Tram-train system approval procedure

Nermin Čabrić, Nedžad Branković, Aida Kalem

University of Sarajevo, Faculty of Traffic and Communications,Bosnia and Herzegovina

Abstract

Tram-train is a type of light rail vehicle that meets the standards of a light rail system, usually a city tram, but that also meets national mainline standards, which allow it to operate alongside mainline trains. A tram-train can be a viable solution as it can integrate features of rail and tram systems using specially adapted light rail vehicles. When the tram-train system as a public transport concept enabling the combined development of transport on both light rail and heavy rail infrastructure use railway infrastructure, compliance with all essential requirements should be ensured, as well as compliance with the expected level of safety on the relevant lines using two different networks and mixing heavy rail and tram operations increase complexity and often require compromise solutions. The procedure, based on risk analysis, compliance check, and approval of the tram-train system, is presented in this paper. Transit networks based on the light rail can be a good option that aims to reduce the negative effects of individual mobility following the principles of sustainability.

***Keywords**: Tram-train, Risk analysis, System approval, Sustainability*

1 Introduction

To address the need for enhanced mobility in urban areas, a new transportation system called the tram-train was developed in Europe during the 1990s. The tram - train is a public transport system, which originated in Germany, based on light rail vehicles and rail/tram infrastructure, capable of continuous operation outside and inside the city without passenger transfers [1]. The tram-train concept refers to a type of light rail vehicle that functions as a tram when operating on tramway or non-mainline railway systems, but also as a train on heavy rail mainline railway infrastructure. This type of transportation mode provides passengers with a smooth and uninterrupted journey from suburban areas all the way into the urban center of a city. The tram-train concept consists of the operation of light rail vehicles that can run on either existing or new tram lines, or existing railway lines, so that urban public transport services can be extended to the region over those lines, at a much lower cost than if they were built a completely new line [2]. Also, transit systems based on light rail could be a strategic alternative to decrease individual motorized transportation and promote sustainable travel habits. These systems operate on principles of sustainability, efficiency, effectiveness, and quality.

Trams are integrated into the city's roadways, using specialized track infrastructure. The tram-train is a type of light rail vehicle (LRV) that has been adapted or modified for use on both tramway and railway tracks. Light rail transit (LRT) is, by design and operating characteristics, a system somewhere between a tram and a metro. Light rail transit and trams fall under the category of "Light Rail Vehicles" (LRVs) or "Light Rail Transit systems" (LRTs).

Fast urban transit services are provided on certain routes between stations where electric trains typically operate on railway tracks. Stations usually have high platforms which require trains to allow for safe passenger entry and exit, and to minimize differences in height between the train's entrance platform and the station platform. Urban transport systems are closed systems and are often functionally separated from one another. It may happen that a fast urban transport system that uses conventional railway tracks goes onto the public network, and in that case special provisions are applied when approving mobile means of

Corresponding author: *Aida Kalem (aida.kalem@fsk.unsa.ba)*

transport for traffic. The safety standards of the system should not be compromised by the integration of light vehicles on shared tracks. To ensure complete separation of trains, various measures can be taken that will affect the vehicles, infrastructure, and operations. Ideally, the vehicles that operate on shared tracks will be equipped with compatible operating mechanisms like automatic train protection (ATP). Additionally, the infrastructure must be designed in a way that ensures the vehicles are easily detectable and can interpret the signals in all types of running systems [3]. A procedure based on risk analysis, compliance checking, and approval of the tram-train system is presented in this paper.

2 Tram-Train System

The tram-train concept is a type of transportation system that combines the features of both tramway and railway systems. Tram-trains are light rail vehicles (LRVs) that are designed to operate on both tram tracks in urban areas and railway tracks in suburban and rural areas. The tram-train system enables passengers to travel directly from their local tram stop to destinations that are further away, without having to change transportation modes. This integrated approach offers many benefits, including improved connectivity, reduced travel time, enhanced cost-effectiveness, increased flexibility, and improved sustainability.

Definitions according to the directive 2016/797 [4]:

"tram-train" means a vehicle designed for combined use on light rail infrastructure and heavy rail infrastructure;

"existing railway system" means the infrastructure comprising the tracks and fixed installations of the existing railway network, as well as railway vehicles of all categories and origins that operate on that infrastructure;

"light rail" means an urban and/or suburban railway transport system with collision resistance of C-III or C-IV (in accordance with EN 15227:2011) and a maximum vehicle strength of 800 kN (longitudinal compressive force in the coupling area of wagons); light rail systems may have their own track or share it with road transport and typically do not exchange vehicles with passenger or freight transport over long distances.

Essential features of a tram-train system are [5]:

- Dual-mode capability: Tram-trains must be able to operate on both tramway and railway tracks, allowing them to travel between urban and suburban/rural areas.
- Seamless integration: The tram-train system must be integrated with existing urban and railway transport networks to provide passengers with a seamless journey.
- Compatibility: Tram-trains must be designed to be compatible with both tramway and railway tracks, including signaling systems, track gauges, and overhead power supply systems.
- Flexibility: The tram-train system must be adaptable and flexible to accommodate different types of passenger and freight transportation needs.
- Accessibility: Tram-trains must be designed to be accessible to all passengers, including those with disabilities, with features such as low-floor designs, wide doors, and wheelchair ramps.
- Safety: Tram-trains must meet rigorous safety standards, including advanced train protection systems, crashworthiness, and emergency communication systems.
- Sustainability: Tram-trains should be designed to be environmentally friendly, with features such as regenerative braking, energy-efficient lighting, and reduced noise levels.
- Cost-effectiveness: The tram-train system should be cost-effective, with minimal infrastructure modifications required and the ability to operate using existing tracks and stations.

Successful implementation of tram-train systems in Europe is mostly observed in cities with populations ranging from 100,000 to 300,000 [6]. There are also examples of successful systems in larger cities. For example, the Karlsruhe Stadtbahn in Germany, which is considered one of the most successful tram-train systems in Europe, serves a population of over 1 million people. The success of tram-train systems depends on a variety of factors, including the level of existing public transport infrastructure, land use patterns, and political will. Therefore, the population size of a city is not necessarily a determining factor in the success or failure of a tram-train system.

That being said, tram-train systems are generally considered most suitable for medium-sized cities

where the demand for public transport is high enough to justify the investment in infrastructure, but not so high that heavy rail solutions are necessary.

2.1 Track gauge width

Track gauge width is the distance between the inner edges of the heads of two rails measured 14-16 mm below the rolling surface plane (see Figure 1). The track gauge width is not the same in all countries. In many countries, it varies from region to region. Based on the track gauge width, railways are divided into five categories [7]:

- Standard gauge: mostly includes a width of 1435 mm. This distance was established by the British engineer George Stephenson (1781-1848);
- Broad gauge: mainly includes the following gauges: 1,520/1,524 mm (former Soviet countries), 1,600 mm (Irish gauge), 1,665 mm, and 1,667 mm.
- Metric gauge: mostly includes the following widths: 914 mm, 950 mm, 1,000 mm (meter gauge), 1,050 mm, and 1,067 mm.
- Narrow gauge: includes gauges from 600 mm to 900 mm. These gauges are usually used for secondary lines (e.g. industrial areas, factories, and mining service lines). Narrow gauges are also called "narrow track".
- Mixed gauge: this category includes gauges on which trains with different wheelbase widths can simultaneously operate.

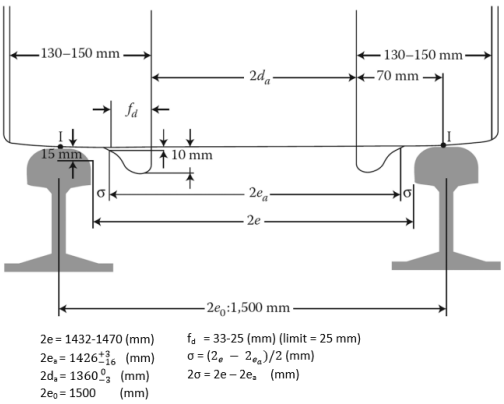

Fig. 1. Standard gauge railway - geometric and constructional dimensions [8]

The track gauge used in tram-train systems can vary depending on the specific system and location. In Europe, the most common track gauge for tram-trains is the standard gauge of 1,435 mm. However, some systems use narrower gauges, such as 1,000 mm or 1,067 mm, particularly in cities where tramways were historically built with narrower gauges. In North America, standard gauge is typically used for tram-trains. The track gauge used in a particular system is determined by various factors, including historical tramway infrastructure, available space, and design requirements. In order to be compatible, the various systems such as trams, light rail, conventional railway, or metro must have the same track gauge. Since the rails in subway tunnels are not exposed to rain, snow, or other forms of precipitation, they are often affixed directly to the ground rather than resting on ballast, like normal railways.

2.2 Power supply system

The traction power supply is a critical aspect to consider for tram-train systems. Light rail systems usually operate on lower voltage supplies, ranging from 600 to 750 Vdc, while conventional railways use higher voltage supplies such as 1,500 or 3,000 Vdc and 15,000 or 25,000 Vac [3],[9]. Electrifying non-electrified railway lines for light rail operations usually poses no technical challenges, and existing clearance requirements can usually be met without the need to raise existing structures to allow conventional rail vehicles to pass under the light rail wires.

However, the line owner may object to light rail electrification, as it could create an entry barrier for other potential train operators who may want to use the line in the future. Adapting existing vehicle traction devices to run on railway or metro lines that have been electrified to higher voltages requires a dual voltage system, which can be complex to design due to the limited available space. In some cases, diesel light rail vehicles may be a suitable alternative, particularly for longer routes with a relatively high degree of separation and low traffic density. Hybrid traction or energy storage systems could be used in similar vehicles in town and city centers. Overall, careful consideration is necessary when choosing the appropriate traction power supply system for tram-train systems.

3 Interconnection in tram-train system

In the tram-train concept, it is important to ensure smooth interconnection between the subway and main railway lines. This can be

achieved by either physically connecting the tracks of the two systems or by providing a seamless transfer of passengers between the two systems at a designated interchange station. The physical connection of tracks is generally preferred as it allows for a more efficient use of infrastructure and rolling stock. However, this option can be technically challenging and may require significant modifications to existing railway and subway systems. The seamless transfer option involves building an interchange station that is designed to facilitate easy transfer of passengers between the two systems, with minimum disruption to the existing operations. This option may be more feasible in cases where physical connection of tracks is not possible or practical. Overall, careful planning and coordination are required to ensure effective interconnection of subway and main railway lines in the tram-train concept.

In some cities, there are two levels of urban railways: a rapid transit system such as the Paris Metro, Berlin U-Bahn, London Underground, and a suburban railway transport system such as the RER in Paris and S-Bahn as a rapid urban rail transit around Berlin. These systems are different and known as S-Bahn trains, suburban services, or regional railways. Suburban transport systems may have their own dedicated rail network with train frequencies as well as fast transit urban lines. In many countries, the national railway company manages suburban transportation. In some cities, these suburban services pass through tunnels in the city center and have direct transfers to rapid transit systems, on the same or adjacent platforms. The Stratford station in London is shared by London Underground trains –left and mainline railway services - right (see Figure 2).

Fig. 2. Interconnection of subway and main railway lines

(https://commons.wikimedia.org/w/index.php?curid= 485689, 10.3.2023.)

In some cases, such as the London Underground, rapid urban transit and suburban transportation run on the same track along certain sections. The California Bay Area Rapid Transit (BART) system, which connects the San Francisco Bay and has 50 stations with six lines, is an example of a hybrid system of two modes of urban transportation. In the suburbs, the lines function as suburban railway lines, with longer intervals and greater distances between stations, while in the city center, the distances between stations are shorter and many lines intersect with intervals characteristic of rapid urban transit.

4 European legislation on tram-train systems

By allowing light rail vehicles to run on conventional railway infrastructure, the tram-train provides a broader range of direct transportation services and minimizes waiting and transfer times. However, implementing this hybrid system poses various technical challenges that must be addressed, including designing compatible traction power supply systems, rolling stock, gauges, tire and rail profiles, ensuring structural strength, facilitating passenger access, and implementing appropriate signaling.

The European legislation on tram-train systems is primarily governed by the European Union's Directive 2008/57/EC [10] on the interoperability of the rail system within the Community. This directive establishes a regulatory framework for the harmonization of technical specifications and procedures for the construction, operation, and maintenance of railway systems, including tram-train systems. The Directive outlines specific requirements for the design, construction, and operation of tram-train systems, such as track gauge, signaling, and rolling stock compatibility. It also requires that all tram-train systems be certified as interoperable before they can be put into service.

Additionally, the European Union has established funding programs to support the development and implementation of tram-train systems. These programs include the Connecting Europe Facility (CEF), which provides financial support for the development of rail infrastructure, and the Horizon Europe program, which supports research and innovation in transportation technologies.

Each EU member state has its own regulations and guidelines for the implementation of tram-train systems, which must comply with

the EU directive. Therefore, the specific legislation and requirements for tram-train systems may vary depending on the country.

Subways, trams, and light rail systems in many European Union member states are subject to local technical requirements. Such local public transport systems usually do not require permits. Trams and light rail systems are often subject to road legislation because they share infrastructure with road traffic. For these reasons, such local systems may not need to be interoperable and should therefore be excluded from the scope of the Interoperability Directive 2016/797 [4]. The 2016/797 directive, also known as the "Technical Pillar" of the Fourth Railway Package, amended the earlier Directive 2008/57/EC on the interoperability of the rail system within the European Union. The amendments made by the 2016/797 directive relate to the certification of railway systems, including tram-train systems.

The Directive sets out new rules for the certification of railway systems, aiming to simplify and streamline the process. It introduces the concept of a single safety certificate and a single entity in charge of maintenance for the entire railway system. This is intended to reduce administrative burdens and costs for railway operators, including those operating tram-train systems.

Like the earlier Directive 2008/57/EC, the 2016/797 directive applies to all railway systems within the European Union, including tram-train systems. It is designed to ensure a high level of safety and interoperability for these systems, while also promoting innovation and reducing administrative burdens for operators.

This does not prevent voluntary application of the provisions of this Directive to local railway systems if deemed appropriate.

Tram-train is a public transport concept that enables combined operation on both light rail and heavy rail infrastructure. Vehicles primarily used on light rail infrastructure, but equipped with certain heavy rail components necessary for limited operation on heavy rail infrastructure solely for the purpose of connectivity, may be excluded from the scope of measures implementing the Interoperability Directive. When tram-train systems use rail infrastructure, compliance with all essential requirements as well as with the expected level of safety on the relevant lines should be ensured.

5 Procedure for approving a rail vechicle

Overall, the approval procedure for tram-train systems is a complex and multi-step process that involves a variety of stakeholders, including government agencies, transportation authorities, and private sector partners. Effective communication and collaboration between these stakeholders is critical to the success of the approval process and the safe and successful implementation of tram-train systems.

Commercial train traffic across the entire railway network requires the alignment of the properties and infrastructure of the vehicles. The quality of service, safety, and interoperability of the railway system as a whole depend on such alignment and interconnection [11]. Before putting vechicle into operation, their technical compliance and safe integration with the system they are being connected to are thoroughly checked. Approval of mobile units for operation on the infrastructure network is based on an assessment of safety levels. The official safety assessment procedure was introduced by the British Coastal Protection Agency and incorporated in 1977 into the Safety Assessment Directive by the IMO (International Maritime Organization) (see Figure 3). This risk assessment method consists of five stages: risk identification, risk assessment, risk management, cost-benefit analysis, and decision-making.

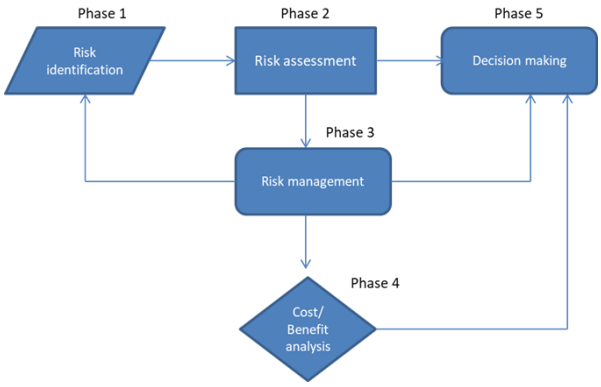

Fig. 3. Structure of safety assessment [12]

Also, the approval procedure for vehicles in tram-train systems is a rigorous process that involves a variety of technical and safety considerations. Effective communication and collaboration between vehicle manufacturers, system operators, and regulatory agencies is

critical to the success of the approval process and the safe and successful operation of tram-train systems.

5.1 Risk assessment

The role and responsibility of assessment bodies within the Common Safety Methods (CSMs) for risk assessment and evaluation are defined by Regulation (EU) No 402/2013. Essentially, the process of risk assessment and evaluation within the CSMs is carried out in three steps [13]:

1 Identification of hazards;
   a. Safety requirements,
   b. Safety measures.
2 Analysis and assessment of risk based on the principles of risk acceptance;
3 Demonstration of the system's compliance with identified safety requirements.

Directive 2016/798 is another component of the Fourth Railway Package, and it specifically addresses the safety of tram-train systems. The directive sets out safety requirements for the design, construction, and operation of tram-train systems, with the aim of ensuring a high level of safety for passengers and workers. The directive requires that all tram-train systems be subject to a safety assessment, which must take into account the specific characteristics of the system, including its integration with existing infrastructure and the use of both tram and train modes of operation. The safety assessment must be carried out by an independent body, and it must be updated regularly. In addition, the directive sets out specific requirements for the training and certification of drivers and other staff involved in the operation of tram-train systems. It also requires that appropriate safety management systems be put in place to ensure ongoing safety of the system

Directive 2016/798 stipulates that infrastructure managers and railway companies establish their Safety Management Systems-SMS [14]. The Safety Management System includes procedures and methods for performing risk assessment and implementing risk control measures whenever changes in operational conditions or the acquisition of new assets impose new risks on infrastructure or operational activities. (Figure 4).

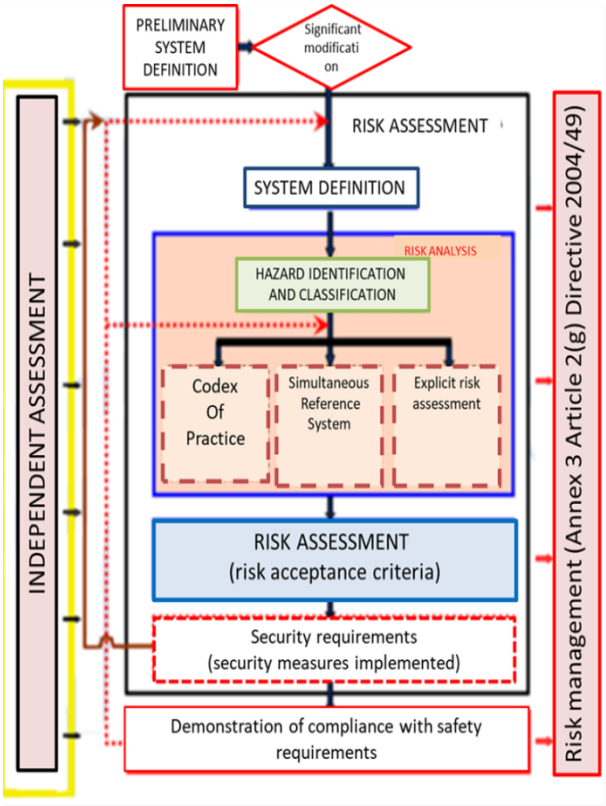

Fig. 4. Risk management process [13]

Like other EU railway directives, Directive 2016/798 is binding on all member states of the European Union, and it applies to all tram-train systems operating within the EU. Its aim is to ensure a high level of safety and interoperability for these systems, while also promoting innovation and reducing administrative burdens for operators.

5.2 Acceptability of risk

The railway company should define principles for adopting the level of acceptable risk and levels that will be defined for different risk categories. Possible consequences (category of consequences depending on the size of damage/loss) of hazards that may occur must be identified. Categories of severity of consequences of hazardous situations are those defined in standard EN 50126. The risk of a hazard is determined not only by the size of the damage it can cause, but also by its likelihood or probability of occurrence. Calculated risks must be classified into risk classes, and for each risk class, conditions of its acceptability must be defined [6]. The acceptability of risk of tram-train systems is a complex issue that involves balancing the benefits of the system against its

potential risks. Tram-train systems, like all forms of transportation, involve some level of risk, including the risk of accidents or collisions. However, the level of risk can be mitigated through the implementation of appropriate safety measures and the adherence to safety regulations and standards.

The acceptability of risk for a tram-train system will depend on a number of factors, including the level of safety measures in place, the level of demand for the system, the potential benefits to the community, and the availability of alternative transportation options . Ultimately, the acceptability of risk will depend on the perception of the system by the public, as well as the regulatory and decision-making bodies responsible for its implementation. It is important that these stakeholders carefully consider the potential risks and benefits of tram-train systems in making decisions about their implementation. In many cases, the acceptability of risk can be improved through a transparent and open communication process with the public, including regular updates on safety measures and ongoing efforts to improve the system's safety performance.

6 Conclusion

Tram-train systems are a valuable form of public transportation that can provide many benefits, including improved mobility, reduced congestion and emissions, and increased accessibility to jobs, education, and other services. Tram-train systems combine the flexibility and convenience of light rail transit with the speed and capacity of heavy rail, allowing for seamless integration with existing infrastructure and increased connectivity between urban and suburban areas. While the implementation of tram-train systems can be complex and challenging, with careful planning and investment, they can be successfully integrated into the transportation network of cities and regions. However, it is important to carefully consider factors such as safety, cost, and public acceptance when making decisions about the implementation of tram-train systems. Approval procedure is required to ensure their safe operation and interoperability with the infrastructure. Overall, tram-train systems represent a promising solution to many of the challenges facing modern transportation systems, and as technology and innovation continue to evolve, they are likely to play an increasingly important role in shaping the future of public transportation.

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