ZESZYTY NAUKOWE POLITECHNIKI POZNAŃSKIEJ
Nr 91 Organizacja i Zarządzanie 2025

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DIGITAL AUTOMATIC COUPLINGS AS AN OPPORTUNITY AND A THREAT TO THE DEVELOPMENT OF RAIL FREIGHT TRANSPORT IN EUROPE

DOI: 10.21008/j.0239-9415.2025.091.05

The article examines the role of digital automated couplings (DACs) in the development of rail freight transportation in Europe. Digitization and automation are playing a key role in transforming the transportation industry, including rail transportation. The article discusses the DACs' origins and current DAC technologies, outlining the potential benefits and risks of introducing them. The benefits of DACs include increased operational efficiency, improved productivity and on-time delivery, reduced operating costs and greater safety. Automating the processes of coupling and uncoupling railcars reduces train formation times and minimizes the risk of human error and accidents. Implementing DACs along with the European Rail Traffic Management System can also increase the capacity of rail lines. However, the introduction of new technologies also brings risks. The article identifies the main areas of risk. Firstly, there is the risk of cyberattacks that could disrupt rail operations and threaten safety. Secondly, personnel require retraining. Thirdly, there is a need to harmonize and standardize technology internationally to ensure interoperability and security. Finally, the financial aspect related to investing in and migrating to DAC technology, which is a key risk area. The conclusions of this article have relevance for policy makers, rail operators and railcar owners, who are making decisions on DAC investments. The need to take into account the benefits and risks and to develop a strategy for DAC deployment in order to effectively realize the potential of these technologies for the development of rail freight transport in Europe.

Keywords: railway challenge, digital automatic coupler, freight transport, railway vehicles

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1. INTRODUCTION

The rail vehicle coupling system constitutes a key element of the draft and buffing gear. Its primary function is to transmit longitudinal forces – both compressive (which arise during braking, coupling, and shunting operations on marshalling humps), and tensile forces (generated when the train accelerates). The draft and buffing gear also plays a crucial role in the proper longitudinal dynamics of the train during its passage on straight tracks, curves, and turnouts, ensuring operational stability and safety.

In Europe, the most commonly used rail vehicle coupling system is the draft and buffing gear, comprising a screw coupling and buffers. This system is based on a manual coupling process, in which compressive forces are transmitted via the buffers, while tensile forces are conveyed through the screw coupling. Historically, the design of railway vehicle underframes accounted for the transmission of compressive forces via longitudinal beams aligned with the axis of the buffers, while tensile forces were transferred through a central beam (in the non-diagonal system) or through continuous draft devices running the length of the wagon (in the diagonal system). In addition to screw couplings, other types of coupling systems are also used worldwide, including automatic couplers that allow for partial automation of the wagon connection process.

The introduction of UIC Leaflet 530-1 established in past new design requirements for the construction of wagon and locomotive underframes, mandating the use of both screw and automatic couplers. This standardization facilitates the integration of automatic couplers into rail vehicles whose design meets the criteria specified in the referenced card.

2. TYPES OF COUPLING SYSTEMS AND THEIR CHARACTERISTICS

The early development of railways around the world was based on the construction of individual railway lines operating according to their own local technical standards. One of the key aspects was the rail vehicle coupling technology, which varied depending on the operator or region. As rail transport developed and individual lines were integrated into larger systems, the need for unification arose. This process led to the creation of national railway networks, within which industry regulations and standards were developed to govern the technical elements of both infrastructure and rolling stock.

As national railway networks began to interconnect, associations and international organizations were established with the goal of setting common technical standards. These standards aimed to facilitate mutual cooperation, including the implementation of international railway connections.

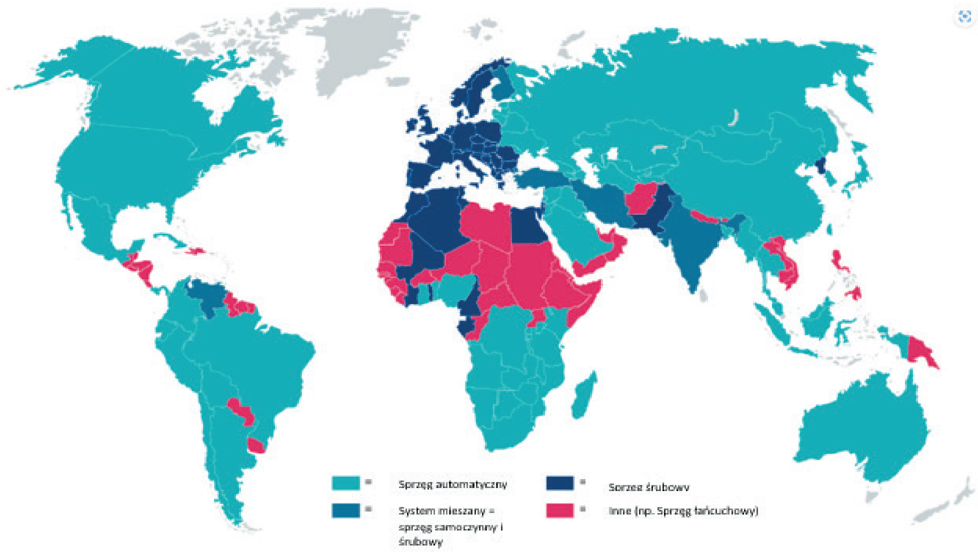

Fig. 1. Map of the Use of Different Freight Wagon Coupling Systems Worldwide (Europe's Rail, 2025)

Based on their rail vehicles' mode of operation, their coupling systems can be divided into non-automatic couplers and automatic couplers.

Non-automatic couplers are systems in which the coupling and uncoupling process requires the direct physical involvement of a worker (typically a member of the shunting crew). Due to their simple construction, many variations of non-automatic couplers have been developed and implemented, enabling their wide application across different types of rail vehicles. Non-automatic couplers are responsible for transmitting the tensile forces within the train, which is why they must be used in conjunction with buffers, which absorb the compressive forces. The most commonly used types of non-automatic couplers in rail vehicles include:

– Trumpet coupler (also known as buffer-and-chain, link and pin, or Johnston coupler). In this design, both compressive forces (through the coupler body and buffers) and tensile forces (through the link or chain) are transmitted via the coupling system. Due to its low strength, this solution is primarily used in lightweight narrow-gauge railways. The coupling types are illustrated in figure 2.

Fig. 2. Link and Pin Coupler (Wikipedia, 2025a)

- Bell and hook coupler (also known as the Norwegian type or Lloyd coupler). This is a central coupling system, where compressive forces are transmitted through a central buffer, while tensile forces are carried by a hook and link mechanism integrated into the buffer. It is a manual coupler that allows for partial automation of the coupling process. This type of coupler is often used in light rail systems, narrow-gauge railways, and industrial or mountain railways, where lower speeds and forces are involved. An example is shown in figure 3.

Fig. 3. Bell and hook coupler (Wikipedia, 2025a)

- A drawbar coupler is a type of mechanical coupling used in rail transport. Its characteristic feature the transmission of compressive forces through a central buffer, while tensile forces are transmitted via two special yokes equipped with turnbuckles, which allow for precise tension adjustment. These yokes are mounted on the outer sides of the buffers and are fitted with hooks that serve as attachment points. This type of coupling provides a robust mechanical connection and is suitable for specific rail applications requiring enhanced control over tension and alignment. The design of the drawbar coupler is illustrated in figure 4.

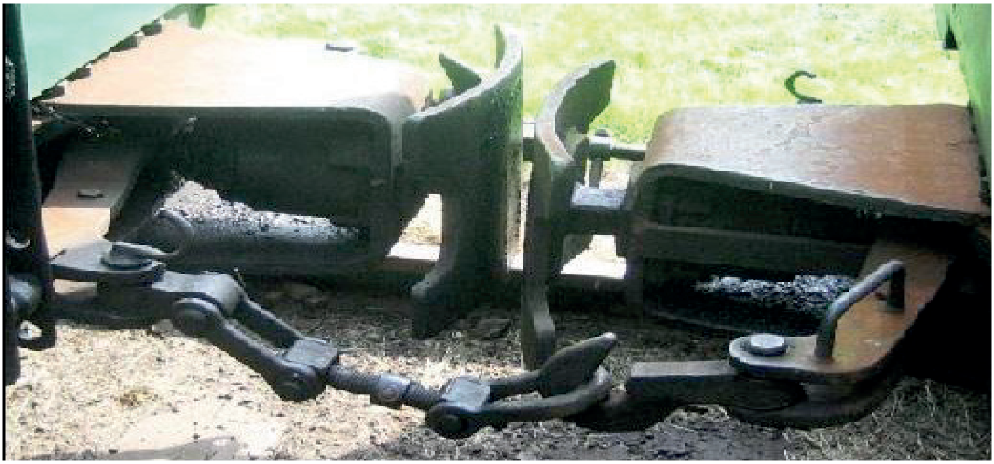

Fig. 4. Drawbar coupler (Transportszynowy.pl, 2025)

– A chain coupler is a type of mechanical coupling, in which tensile forces are transmitted via a hook and chain, while compressive forces are absorbed by a pair of buffers. A characteristic feature of this solution is the limited ability to adjust the coupling tension, which may result in slack between vehicles during operation. The design of the chain coupler can be seen in figure 5.

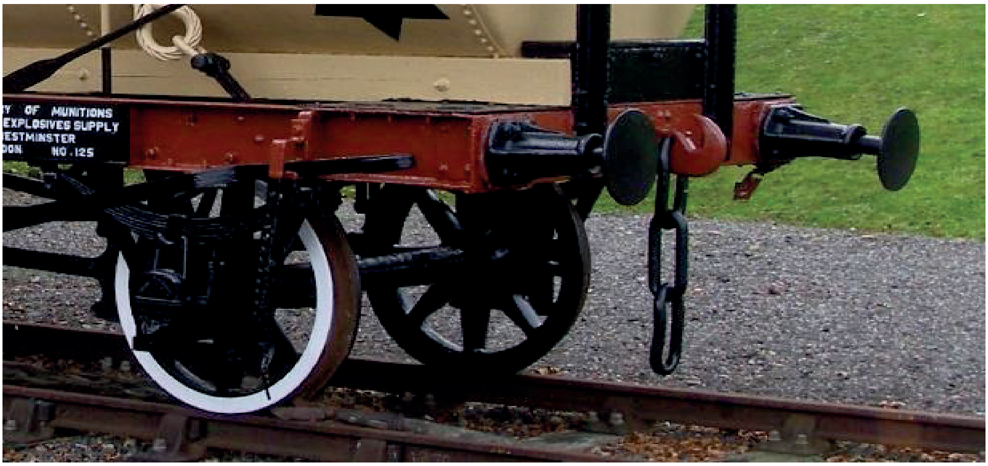

Fig. 5. Chain coupler (Wikipedia, 2025a)

– An Albert coupler represents a coupling design in which both compressive and tensile forces are transmitted centrally. It is characterized by a specially shaped coupling head and a pin that is connected to the rest of the coupler by a chain. This type of coupler is primarily used in older types of trams, where relatively low forces and speeds make this simple and robust solution sufficient. This is depicted in figure 6.

Fig. 6. Albert coupler (Wikipedia, 2025a)

– The screw coupler is the most commonly used type of non-automatic coupling in European railways, particularly in freight and passenger transport. It transmits tensile forces through a central hook and adjustable turnbuckle, while compressive forces are absorbed by side buffers. The coupling and uncoupling process is entirely manual, requiring physical effort from railway personnel.

All of the coupling systems mentioned above – including the screw coupler – require separate manual connection of pneumatic lines, electrical cables, and, in the case of passenger cars, also data transmission links. These additional connections are essential for the operation of braking systems, lighting, heating, control functions, and other onboard systems distributed along the train.

Over the past two hundred years, the screw coupler with buffers has remained the primary coupling system for railway vehicles and continues to be used in most European countries. This system belongs to the group of non-automatic couplers in which the yoke with hook is responsible for transmitting tensile forces, while compressive forces are absorbed by the buffers. Over time, the coupling system has evolved, particularly in terms of the use of modern elastic materials and energy absorption technologies in the construction of buffers. These innovations help reduce the impact of uncontrolled collisions involving rail vehicles, whether within a single train set or between two trains. These developments are aimed at minimizing the consequences of accidents, enhancing passenger safety, and reducing damage and the overall impact of potential railway incidents.

Fig. 7. Draft and Buffing Gear with Screw Coupler (Wikipedia, 2025b)

Non-automatic couplers are designed with structural redundancy by incorporating both a hook and yoke in each coupler set. This configuration makes it possible to couple railcars even if one of these elements is damaged on either vehicle, thus ensuring continued operability.

The second category of coupling systems includes automatic couplers. These systems allow for automatic coupling (and in some cases also uncoupling) as railcars approach each other, provided they are not set in "buffer mode". Automatic couplers can be classified into rigid and non-rigid types, which differ in how longitudinal forces are transmitted between vehicles.

Non-rigid couplers provide additional degrees of freedom between connected railcars, allowing the train to better adapt to track conditions and reducing stresses in the train formation during motion. However, in extreme situations, this intentional slack between vehicles may lead to accidental decoupling.

Basic types of non-rigid automatic couplers typically ensure only a mechanical connection, while pneumatic, electrical, and data transmission systems are connected separately using flexible hoses, electric cables, and communication lines. The most widely used types of non-rigid automatic couplers include:

– the Janney coupler, now commonly referred to as ARR coupler (from the American Association of Railroads), was developed in 1876 and introduced

to American railways; it has undergone continuous development, resulting in the numerous variants used across North America and beyond;
- the Willison coupler, developed in the United States in 1916, did not gain popularity in its region of origin due to its incompatibility with the already widely adopted Janney coupler; however, it influenced the development of the SA-3 coupler, which was adopted by the railways of the former Soviet Union starting in 1935; the SA-3 system was implemented gradually, over a period of 22 years.

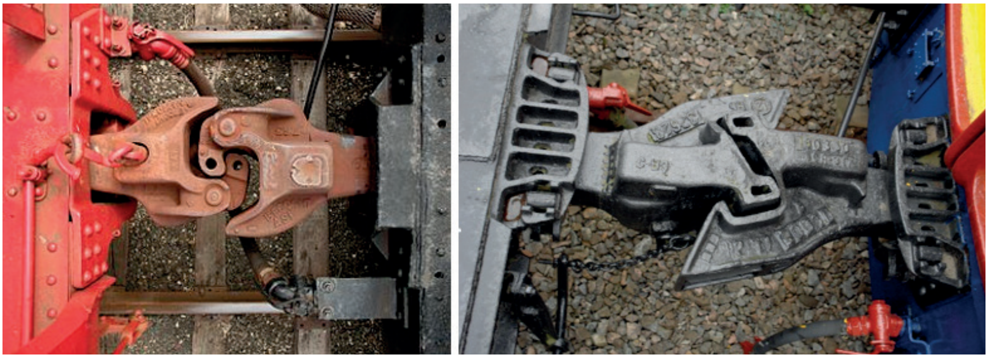

Fig. 8. Janney Coupler (AAR) on the left, Willison Coupler (SA-3) on the right (Wikipedia, 2025c)

Rigid couplers are coupling systems that, once engaged, do not allow relative motion between the connected vehicles. Any necessary degrees of freedom (e.g., for track adaptation) are provided by elastic elements integrated into the coupler's design. The use of rigid couplers allows for precise control of the interaction between railcars, leading to improved train stability during movement.

However, these couplers require consistent and proper maintenance, especially for components subject to operational wear. The technical condition of these components significantly affects the dynamics of movement between coupled vehicles. There are various types of rigid couplers, with the most commonly used including:
- Scharfenberg coupler (Schaku): Coupling is achieved by guiding the coupling loop of one unit into the centre of the other, sliding along the edge of an eccentrically shaped coupling plate. This plate is connected to a spring, which returns it to its neutral position upon uncoupling. Uncoupling requires manual or mechanical rotation of one of the plates using a lever.
- Shibata coupler: A popular type used in Japan, developed in the 1930s by Mamoru Shibata, an engineer from the Japanese Government Railways (JGR), for use with electric multiple units.
- BSI coupler: Introduced by Bergische Stahl Industrie (now Faiveley Transport), this coupler functions similarly to the Scharfenberg and is widely used for lightweight passenger units.

- APTA Type H (tightlock coupler): A variant of the tightlock system used by some U.S. passenger operators. It may include automatic connections for air brakes and electrical systems. It was also used temporarily in the UK.
- Wedgelock: A rigid automatic coupler known for its robust design, used in specific regional or industrial applications.
- Schwab coupler: Developed by Schwab Verkehrstechnik AG (now part of Wabtec Corporation), this automatic rigid coupler was introduced on Swiss railways (SBB/CFF/FFS, BLS).

As part of efforts to implement a universal automatic coupler to replace the traditional screw coupler in European railways, several concepts have been developed within international railway organizations. These efforts have led to prototype systems proposed by both industry groups and individual companies. Notable among these are:

- Unicoupler: A prototype developed as part of the European universal coupling project. Despite testing, this design was never adopted for widespread use.
- Eurocoupler / UIC (also known as Intermat or AK69): A planned European automatic coupler intended to also allow for automatic connection of brake pipes and electrical systems, including future support for electropneumatic brakes.
- Z-AK: Developed in 1994 by Knorr-Bremse, this automatic draw-type coupler requires side buffers and is compatible with traditional drawhooks. It enables the automatic connection of brake and electrical lines, but does not couple with SA-3. It features an automatic device for switching between short and long operational positions.
- C-AKv Transpact: Developed and introduced in the 1990s by SAB Wabco BSI Verkehrstechnik Products GmbH (now Wabtec). This is an evolution of the SA-3 coupler, enhanced by:
  - vertical stabilization components (making it rigid),
  - automatic connection of brake and electrical lines,
  - and high load capacity (2500 kN tensile, 3000 kN compressive).

It is compatible with screw couplers (when buffers are present), SA-3, and AK69, making it a hybrid solution.

The diversity of coupling systems in use presents a significant barrier to interoperability of rail vehicles. To enable the connection of vehicles equipped with different coupling systems, the following solutions are applied:

- Intermediate vehicle – most commonly a wagon equipped with different types of couplers at each end. This solution is used to bridge vehicles with incompatible coupling systems, enabling them to operate within the same train consist. The intermediate vehicle allows for mechanical connection between different coupler types (e.g. screw coupler on one end, automatic coupler on the other) and often includes systems for transferring pneumatic, electrical, and data lines across the interface. It is especially useful during transitional periods when part of the fleet is being modernized.

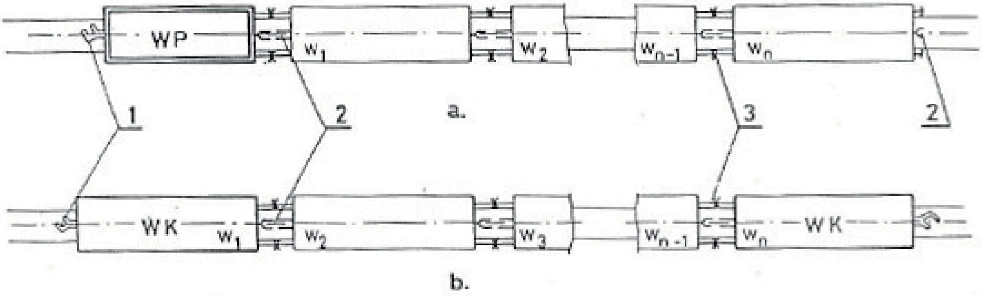

Fig. 9. Use of an intermediate wagon: in a unidirectional configuration (a), in a bidirectional configuration (b); automatic coupler (1), screw coupler (2), buffer (3) (Sorchtej)

– Transition coupler (emergency coupler) – a device installed between vehicles that enables temporary connection between two different types of couplers. Such a connection typically does not provide full mechanical strength and is used only in emergency or non-standard situations, such as towing a malfunctioning train or moving incompatible rolling stock in depot or rescue operations. Transition couplers are not intended for regular service use, and their application is usually limited to low-speed or short-distance movements.

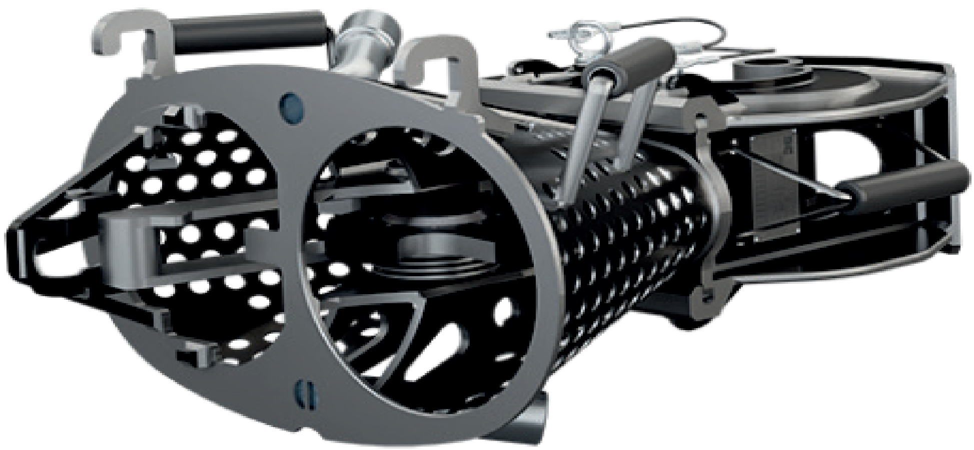

Fig. 10. Emergency coupler used as an intermediate connection between a Scharfenberg coupler and an AAR coupler (Dellner, 2025)

– Hybrid coupler – a coupling system designed to interface with at least two different types of couplers. This type of coupler integrates features of multiple coupling systems, for example, combining elements of a screw coupler and an automatic coupler, allowing it to connect with various vehicle types without the need for additional adapters. Hybrid couplers are particularly useful in mixed fleets and during fleet modernization, offering greater operational flexibility and reducing the need for intermediate vehicles or transition devices.

Fig. 11. Hybrid coupler combining a screw coupler and an AAR coupler (HandWiki, 2025)

The above-mentioned solutions enable the coupling of train sets that include rail vehicles equipped with different coupling systems. However, their use comes with certain limitations, such as:

– increased operating costs,
– reduced performance parameters, for example lower maximum speed, reduced permissible train mass,
– greater complexity in train operation and logistics, including planning, shunting, and maintenance.

These trade-offs mean that such solutions are typically used as interim measures during transition periods or in special cases, rather than as a long-term or large-scale strategy.

Table 1. Summary of Rail Vehicle Coupler Types

Type of Coupler	Technology Examples	Characteristics
Non-automatic	Screw, chain coupler	Manual coupling, separate cable connections
Automatic non-rigid	Janney, SA-3	Automatic coupling, slack between vehicles
Automatic rigid	Scharfenberg, BSI	Automatic coupling, rigid connection
Hybrid	Transitional couplers	Connecting different standards
Digital automatic (DAC)	DAC	Full automation (energy, air and data exchange)

Table 1 presents a comparison of the main types of railway couplers used in rail transport, focusing on their functions and level of automation.

3. DIGITAL AUTOMATIC COUPLERS (DAC)

Digital Automatic Couplers (DAC) represent the advanced evolution of automatic coupler technology. Not only do they enable automatic mechanical coupling but also the automation of pneumatic, electrical and data connections between rail vehicles.

Digital Automatic Couplers (DAC) are defined as innovative systems designed for automated coupling and uncoupling of freight rail vehicles, covering both the physical connection (mechanical and pneumatic) and digital integration (power supply and data transmission).

The implementation of the DAC system is expected to become a key factor in boosting the efficiency and transparency of operations in freight rail transport (International Union of Railways, 2002).

This type of coupling system is already the standard in multiple passenger units operated across Europe. The Scharfenberg coupler is the most commonly used type in this context. However, despite its widespread use, differences in electrical and data interfaces between unit types result in limited compatibility. In practice, this means that multiple units typically operate only with others of the same type, when coupled into longer train sets.

In addition to challenges with the physical coupling of vehicles, there may also be software-level compatibility issues, which can affect the reliability of train operation.

As part of the revision of the Technical Specifications for Interoperability (TSI), a regulatory change is being prepared to enable the deployment of digital automatic couplers (Rilo, Rozynek, Sawczuk, 2022). This change is significant, as it includes the possibility of making the use of DAC mandatory. The main argument for such a requirement is the risk of reduced railway interoperability if two different coupling systems are allowed to coexist indefinitely.

In the course of analysing possible solutions for DAC implementation, a new classification of coupler types has been developed, based on the level of automation. This classification is presented in table 2.

Table 2. A new typology of coupling systems based on their level of automation

Automated Function	Mechanical Coupling	Pneumatic Coupling	Electrical Coupling	Data Exchange Coupling	Uncoupling
Type 5 DAC	YES	YES	YES	YES	YES
Type 4 DAC	YES	YES	YES	YES	NO
Type 3 DAC	YES	YES	YES	NO	NO
Type 2 DAC	YES	YES	NO	NO	NO
Type 1 AC	YES	NO	NO	NO	NO
(Basic version: SA-3 and AAR)	YES	NO	NO	NO	NO
Type 0 (Screw Coupler)	NO	NO	NO	NO	NO

As part of the ongoing work, it has been determined that the long-term viability of implementing Digital Automatic Couplers (DAC) is achieved only for couplers with an automation level higher than 4. Level 4 couplers still require manual intervention during uncoupling, which is why the system should ultimately aim to reach Level 5, offering full automation.

During the research phase, the optimal solution was identified as the Scharfenberg Type 10 mechanical head, which best meets the technical and operational requirements. Furthermore, automatic couplers will also be made available in a hybrid version, which is intended for installation on locomotives. This hybrid design will allow coupling with both screw couplers and automatic couplers, thus ensuring interoperability during the transition period between coupling systems.

As part of the FP5-TRANS4M-R project supported by Europe's Rail Joint Undertaking, four major suppliers presented their latest Digital Automatic Coupling (DAC) solutions aimed at achieving full interoperability in European freight transport (fig. 12). Each manufacturer proposed a different technical concept adapted to varying operational needs:

- Dellner introduced a hybrid DAC solution, enabling both mechanical and digital connections, suitable for mixed train configurations,

- Knorr-Bremse developed a Level 5 DAC system capable of fully automated coupling and decoupling, including pneumatic and electrical interfaces,
- Voith presented the CargoFlex Hybrid, a coupler allowing both automatic and manual operation, designed to ensure flexibility during the transition phase,
- Wabtec showcased an interoperable DAC concept designed to support seamless integration into existing and future rolling stock fleets.

Fig. 12. Examples of Automatic Couplers by Manufacturers
(own materials, collected during InnoTrans 2024)

These diverse technological approaches reflect the industry's commitment to developing a unified, scalable DAC system that meets the functional and safety requirements of next-generation digital freight trains.

4. OPPORTUNITIES ARISING FROM THE IMPLEMENTATION OF DAC (DIGITAL AUTOMATIC COUPLING)

The implementation of Digital Automatic Couplers (DAC) represents a breakthrough technological innovation in the railway transport sector, particularly with regard to freight trains.

While automatic couplers are already widely used in passenger multiple units, the deployment of DAC in wagon-based trains – both passenger and freight – will enable the automation of marshalling processes, reductions in staff requirements, enhanced operational safety, and the integration of new technologies into rail freight transport. The key opportunities offered by DAC implementation include:

Automatic brake testing, allowing for fast and automated execution of brake tests without the need for large crews. This can shorten train preparation time by several dozen minutes and significantly improve turnover rates at terminals and classification yards.

Real-time brake system diagnostics, enabling continuous monitoring of the braking system's technical condition during operation. This will allow for early detection of faults and effective maintenance planning to prevent serious failures or accidents.

Illuminated end-of-train signal and improved train visibility, which will significantly enhance rail traffic safety, especially at level crossings and under adverse weather conditions.

Wheelset bearing diagnostics, where the DAC system will continuously monitor temperature and vibration, allowing early detection of bearing damage and preventing serious incidents such as derailments.

Real-time cargo condition monitoring, made possible through digital communication, enabling supervision of transport conditions, for example, in refrigerated wagons, and rapid detection of tampering or theft attempts.

Improved ETCS (European Train Control System) operation through the transfer of up-to-date data on the length, weight, and composition of the train, thus enabling more efficient traffic management and increased line capacity.

Automatic access to train consist data, streamlining logistics processes related to train formation, disassembly, loading, and unloading at intermodal terminals and industrial sidings.

Implementation of electropneumatic braking, enabling dynamic control of braking force, which will shorten braking distances, enhance operational safety, and allow for higher commercial speeds in freight operations.

5. RISKS ARISING FROM THE IMPLEMENTATION OF DAC

Despite the technological advancements enabled by the implementation of Digital Automatic Couplers (DAC) in freight trains, there are significant risks that require special attention and appropriate preventive measures.

The primary challenge associated with DAC deployment is the substantial financial impact on railway market stakeholders, especially railway operators, who will ultimately bear the main financial burden of this transformation. The costs involve not only purchasing the couplers themselves but also modernizing the rolling stock, adapting terminals, and implementing new diagnostic systems. Initial estimates suggest that the total cost of DAC implementation across Europe could reach several billion euros. As a result, dialogue is underway with the European Commission regarding potential funding support for the railway sector to offset the investment burden and prevent a decline in the competitiveness of rail transport.

Another significant risk lies in the varying capacity of railway operators to implement new technologies. In particular, smaller and private operators may struggle to carry out such costly upgrades, which could lead to increased market inequality and sector consolidation favouring large entities. Without adequate support mechanisms, this could result in a decline in the number of operators and reduced competitiveness on the freight rail market.

Attention must also be paid to operational safety issues. The transitional period, during which both traditional and digital coupling systems will coexist in operation, carries an increased risk of handling errors and a rise in operational incidents. The need to revise operating procedures, the lack of full infrastructure readiness, and limited staff experience may temporarily reduce rail traffic safety.

The digitalization of the coupling process also introduces new risks in the area of cybersecurity. New digital interfaces increase the potential for unauthorized access, communications system sabotage, or data manipulation between wagons. Effectively countering these threats will require the implementation of comprehensive IT security protocols and regular staff training in cybersecurity.

The implementation of DAC will also bring about significant changes in the structure of railway employment. Demand will grow for workers with qualifications in automation, mechatronics, and IT, while the need for traditional roles related to wagon handling and shunting will decrease. This transformation will require the launch of retraining programmes and ongoing investment in developing staff's skills.

Table 3 presents an analysis of the main risks associated with implementing DAC in freight rail transport in Poland. The risks are classified according to their likelihood, and potential impact on the railway sector, and include recommended risk mitigation measures. To facilitate interpretation, colour coding is used: risks with critical consequences are marked in red, while those with serious consequences are marked in yellow.

Table 3. Risk Analysis of DAC Implementation

Risk	Probability	Impact	Mitigating Measures
High investment costs for operators	High	Critical	EU funding programs, cost distribution over time
Difficulties in adaptation by small railway operators	Medium	Severe	Preferential loans, regulatory support
Decreased safety during the transition period (operation of mixed systems)	Medium	Critical	Operational training, emergency procedures, pilot testing
Risk of cyberattacks on the DAC system	Medium	Critical	Development of a cybersecurity strategy, system certification
Changes in the labour market and skills shortages	High	Severe	Retraining programs, new educational pathways
Disruptions in interoperability between EU member states	Medium	Severe	Harmonization of technical standards within ERA, participation in international projects, joint testing and validation at borders, development of DAC interoperability adapters
Social and union resistance to technological changes	Medium	Severe	Social dialogue and consultations with stakeholders, transparent communication of goals and benefits, job protection, employment guarantees, support packages
Lack of infrastructure readiness (e.g., technical facilities)	High	Critical	Mapping modernization needs, dedicated investment funding, creation of service hubs, phased implementation plan tailored to technical capacity
Market monopolization by DAC suppliers	Medium	Severe	Promotion of open standards, support for technological competition, procurement with interoperability clauses, support for startups and tech SMEs
Delays in legislative or technical approval processes	Medium	Critical	Active participation in EU legislative processes, consultations with regulators, monitoring of regulatory changes, lobbying for process acceleration

To mitigate the impact of the identified risks, it is recommended to implement investment support programmes, provide assistance to smaller railway operators, launch intensive training programmes focused on safety and cybersecurity, and promote educational initiatives tailored to meet the emerging needs of the labour market.

Among all the risks identified, particular attention should be paid to two areas classified as critical:

– reduced operational safety during the transition period,
– the risk of cyberattacks on the DAC system.

Although both risks are assessed as having medium probability, their potential consequences are critical. Therefore, these issues must be prioritized to ensure that the implementation of Digital Automatic Coupling (DAC) proceeds in a safe and controlled manner.

The reduction in operational safety arises from the need to manage two coupling systems in parallel – traditional and digital – in the initial deployment phase. Changes in operating procedures, lack of full standardization, and limited staff experience can lead to an increase in incidents, failures, and delays. To mitigate this risk, it is essential to implement:

– comprehensive training programmes,
– early pilot testing,
– well-defined emergency procedures for critical situations.

The cybersecurity risk is a consequence of the digitalization of the coupling process and the integration of communication systems between vehicles. The introduction of new interfaces and real-time data exchange exposes the system to potential manipulation, sabotage, or unauthorized access. To reduce this risk, a cybersecurity strategy must be developed, including:

– encrypted communications,
– certification of hardware and software,
– ongoing security audits, and
– cybersecurity training for personnel.

In summary, effective control of these two critical risk areas is a prerequisite for the safe, smooth, and sustainable implementation of DAC technology in rail freight transport.

6. CONCLUSIONS

The dynamic growth in rail freight transport in Europe requires the implementation of innovative technologies that enhance its efficiency, safety, and competitiveness. One of the key directions of this transformation is the deployment of Digital Automatic Couplers (DAC), which represent a significant advancement over traditional rail vehicle coupling systems.

This article outlines the origins and evolution of coupling systems, highlighting the diversity of existing solutions and their impact on railway interoperability. It provides a detailed description of both traditional non-automatic and automatic couplers, as well as modern digital designs. Special attention is given to the opportunities and challenges related to DAC implementation, emphasizing its role in automating operational processes, introducing new diagnostic technologies, and improving the operational performance of freight trains.

However, DAC implementation also presents several challenges – from high investment costs, to the need for organizational and infrastructure adaptation, and the risks associated with cybersecurity. Therefore, it is essential to ensure adequate financial support and to develop comprehensive implementation strategies to prevent the transformation from limiting the accessibility and competitiveness of rail transport.

Digital Automatic Couplers have the potential to become a catalyst for further development of the railway sector in Europe. Their successful implementation would not only modernize rail freight transport but also contribute to the broader objectives of the European sustainable transport policy. A key condition for success will be a coordinated approach involving all market stakeholders: operators, infrastructure managers, financial institutions, and regulatory bodies.

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CYFROWE SPRZĘGI AUTOMATYCZNE JAKO SZANSA I ZAGROŻENIE DLA ROZWOJU KOLEJOWEGO TRANSPORTU TOWAROWEGO W EUROPIE

Streszczenie

W artykule zanalizowano funkcję cyfrowych sprzęgów automatycznych (DAC) w rozwoju kolejowego transportu towarowego w Europie. Cyfryzacja i automatyzacja odgrywają kluczową rolę w transformacji branży transportowej, w tym transportu kolejowego. W pracy omówiono genezę powstania i aktualną fazę rozwoju technologii DAC, przedstawiając potencjalne korzyści i zagrożenia wynikające z ich wprowadzenia. Korzyści płynące z zastosowania DAC obejmują zwiększoną efektywność operacyjną, poprawę wydajności i punktualności dostaw, redukcję kosztów operacyjnych oraz wzrost poziomu bezpieczeństwa. Automatyzacja procesów sprzęgania i rozprzęgania wagonów skraca czas formowania pociągów i minimalizuje ryzyko błędów ludzkich, a w konsekwencji wypadków. Wprowadzenie DAC wraz z Europejskim Systemem Zarządzania Ruchem Kolejowym może również zwiększyć przepustowość linii kolejowych. Wprowadzenie nowych technologii niesie jednak także zagrożenia. W artykule wskazano główne obszary zagrożeń. Po pierwsze, ryzyko cyberataków, które mogą zakłócić operacje kolejowe i zagrozić bezpieczeństwu. Po drugie, konieczność przekwalifikowania personelu na obsługę zautomatyzowanego systemu. Po trzecie, potrzeba harmonizacji i standaryzacji technologii na poziomie międzynarodowym, aby zapewnić interoperacyjność i bezpieczeństwo. Ostatni wśród poruszanych elementów ryzyka to aspekt finansowy związany z inwestycjami i migracją technologii DAC stanowiącą kluczowy obszar zagrożeń. Wnioski płynące z tego artykułu mają znaczenie dla decydentów, operatorów kolejowych i właścicieli wagonów, którzy podejmować będą decyzje dotyczące inwestycji w DAC. W pracy podkreślono korzyści i zagrożenia wynikające z wdrożenia DAC oraz konieczność ich uwzględnienia w opracowaniu strategii firm, aby skutecznie wykorzystać potencjał technologii opartych na DAC dla rozwoju kolejowego transportu towarowego w Europie.

Słowa kluczowe: transport kolejowy, cyfrowy sprzęg automatyczny, transport towarowy, pojazdy szynowe