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A safety comparison between urban transportation modes

Agathe Goyet
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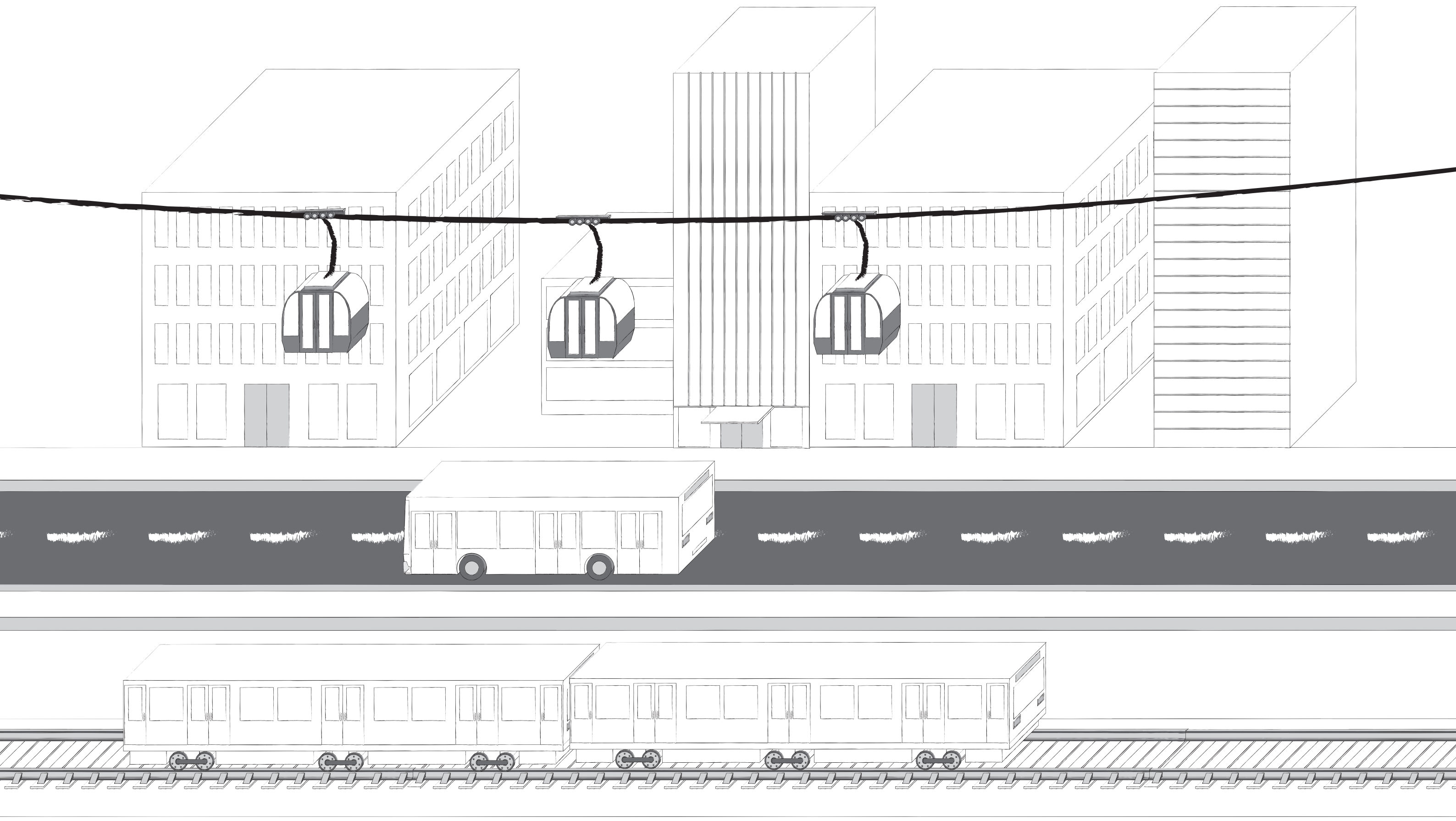

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Contents

1 Introduction

1.1 Context

As urban populations grow, the shift from rural to urban areas accelerates. (Knudsen, Moreno, Arimah, Otieno, & Ololade, 2020, p. 11) (Buhl, 2021, p. 103) Consequently, mobility demands increase rapidly, necessitating a robust transport infrastructure. Safety in public transport is a paramount concern, given its essential role in daily urban life. Whether commuting to work, pursuing hobbies, or meeting personal needs, millions of people worldwide rely on public transportation. As users, we expect reliable and secure systems. (Buckert & Schlecht, 2019, p. 137)

In this article, we delve into a safety comparison between buses, trains and ropeways — three increasingly prevalent modes of transport in our cities. Buses and trains have long been the standard for urban transportation, offering reliable and efficient means for daily commuting. While ropeways, traditionally associated with ski resorts and mountainous regions, are emerging as innovative solutions in urban areas, they are still relatively new in this context. (Buhl, 2021, p. 120) Cities like Medelin in Colombia, La Paz in Bolivia and Mexico City have adopted ropeways to alleviate traffic congestion and provide a swift, eco-friendly alternative. (BBC, 2019)

This analysis will explore the safety aspects of these transportation modes. Each mode has its own advantages and disadvantages. The risks associated with each mode of transport are aimed to be quantified by examining both theoretical foundations and accident statistics. This comparative assessment will provide statistics about the safety of buses, trains and the emerging role of ropeways in urban environments. Due to the comprehensive data available for all modes of transport and the extensive, well-developed public transport network, this analysis primarily focuses on European countries.

Figure 1: Transport hub (Doppelmayr, 2024b, p. 17)

1.2 Motivation for this paper

Our motivation for writing this paper stems from a deep interest in urban transportation and its critical role in daily life. Being in touch with bustling cities, we all have relied on public transport for commuting, education and leisure. This experience has made us acutely aware of the importance of safety in public transportation systems.

Considering that safety is the paramount concern in transportation, this gap in the literature is particularly significant. Currently, there is a notable absence of research directly comparing the safety of busses, trains and ropeways for public transport. Through this scientific paper, we aim to provide valuable insights that city / transport planners can refer to, ultimately helping to substantiate their decisions and contributing to the development of safer, more reliable transport options for everyone.

Furthermore, the rapid urbanization and increasing population density in cities worldwide underscore the urgency of addressing safety concerns in public transportation. By systematically analysing and comparing the safety records of various modes of transport, this paper seeks to identify key areas for improvement and recommend evidence-based strategies to enhance the overall safety and efficiency of urban transportation systems.

It is the goal to bridge the existing knowledge gap and offer a detailed study that can be considered by policymakers, urban planners and transportation authorities. Through thorough analysis and thoughtful recommendations, we hope to foster a safer, more inclusive and sustainable urban transportation network that benefits all members of society.

2 Theoretical framework

Before starting to analyse the numbers, defining the term safety itself and introducing the different means of transport helps to get a homogenous understanding of the following paragraphs.

2.1 Safety in terms of urban public transport

The term "safety" denotes the condition of being secure, free from the threat of injury, danger or loss. This broad definition underscores the inherent connection between safety and risk. However, safety is not a static attribute – it requires continuous maintenance and improvement. (Wac & Wulfovich, 2022, p. 121)

A robust safety culture exerts a positive impact on various organizational aspects, including quality, reliability, competence and productivity. By prioritizing safety, businesses can foster an environment that not only protects individuals but also enhances overall performance. (Gallo, 2023)

Transportation safety focuses on protecting lives through regulation, effective management, technological advancements and strategic infrastructure design. Its primary objectives are to prevent accidents and mitigate the impact on those involved. (European Agency for Safety and Health at Work, 2022)

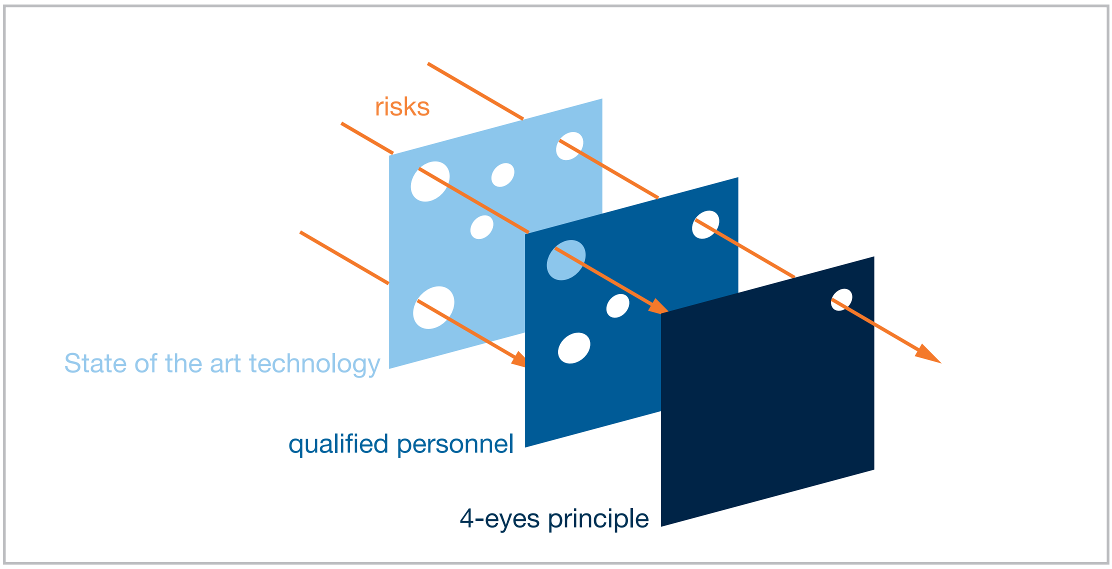

Figure 2: Layers for safety strategies (Schober, 2024)

2.2 Transportation via bus

Buses are an essential means of public transportation in urban and rural areas. According to the European directive, a bus is a vehicle used for the carriage of passengers comprising more than eight seats in addition to the driver's seat. (European Parliament & European Council, 2019, p. 13)

2.2.1 Types of buses

Buses come in various types, each designed for specific transportation needs. "Standard" buses are used for urban transport, serving densely populated areas with frequent stops and accommodating 40 to 100 passengers. Articulated buses, an extended version of urban buses, feature a central articulation for better manoeuvrability and can carry 100 to 200 passengers. Trolleybuses are electric buses powered by overhead wires, navigating regular traffic and accommodating 70 to 100 passengers, with articulated versions increasing capacity to 120 to 160 passengers. Coaches, used for long-distance travel, offer enhanced comfort with amenities like luggage compartments and toilets, seating 30 to 65 passengers, while double-decker coaches can carry 70 to 100 passengers. (Reinhardt, 2018, pp. 338-371)

2.2.2 Infrastructure required for buses

The infrastructure required for efficient bus operation is consistent across all bus types:

- A bus stop is the point where passengers board and deboard.
- A bus station is a transfer hub between multiple bus lines. It has several platforms for passengers boarding and deboarding, waiting areas and food areas.
- In certain cities, dedicated bus lanes are designated on specific road segments to alleviate delays during heavy traffic.
- A bus depot is a facility where buses are parked, maintained and repaired. Additionally, it typically includes washing stations and refuelling or recharging stations.
- A trolleybus requires the installation of an overhead line. The depot has to be equipped with this too.

2.2.3 Operation of buses

Various individuals work together to ensure the smooth operation of buses. Bus drivers operate the vehicles, adhere to schedules and routes, ensure passenger safety and maintain vehicle efficiency. Generally, there is only one driver per vehicle. Inspectors may also occasionally board buses. Their role involves patrolling designated vehicles for scheduled checks, verifying ticket validity, ensuring passenger compliance with rules and providing information.

On specific routes, regulators monitor traffic, inform passengers about regulations, handle technical issues, manage accidents and implement traffic control measures.

Additionally, bus dispatchers coordinate all bus routes. They manage daily schedules, provide navigation guidance, handle troubleshooting and liaise with maintenance teams as well as monitoring traffic and weather conditions to ensure safe operations.

Service and maintenance personnel at bus depots handle regular maintenance and repairs, ensuring buses are in optimal condition for safe service. Maintenance schedules, based on vehicle usage, are usually provided by manufacturers. Public transport vehicles undergo mandatory regular technical inspections, focusing on safety aspects like brakes, lights, steering and chassis. (Reinhardt, 2018, pp. 465-523)

2.3 Transportation via train

Trains are vital for transportation in both urban and rural areas, connecting cities as well as different regions. According to the European directive, trains consist of one or more units, collectively known as rolling stock, which includes the structural body, control systems, electric current devices, traction units, braking systems, running gear, doors, interfaces for drivers and passengers, safety devices and health requisites for passengers and staff. (European Parliament & European Council, 2016, p. 51)

2.3.1 Types of trains

Trains come in various types, each designed for specific transportation needs. High-speed trains, running at speeds over 250 km/h on specialized lines, offering space for several hundred passengers, link major cities and countries. Regional and intercity trains cover medium to long distances with fewer stops and fewer passenger capacity. Commuter trains connect city centres with outlying districts and towns, characterized by shorter routes and frequent stops. Metros, often underground, serve urban areas with frequent stops and a higher passenger flow rate compared to commuter trains. Trams, which are slower electric trains using street-embedded rails, also serve urban areas with even more frequent stops. They typically have a lower passenger capacity than metros with around 100-300 passengers per vehicle. (Reinhardt, 2018, pp. 270-331) (Ihme, 2019, pp. 4-12)

2.3.2 Infrastructure required for trains

The development of an efficient railway network requires robust and well-planned infrastructure:

- Rail tracks consist of two parallel steel rails anchored perpendicularly to sleepers, which can be made of timber, concrete, steel or plastic. The purpose is to maintain a consistent distance between the rails, known as the rail gauge. (Fendrich, 2019, pp. 69-78)

- A railway station serves as an area where passengers can board and deboard trains. Stations must be adapted according to the types of services offered:
  - Main stations: Large facilities often located in city centres, serving multiple types of trains. (high-speed, intercity, regional)
  - Suburban stations: Smaller stations primarily serving commuter trains with facilities adapted for short trips.
  - Depot areas are places where trains are parked when not in use or in service. It needs to be secure and well-equipped for quick checks. (Fendrich, 2019, pp. 429-432)

- The signalling system is a system used to control railway traffic safely to prevent trains from colliding. (Fendrich, 2019, pp. 525-533)

- Trains necessitate regular maintenance to uphold safety and reliability. Dedicated maintenance workshops are equipped for train servicing and repairs. (Reinhardt, 2018, p. 497)

2.3.3 Operation of trains

Various staff is required to operate trains. Train drivers, responsible for operating trains, ensure that they reach their destination safely and on time. They are also responsible for inspecting and supervising if maintenance is needed. In general, there is only one driver per train. For longer journeys, there are replacements to do rotations.

There are also train dispatchers, they are responsible for monitoring train movements, communicating with train crews and making sure that trains run on schedule. They are responsible for the safe and efficient movement.

Passenger train crews play a critical role in ensuring the safe and efficient transportation of travellers between destinations. Their responsibilities include ticket verification and serving as emergency contacts during the journey.

Maintenance staff is essential for the safe and reliable operation of rail systems. They handle rolling stock and infrastructure tasks, including track upkeep, electrical and mechanical signalling and catenary maintenance for electric locomotives. (Reinhardt, 2018, pp. 507-523) (Fendrich, 2019, pp. 427-438)

2.4 Transportation via ropeway

A ropeway is an aerial or ground based public transport technology in which engine-less cabins, suspended and propelled by cables, are used for transportation. In accordance with the European regulation 2016/424, ropeway installations consist of various components that are designed, manufactured, assembled and commissioned to transport individuals. (European Parliament & European Council, 2016a, p. 3) These installations facilitate the movement of people using carriers or towing devices, with suspension and/or traction provided by one or more ropes aligned along the travel route. Unlike buses and trains, ropeways act on an elevated level, above streets and walkways. A special ropeway type called funiculars are an exception because although they are cable-drawn, they run on rails on the ground. (see chapter 2.4.1.4.) Predominantly located in ski resorts and mountainous tourist regions, ropeways are also gaining popularity as an alternative mode of urban transportation. (Ambs & Pipahl, 2020, pp. 102-107) There are several types of ropeways for different use cases available.

2.4.1 Infrastructure for different ropeway installations

2.4.1.1 Aerial tramways

Aerial tramways are cableway installations in which the carriers are hauled by one and suspended by one or several ropes, offering two cabins, moving back and forth. These cabins can carry from 6 to 200 people. Aerial tramways consist of several key components. At least one track rope supports the load of the cabin, with the cabin's rolls running along this track rope. Additionally, the carrier truck is attached to the haul rope, which is driven by a motor located in one of the stations, enabling the vehicles to move. (Doppelmayr, 2022, p. 4)

Figure 3: Ropeway installation in Mexico City (Schober, Persönliches Bildarchiv, 2025)

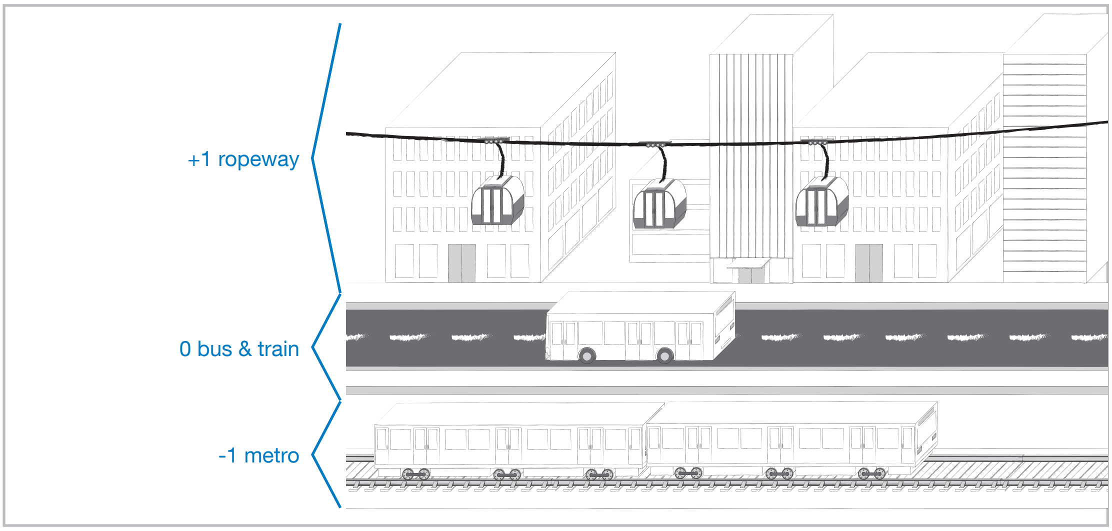

Figure 4: Different transport levels (own illustration based on Doppelmayr, 2024b)

Figure 5: Aerial tramway in Portland (Doppelmayr, 2022, p. 41)

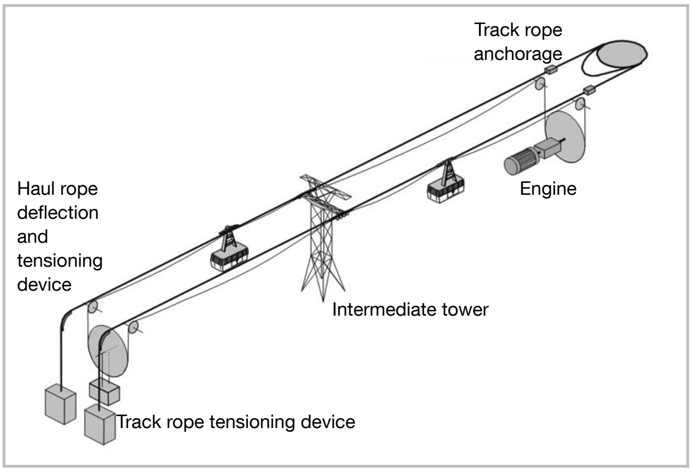

Figure 6: Schematical drawing for aerial tramways (Fottner, Johannes, 2024)

2.4.1.2 Gondola installations

Gondola installations are uni-directional loop running ropeways featuring a series of cabins. Usually, these cabins are smaller than aerial tramways. Each cabin can hold 4 to 35 people. Gondola installations can be divided in two different types. The monocable installation has a detachable grip, which connects the cabin with a continuously moving cable that hauls and suspends the vehicle. Bi- and tri-cable installations use a detachable grip too, that connects the cabin with the continuously moving hauling rope. But the other one/two ropes are just for the suspension of the vehicle, they are in a fixed position. The suspension on the cabin side includes rolls that are running on these suspension ropes. Both installations offer the uncoupling function that allows the cabin to pass through the loading/unloading areas with reduced speed. While the continuously moving cable still runs, the cabin is detached and moves slowly on rolls through the stations. There are usually only two stations, but some systems may have intermediate stations. (Fottner, Johannes, 2024)

Figure 7: Monocable installation in La Paz (Doppelmayr, 2024b, p. 20)

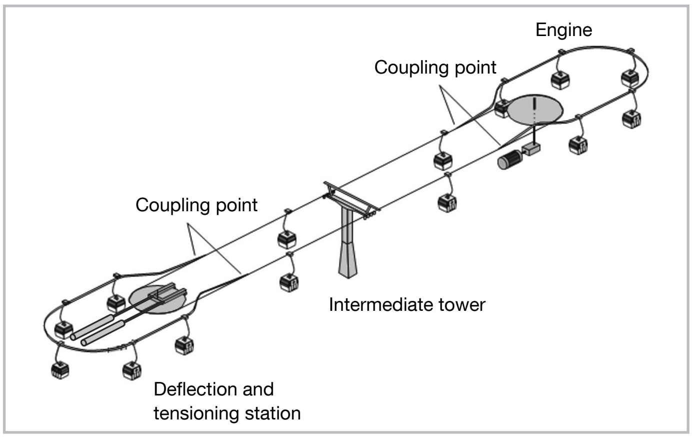

Figure 8: Schematical drawing for monocable installations (Fottner, Johannes, 2024)

Figure 9: Tri-cable installation in Koblenz (Doppelmayr, 2022b, p. 4)

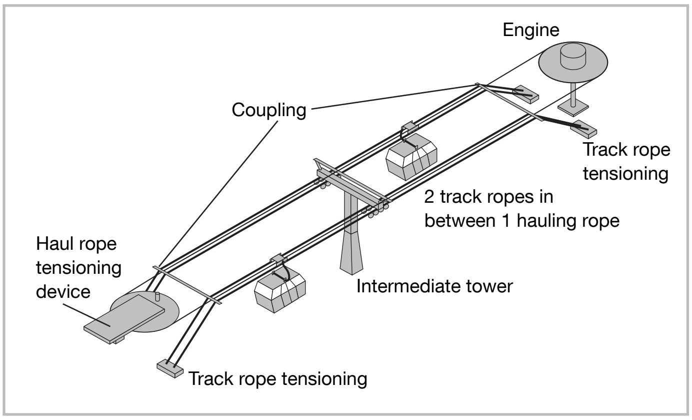

Figure 10: Schematical drawing for tri-cable installations

2.4.1.3 Basic installation requirements for aerial ropeway installations

The necessary infrastructure of aerial ropeways is limited:

- Towers are supporting the weight of the rope(s) and cabins.
- Ropes can be used as a haul rope (for the propulsion), as a track rope (for the suspension) or for both functions.
- Stations are the points where cabins are slowed down and passengers board and deboard. A ropeway has at least two stations but sometimes, ropeways can have intermediate stations as well to pick up and drop off passengers between the end stations.
- The central electric drive that propels the rope is located in one station.
- Unlike buses and trains, ropeways do not require an extra depot or a signal and traffic control technology. They just need a specific ropeway controlling software. (Leitner, 2024) (PwC, 2022, p. 9)

2.4.1.4 Funicular railways

Funicular railways, which include carriers hauled by one or several ropes along a track that may lie on the ground or be supported by fixed structures, require rails for track guidance. These ground-based cable railway systems feature two counterbalanced

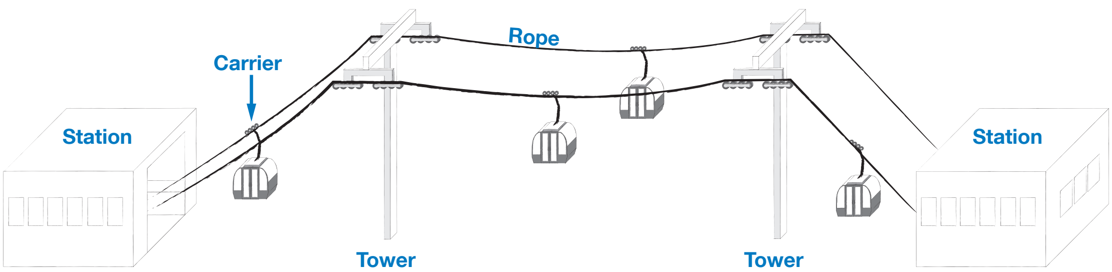

Figure 11: Ropeway main elements (own illustration based on Petrova, Hoffman, & Liehl, 2007)

cars that transport passengers up and down steep slopes, commonly found in mountainous regions or urban areas with significant elevation changes, (Hoffmann, 2006, pp. 4-8). Funicular systems look very similar to railways, but they are at some essential points very different to common railways and that is the reason why they are regulated under european cableway regulation 2016/424, (Fottner, Johannes, 2024) p. 27ff:

- drive and brake units are in bottom or top station, not on the vehicle itself
- position of the vehicle is fixed by the cable, no headway measurement necessary
- inherent safe switches, due to the principle of the Abt'sche switch with no moving parts
- no signalling on the track needed, due to rope position monitor checking.

Througout these system specific advantages, such installations are much easier to operate in GoA4 (Grade of Automation) Mode.

Figure 12: MiniMetro Perugia, urban detachable funicular system (TÜV SÜD Industrie Service GmbH)

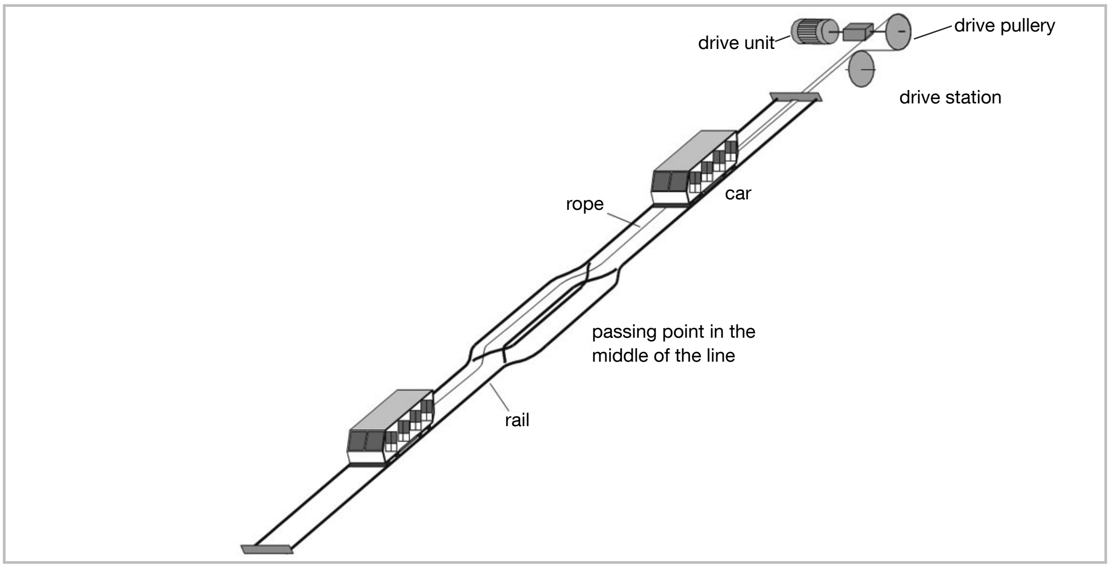

Figure 13: Schematic drawing for funicular railways (Fottner, Johannes, 2024)

2.4.2 Operation of ropeways

Very few individuals work together to ensure the smooth operation of a ropeway. Ropeway operators are responsible for operating the installations. They handle commissioning tasks, operate and monitor the ropeway installation, check technical components and provide information to customers. Every day, before the start-up of a ropeway, tests and visual inspections must be carried out on the entire line: loading/unloading areas, engines, wheel sets, ropes and towers. At the loading area, an operator monitors passengers board safely, supervises the opening and closing of automatic doors and manages access control systems. At the unloading area, another operator supervises passenger disembarkation. On aerial tramways, a cabin attendant may be present during the ride to ensure passenger safety, provide information and answer questions. The number of operators needed depends on the type and size of the installation. (Bundesministerium für Digitales und Verkehr, 2022, pp. 98-110)

Newly developed ropeways can operate autonomously without staff. This type of ropeway is equipped with cameras and sensors to monitor the installation. There is no staff in the station, but an agent keeps an eye on the installation from a control centre so that he can act if necessary. (Doppelmayr, 2024a)

Maintenance staff is needed to carry out regular inspections of the rails and cables, intervene in the event of breakdowns or technical problems and manage preventive maintenance. For more specific and complex maintenance, experts can be called to reinforce the maintenance teams. (Leitner, 2024a).

Figure 14: Autonomous operating ropeway with special infrastructure (Doppelmayr, 2024a)

3 Standards and regulations in public transport

Safety in transportation is essential to ensure the protection of passengers. It helps to prevent accidents, reduces the risk of injuries and guarantees the proper functioning of transport infrastructure. For European transport, where the focus of this paper lies, standards and directives are put in place by the European Commission. They define precise criteria for equipment, staff training, and operational procedures. By adhering to these standards, transport operators can ensure a high level of safety. Below is an overview of the various European safety standards relating to construction, operation, maintenance and safety. Tramways are subject to country specific regulations and follow their own standards incorporating both aspects from buses and trains. In most countries with a long term and successful history of ropeway, even regarding safety, experienced and accredited 3rd party inspections are mandatory to ensure this high level of safety and identify risks and damages in time, (Schober, 2024). Unlike buses and metro systems such as underground railways or trams, cable cars are subject to sectoral regulation in the EU with regard to design, construction, manufacture, and commissioning.

	Bus	Train	Ropeway
Construction	UN No.107 EU 2019/2144 EU 661/2009	EU 1299/2014 EU 1300/2014 EU 1301/2014 EU 1302/2014 EU 2016/919	EN 1908 EN 12927 EN 12929-1 /-2 EN 12930 EN 13107 EN 13223 EN 13243 EN 13796
Reliability & Maintenance	EN 13816 EU 2014/45	EU 15380 EN 50126	EN 1709 EN 12408
Operation	National specific	EU 2051/995 EU 2019/776 EU 2019/772	EN 12397
Safety	National specific	EU 1303/2014 EU 2016/798 EN 50126 EN 50128 EN 50129	EU 2016/424 EN 1709 EN 12927 EN 17064

Table 1: Most relevant european standardization for means of transport (own table based on the information retrieved from eur-lex.europa.eu)

4 Factors influencing safety

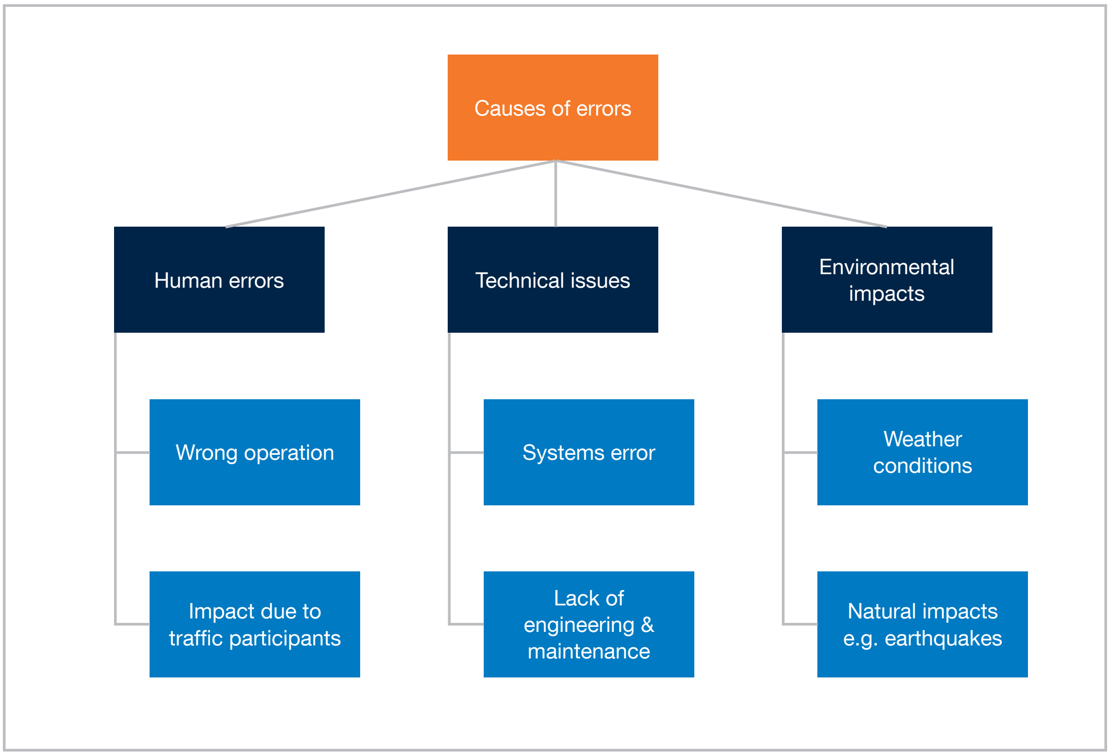

Figure 15: Potential causes of errors (own illustration based on the findings from chapter 4)

4.1 Human errors

The safety of public transportation can be influenced by human factors, which are the largest cause of accidents across all transport modes. Human error is involved in about 95% of all road traffic accidents (European Parliament, 2019):

- An operator can make mistakes due to fatigue, stress, wrong/missing communication, inattention or lack of adequate training. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 10)

- Rules or procedures can be broken by an operator. (Charbit, 1997, p. 25)

- Unauthorized people in sensitive areas, such as control cabins or technical facilities, can pose significant risks. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 11)

- Inattentive passengers may not notice potential risk, such as approaching buses or slippery floors. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 11)

- Misbehaviour and disregard of safety rules by passengers can lead to safety risks. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 11)

- There may be a risk from all other traffic participants. However, the ropeway is excluded from this because it operates in its own +1 floor territory. (PwC, 2022, p. 7)

4.2 Technical issues

Technical issues can cause a wide range of problems and definitely influences safety.

- Systems errors like signal failures can disrupt the entire public transport network, leading to delays and cancellations. These errors often stem from outdated technology, software glitches or inadequate maintenance of signalling equipment. Ensuring regular updates and rigorous testing of signal systems can help mitigate these issues. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 11)

- Poor design in construction engineering can result in structural weaknesses, inefficient layouts and safety hazards. Implementing comprehensive design reviews and adhering to stringent engineering standards can reduce these risks. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 11)

- Mechanical breakdowns, such as engine failures or brake malfunctions, can cause significant disruptions. These failures are often due to wear and tear, lack of regular maintenance or substandard parts. Establishing a robust maintenance schedule and conducting frequent inspections can prevent such issues and ensure the reliability of public transport vehicles. (Brightly, 2023)

- Infrastructure issues, such as deteriorating tracks, bridges and stations, can lead to service interruptions and safety concerns. These failures are often a result of aging infrastructure, insufficient funding for repairs and lack of proactive maintenance. Prioritizing infrastructure investment and implementing regular inspection and repair programs are crucial for maintaining a safe and efficient public transport system. (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, 2024, p. 13)

4.3 Environmental impacts

Apart from human errors and technical issues, environmental impacts should not be underestimated.

- Strong winds can disrupt bus, train and ropeway schedules by causing delays or even halting services, especially in areas prone to high winds. This can lead to increased travel times and reduced reliability.

- Heavy rainfall can cause flooding, which affects road and rail infrastructure. Flooded tracks or roads can lead to significant delays and service cancellations. The +1 level, where ropeways act, is not affected in such situations.

- Snow and ice can make roads and tracks slippery, leading to delays and accidents. This is particularly problematic for buses and trains operating in regions with harsh winter conditions. Ropeways originally come from winter tourism and are therefore resistant to snow and ice.

- Extreme heat can cause rail tracks to expand and buckle, leading to speed restrictions or service suspensions. It can also affect the performance of buses, ropeways and other vehicles.

- Dense fog reduces visibility, making it difficult for bus and train operators to maintain schedules. This can lead to longer travel times and increased risk of accidents.

Ropeways are not affected by fog because they can basically operate fully automated and no "driver" has to see the track.

- Thunderstorms can also affect the safety of public transport especially lightnings can paralyze technical systems.

- Natural catastrophes like flooding, earthquakes, storms, wildfires and landslides can disrupt public transport by damaging infrastructure, causing closures and leading to service interruptions. These events pose significant safety risks for passengers and operators.

(Gössling, Neger, Steiger, & Bell, 2023, p. 1347) (PwC, 2022, p. 7)

5 Analysis

5.1 Transfer to the objectives of the study

The theoretical framework is established in the first section of the document by outlining the various types of urban transportation, examining their operations and discussing the associated safety standards.

The safety of these transportation modes is governed by standards and directives formulated by the European Commission. These directives set common objectives and deadlines for member states to adopt these standards, ensuring uniform and highest safety levels in public transport.

Human errors, such as operator mistakes and rule violations, cause most public transportation accidents. Environmental factors like strong winds and heavy rainfall also disrupt safety. Additionally, technical issues can contribute to risks too.

With this foundational understanding of transport types, safety standards and factors influencing safety, the second part of this article will compare accident statistics for each mode of transport and analyse data from various countries.

5.2 Statistical basis for ropeways

Due to its extraordinary appearance and its "obvious risk of falling to the ground", ropeways have been in the focus of transport authorities since its beginning in the early 20th century. A key role in this process, plays the international organization for the transport by rope (OITAF), founded in 1959. This organization brings together all stakeholders within the ropeway sector – authorities, manufacturers, operators and inspection organisations. As a result there are many OITAF recommendations, seminars and congresses where an expert exchange is in place, such as the puplication show up, (Schober, 2024).

OITAF is also participating member of the annual meeting of the responsible technical govermental authorities (ITTAB), were more than 60 countries around the globe are taking part. A important part of this meetings, is the annual statistic on transported passengers by rope and the statistic on incidents and accidents with its specific causes and hazards. The aim is the further development and research on legal and safety aspects of ropeways for passenger transport.

As the overview in Figure 18 shows the most relevant countries, regarding the number of ropeway installations are France, Switzerland and Austria. Germany is on 6th position. These 4 Countries have the most accurate and comparable statistical basis, also through its comparable regulatory frameworks.

As Figure 19 shows, ropeways with a high portion of passenger interaction, such as skilifts show a higher ratio of incidences. For urban transport solutions these types of ropeways are not relevant, therefore they are excluded from the further comparison with other modes of transport.

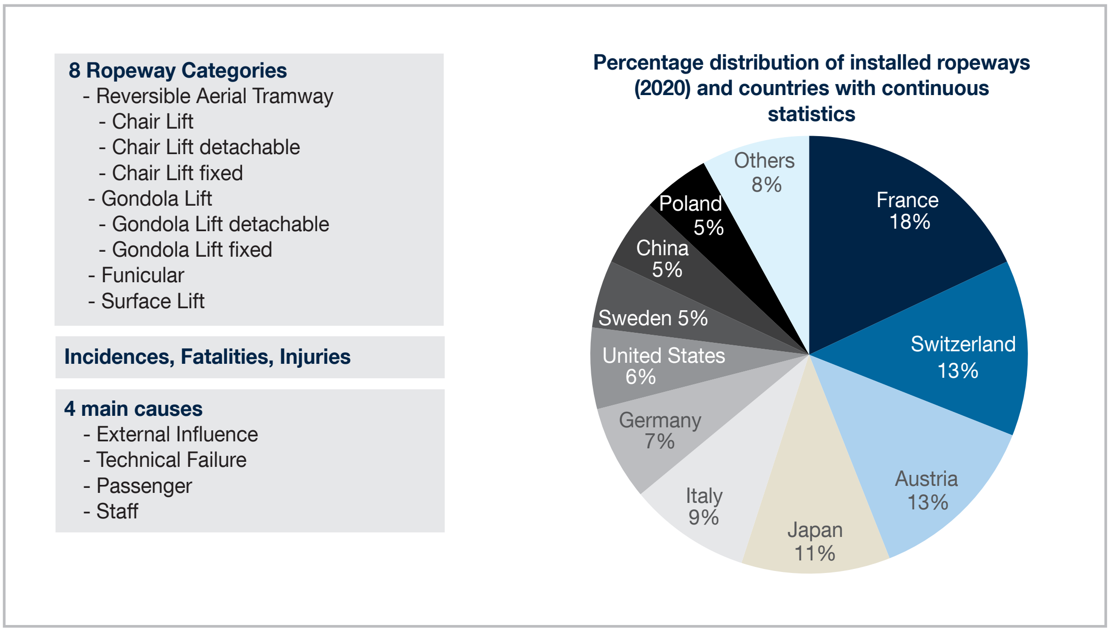

Figure 16: Structure of ITTAB Statistics, published in (Schober, 2022)

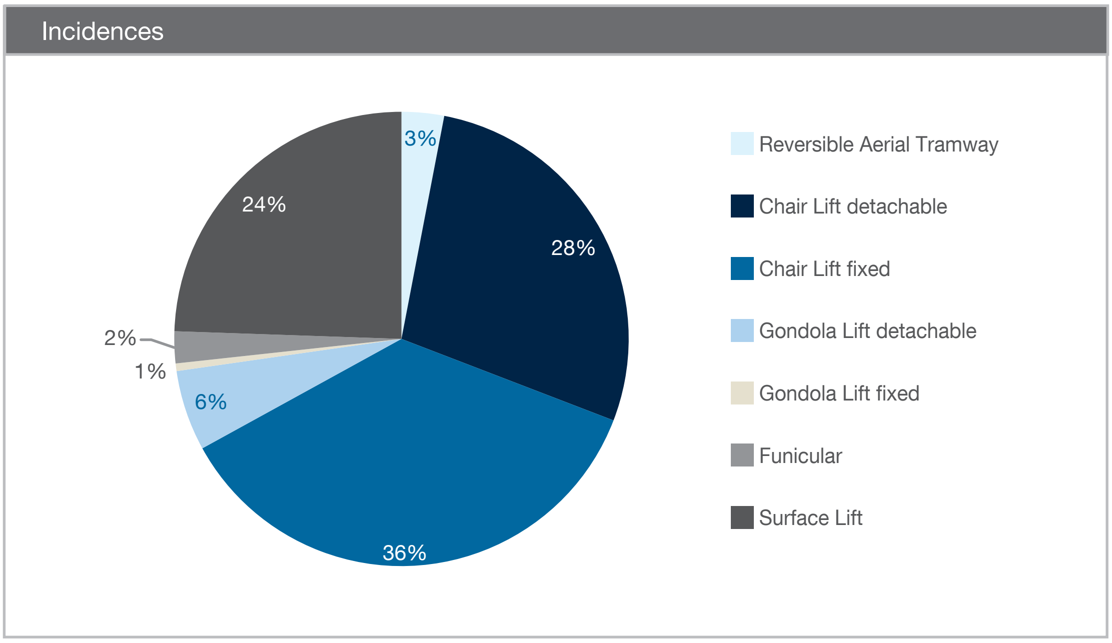

Figure 17: Average of Incidences related to the types of ropeways (Schober, 2022)

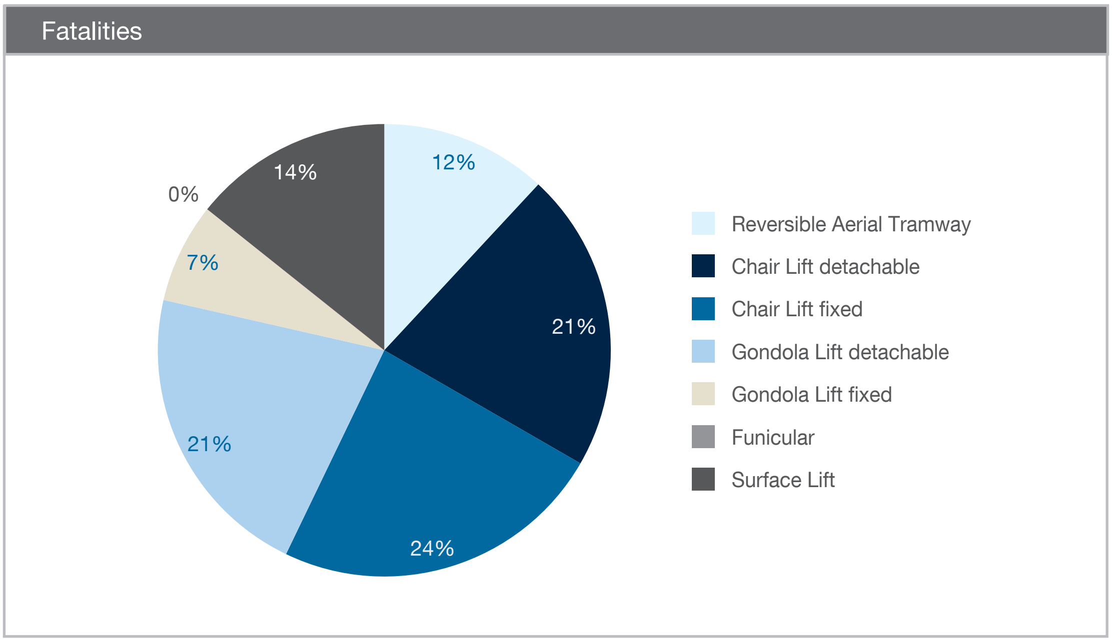

Figure 18: Average of fatalities releated to the type of ropeway (Schober, 2022)

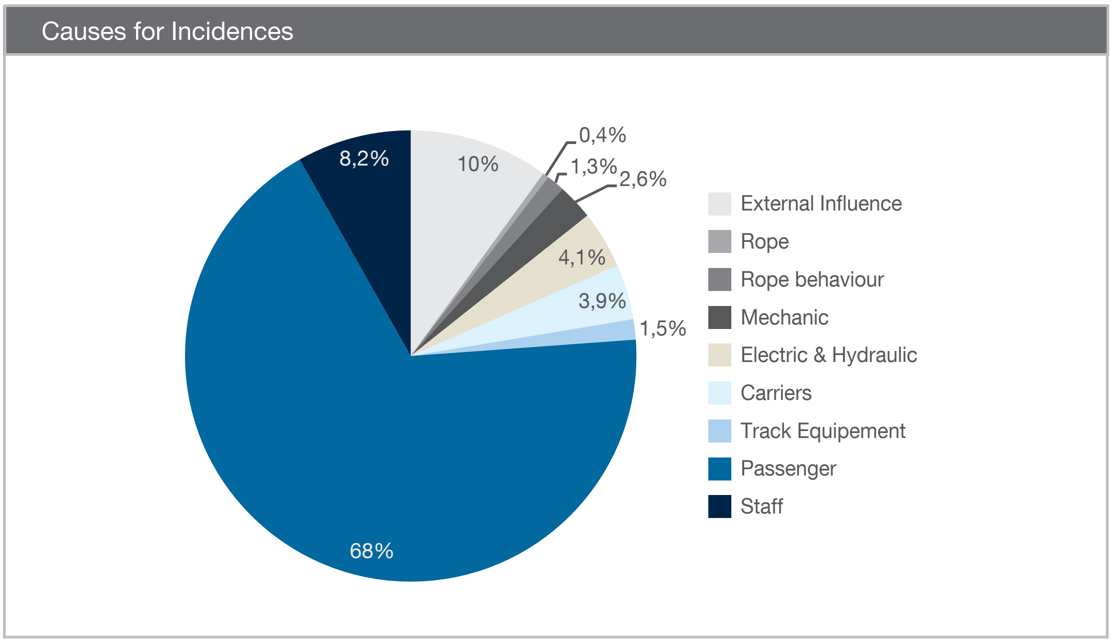

Figure 19: Average of fatalities releated to the causes for incidences (Schober, 2022)

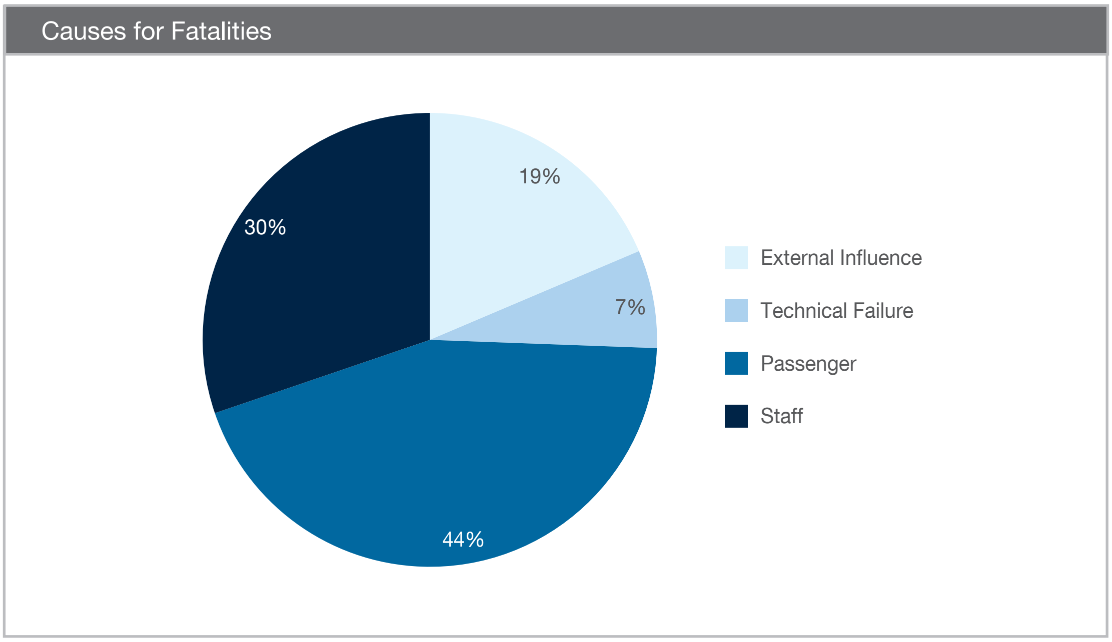

Figure 20: Average of causes for fatalities at ropeways (Schober, 2022)

5.3 Methodology

The main objective is to summarize key information and facilitate its interpretation. To achieve this, a descriptive analysis of the statistics will be conducted. This type of analysis allows for the description and summarization of the data in a meaningful way.

Our primary focus is on four European countries: Germany, France, Austria, and Switzerland. These nations boast extensive public transport networks and utilize ropeways, providing us with a comprehensive overview and necessary data.

For the following analysis, the number of inhabitants is a key figure for comparability and understanding.

To compare the safety of different modes of transportation, accident statistics for each mode of transportation in the countries mentioned before will be compared. An accident is an unwanted or unintended sudden event or a specific chain of such events (occurring during operation) which has harmful consequences. (Eurostat, 2019, p. 28) Accident statistics provide data on the frequency and severity of incidents related to each mode of transportation. A special focus will be placed on some KPIs of these accident data. They are used to monitor progress and identify areas needing improvement. The various KPIs compared in these articles are:

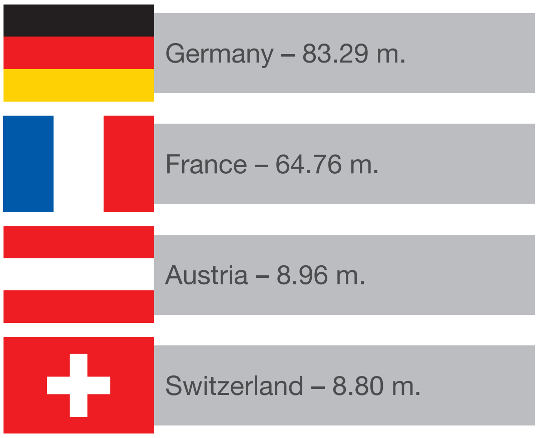

Figure 21: Numbers of inhabitants for each country (own illustration based on Statista, 2024)

Traffic volume	The number of people who use this mode of transportation over a year.
Number of injuries	Any person who as result of an accident was not killed immediately or not dying within 30 days, but sustained an injury, normally needing medical treatment, excluding attempted suicides. * (Eurostat, 2019, p. 55)
Number of fatalities	Any person died immediately or dying within 30 days as a result of an injury accident, excluding suicides. (Eurostat, 2019, p. 55)

**When it comes to injury statistics, there are varying interpretations among countries regarding what constitutes an injury. The ambiguity lies in whether to include minor, harmless injuries or only those requiring hospitalization. This discrepancy can lead to a somewhat distorted analysis of injury data.*

Table 2: Definition of KPIs used based on Eurostat, 2019.

To access these various data, national and international organizations that handle these statistics were approached. Research was conducted by exploring various websites and directly contacting statistical organizations in different countries. This led to the examination of several documents, including databases and annual reports. Specific sources are mentioned in the corresponding chapter of the analysis.

In figure 18, a basic overview of the different institutions where the statistics originate is shown.

A study was then carried out to extract important information from these sources. These data are essential as they will enable the safety comparison for different modes of transportation. The following data in table 3 were collected.

Making a statement in terms of our purpose, the safety comparison between means of transport, just by comparing the absolute numbers of injuries and fatalities in total for each country does not make sense due to the huge differences in passengers.

For a serious comparison, several steps must be taken. The process of determining the probability of 100,000,000 passengers being injured

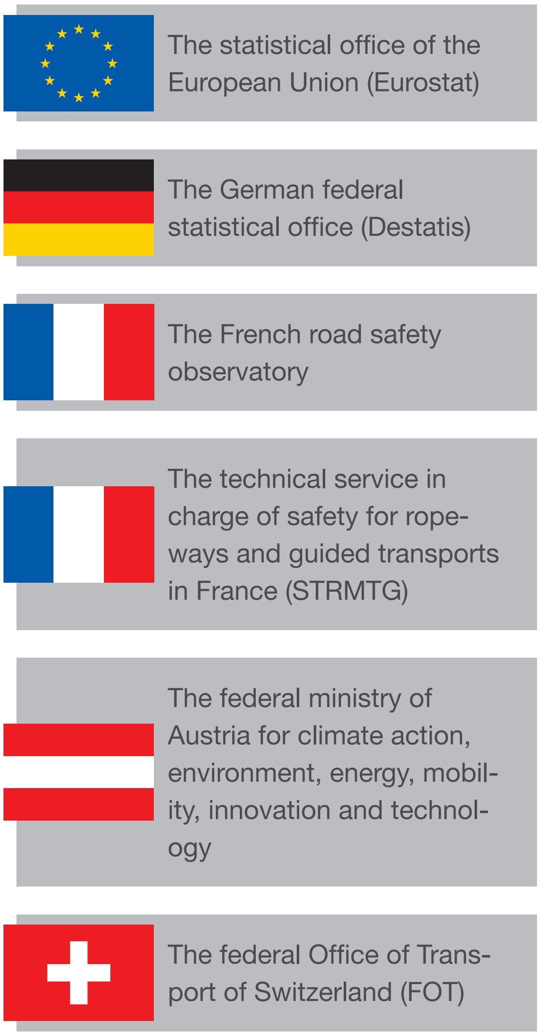

Figure 22: Institutions serving as sources for statistical data (own illustration based on the institutions used as sources for this paper)

Buses	**Type of buses included:** – standard buses – articulated buses, trolleybuses – coaches – double-decker coaches – tramways*
Trains	**Type of trains included:** – high-speed trains – commuter trains – regional / interurban trains and metros
Ropeways	**Type of ropeways included:** – aerial tramways – gondola installations – funiculars

Data available for the period from 2015 to 2022:
– Number of passengers per year,
– Number of injuries per year,
– Number of fatalities per year

**Statistics regarding tramways will be included in the statistics for buses. Indeed, in some classifications, tramways and buses are grouped under a general category of "urban public transport". Therefore, in this study, no distinction will be made between buses and tramways.*

Table 3: Methodology Database (own table summarizing the methodology applied)

or die based on the mode of transport has to be carried out. This particular number was chosen to get into a range of values that allows a more realistic imagination and interpretation of the results by the reader. It means the following:

When 100,000,000 passengers use a specific type of transport in a country shown before, X people will be injured or die.

The results are calculated based on the number of passengers per year, but they vary depending on the years and the modes of transport. The following schematical drawing explains the procedure to obtain this data.

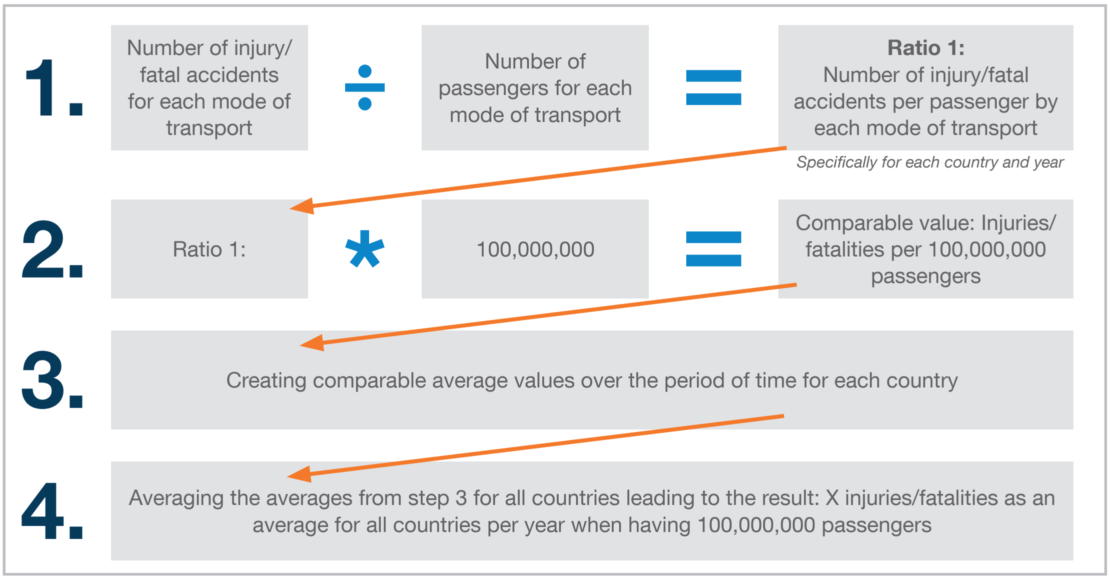

Figure 23: Structure of ITTAB Statistics, published in (Schober, 2022)

6 Research results

6.1 Buses

6.1.1 Traffic volume

The graph below (figure 24) shows the number of passengers transported by buses and tramways from 2015 to 2022 in Austria, Germany, France and Switzerland. After relatively consistent amounts of passengers, a decline can be observed in 2020 and 2021, likely due to COVID-19 restrictions and the necessity / opportunity for new work (e.g. remote work). However, after the pandemic, the number of passengers increases, though pre-pandemic levels have not yet been fully restored. (Eurostat, 2023)

French data concerning the number of passengers transported per year was not directly available, so an estimation was necessary. The single available data was the number of passenger-kilometres, which is calculated by multiplying the number of trips with the average distance travelled. According to the 2019 mobility survey, the average distance per trip using public transport is estimated at 11.8 km. (French ministry for ecological transition and territorial cohesion, 2021) Therefore, the number of passengers was estimated by dividing the total number of passenger-kilometre by this average distance.

The Austrian data for the number of bus passengers transported per year was found at WKO. (Wirtschaftskammer Österreich - Transport & Verkehr, 2023, pp. 28-29) Tram passenger numbers were found by directly contacting each tram operator in Austria and cumulating those figures.

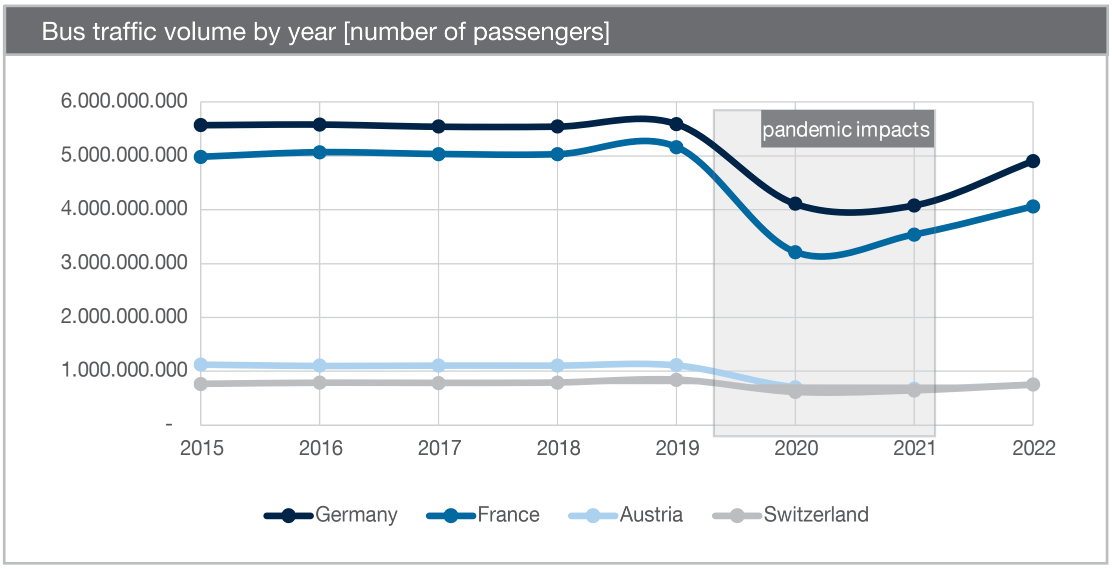

Figure 24: Bus traffic volume (own illustration based on DESTATIS, 2024; FOT, 2024; French ministry for ecological transition and territorial cohesion, 2021; WKO, 2024).

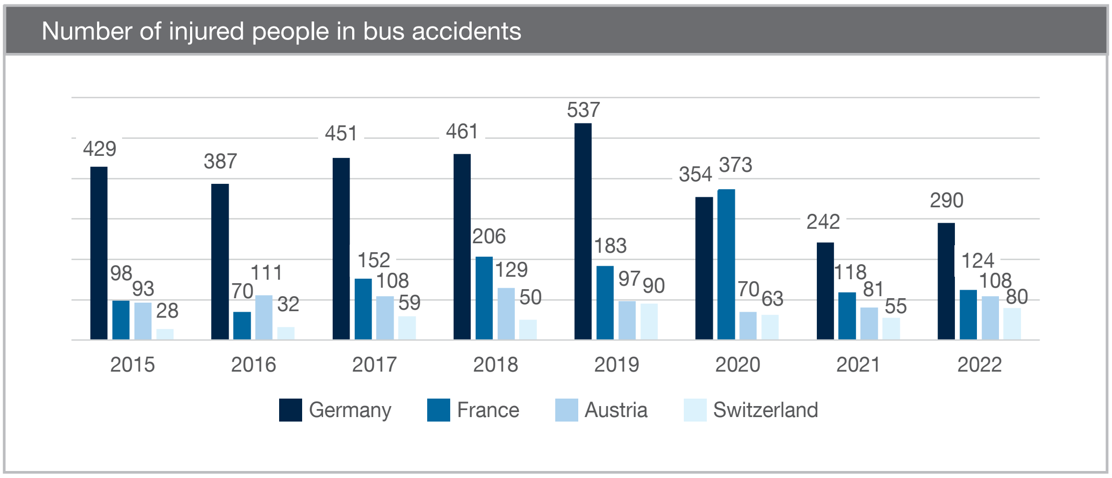

Figure 25: Absolute number of injured people in bus accidents per year / country (own illustration based on DESTATIS, 2022; DESTATIS 2023; BMK, 2024; FOT, 2024; DSR, 2024).

6.1.2 Accidents

6.1.2.1 Injury accidents

Figure 25 shows the absolute number of bus and tramway accidents per year in each country. The number of accidents varies from year to year, with increases and decreases that may be influenced by various factors. In general, the number of injuries follows almost the same trend as the passenger numbers.

The graph below (figure 26) shows the relative injury rate per 100,000,000 passengers annually from 2015 to 2022 across all four countries. Despite their low number of injury accidents, Austria and Switzerland have higher rates of injury accidents per 100,000,000 passengers. France shows an outlier just in 2020, where although the decrease of the passenger numbers, a high increase of injuries happened. In Germany, the number of injury accidents per 100,000,000 passengers remains constant and has been decreasing since 2020.

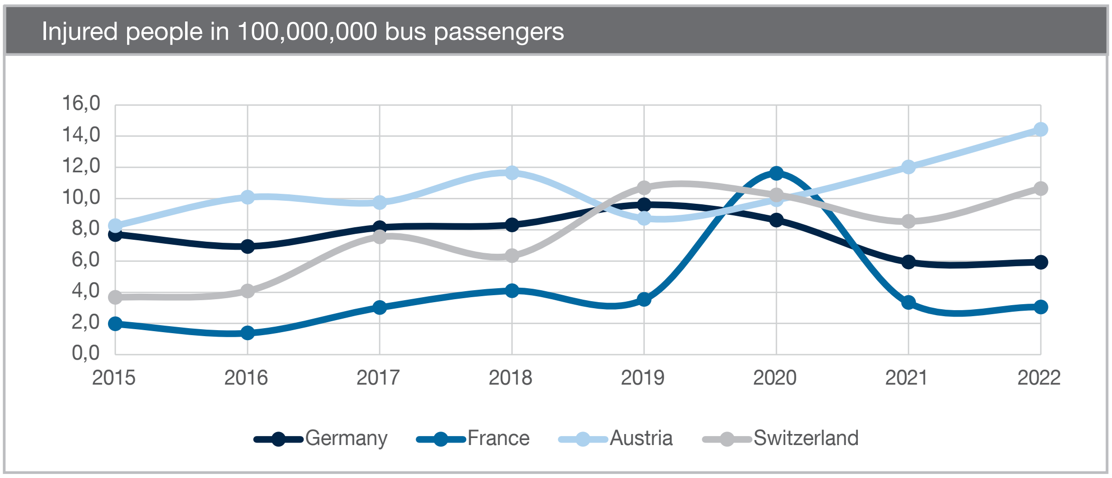

Figure 26: Relative number of injured people in bus accidents per year / country (own illustration based on the traffic volumes and absolute numbers mentioned before)

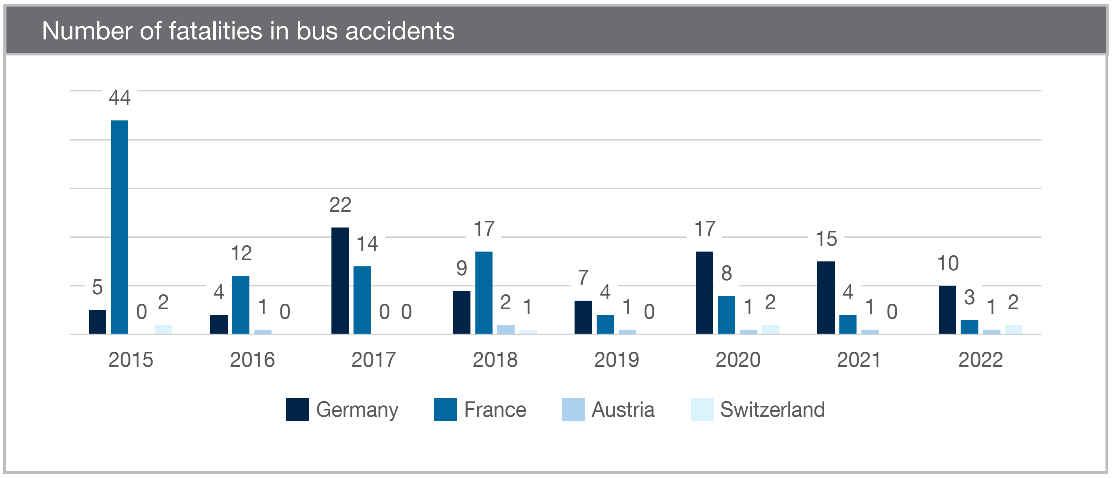

Figure 27: Absolute number of fatalities in bus accidents per year / country (own illustration based on BMK, 2024; FOT, 2024; DSR, 2024; DESTATIS, 2022; DESTATIS, 2023).

6.1.2.2 Fatal accidents

The absolute number of bus and tramway fatalities per year in each country is shown in figure 27. It remains low across all countries, with annual variations. A single major accident can significantly impact the total number of fatalities. This is evident in France, which recorded the highest number of fatal accidents in 2015, with 44 deaths. Notably, 43 of these fatalities resulted from the tragic bus accident in Puisseguin. (CNN, 2015)

The graph below (figure 28) shows the relative fatality rate per 100,000,000 passengers annually from 2015 to 2022 across all four countries. A very low increase in their rate of fatal accidents per 100,000,000 passengers can be observed. Switzerland and Austria stand out for their low fatal accident rates per 100,000,000 passengers, which are zero in some years. Germany and France maintain variations depending on each year.

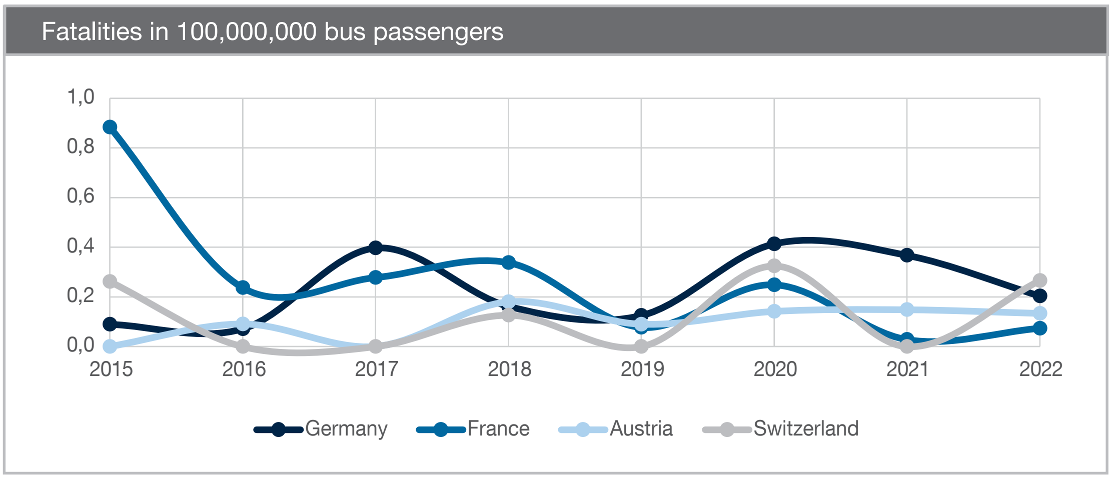

Figure 28: Relative number of fatalities in bus accidents per year / country (own illustration based on the traffic volumes and absolute numbers mentioned before)

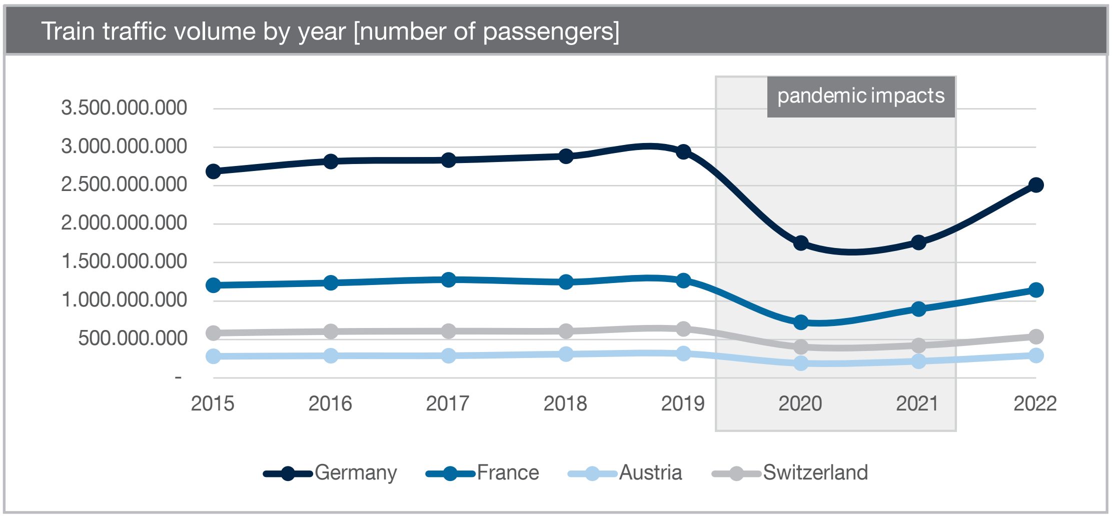

Figure 29: Train traffic volume by year / country (own illustration based on Eurostat, 2023)

6.2 Trains

6.2.1 Traffic volume

The illustration (figure 29) provides statistics on rail transport in Germany, France, Austria and Switzerland from 2015 to 2022. Germany consistently records the highest number of passengers each year, attributed to its large population and the huge rail network. (Eurostat, 2024a) France, Switzerland and Austria follow in that order.

From 2015 to 2019, all four countries experienced a gradual increase in passenger numbers. However, there was a notable decline in 2020 due to the COVID-19 pandemic. Passenger numbers began to recover in 2022. (Eurostat, 2023)

6.2.2 Accidents

6.2.2.1 Injury accidents

To gauge the safety of train transportation, examining the absolute number of injury accidents is essential for understanding. Basically, the injuries follow a narrow trend to the whole passenger volume, but as outlined in the methodology, absolute numbers can be misleading due to significant variations in passenger volumes.

Relative injury rates per 100,000,000 passengers annually from 2015 to 2022 across all four countries are shown in figure 30. Analysing the data, it is evident that France and Germany, despite having significantly higher passenger volumes, have fewer accidents per 100,000,000 passengers compared to Austria. Notably, Austria experienced a peak of approximately 6.2 injury accidents per 100,000,000 passengers in 2016. Switzerland consistently demonstrates a very low or zero injury rate each year, setting it apart from the other countries.

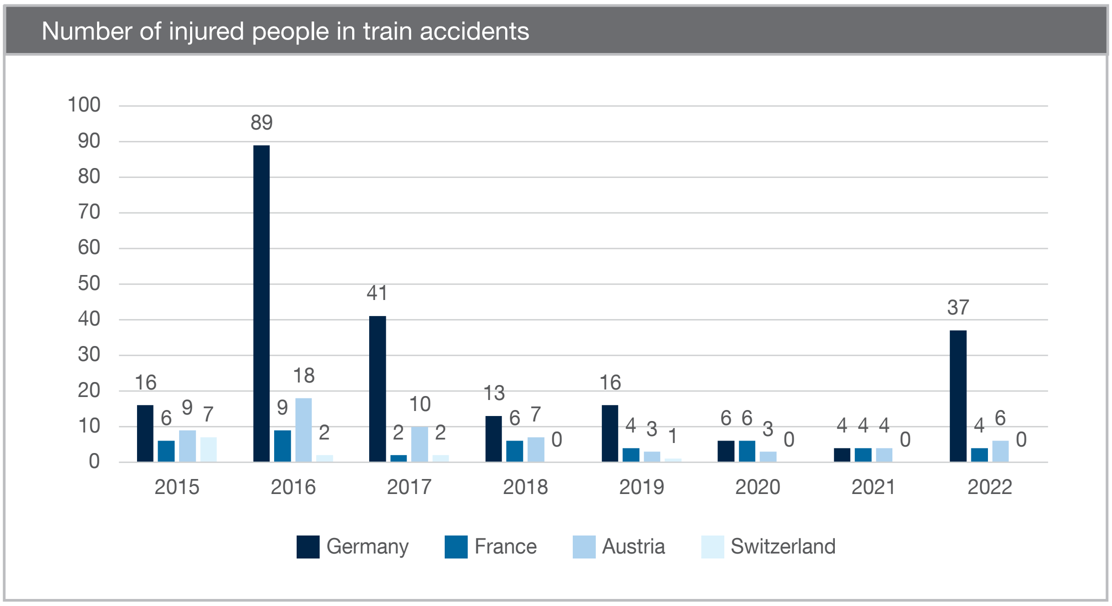

Figure 30: Absolute number of injured people in train accidents per year / country (own illustration based on the numbers from Eurostat, 2024b), (DESTATIS, 2025)

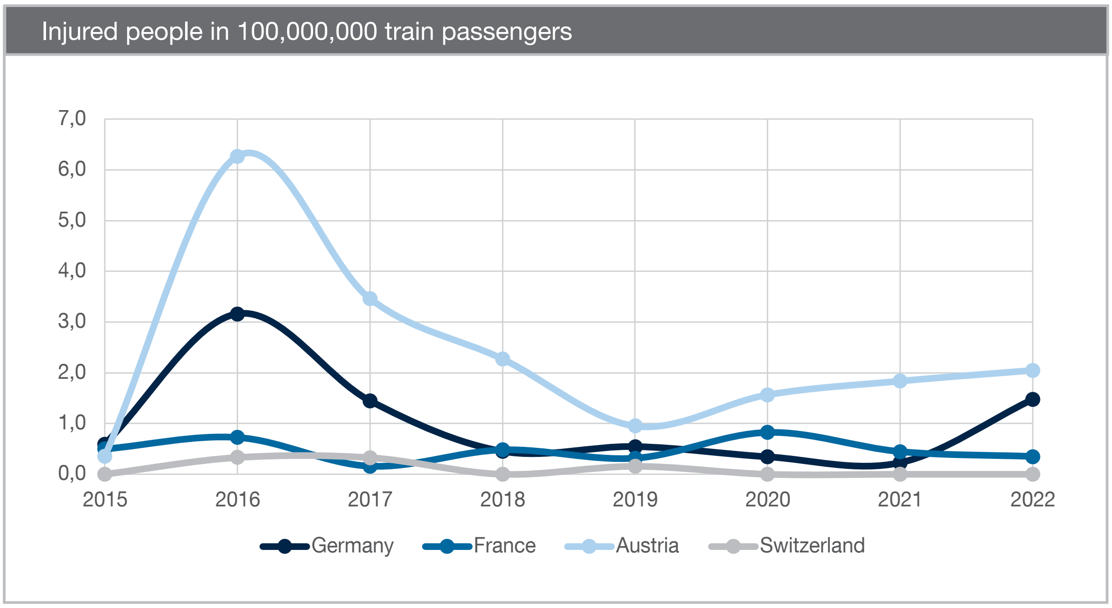

Figure 31: Relative number of injured people in train accidents per year / country (own illustration based on the traffic volumes and absolute numbers mentioned before)

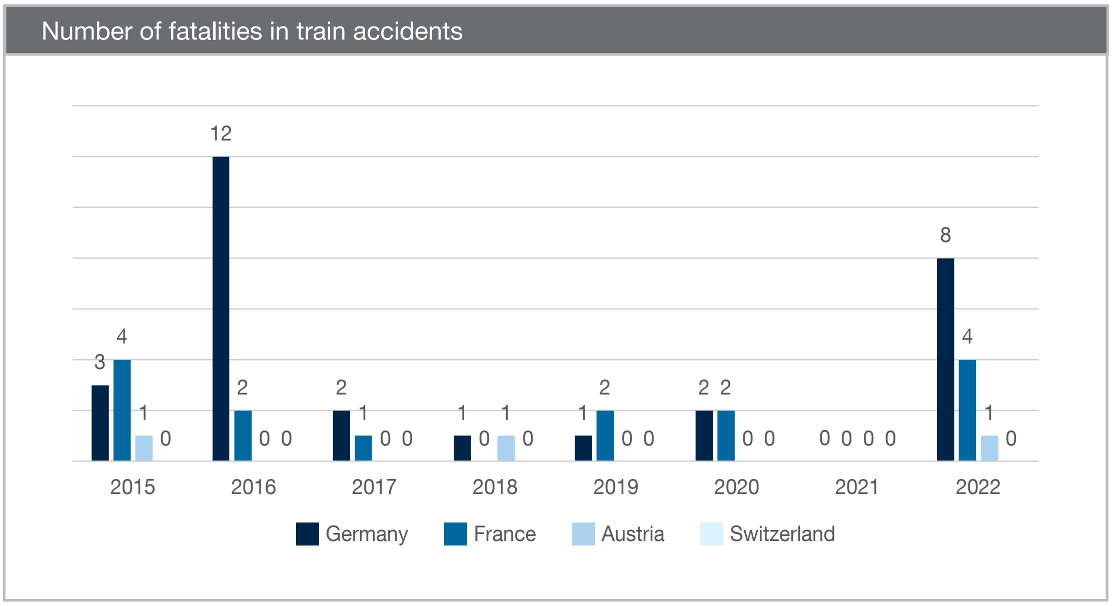

Figure 32: Absolute number of fatalities in train accidents per year / country (own illustration based on the numbers from Eurostat, 2024c), (DESTATIS, 2025)

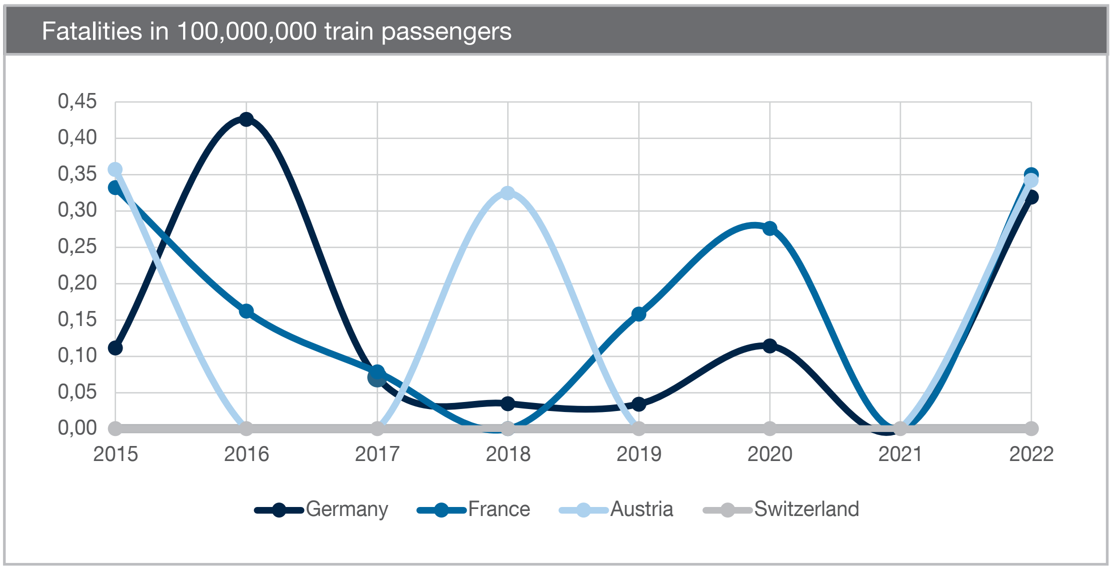

Figure 33: Relative number of fatalities in train accidents per year / country (own illustration based on the traffic volumes and absolute numbers mentioned before)

6.2.2.2 Fatal accidents

To accurately assess the safety of train transportation, it is crucial to examine the absolute number of fatal accidents.

The graph (figure 33) illustrates the relative fatality rate per 100,000,000 passengers annually from 2015 to 2022 across all four countries. Passenger deaths from train accidents are even rarer than injuries, with most countries recording very few fatalities each year. The number of fatal accidents remains consistently low across all studied countries, showing a slight downward trend over the years, particularly in Germany. In general, all peaks shown in the graph may occur due to single major accidents. Notably, 2021 saw no fatal accidents in any of the countries, likely a result of the reduced passenger numbers and less traffic overall during the COVID-19 pandemic. Switzerland is distinguished by its complete absence of fatal accidents since 2015.

6.3 Ropeways

6.3.1 Traffic volume

This section focuses exclusively on three specific ropeway types used for urban transportation. This includes aerial tramways, gondola installations and funiculars. The figures analysed come from the ropeway types mentioned before but are independent of the location and purpose (urban, mountain and tourist attraction).

Figure 34 shows the accumulated number of passengers transported by ropeways in Austria, Germany, France and Switzerland. The amount of people using ropeways has remained almost constant over the years. Austria has the highest number of passengers of the four countries observed. As no Austrian figures were provided for the years 2015 and 2016, the accumulated volumes appear to be lower. However, the analysis can still be carried out because the safety figures are set in relation to the number of passengers transported, as described during the methodology chapter. Another decrease in the number of passengers can be observed in 2020 due to the COVID-19 pandemic. Some countries had administrative closures and didn´t report numbers for this year.

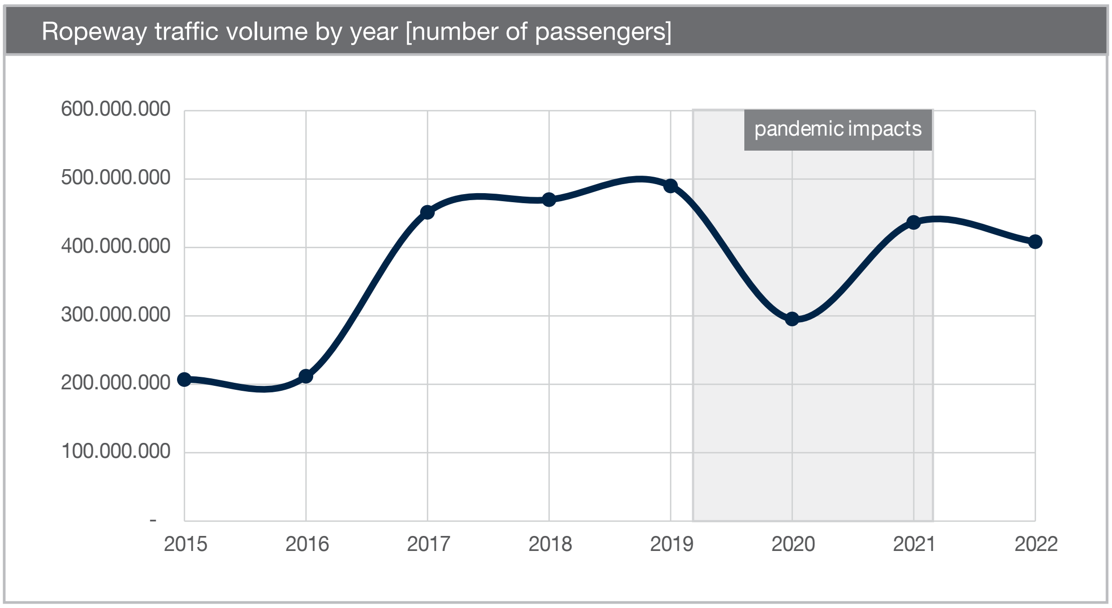

Figure 34: Ropeway traffic volume by year (own illustration based on the numbers from BMK, 2024; STRMTG, 2024; FOT, 2024; OITAF, 2024).

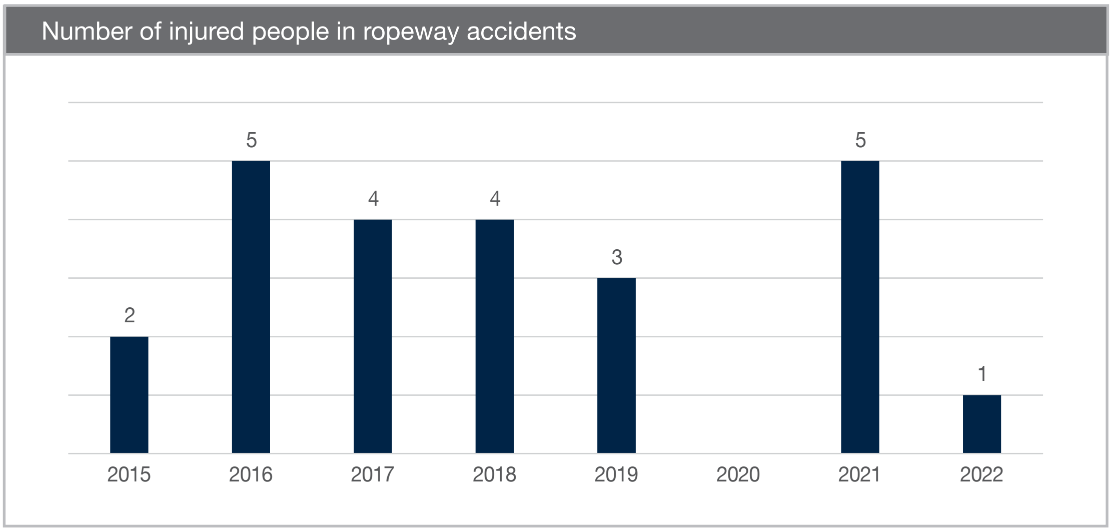

Figure 35: Absolute number of injured people in ropeway accidents per year (own illustration based on the numbers from BMK, 2024; STRMTG, 2024; FOT, 2024; OITAF, 2024).

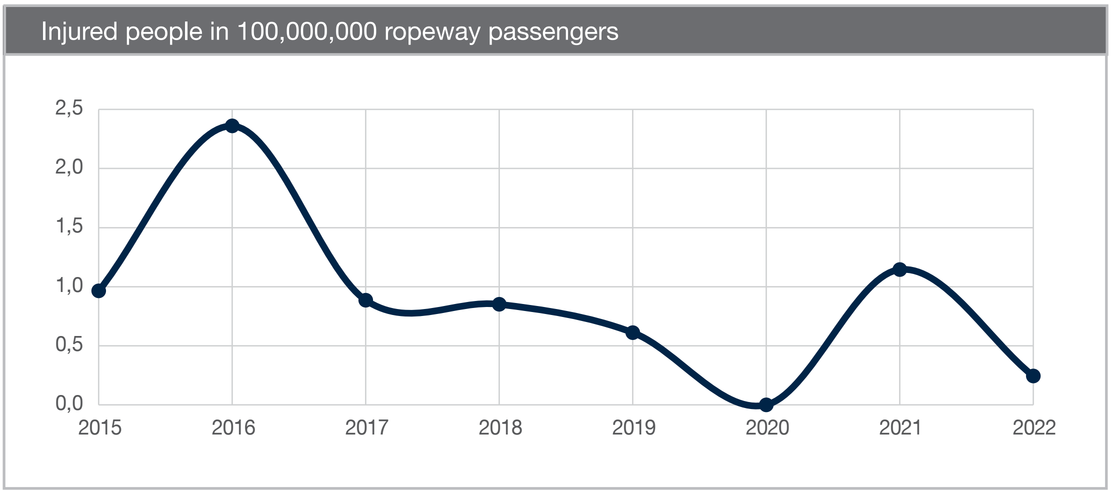

Figure 36: Relative number of injured people in ropeway accidents per year (own illustration based on the traffic volumes and absolute numbers mentioned before)

6.3.2 Accidents

6.3.2.1 Injury accidents

Absolute injury numbers per year for the countries observed are listed in figure 35. The number of accidents is on a very low level and does not show a big variation.

The graph (figure 36) shows the relative injury rate per 100,000,000 passengers annually from 2015 to 2022 across all countries observed. Since the number of injury accidents is low, the injury accident rates per 100,000,000 passengers are also low. However, while the absolute number is almost constant, it shows some variation when compared with the annual passenger volumes. With absolute numbers that low, a single event can have a huge impact. Letting the one-time peak aside, the longtime average seems to be around 1.0.

6.3.2.2 Fatal accidents

Absolute numbers of fatal accidents per year in the countries observed are drawn in figure 37. There were no fatal accidents from 2015 to 2020 and one fatal accident each in 2021 and 2022.

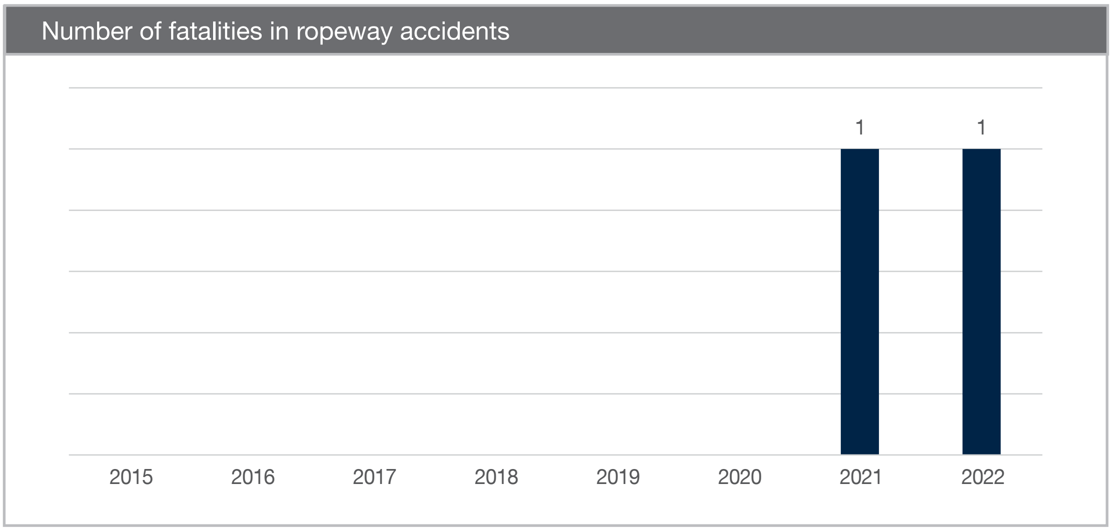

Figure 37: Absolute number of fatalities in ropeway accidents per year (own illustration based on the numbers from BMK, 2024; STRMTG, 2024; FOT, 2024; OITAF, 2024).

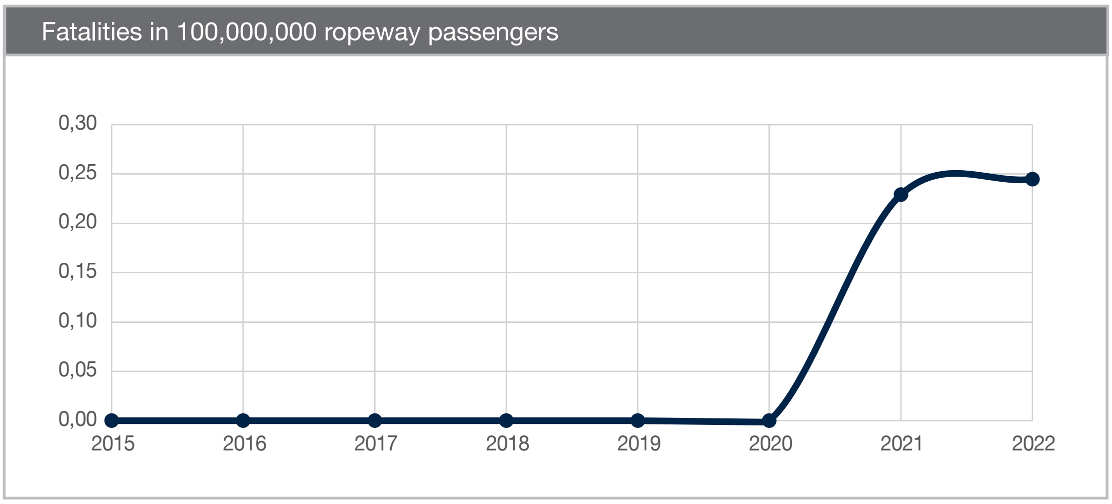

Figure 38: Relative number of fatalities in ropeway accidents per year (own illustration based on the traffic volumes and absolute numbers mentioned before)

Figure 38 shows the relative fatality rate per 100,000,000 passengers annually from 2015 to 2022 across all four countries. Due to the low number of accidents, the fatal accident rates per 100,000,000 passengers are 0 in most cases. However, two single events in 2021 and 2022 show again the huge influence a single accident can have.

Note: This analysis contains the values of France, Germany, Austria and Switzerland to make it comparable to the other sectors – bus and train.

In 2021 there were two serious accidents with 14 fatalities in Italy (Stresa/Monte Mottarone), (DiGIFeMa, 2023) and 1 fatality in Czech Republic/Jested, (ČR, 2021). And on 17.04.2025 in Naples/Italy, (ZDF, 2025) with 4 fatalities. In all 3 cases a rupture of the haul rope in combination with a malfunction of the track-rope brake was the reason. This hazard is very well known since the 1960s, and the mitigations are clearly defined in EN 12929-1 /-2 and EN 12927 since 2005. According the investigation reports, in both cases a lack of knowledge of the operators and no effective legal supervision and inspection strategy was origin.

7 Safety comparison between means of transport

In the preceding sections, the findings related to the modes of transport observed were presented. This section provides a comprehensive safety analysis of buses/trams, trains and ropeways by comparing the average numbers of injuries and fatalities per 100,000,000 passengers as detailed in the methodology.

The first two charts show the average injuries and fatalities per 100,000,000 passengers based on the mode of transport for the four countries studied. The table below the charts shows the relative differences between each mode of transport and provides another understanding of the results. By analysing these charts, the following summary can be drawn:

Buses and trams, although widely used in urban areas, stand out as the mode of transport analysed with the worst safety properties, by counting more than eight times higher rates of injuries compared to ropeways and three times more fatalities. In particular, buses and trams record an average of 7.49 injuries and 0.18 deaths per 100 million passengers, which is significantly higher than the rates for trains or ropeways. Compared to other modes of transport this high accident rate may be related to several factors, such as interaction with road traffic. Buses and trams share the road with other vehicles, which increases the chance of collisions and accidents. Intersections, traffic lights and unpredictable traffic conditions add to these risks. Additionally, passengers often stand in those vehicles or sit without seat belts, making them more vulnerable to incidents during dynamic manoeuvres, compared to sitting or even standing in a ropeway cabin.

While trains are not the safest mode of transport, they come closer to ropeways. Trains experience 6% more injuries and 50% more fatalities than ropeways. On average, trains record 0.93 injuries and 0.09 fatalities per 100 million passengers. The safety of trains can be attributed to several factors.

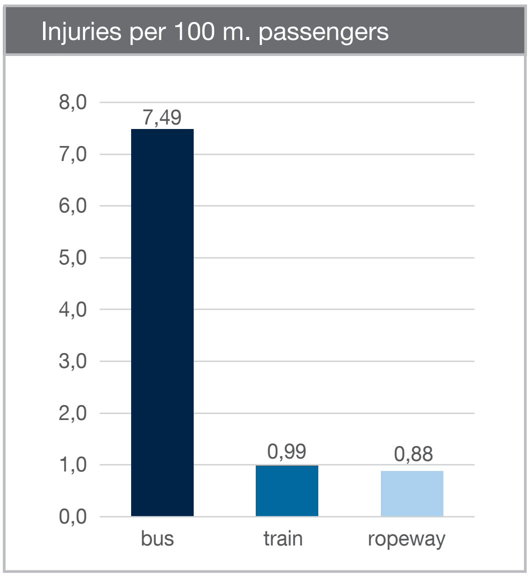

Figure 39: Comparison of injuries between modes of transport (own illustration based on the average values from chapter 6)

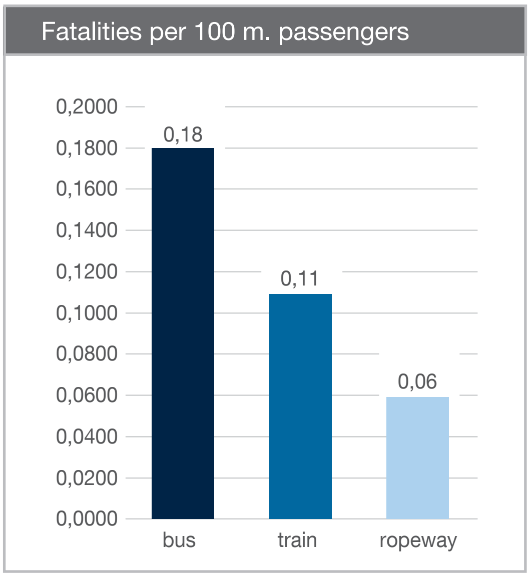

Figure 40: Comparison of fatalities between modes of transport (own illustration based on the average values from chapter 6)

	Injuries	Fatalities
Ropeway*	1	1
Train	× 1.13	× 1.83
Bus/tram	× 8.51	× 3.00

**set as benchmark due to the lowest value*

Table 4: Relative comparison for different modes of transport (own table based on Figure 39 and Figure 40)

Like ropeways, trains operate on dedicated tracks, thus minimizing interactions with other types of transportation. Another factor contributing to the reduced safety of trains is the risk of derailment and collision due to the rail network and its operational practices.

Ropeways stand out as the safest mode of transport, with a very low number of injury or fatal accidents. The number of fatal accidents is practically zero for almost all years observed, highlighting the two single accidents recorded that have a huge impact on the numbers of the result. The average accident rate is 0.65 injuries and 0.07 fatalities per 100 million passengers. Ropeways benefit from several factors contributing to their safety. Unlike buses and trams, which share the road with other vehicles and pedestrians, ropeways are isolated from ground traffic, making operations less complex, easier to control and automated. Ropeways also follow a wide range of standards and protocols with 3rd parties, that enlarges safety even more, see (Schober, 2024).

This comparative analysis of accidents reveals that ropeways, due to their unique design, offer superior safety compared to other modes of transport studied. The physical separation from other road users and pedestrians, combined with advanced safety technologies, makes ropeways a safe choice for passenger transport in both mountainous and urban environments. Trains, while presenting a slightly higher risk, mainly due to their dedicated infrastructure and safety systems. Finally, buses and trams, despite their utility and indispensability, are the most vulnerable to accidents. These conclusions highlight the importance of continuing to provide adequate infrastructure and invest in technologies that reduce accident risks and protect passengers, based on evident statistics.

8 Conclusion

In urban settings, different modes of transportation serve distinct purposes and capacities. Buses and trams are widely used for their flexibility and ability to navigate city streets. They are essential for short to medium distances and provide frequent stops, making them accessible and convenient for daily commuters. Trains offer a higher capacity and speed, often utilized for longer distances within cities and are crucial for connecting suburban areas to city centres. Ropeways, a relatively new addition to the urban transport network, provide a unique solution for overcoming topographical challenges, connecting transportation hubs and relieving congestion by offering new and time-saving routing options.

As shown in the analysis, in terms of passenger safety, the numbers for all modes are low and often linked to single events. Although, when comparing the three modes directly, buses and trams can be considered the least safe mode of transportation due to their exposure to traffic participants, the influence of environmental aspects and other urban hazards. While trains are generally much safer, they still operate more or less exclusively on ground level and can be affected by weather conditions, track obstructions and potential collisions with vehicles. Ropeways stand out as the safest mode of transportation, with the lowest number of accidents reported. As they operate on an independent level, they are not affected by road traffic or congestion and have less operation issues.

For this paper, we used an approach that made it possible to draw an equal comparison based on the information currently available. However, this does not mean that this approach is the only and best methodology. In particular, our approach does not consider the duration a passenger spends while riding on one of the modes investigated. From a technical point of view, a comparison based on operating hours rather than the absolute number of passengers would therefore be interesting. It would also be interesting to extend this to other countries in the future to achieve an even broader database.

From a safety perspective, there is no reason why buses should not be included in the portfolio of possible public transport options in urban areas. In addition to them, an investment in ropeway technology can significantly enhance urban mobility. However, an integrated approach that combines buses, trains and ropeways is essential to meet diverse transportation needs. Each mode has its strengths and should be utilized according to the local requirements. Buses and trams are vital for their flexibility and extensive coverage, trains for longer distances offering high capacity and speed and ropeways for their safe and flexible extension function with the ability to navigate challenging terrains. As urban areas continue to grow and face increasing transportation difficulties, ropeways should be considered more often as a safe and reliable addition to existing transport modes.

9 List of figures

10 List of tables

11 Bibliography

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