Recent, the first successful deployment of a fully automated commercial freight train operation was announced. This is the world’s first automated heavy-duty and long-haul rail network. It’s an impressive achievement, but why has it taken so long to achieve this when driverless urban metros have been in operation for more than 50 years? Although urban metros and freight trains are vehicles moved on rails, their operation and environment differ significantly. Metros operate in closed rail networks, while freight trains operate in open rail networks. However, the same taxonomy is often used to classify automation interchangeably in both environments. This paper provides the context and overview of driving automation in freight rail and reviews the existing taxonomies. This paper starts by providing context with an overview of the general process of driving a vehicle by delimiting its different stages. Next, we describe the overall process of driving a freight train to show the distinctive features of its setup and operation. In this analysis, we will point out the essential differences between open and closed rail networks, and the tasks that can potentially be automated. Additionally, we examine the evolution of level-based automation taxonomies and review those that have been proposed exclusively for driving automation in open and closed railway networks. It is our objective to provide a thorough summarization of the most relevant taxonomies to advance the definition of a suitable taxonomy and framework to classify automation capabilities in rail freight transport, as well as to identify some complex challenges ahead.

**INDEX TERMS** Automation taxonomies, Driverless trains, Driving Automation, Grades of Automation, Levels of Automation, Railway Automation, Self-driving Vehicles.

**I. THE OVERALL DRIVING PROCESS**

In driving a vehicle, the driver must have a set of essential knowledge and skills, instruments that provide information about the vehicle, and the elemental driver's attention and concentration to apply the above to drive safely into a changing environment. This activity involves a variety of decisions and actions before and after the vehicle gets in motion.

The overall driving process can be divided into two phases with three types of efforts. The first phase covers the activities carried out with the vehicle in a static position or Static Driving Tasks (SDT). The second phase includes the activities made once the trip has started or Dynamic Driving Tasks (DDT) [1]. The related efforts are Strategic, Tactical, and Operational [2]. The whole driving process is illustrated in Fig. 1.
for Object and Event Detection, Recognition, classification, and response to maneuver the vehicle, also known as OEDR tasks [1]. The operational effort involves execution tasks related to vehicle preparation and control of the vehicle’s direction. Additionally, the driver performs regular settings and verifications for a safe and comfortable trip, and these are operational efforts for vehicle preparation (see Fig. 2).

Driving a road vehicle (car or truck), the driver almost unconsciously does the SDT phase. As part of the driving routine, the driver sets the destination in an app to generate several trip itineraries, an essential strategic effort. Nevertheless, people do not usually include these tasks as part of the driving definition. This presumption reduces the driving to be aware of the environment and operate the controls to direct the vehicle’s course (DDT phase). Despite this, the limited understanding of driving seems to be only theoretical. In practice, the driving process is done entirely, although some tasks may be omitted.

The driving process analysis, taking a road vehicle as an example, is more straightforward than other means of transport. In a car or truck, it is generally a single person who performs the entire process, and it is an experience accessible to most people with relatively low training.

Although the same phases and efforts are present also in rail freight transport, the driving of railway vehicles presents much more complexity. Several teams of highly qualified people take part in the driving of a freight train. The overall process is reviewed in detail in the following sections.

II. DRIVING A FREIGHT TRAIN

Moving vast amounts of goods requires large and complex heavy haul vehicles. The freight train can efficiently move large volumes of goods, but its operation involves more complex tasks than road transport. A detailed review of the overall process of driving a Freight train includes the SDT and DDT phases, named in this section as train preparation and train operation.

A. TRAIN PREPARATION

The strategic effort in freight trains can be divided into logistic programming for pre-trip planning and physical train preparation. The trip planning refers to the requirements to determine the train consist based on different aspects, e.g., the kind of cargo, destination, and hazardous material considerations. On the other hand, it also refers to the requirements to define the curves of both acceleration and braking strategies for theoretically optimal driving generating proper procedures to operate safely and efficiently. The availability and priority mainly define the itinerary in using the railway lines, the location and availability of the load to be transported in the yards, or environmental conditions.

The freight train preparation is performed in specialized stations where no passenger trains and access are restricted to rail staff. These stations are known as marshaling yards, and there are several parallel tracks where trains arrive and depart. The essential yard functions are classification, sorting a block of wagons based on their next destination, blocking, sorting wagons into groups bound for a specific destination, and putting for the most efficient delivery. Trained rail staff performed essential yard functions using hardware or software tools to have a semi-automated process. In any case, there is always staff that is responsible for supervising these tasks.

Train inauguration is the process of couple one or several locomotives with a block of wagons. After a train consist is complete, visual, auditive, and electric inspections per safety protocols to set up the train’s readiness to drive are performed. Each country’s protocols and procedures are determined and regulated, with many similarities but without universal standards. Table I shows typical rail staff tasks during train preparation [3].

| Tasks | Description |
|-------|-------------|
| Paperwork | Reviewing and recording train and cargo information. |
| Take over a parked train | Coupling and uncoupling locomotive and wagons. |
| Inspection and Control | Turn on or turn off the locomotive systems. |
| Train Data Input | Visual, electric, and acoustic inspections to locomotive and wagons; check safety controls. |
| Perform tests | Set all predefined trip parameters for the train’s systems. |

B. TRAIN OPERATION

In contrast with other vehicles, rail vehicles have the peculiarity that only longitudinal displacements can be done to drive. Accelerating and braking are virtually the only two options to direct trains course on the tracks. Changing track is generally carried out remotely from the Operating Control Centre (OCC) or manually by rail staff, but not by the train driver.
Nowadays, American safety regulations for freight train operations establish a minimum rail crew of two persons. However, in Europe, only one person is required. The train driver is responsible for safely driving the train and efficiently reaching the destination by following specific rules and procedures. A general list of crew tasks during train operation is shown in Table II [4].

Freight trains have vital systems to assist the driver in these tasks. Electronic communication and navigation systems, both onboard and wayside, assist the train driver in their duties along the trip. Besides adhering to regulations and protocols, the train driver must use their experience to manage and priorities their attention to respond to signals, alerts, and communications received from the instruments onboard and the OCC.

| Tasks                  | Description                                                                 |
|------------------------|----------------------------------------------------------------------------|
| Monitoring             | Maintain attentiveness and awareness to the locomotive control panel, wayside signaling warnings, and environmental conditions. |
| Communicating          | Keep constant communication with the OCC to share relevant information.       |
| Paperwork              | Recalling information issued on track bulletins.                             |
| Operating controls     | Maneuver locomotive control system for throttle, braking, and other subtasks to reach the destination. |
| Exception Handling     | Attend unexpected or unusual situations maneuvering in anticipation of oncoming dynamic motion requirements (e.g., temporary speed restrictions, tracks obstruction). |

Before starting the trip, a traffic management system allows traffic control to provide movement authorization. Signaling systems are used to monitor the occupation of the tracks and follow the movement of each train. Besides adhering to regulations and protocols, the train driver must use their experience to manage and priorities their attention to respond to signals, alerts, and communications received from the instruments onboard and the OCC.

III. DRIVING AUTOMATION IN FREIGHT TRAINS

Since its inception, automation has been crucial to increasing safety and efficiency in wide-range applications, replacing or reducing human intervention. Repetitive or dangerous tasks are potentially attractive to automate, which has been the case for driving vehicles.

The riskiest part of driving a vehicle is in motion, especially the tactical task, which is why tremendous efforts are put into developing systems that automate these tasks. The required system to perform automated train operation tasks must be designed based on assumed conditions under which optimum performance can be ensured. Operational conditions under which the systems will perform reliably (e.g., environmental, infrastructure, vehicle settings) are known as Operational Design Domain (ODD) [1]. Clearly defining the ODD and the specific capabilities in task automation are essential to ensuring its safety and optimal implementation and operation.

There are significant differences between driving a rail vehicle in a close and open rail network. A close rail network...
is one in which the variability of conditions is reduced and controlled to a greater extent. There is usually only one type of vehicle configuration; the schedules and routes are typically periodic and constant. Its operation involves regular and repetitive processes, and there is a minimal intervention of external elements. This scenario is the one that can be found in an urban metro network.

On the other hand, open rail networks are typically characterized by various train types with variably configurations, complex traffic scheduling with many conflicting movements, and operations by multiple rail transport companies, including passengers and cargo. These networks are the mainline railways.

From the above, it can be noticed that the ODD for open and close rail networks would be very different. Solutions that allow automation in a metro operation are not necessarily applicable to trains on mainlines. However, some functions and systems can be generalizable.

In metro systems, the driving mode known as Automatic Train Operation (ATO) is usually used, which in turn is enabled by Signaling and train control systems technologies as Automatic Train Protection (ATP) and Automatic Train Supervision (ATS). These same terms are used in the open rail environment, although with their enabler technologies such as modern signaling control systems such as the European Train Control System (ETCS) in the European Union (EU) and Positive Train Control (PTC) in the United States (US).

Currently, automation in closed rail networks is a mature technology with high acceptance. In 2018, the International Association of Public Transport (UITP) reported 64 fully automated metro lines in 42 cities, operating 1,026 km, a 27.7% increase in km over the 2016 World Report. [26]. In the metro and aviation industry, automation has already been developed and applied for a long time. Moreover, autopilot functionality has been used for many years in the airline industry. Table III shows a comparison of automated technology in various transport modes [5].

| Transport  | Technological maturity | Technology acceptance |
|------------|------------------------|-----------------------|
| Metro      | High                   | High                  |
| Airplane   | High                   | High                  |
| Car        | Medium                 | Medium                |
| Train      | Low                    | Unknown               |

Nowadays, few initiatives pursue driving automation for open rail networks. In Europe, national railway operators from Belgium, Switzerland, Czech Republic, United Kingdom, Netherlands, Denmark, Germany, and France have projects implementing different ATO levels over ETCS, most for passenger trains [5]. The French national railway operator (SNCF) has two consortiums to develop and deploy driverless train prototypes, an autonomous freight train and an autonomous regional express passenger train [27]. In 2019, their first remotely driven train test run was successful. SNCF envisages remote control to move trains between stations and maintenance depots and as a “last mile” service to and from customer sidings or terminals [28]. More recently, a semi-automated train was tested. As test drivers monitored their performance, the train ran under actual operating conditions, with fully automated longitudinal motion. SNCF aims to have fully automated prototypes running by 2023, with scale-up starting in 2025 [27].

The EU summarizes the current and future developments, opportunities, and challenges of AI in railway transportation in a briefing report [29]. In this report, the application of AI in Intelligent train automation (train control), Operational intelligence (predict and prevent), and Asset Intelligence (long-term performance of rail assets) are considered crucial. The EU also promotes programs to drive research and development in modernizing the community rail environment. The Shift2rail initiative aims to accelerate the integration of new and advanced technologies into innovative rail product solutions, including automation in different areas [11].

The introduction of automation is also considered for automated processes at transshipment nodes and timetable planning to improve efficiency as security [30]. In Germany, the Lehrter marshaling yard is already operating an automated mega-hub for intermodal interchange. The mega-hub optimizes cargo handling and exchange, automating the costly, time-consuming shunting of freight cars, enabling more cargo to be transported by rail [31]. The automation of the shunting yard operation is also considered by DB Cargo in Germany [71]. In the Netherlands, the running tests on shunting locomotives using ATO with the highest grade of automation (GoA4) are programmed to start in 2021. For this, diesel shunting locomotives will be equipped with automatic control technology, intelligent obstacle detection, and environment recognition [32]. Typical shunting yard tasks will be fully automated, such as starting and stopping, pushing wagons, and controlling traction and brakes. Train staff remaining aboard to ensure safety protocol during the tests. A similar initiative is tested on Swiss operator SBB Cargo’s locomotives. A vision-assisted remote shunting system is used to help detect and classify obstacles on and along rail tracks, providing both drivers and remote operators with critical real-time alerts [33].

However, the most advanced application in freight train automation was completed in 2018 and is currently in operation. With the aim to automate its operations, Rio Tinto, a mining company, deployed the only known fully automated freight railway in Western Australia. The automated freight rail network, described as the world’s largest robot, operates 200 locomotives in circuits with more than 1700 Km of tracks to carry iron ore from 16 mines to four port terminals controlled in a safe manner [6]. This breakthrough solution
was based on the international standard digital radio-based signal and train protection system ATO over ETCS (Level 2) to provide fully automated train operation [7].

This massive automation project was entirely designed, tested, and deployed for a specific application. The trains in this network operate in a restricted environment in the middle of the desert, using tracks exclusively for this purpose (so-called "closed service"), meaning that the operation is developed in a limited ODD, more likely to a closed rail network. There is no doubt about the impressive progress in technological development to achieve this milestone, but its application in open railway systems still requires solving complex challenges.

IV. AUTOMATION TAXONOMIES

Since their appearance, automation systems have evolved and found new application areas, helping to solve increasingly complex problems. Given the wide application of these systems, it was considered necessary to find a way to classify them. One of the first ways to classify automation was the appearance of the Levels of Automation (LoA) taxonomy. A taxonomy is a set of rules or principles applied to classifying concepts in a specific knowledge field. Classifying implies organizing elements logically and consistently based on defined rules. These rules usually prioritize specific characteristics of the elements to be classified and omit many others. The classification exercise implies a simplification, an abstraction that allows synthesizing information about a set of elements.

The taxonomies applied to automation systems were initially conceived to classify them according to the type of human-machine interactions and describe the types of automation [34]. A literature review on the Levels of Automation and its modern implementations show the evolution in the different taxonomies proposed [35]. This review article presents the evolution of the taxonomies based on levels of automation applied in different areas, e.g., avionics, teleoperation systems, advanced manufacturing, and automation systems in a general context. The taxonomies mentioned above were proposed from the end of the 1950s to the early 2000s and included between 4 and 12 continuous and incremental levels of automation starting from completely manual systems, or operated entirely by humans, to full automation, without any human intervention in operation.

The LoA classification approach conceived in the late '70s by Sheridan and Verplank [34] is one of the oldest and the most widely cited and used taxonomies [35]. They introduce an LoA divided into ten levels, proposing a variety of interactions and cooperation between operator and machine. They also include an analytical description of who can control in every stage and have been the basis for many others presented later [34]. Several taxonomies have been proposed since then, but all with just a few differences in criteria in level number and tasks distribution [36-40]. In 1989, Riley proposed a novel approach introducing the idea of the system's intelligence, understood as the levels of sophistication in the information processing functions of the system [37]. With this approach, both the level of autonomy and the levels of intelligence was considered. The taxonomy is presented as a 2-dimension matrix. The rows correspond to the LoA, while the columns to the levels of intelligence. Each cell in the matrix is called an "automation state" and corresponds to a unique and predefined form.

Several years later, a new proposal extended to 3-dimensions the taxonomy structure for classifying human-mediated control of remote manipulation systems [39]. The three axes are: the autonomy in remote operations, from manual teleoperation to autonomous robotics; the structure of remote worlds, from entirely unstructured to highly structured; and the extent of world knowledge or modellability of the remote world, from entirely unknown to fully modeled. This form of classification does not establish staggered or clearly defined levels for any of its axes. Each of the axes of the taxonomy is presented as a continuum between the lower and upper levels. Finally, the consolidated taxonomy of remote control indicates the volume in the taxonomic space for which Virtual Telerobotic Control is intended.

In 2000 another taxonomy based on previous works contributed a new approach applied to four broad functions: information acquisition; information analysis; decision and action selection; and action implementation [40]. This proposal did not provide defined levels but instead suggests that each of the four factors can be automated at a different level, each continuum from manual operation to full automation. The article also proposes a framework pointing to the performance consequences as primary evaluative criteria for automation design. The second criteria are the evaluation of automation reliability and costs of decision/action outcomes. This article became one of the primary references for elaborating automation taxonomies and evaluating and comparing automation systems.

Taxonomies based on LoA served as the basis and were applied to different sectors, including autonomous driving for on-road and rail vehicles. The first classification to appear on autonomous driving for road vehicles was published in 2012 by the German Federal Highway Research Institute (BAST). This approach aimed to identify and define the different automation degrees beyond Driver Assistance Systems for clarifying liability [41]. This classification does not contemplate the automation of the vehicle but rather the driving tasks where the human is on the control loop. Thus, at the highest level of autonomy, the system takes over longitudinal and lateral control. In case of a takeover request that is not carried out, the system will return to the minimal risk condition by itself [42]. By the time, the US National Highway Traffic Safety Administration (NHTSA) had drawn up five levels for self-driving vehicles based on the BAST proposal. NHTSA had called Level Zero "no automation"
and Level Four “full automation,” and focused primarily on the role of the human operator in carrying out “safety-critical control functions” [43].

Soon after, the Society of Automotive Engineers (SAE), after reviewing the BASI document, chose to adopt the BASI formulation with a few fundamental changes broadly [44]. SAE team added a sixth level, "Level Five," above BASI's "Level Four" and called their Level Four "High Automation." Additionally, SEA added" Full Automation" above it to disambiguate the conditions under which such a vehicle could operate. The SAE approach gave the levels a technologically-centered and less ambiguous set of descriptions than NHTSA had provided [47]. Since then, the SAE levels have not changed their overall structure. However, there have been updates and upgrades in the following three versions in 2016 [45], 2018 [46] and 2021 [1]. The new version integrated more descriptive examples, especially around ambiguities and edge cases in the levels, and switched to increasingly specific technical language to describe all aspects of the taxonomy.

The SAE taxonomy aims to clarify expectations about the system's capabilities and delineate both the driver and the automated driving system's functions. Moreover, it also helps to understand each level's relative capabilities and limitations. The SAE documented taxonomy was not intended as an international standard but a recommended practice and compendium of automation-related terms. The SAE Recommended Practice J3016 [1] describes the six levels for the full range of driving automation features in on-road motor vehicles. This document provides a clear framework for driving automation specifications and technical requirements. Each level has a specific set of capabilities and features, and the role of the driver and the Automated Driving System (ADS) is clarified. A formal international standard taxonomy, and definitions for terms related to driving automation systems for on-road motor vehicles, was developed, and recently released by the International Organization for Standardization (ISO) [8].

V. TAXONOMIES FOR RAILWAY DRIVING AUTOMATION

This subsection includes taxonomies applied specifically to rail automation. Various classifications have been proposed for the autonomous driving of rail vehicles based on grades or levels. For the sake of clarity, Fig. 4 shows a compendium of taxonomies for rail vehicles on open and closed rail networks. The taxonomies boundaries are just an approximation to facilitate the comparison. Table IV summarize the objectives and international standards related to each taxonomy.

The first mention of automation levels in rail vehicles was published in 1976. The document is a report that presented an evaluation of automatic train control technology in rail rapid transit systems in the US [48]. The United States Congress requested the report from the Office of Technology Assessment (OTA). This document describes the technology of Automatic Train Control systems. It assesses the operational, planning, and policy issues arising from using automated devices to control and direct rapid transit vehicles. The report also contains background helpful material for understanding the application of automation technology in urban rail transit systems [48]. Representatives of the transit

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**FIGURE 4. Taxonomies for railway driving automation**

...
industry, engineering firms, planning and development organizations, universities, and citizen participation groups participated in its preparation. The automation levels used in this report have the general LoA's approach suggesting that train control automation can be viewed as a continuum. At one extreme, all functions are performed by human operators; at the other, all are performed by machines [48]. This classification was intended to describe the historical evolution of automation during the manual to automatic conversion processes implemented in rapid rail transit systems in the US.

The classification has seven levels that go from essentially manual to full automation, clarifying that none of the systems implemented so far in the US achieved the highest level but the other lower six. The level's distribution was essentially based on integrating the ATO, ATP, and ATS systems, and they were not assigned a numbering but a specific name. In the lower level, train protection was applied by rules and procedures, train operation fully manual (with or without the aid of advisory wayside signals), and train supervision done by control tower personal or central dispatched. In the Wayside Signal Protection level, train operation runs manually with wayside block signals with trip stops for train separation and overspeed protection; supervision was also manual with some automation of dispatching and route interlocking. At the Carborne Train Protection level, train operation remains manual, cab signals, and equipment-enforced for train protection and train supervision as the level above. The Automatic Train Operation's primary advantage was the train operation, either completely automatic or manual door operation. Train starting, train protection, and supervision are like a level above. ATP and ATO remain at the level above in the Automatic Train Supervision level, but train supervision runs automatic (or mostly so) under central computer control. The Unmanned Operation level's main characteristics are the absence of any operator onboard, and the system is handled only by a small number of central control personnel. The Full Automation level includes ATP, ATO, ATS as the level above but with automatic, not manual, backups for each one; it also requires automated yard operation and a minimum amount of personal at central control.

In the 1990s, the International Association of Public Transport (UITP) proposes a classification with five Grades of Automation (GoA) in urban metro driving automation [9]. Each of the five grades attempts to classify the types of train operation based on the distribution of responsibilities in four main basic functions. The four primary functions defined in this taxonomy are: Setting train in motion or driving; Stopping train or supervise guideway; Door closure or supervise passenger transfer; and Operation in event of disruption. The GoA 0 would correspond to on-site operation with full responsibility in the driver. The GoA 1 relates to operating an ATP system with the driver, but the responsibility for the four basic functions is entirely on the driver. The GoA 2 corresponds to train operation with ATP and ATO systems. The basic functions responsibility is divided into the driver for functions 3 and 4 and the automation system for functions 1 and 2. The GoA 3 relates to train operation without a driver, and all four basic functions are performed automatically; only one train attendant is on board for functions 3 and 4. At GoA 4, an Unmanned Train Operation (UTO) is reached; this means the four basic functions in train operation are performed without human intervention. ATP, ATO, and ATC systems are robust enough and work within an overall signaling system with interlocking, automatic train supervision, track vacancy detection, and communication functions for the maximum degree of automation. A formal and detailed description of the classification and its framework is well documented by the International Electrotechnical Commission (IEC) with standards for requirements and specification [10], [11], [12] and its related safety requirements and procedures [13], [14]. Additionally, the American Society of Civil Engineers (ASCE) and the American National Standards Institute (ANSI) define the term Automated People Mover (APM) for automated transit systems, such as magnetic levitation, air cushion, and monorail systems for passengers [15]. ANSI/ASCE outlines a four-part standard that establishes the minimum requirements for safety and performance for APM systems [15]-[18]. This Standard includes minimum requirements for the design, construction, operation, and maintenance of APM systems.

The GoA taxonomy was proposed exclusively for Automated Urban Guided Transport (AUGT) systems in closed rail networks, which means rail vehicles for passenger transportation, e.g., urban metros or trams. The open rail networks have different characteristics due to the vehicles involved and their specific operation. These notable dissimilarities have already been considered, resulting in new
classification proposals. Some of these proposals generalize their application to passenger and freight trains, and only one is exclusively for freight trains. However, none of these proposals currently have a framework or detailed description. The classifications mentioned above have appeared recently and are limited to offering new options for categories or levels for driving automation in trains.

Researchers at the Institute of Rail Vehicles and Transport Systems of RWTH Aachen University indirectly generate a different classification. They grouped the GoA taxonomy grades into three kinds of digital vehicle operation: Assisted, Automated and Autonomous driving, and used the term "Triple A" [20]. The authors discussed potential applications and train braking strategies for railway traffic control. They present the Triple A taxonomy to summarize three kinds of digital vehicle operation support. First A is for Assisted Driving operation related to using support systems for the driver operation tasks. Assisted driving operation group GoA 1 and GoA 2 operation modes. The second A stands for Automated Driving, where the vehicle is not operated entirely by itself and relates this operation mode to the GoA 3. Automated Driving does not have a clear boundary and suggests that in some cases, mixed forms of GoA 3 and GoA 4 are implemented in driverless operation mode. Finally, the third A is for Autonomous Driving, where the vehicle can operate safely without any extraneous control. This classification is presented in a supplementary way to establish the main point of his article on train braking strategies. However, it is relevant because it is a first attempt to classify automation in trains in general for passengers and freight.

Moreover, professionals in the railway industry published their vision on the opportunities offered by automation in the railway sector, particularly the application of Artificial Intelligence (AI) and Machine Learning to solve safety challenges [19]. They intend to exhibit challenges related to managing AI implementation risks in safety-critical areas in digital train operation. The authors’ approach consists of differentiating automatic systems from autonomous systems, Numbers of authors have approached the differentiation and use of automatic and autonomous terms in automation systems [35]. In this case, authors define automatic systems as those capable of executing tasks based on predefined rules within a segregated environment (closed rail networks), predominantly deterministic systems. On the other hand, autonomous systems would be able to make independent decisions to respond in real-time to situations without previous references or instructions in open environments (open rail networks). These systems will be predominantly non-deterministic. Autonomous systems must manage the functions of situation comprehension, environmental awareness, and spontaneous decision-making to operate safely. In their opinion, it is necessary to expand the excepted definitions in the GoA taxonomy to cover the characteristics of automatic, semi-automatic, and autonomous rail operation, including the open rail networks.

Thus, the authors restructure the GoA taxonomy and call it "Levels of Automation for Open Rail Networks" [19]. This classification consists of six ascending levels identified by a letter from A to F, grouping the levels into the No automation, Automatic, Semi-autonomous (SAGoA), and Autonomous (AGoA). Level A is for systems with no automation. The Automatic category includes levels B and C, both with the driver present. Systems in Level B perform manual onboard driving with ATP support and Level C using ATO over ETCS. Authors consider that the Unattended Train Operation (UTO) in urban metros, achieved in segregated environments (GoA 4), must be classified in Automatic category levels. The Semi-autonomous and Autonomous categories are reserved for systems that operate on open rail networks. There is still a driver on board in Level D, and in Level E, remote driving is available. The Level F for fully autonomous operation is achieved only when a fail-safe operation is insured with no human intervention.

Based on the above, the authors argue that AI implementation can help manage the risks associated with automation in predominantly non-deterministic environments. Hence, they consider relevant the current initiatives to define international standards in AI implementation [51]-[56]. The ongoing IEC/ISO new International Standard for a risk management framework for AI [49], the IEEE draft standard for the Fail-Safe Design of Autonomous and Semi-Autonomous Systems [50], and the IEEE Guide for Architectural Framework and Application of Federated Machine Learning [51], were mentioned as initiatives to standardize the AI application.

A different taxonomy approach was proposed for automation in the freight rail environment. In 2018, the US Department of Transportation (DOT), through the Federal Railroad Administration (FRA), requested information and comments from industry stakeholders, the public, State and local governments, and any other interested parties about the potential benefits, costs, risks, and challenges of implementing automated railway operations [21].

The FRA seeks to understand the current stage and development of automated railroad (or railway) operations and how the agency can adopt an open position to support integrating and implementing new automation technologies to increase the US railroad system’s safety, reliability, and capacity. The FRA also seeks comments on the appropriate taxonomy to build a framework for the continued development and implementation of automated technology in the rail industry. FRA cited as an example the SAE and GoA taxonomies requesting comments on whether these or other taxonomies for automation should apply to freight railways.

In this context, the Association of American Railroads (AAR) proposed their approach defining the taxonomy for automated driving in freight trains based on SAE automation levels, named "Automated Rail Taxonomy" [22]. The criteria
for this classification are based on the freight rail system's environment in the US, where a crew of two is required to drive a freight train. Likewise, proper terms such as Engineer refer to the train driver and Switching as the track change operation. This approach consists of a schematic-frame taxonomy, and no detailed information for each level is provided. The first level is No Automation, and the crew is in control in the absence of technology support. At the Engineer Assistance level, the crew is responsible for safety and operation, but with advisement. The Initial Automation level considers acceleration and deceleration are partially automated (longitudinal motion control). Additional crew tasks are automated in the Enhanced Automation level, which means the one-person crew is admitted. The High Automation level is for fully automated execution under specific operational conditions (delimited ODD). For this level, human intervention is still considered. The Full Automation level is designed for fully automated execution with no human intervention and may include automated switching operations [22].

Despite these recent classification proposals, it is widespread to use the GoA taxonomy for automation in open rail networks, primarily for passenger trains. The main problem with this is not whether the classification is chosen but that there is a detailed reference framework for this specific application.

VI. CHALLENGES AHEAD IN SELF-DRIVING TRAINS

The successful case in the automation of Rio Tinto's freight train driving is an example of the high automation level achieved with current technology. Current trends and technologies in autonomous trains have been presented in a recent article [57]. This article showing the technology used for on-road autonomous vehicles and some technical challenges ahead. However, we perceive the deployment of automation on conventional open rail networks entails critical challenges, and they mainly appear non-technical related.

A. FINDING THE BEST ROADMAP

It is often taken for granted that automated and autonomous systems would solve efficiency and security problems. Under this assumption, the higher the automation level, the better the benefits. Several authors have delved into this situation and pointed out the existence of widely spread modern myths about the true scope of robotics and automation [58]-[62]. Mindell [58] finds three main myths:

- The linear progression from non-automation to full automation.
- The human replacing reduces humans' role to mere observers.
- The complete autonomy where the machines will operate entirely by themselves, learning and deciding without human direction.

These myths would mean automation is pushing humans out of the control of machines. However, experience suggests humans are moving into deeper intimacy with their machines rather than being released from the control loop [58]. Taxonomies like the LoA seem to be instrumental in spreading and reinforcing automation myths and misinterpreting concepts [47]. Bradshaw et al. [60] find seven misconceptions that have become myths in autonomous systems. According to the authors, the general assumption that LoA provides a scientific foundation for creating roadmaps of autonomous systems is a myth. This idea is shared by the US Department of Defense (DoD) according to a report on the role of autonomy in DoD Systems. This report concludes that the LoA taxonomy is not particularly helpful to the autonomy design process. The report also recommends that the DoD abandon the use of LoA taxonomies and replace them with an autonomous systems reference framework [62]. This framework will establish explicit relationships between cognitive functions and responsibilities between the human and computer to achieve specific capabilities for each application.

Some authors found LoA taxonomies useful providing a simple way of labeling various sets of technological capabilities [47]. Moreover, all LoA taxonomies perspectives help identify how humans interact with isolated automation elements but fail to address issues that emerge from the network of interconnections between automation elements and are not intended necessarily to reflect relative levels of technological sophistication [64]. The current debate on the convenience and scope of automation taxonomies is evidenced with the above. In addition, there is a debate on how and when it is convenient to use automation. It is considered a myth that full autonomy is not only possible but is always desirable as an ultimate goal [60].

The spread of automation myths in the population also affects how society perceives and values the benefits of this technology [65]. Reactions can be opposite, from exalted positive expectations to rejection and fear of any implementation. To a large extent, the population's degree of acceptance and confidence would be decisive for the approval of regulations in the use of automated systems for driving freight and passenger trains in open rail networks.

Defining an appropriate taxonomy is only one part of defining a roadmap to implement automation in railway systems. The conceptualization process for the gradual introduction of automation in rail systems in open networks seems to be one of the main challenges.

B. STANDARDISATION AND REGULATIONS

There are currently numerous regulations, standards, directives, technical specifications, and detailed literature for the autonomous driving of automobiles and, to a lesser extent, for passenger trains, all motivated by vigorous competition from the industry.

Achieving standardizations for automatic freight train driving requires the international rail industry actors (e.g., operators, infrastructure managers, manufacturers, system integrators). This effort is not feasible without substantial
interest and a clear trend. Sometimes government regulations can serve as an incentive for the industry to develop along that path. On other occasions, private actors in the railway sector have to push for updated and advanced technological development regulations [66].

Great efforts have been made to promote the implementation of standardized railway signaling systems like ETCS and PTC. Both systems have been adopted in other parts of the world and are now the standard systems [67]. Although these systems are equivalent, they are not interoperable with each other. The search for the greatest possible interoperability will be vital to form economies of scale that make the rail ecosystem attractive.

Various international standards regulate safety in developing and implementing electronic systems and software for the railway environment [23]. These norms specify design rules and test procedures to attain a particular Safety Integrity Level (SIL). Many current standards are so stringent that they leave very little room for innovation and implementation of new technologies [68].

C. INCENTIVES AND INVESTMENTS

The main objective of freight trains' automation is to increase security and efficiency to be a competitive option for transporting goods. For decades, freight trains have been losing competitiveness against road transport, particularly in Europe. The rapid development of self-driving freight trucks will make competition for rail transport even more difficult [69] [70].

The cost of signaling, control, and other systems required for driverless operation in rail freight is likely to be significant, with the need to add the associated maintenance costs. The substantial economic investment required to implement improvements in the railway system seems to be an essential limitation of investing in it.

Governments can accelerate the modernization of the rail system through regulations, incentives, and strategic investments [target railway]. The benefits of such investments would not always give immediate results of high profitability. The improvements can have a significant ecological and safety impact on many occasions, and therefore the investments can be justified.

The full implementation of PTC in the US rail network has recently been announced. This achievement is a remarkable milestone on the goal towards achieving to modernize the train operation. Nevertheless, the implementation process required around 12 years and an investment of 3.4 billion US dollars in grant and loan funding to support railroads and other entities that sought Federal financial assistance for that purpose [24]. In this case, the PTC implementation was a mandatory requirement for railway companies to continue operating, although the companies were encouraged by financial aid to invest.

In the EU, the ETCS implementation is still going after more than twenty years. European initiatives as Shift2Rail for European railway modernization with more than ten years and significative investment [30]. Those are examples of how complex, slow, and hard a standard implementation and railway modernization have been.

VI. CONCLUSIONS

A complete interpretation of the overall driving process helps understand the scope of a vehicle's automated driving system more clearly. Through this analysis, other potential areas of automation application can be detected in addition to the operational task of the vehicle's driving process.

The preparation of a freight train can potentially be automated due to the amount of manual work required and the risk it poses to rail personnel. Any improvement in automating these tasks could significantly influence the railway system's efficiency and safety. Marshaling/shunting yards compared to open mainlines are a closed environment or at least much more controllable. Therefore, the complete automation of the yard operation would seem relatively more viable to be achieved in the medium term and with less investment than automating the entire operation in the mainlines.

The differences between freight and passenger trains' operation and the environmental differences on close and open rail networks could justify the need to have different taxonomies for each case. However, the delimitation of specific operation domains and related frameworks and standards seem to be more priority. Although taxonomies have the same structure by levels, they usually fulfill a specific function in which their scope and limitations are known. The use of taxonomies outside of the context for which they were intended can be misinterpreted. A classification taxonomy without a due framework and a detailed description can lead to confusion, inefficiency, and security problems.

At present, standardization and investment appear to be considerable obstacles in the way to driverless train operation. Driverless function in a freight train is perhaps the most complex modality but not the only one to make it more intelligent. In the meantime, gradual implementation of enabling technologies will improve the railway network's safety and efficiency.

APPENDIX

| AAR     | Association of American Railroads |
| ADS     | Automated Driving System         |
| AGoA    | Autonomous GoA                   |
| AI      | Artificial Intelligence          |
| ANSI    | American National Standards Institute |
| APM     | Automated People Mover           |
| ASCE    | American Society of Civil Engineers |
| ATO     | Automatic Train Operation        |
| ATP     | Automatic Train Protection       |
| ATS     | Automatic Train Supervision      |
| AUGT    | Automated Urban Guided Transport |
| BAS   | Bundesanstalt für Straßenwesen (DE) |
DB  Deutsche Bundesbahn (DE)
DDT Dynamic Driving Tasks
DOT Department of Transportation (US)
ETCS European Train Control System
EU European Union
FRA Federal Railroad Administration (US)
GoA Grades of Automation
IEC International Electrotechnical Commission
ISO International Organization for Standardization
LoA Levels of automation
OCC Operating Control Centre
ODD Operational Design Domain
OEDR Object and Event Detection, Recognition, classification, and response
OTA Office of Technology Assessment (US)
PTC Positive Train Control
SAGoA Semi-autonomous GoA
SDT Static Driving Tasks
SIL Safety Integrity Level
SNCF Société Nationale des Chemins de Fer (FR)
UITP Union Internationale des Transports Publics (FR)
UTO Unmanned Train Operation
US United States of America

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