US and Russia by the use of bogie-provided wagons. This solution would be really risky for European wagons</p>	<p>Higher longitudinal play than the ACs, leading to a higher risk of derailment, even more in European wagons The autocentering capacity should be studied, as it is positive for European wagons</p>	<p>Very low longitudinal play, good dynamics and lower derailment risk The autocentering capacity should be studied, as it is positive for European wagons Transversal play: +/-0,85 mm Longitudinal play: 0,8 mm</p>	<p>Small longitudinal play, good dynamics The autocentering capacity should be studied, as it is positive for European wagons</p>	<p>Small longitudinal play, good dynamics The autocentering capacity should be studied, as it is positive for European wagons</p>	<p>Small longitudinal play, good dynamics The autocentering capacity should be studied, as it is positive for European wagons</p>	<p>Longitudinal play is reduced to the minimum, which is very positive for dynamic performance</p>
	3	3	5	5	5	5	5

	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
<p><b><u>Mechanism strength</u></b></p> <p>5: Tens. &gt;=1500 kN; Compr. &gt;=1500 kN</p> <p>3: Tens. 1000-1500 kN; Compr. 1000-1500 kN</p> <p>1: Tens. &lt;1000 kN; Compr. &lt;1000 kN"</p>	<p>Based on a knuckle and its blocking mechanism. Very simple but more prone to suffer damage or breaks under shock loads</p>		<p>Based on a concept in which the latches work under compressive forces. A minimum play should be added, to be sure that the latching mechanism does not get stuck due to high friction forces. This needed play will be translated into longitudinal play. Even though this is a more robust solution, a break in the system will lead to a replacement of the whole coupler head castings</p>		<p>The same concept as the classical Scharfenberg solution, based on a couple of rotary disks</p>		<p>Based on a door latch system. A set of two latches get into contact and fix the two heads. It needs a slight backlash to be able to completely activate the latch and minimize the friction forces that could lead to a failure in the latch deployment. However, some solutions with zero backlash but a higher decoupling forces could be assessed</p>		<p>Very similar mechanism to the BSI one, with the difference that the</p>		<p>Very similar to the BSI mechanism, expecting to have similar performance. However, the fixation mechanism is slightly different and solves the BSI problems associated to the spring oscillation in operation.</p>		<p>Intelligent and good engineering solution, that minimizes the number of components, and assures a backlash free latching mechanism</p>	

	Concept 1 AAR Janney Tightlock		Concept 2 Willison: SA-3, C-Akv AK69, Z-AK		Concept 3 Scharfenberg		Concept 4 BSI		Concept 5 Tomlinson		Concept 6 GF Fischer		Concept 7 Schwab	
"Price 5: ≤8 k€ 1: ≥10 k€"	All the components come from cast steel; there is no need to machine parts and this lowers down the price. The knuckle is the element that suffers the most from wear. This component is easily replaceable, and thus, the maintenance costs are low		Lower costs, based on the SA-3 solution		10 k€ approx. Effort should be paid to reduce costs respect to the classical Scharfenberg solution		10 k€ approx. Effort should be paid to reduce costs respect to the classical BSI solution		Expected price around 10 k€ Effort should be paid to reduce costs		Expected price around 10 k€ Effort should be paid to reduce costs		Expected price is high. This is because the head is formed by many machined parts. This is the main drawback of this solution. Moreover, the active pneumatic connection release mechanism increases the price more	
	8 k€	5	10 k€	1	10 k€	1	10 k€	1	10 k€	1	10 k€	1	10 k€	1

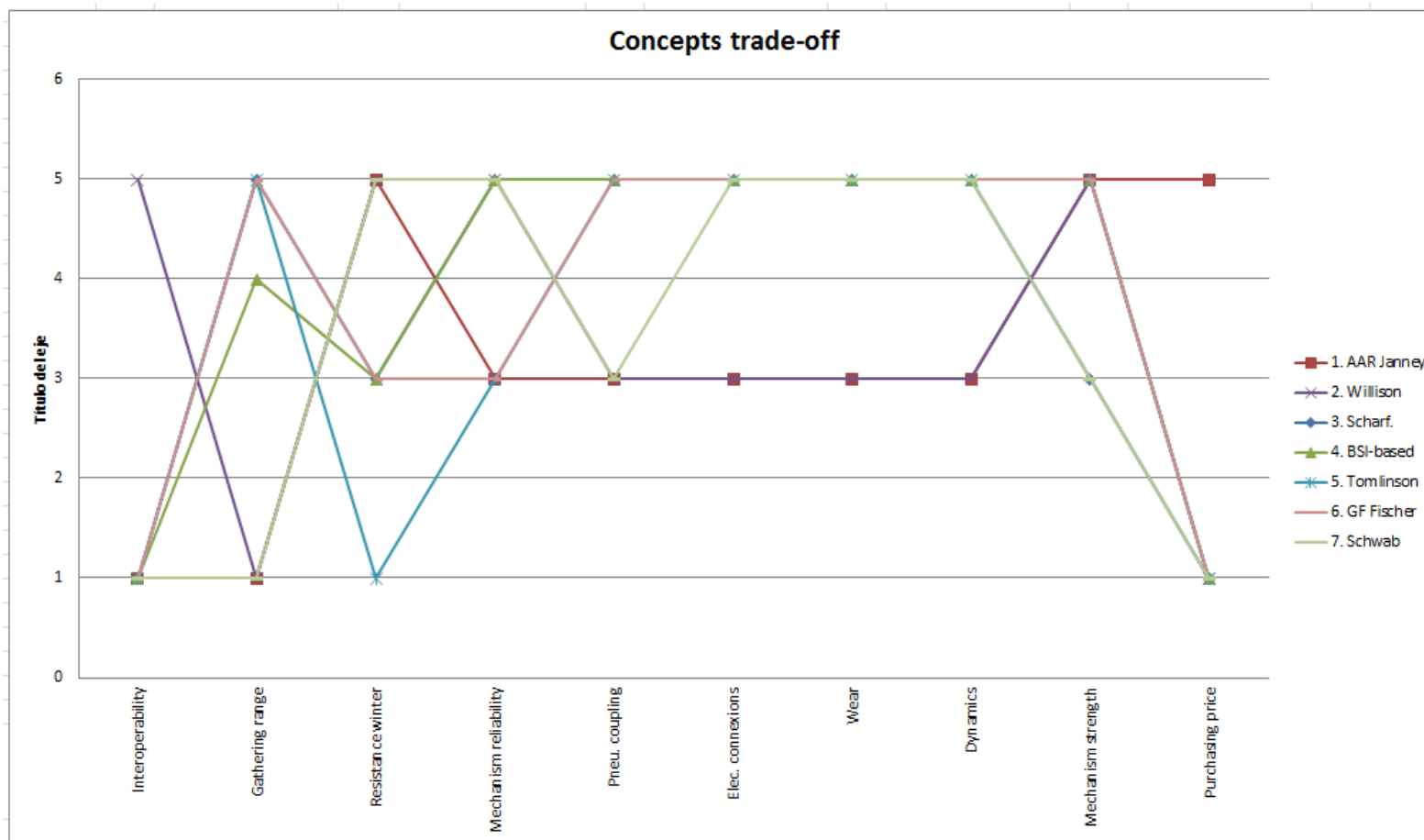
	Concept 1 AAR Janney Tightlock	Concept 2 Willison: SA-3, C-Akv AK69, Z-AK	Concept 3 Scharfenberg	Concept 4 BSI	Concept 5 Tomlinson	Concept 6 GF Fischer	Concept 7 Schwab
<p><b>(1)</b></p> <p><b><u>Comments for a freight implementation</u></b></p>		<p>Even though the vertical stroke is limited, it will always have backlash, and pneumatic/electric couplings will always be provided with guiding elements and compliance (floating)</p>	<p>Modify the coupler head, to minimize the inner cavities and thus the risk of having snow/ice packed. Better to use an open head geometry.</p>	<p>Modify the coupler head, to minimize the inner cavities and thus the risk of having snow/ice packed.</p>	<p>Modify the coupler head, to minimize the inner cavities and thus the risk of having snow/ice packed.</p>	<p>More components than other solutions, more contact surfaces and thus, more friction and risk of failure</p>	<p>This is a good solution that can work, but it has some drawbacks. First, the maximum Tractive forces should be addressed. Second, expected production costs are high</p>

	Concept 1 AAR Janney Tightlock	Concept 2 Willison: SA-3, C-Akv AK69, Z-AK	Concept 3 Scharfenberg	Concept 4 BSI	Concept 5 Tomlinson	Concept 6 GF Fischer	Concept 7 Schwab
<b>(2)</b> <b><u>Comments for a freight implementation</u></b>			Still an expensive mechanical solution due to the number of parts and complex geometry. Special efforts should be paid to optimize the design of parts, in order to minimize costs	. Simpler solution, easy to optimize and minimize costs. Special effort should be paid to the head design, to minimize the risk of ice/snow packing	More parts than the BSI lead to a more complex solution. The only advance is the full release of the system by using a single lever, but it makes a more complex and weak mechanism	Many parts that could fail due to fatigue, wear and winter conditions. Higher frictions will lead to higher risk of jamming in winter, with moisture	

**Table 6: Comparative table between different coupler solutions**

	Weight [1-5]	Trade-off													
		Concept 1. AAR Janney Tightlock	SxW	Concept 2. Willison SA-3 C-Akv AK69 Z-AK	SxW	Concept 3. Scharfenberg	SxW	Concept 4. BSI	SxW	Concept 5. Tomlinson	SxW	Concept 6. GF Fischer	SxW	Concept 7. Schwab	SxW
Interoperability	5	1	5	5	25	1	5	1	5	1	5	1	5	1	5
Gathering range	4	1	4	1	4	5	20	4	16	5	20	5	20	1	4
Resistance winter	5	5	25	5	25	3	15	3	15	1	5	3	15	5	25
Mechanism reliability	5	3	15	5	25	5	25	5	25	3	15	3	15	5	25
Pneu. coupling	1	3	3	3	3	5	5	5	5	5	5	5	5	3	3
Elec. connexions	1	3	3	3	3	5	5	5	5	5	5	5	5	5	5
Wear	3	3	9	3	9	5	15	5	15	5	15	5	15	5	15
Dynamics	2	3	6	3	6	5	10	5	10	5	10	5	10	5	10
Mechanism strength	1	5	5	5	5	3	3	5	5	5	5	5	5	3	3
Purchasing price	5	5	25	1	5	1	5	1	5	1	5	1	5	1	5
<b>TOTAL SCORE</b>			<b>100</b>		<b>110</b>		<b>108</b>		<b>106</b>		<b>90</b>		<b>100</b>		<b>100</b>

Table 7: Results classification, according to one weighting scenario



**Table 8: KPI comparison for the different AC-types, without considering weighting factors**

Table 8 shows a comparison table, showing the score values obtained for each coupler. In order to eliminate the subjectivity that implies adding more or less importance to the different parameters, the table considers different weighting scenarios, named as W1, W2,... This helps to find a convergence in the results even though we consider a slight variation in the weight of each parameter. According to this, each column provides an individual weighting configuration. On the lower part of the table the score obtained by each coupler concept is shown. For a faster review of the

results, together with the numerical results a colour fringe has been included in each cell. The green cells show the better-scored solutions, whereas the red ones show the worse options.

KPI	W1	W2	W3	W4	W5
Interoperability	5	5	5	5	5
Gathering range	4	3	4	3	3
Resistance to winter	5	5	5	5	5
Reliability	5	5	5	5	5
Pneumatics	1	1	1	1	1
Electric sign.	1	1	1	1	1
Wear	3	4	3	3	3
Dynamics	2	4	3	3	3
Strength	1	2	3	2	1
Price	5	5	5	5	5
<b>Technical solutions</b>					
1. AAR Tightlock	100	113	113	107	102
2. Willison-based	110	123	123	117	112
3. Scharfenberg	108	121	119	111	108
4. BSI	106	122	121	112	107
5. Tomlinson	90	105	105	95	90
6. GF Fischer	100	115	115	105	100
7. Schwab	100	117	111	107	104

**Table 9: Coupler types trade-off, for the different weighting scenarios**

## 9. CONCLUSIONS AND DESIGN DRIVERS

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The weighting values have been selected according to the following justification:

- **Interoperability:** Has been considered one of the most relevant factors, because it will have an impact in the deployment of the solution in Europe. The highest level of interoperability will allow for a higher number of business cases.
- **Gathering range:** It is considered a relevant factor, so it is in the medium-high range. The higher the gathering range, the higher number of coupling areas there will be.
- **Resistance to winter:** It is considered one of the most relevant factors, so it is on the top range. In Europe there are a high number of lines in the freight network that operate under winter conditions for long periods of time. The use of heaters is not possible in freight because of the high costs that will include, so a high resistance to winter is a clear requirement and a main driver.
- **Reliability:** It has been considered one of the most relevant factors, so it is on the top range. Reliability considers the mechanisms complexity and therefore, the risk of failure.
- **Pneumatics:** The lowest mechanical play, the better the pneumatic coupling will be possible. Pneumatics has been considered a low impact factor, because even with high plays, such as the ones in the SA-3, pneumatic contact is possible. For this reason, this is not the main driver.
- **Electric signals:** Electric connections are very sensible to the mechanical play. However, at IP5, wireless solutions for signal transmission are the baseline. For this reason, this factor has been weighted in the lowest range.
- **Wear:** It has been considered as a medium-high range parameter, because the availability of the vehicle depends, among other factors, on how much the system resists to wear.
- **Dynamics:** This has been considered as a medium range parameter. In freight applications, dynamics is more related to safety against derailment, whereas in passengers it is a very important factor because the vehicle comfort depends on it. In order to mitigate the impact force levels due to the longitudinal play in curves, for two-axle wagons that can lead to derailment, elastic drawgears are used.
- **Strength:** Has been considered a low-rate parameter, because the analysis is focused in the concept, more than in the performance of the existent solutions. In case that the selected concept is weak, regarding strength, engineering effort can be paid to enhance that feature. As a result, this parameter is not the driver to select the right concept.
- **Price:** Has been considered as a high-rate parameter, and one of the main design drivers. Price has been the reason why many of the previous solutions have failed all along history.

The analysis shows that the most competitive solution, according to the current weighting scenarios, is the Willison, followed by the BSI and Scharfenberg types. After this technical analysis, some clear conclusions, and basic design drivers can be extracted, in order to establish a baseline concept to work on, at further steps of the project.

After this study, some conclusions and statements can be considered:

1. Considering interoperability with East Europe and other countries, such as Russia, Turkey and Iran, as one of the drivers, compatibility with SA-3 is a clear requirement.
2. Due to the interest in FR8RAIL on wireless solutions for data and signal transmission, the importance of the mechanical longitudinal play given by solutions such as Scharfenberg and BSI, is reduced and other factors are considered of higher priority.
3. In order to deal better with winter conditions in Europe, the coupler head should be based in an open geometry, which is the case of the C-AKv, the Schwab, and the improved AAR solutions (Tightlock). This is because they lead to fewer cavities, in which ice and snow can be packed. The coupler head part will be made in cast steel. It can be divided into two parts. A special effort should be paid in minimizing the number of machined surfaces.
4. Enhancement of the gathering range is important, in order to increase the operative performance of the new solution. This will lead to the use of horns or deflectors in the head, that can be part of the head cast iron geometry or external additional elements, such as in the Schwab or C-AKv solution.
5. The most reliable latching mechanisms to use are the BSI and the GF Fischer ones. However, they are expected to be more expensive, and it's not necessary such a reduced mechanical play. A latch system such as the SA-3 could be enough for the freight requirements, on the basis that wireless signal transmission is used.
6. Pneumatic connections require rigid couplers with reduced transversal play, ranging 2-3 mm. Depending on the head geometry, this can be achieved with the Willison profile concept, but special care should be taken not to increase too much this value, as it will generate higher wear rates.
7. Wear should be minimized, in order to reduce LCC costs, increase safety and availability. The best results are achieved with the Scharfenberg and BSI, as a result of the low mechanical play. However, these solutions lead to higher costs and lower interoperability. On the other side, SA-3 suffers higher wear rates, due to the higher mechanical play. However, the low cost associated to the production, together with the large number of existing units, leads for a fast replacement and low out of order periods.
8. When analysing dynamic behaviour the existent longitudinal play is evaluated, and therefore, the range of impacts in service, when shifting from tractive to compressive forces. Even though the SA-3 provides higher play, in comparison to Scharfenberg and BSI, the performance of the SA-3 is still good enough for the European corridors. Special elements can be included to mitigate the impact levels in two-axle wagons, such as elastic drawgears.play
9. Strength is one of the most important parameters of the coupler. This limits the operative capacity and therefore, is a limitation to the speeds and train lengths, which will have a direct impact in the profitability of the different European business cases. A goal value of 1.500 kN could be set up for next stages. SA-3 solution offers good strength values and is considered a good choice.

10. Price is probably the main driver of the development. This should be considered at every stage of the project. Price has been the main reason why previous solutions have failed in the European freight sector. Therefore the target price for an Automatic Coupler with automation level I (only automatic mechanical coupling) should correspond to the price of a (one) screw coupler with buffers, i.e. be in the range of ca. 1.300 – 1.500 EUR. This ensures that the use of Automatic Couplers can be economically justified even in cases where due to the operational or cost situation no or only very limited cost-relevant benefits can be realized, which is a pre-condition for the introduction of Automatic Couplers on a broad front as a general system in European rail freight. Preliminary price investigations for Automatic Couplers on the world market indicate that such a target price could be achievable. For Automatic Couplers with higher automation levels higher prices can be accepted, depending on the benefits in the specific application. The target prices may be updated along the project development taking into account with the results of other parallel and subsequent studies, i.e. a deeper analysis of costs and benefits and possible migration strategies based on economic issues and migration
11. Considering the different business cases and economic differences in Europe, it seems a good approach to focus on a modular solution that offers different automation levels to target better each case. According to the Automation Levels considered, SA-3 could be established as the lowest automation solution, but higher automation solutions can be developed, based on existent couplers like the UIC AK69 or C-AKv.
12. A migration strategy is under development in task 5.3 of the current project. This study provides some clear ideas, on how should the migration process should be configured. One of these ideas is the need of a progressive Migration Process. This is required due to the difficulty of isolating traffics in Europe. According to this, the new Automatic and the old Screw couplers will coexist within a period of time that will be defined at further steps of the project. Overall, the simultaneous Migration Process is rejected from the beginning, and therefore, we can state the importance in providing the new concept with a compatibility with the existing Screw Couplers. Special care should be taken in order to maximize the operator's working area (Berne rectangle), in order to fulfil the European safety requirements.

## 10. FUTURE RESEARCH AREAS

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As indicated in the previous section, the new concept should be based on the existing Willison profile solutions. According to this, special effort will be paid to investigate the existing technical and operational limitations of the current SA-3, AK69, C-AKv and Z-AK couplers, in order to enhance their performance and propose a new conceptual design. Nevertheless, a second concept, based on the BSI or Scharfenberg concept should be investigated, as a backup solution, in case that wireless techniques for signal and power transmission are proved to be unfeasible.

Also possibilities for reducing manufacturing costs of Automatic Couplers should be investigated, in particular – but not limited to – couplers with Automation level I.

Regarding the electric signal transmission, in previous chapters it has been stated the interest of the IP5 participants in using wireless solutions for wagon signal transmission. As said before, this will help to reduce the current mechanical play requirements to the couplers. However, electric signal transmission as well as remote uncoupling requires electric power in wagons, in order to feed the transmissor/receptor and actuator or electrovalve. For this reason, further research should be done in the frame of this project, in order to determine the type of onboard power generation/storing elements.

Another technology that should be investigated is the power transmission between wagons. According to the current strategy that avoids electric connections between wagons, it can be stated that wireless solutions can't be used for power transmission. There are some technologies under development that use the inductive effect to transfer power. However, the power losses between each transmission element are high and for a unit with a large number of wagons, this technology might not fit well.

## 11. REFERENCES

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- /1/ Edgar Salin: Die Automatische Mittelpufferkupplung Basel 1966
- /2/ Dorner et al: Die automatische Mittelpufferkupplung - ein wesentlicher Beitrag zur Rationalisierung des Eisenbahnbetriebes Bielefeld 1969
- /3/ TIS Study „Automatische Kupplungssysteme im Schienengüterverkehr –eine Übersicht“, Karlsruhe February 2015 -> <http://www.innovative-freight-wagon.de/wp-content/uploads/TIS-uebersicht-Kupplungssysteme.pdf> (checked 23rd of January 2017)
- /4/ Dr. Reiner Seibt: Die automatische Mittelpufferkupplung für die europäischen Eisenbahnen: <http://wirtschaftssenioren.ba-bautzen.de/amk/index.html> (checked 15<sup>th</sup> of January 2017)
- /5/ Dr. Helge Stuhr: Untersuchung von Einsatzszenarien einer automatischen Mittelpufferkupplung, Berlin 2013
- /6/ web site Voith Salzgitter: <http://www.voith.com/en/products-services/power-transmission/scharfenberg-couplers/scharfenberg-couplers-metros-14054.html> (checked 15<sup>th</sup> of January 2017)
- /7/ Tri Coupler development:  
[http://www.sharma-associates.com/projects/projects\\_railvehicles.aspx#TriCoupler](http://www.sharma-associates.com/projects/projects_railvehicles.aspx#TriCoupler) (checked 15<sup>th</sup> of January 2017)
- /8/ ADOPTION OF AUTOMATIC COUPLERS ON JAPANESE RAILWAYS, The Ministry of Railways of Japan, Tokio 1928
- /9/ Lexikon der Eisenbahn, Transpress VEB Verlag für Verkehrswesen, Berlin 1979
- /10/ INTERMAT; Dokumentation der im Rahmen der Vereinbarung zwischen den interessierten OSShD-Mitgliedern entwickelten automatischen Kupplung; gemeinsames Konstruktionsbüro DR/SZD ca. 1970
- /11/ UIC Meeting Paris: Status SBB Cargo on Automatic Coupling: Anna-Maria Sonntag, 08.12.2016 (not published)
- /12/ Neue Automatische Kupplung für Vollbahnen, Hug (Zürich); Glasers Annalen January 1958
- /13/ price for AAR couplers: <http://trn.trains.com/railroads/abcs-of-railroading/2006/05/couplers> (checked 22nd of January 2017)
- /14/ Prof. Dr. rer. pol. Bernhard Sünderhauf : The Automatic Centre Buffer Coupler (ACBC) The key to automating rail freight transport in Europe Cost-Benefit Analysis Grünstadt 2009 ISBN: 978-3-940900-14-2; also:  
[https://nrw.vcd.org/fileadmin/user\\_upload/NRW/Themen/automatische\\_mittelpufferkupplung.pdf](https://nrw.vcd.org/fileadmin/user_upload/NRW/Themen/automatische_mittelpufferkupplung.pdf) (checked 23rd of January 2017)
- /15/ Wedgelock coupler: <http://www.trainweb.org/tubep prune/coupling.htm> (checked 23rd of January 2017)