ISSN 1648-4142 / eISSN 1648-3480

TRANSPORT

2024
Volume 39
Issue 3
Pages 250–263
https://doi.org/10.3846/transport.2024.22861

Review Article

FUNICULARS IN LITHUANIA: FROM THE FRUIT BASKET TO GEDIMINAS HILL

Lijana MASKELIŪNAITĖ ✉

Dept of Mobile Machinery and Railway Transport, Vilnius Gediminas Technical University, Lithuania

Highlights:
- modern funiculars are equipped with advanced rope position detection systems;
- the number of funiculars is weakly correlated with the mountainous terrain of the country;
- the number of funiculars is influenced by the country's economic development and tourism;
- the correlation between variables is indicated by the coefficient of determination.

Article History:
- submitted 6 September 2022;
- resubmitted 14 December 2023, 22 January 2024;
- accepted 1 February 2024.

Abstract. Technological advances in transport of the 20th century include aeroplanes, human spaceflight and Moon landings, submarines, and magnetic levitation trains. In the fast-paced world of technology, the achievements of previous centuries are often forgotten. One of the examples of human ingenuity is the funicular railway. Its technology has hardly changed over the years. Using a simple pulley system, passengers and freight are still lifted steep slopes with minimal energy consumption. This demonstrates the lasting value of simple solutions and engineering intelligence. The article discusses the world's funiculars and their design characteristics. A correlation analysis for the number of funiculars per country (N) and the country mountainousness index (M) has been carried out. 3 types of regression models have been developed and their determination and correlation coefficients have been calculated. The highest correlation coefficient values are for quadratic and linear mathematical models. The critical values of the correlation coefficients were calculated and compared with the correlation coefficients obtained from the study. For all 36 countries, the correlation coefficient for N and M variables is above the critical value only when a quadratic regression model is used. The correlation coefficients for all models are above the critical value for the 15 economically advanced and tourism-developing countries. The study shows that the number of cable cars in economically developed countries is more strongly correlated with the degree of mountainousness of the country in question.

Keywords: passenger transportation, public transport, funicular, development history, technical characteristics, Lithuania.

✉ Corresponding author. E-mail: *lijana.maskeliunaite@vilniustech.lt*

1. Introduction

At the end of the 16th century, a new cable-drawn vehicle was developed in Austria. This vehicle was used to deliver fresh food to the castle, that stood on a high hill. And although the vehicle was designed only for uphill drive, the invention was so successful that it extended to other areas. This is how the world's first funicular came out (Ishvetsov.ru 2023). Funicular (in French – *funiculaire*, in Latin – *funiculus* – rope) is a rail device with a cable for lifting passengers uphill (Vaitkevičiūtė 1999). The 1st funicular cars were powered by either people or animals. Water was another driving force. These devices moved as the level of water in reserve tanks filled and emptied. Several water-powered funiculars are still in operation today. Some funiculars have been set up in tunnels. Others were built to descend into caves or underground mines (Schwartz 2021).

Nowadays, people are used to various means of transportation – cars, buses, trolleybuses, trams, trains, and airplanes. Bicycles and scooters are also popular means of transport. However, the funicular – a unique means of transport – is often forgotten. The system consists of 2 counterbalanced cars attached at the ends of a long cable that goes up a slope and over a pulley and then comes back down. Therefore, when one car goes up, the other comes down. The weight of the 2 cars counterbalances each other, so that only a minimal amount of energy is required to pull up the ascending car, which is usually provided by an electric motor. Some historic funiculars made the system even more energy-efficient by using water as the motive force (Patowary 2019). They demonstrate the lasting value of simple solutions and are a testament to engineering ingenuity (Harley-Trochimczyk 2009).

Modern technology is being used to increase the capacity of these facilities. A new concept for cable cars with central entry and exit has been presented (Težak, Lep 2019). The new concept utilizes solution geometry as the basis of the idea. 3D computer graphic tools were used for the design. A modified water-powered funicular technology and its feasibility has been presented in Nepal (Karkee *et al.* 2015). Several alternative transport technologies are available for hilly regions. These include electric funiculars and gravity-powered cable ways. Modified funicular technology and its prospects for use in Nepal are under discussion. A method for optimising the funicular system is proposed. The primary objective of the study conducted by Moscariello *et al.* (2005) is to examine the impact of the actuator's law of motion on railroad cars. Initial findings indicate that, particularly during the start and stop transients, the moment versus time law (and consequently, the shape of the law of motion determined by the winch) significantly influences the motion of the railroad cars. This implies that the oscillations observed in railroad cars during these transients can be considerably reduced by employing a well-designed actuator's law of motion. On the other hand, the article authored by Hofer *et al.* (2018) seeks to assess the potential demand for a cable car within the context of public transport, using the City of Graz (Austria) as an illustrative example. While the capacity of cable car systems may not rival that of an underground system, they could represent a cost-effective and efficient alternative to address capacity constraints in the historic city centre of Graz. The modelled passenger trips affirm a satisfactory demand potential for a cable car within Graz's multimodal transport system.

Following the 2016 landslide, measurements of the vibration induced by the funicular on the northern part of the slope of Gediminas Hill (Vilnius, Lithuania) were carried out (Skuodis *et al.* 2017). Gediminas Hill is affected by 2 sources of vibrations: the funicular and traffic around the hill. The funicular moves quite slowly along the rails. Its mass is small regarding the hill (Grigelis *et al.* 2016). The aim of the measurements was to determine whether vibrations caused by the operation of the funicular affect the slope. The analysis of the results gained has shown that the vibrations are not significant, and that the exploitation of the funicular was not the main cause of the landslide that occurred in spring 2016.

In addition to funiculars, the advantages, and disadvantages of cable cars for urban public transport are also examined (Težak *et al.* 2016). Kigali (the capital of Rwanda) is located in a region where it is economically and socially impossible to build roads to reach remote urban areas. While the city population has been growing there, the mobility issue for people living in remote areas has not been solved. Building new roads around cities, especially in hilly areas, is expensive. Traffic congestion and long queues of people waiting for buses are witnesses of daily challenges. The application of the cable car as an alternative means of transport in areas with mobility problems has been studied. The topography has been carried out and proposals for new lines made. Exploring the sites and interviewing local people have also been executed. This mode of transport was found to be sustainable, as the cost of building the line would be recovered within 10 months of its operation (Mbereyaho *et al.* 2018). A simulation model based on discrete-event methodology was created to serve as the foundation for an investigation aimed at comprehending the dynamic characteristics of a people and vehicle transportation system using a funicular-type train beneath a mountain (Otamendi 2009).

Cable cars present a feasible option for enhancing citizens' accessibility in regions where urban public transport faces limitations due to challenging topography. Recently, these systems have been introduced in Latin American areas characterized by high levels of poverty and vulnerability. Guzman *et al.* (2023) aim to evaluate user expectations and perceptions regarding a newly implemented cable car in the southern periphery of Bogota (Colombia). Findings indicate that users highly value benefits such as reduced travel time, increased comfort, and enhanced in-vehicle security. Meanwhile, Escobar *et al.* (2022) assess the impact of a new aerial cable car system on geographic accessibility (contour measures) and CO_2 emission reduction in a case study in Colombia. Utilizing low-carbon evaluation indices for tourist attractions facilitates the promotion of low-carbon tourism. The delicate balance between tourism and environmental considerations has become crucial for the sustainable development of the tourism market (Liu, Hsu 2015). A short underground funicular with 2 stations connecting neighbourhoods in Istanbul has also been studied (Kayaoğlu *et al.* 2014). It is the world's oldest urban underground railway after the London Underground (UK). It was opened on 17 January 1875. This study describes the history of the line and its working principle. It also gives a detailed explanation of the main devices and mechanisms.

Rail transit stands out as a crucial mode of public transportation, particularly in large and densely populated urban centres. Therefore, getting a high customer satisfaction level is an essential task for municipalities and governments. For this purpose, a survey is conducted to question the attributes related to rail transit network (metros, trams, light rail, and funicular) in Istanbul (Turkey). Different improvement strategies are suggested for the rail transit network (Celik *et al.* 2014). The multiple dimensions of mobility decisions made by visitors add additional pressure to the sustainable equilibrium of destinations that combine residents' daily activities with the arrival of tourists. Thus, the use of public transportation by tourists becomes central to improving eco-efficiency and mitigating negative externalities resulting from the massive mobility of tourists at their destinations. The results suggest that tailor-made strategies are required to foster the use of sustainable transportation modes at tourist destinations (Miravet *et al.* 2021).

The global increase in population and urbanization necessitates a reconsideration of transport planning strategies. This involves both the enhancement of traditional transport systems and the strategic integration of new ones, particularly in urban settings. One way to cope with this challenge is to leave behind the already severely saturated urban land use model and move to the 3rd dimension. This includes the use of urban aerial cable cars, which can complement conventional public transport in certain transport relations. The results, especially concerning urban and transport integration, are discussed in detail, emphasizing that cable cars have already partially found their niche, but their role in the urban environment has not yet been sufficiently studied (Flesser, Friedrich 2022).

The aim of this study is to carry out a comparative analysis of the structures, equipment, and technical parameters of funicular railways to identify the potential of this mode of transport. In addition, to carry out a correlation analysis between the number of funicular railways and the mountainousness index of the country.

2. Funiculars in the world

Modern funicular railways operating in urban areas date from the 1860s. The first line of the funiculars of Lyon opened in 1862, followed by other lines in 1878, 1891 and 1900. The Giessbachbahn railway constructed in 1879 in Switzerland was Europe's 1st funicular railway used for transporting passengers. Many different types of cable cars have been developed and operated. They may be classified according to type of construction, the cable system used or the number of cables. Figure 1 shows this classification depending on those different characteristics (Hofer *et al.* 2018). This article deals with railway funiculars.

Not all funicular stories around the world have a happy ending. There was a time when Vesuvius Crater (Italy) could be reached not only on foot, but also by funicular railway. It is a matter of some regret that neither the funicular nor the cable car are now in place, which is primarily the fault of Vesuvius Crater itself. Vesuvius funicular was the only one in the world that could take people to the top of an active volcano. It was built within 2 years. The funicular had 2 steam traction cars. It was opened in 1880 and the Neapolitan song "Funiculi, Funicula", written for the opening ceremony, is well known to many: "<…>. It's gone up, then returned, then it' back… / It's always here! / The summit revolves, around, around you! / The heart always sings, my love /, Let's get married one day! / Let's go up to the top, let's go, / Funicular up, funicular down! <…>" (Roberts 2020). Tourists loved the funicular, but as is often the case, money got in the way. From 1886 onwards, due to the high operating costs, the owners began to change. In 1903, a narrow-gauge railway was built from Paliano (Italy) to the foot of Vesuvius. The funicular workload increased, so 2 more carriages were purchased. Steam traction was replaced by electricity. The funicular was damaged several times by the eruption of Mount Vesuvius, yet the funicular was rebuilt. It was finally destroyed by an earthquake on November 23, 1980 (Uletova 2010).

For funicular rides in Europe, one should visit Zakopane (Poland), Prague (Czechia) and Dresden (Germany). If you want to take the oldest funicular up the mountain, you should visit Budapest (Hungary).

Many of the water-powered funiculars have been fitted with electric motors, however some water-powered funiculars are still running. These funiculars have water tanks built under the floor of each car that could be filled or emptied to weigh them down just enough to allow movement. At the start of the ride, the tanks of the cars are empty. When passengers board the lower station car, the upper station operator is informed of the number of passengers. He then knows how much water to add to the tank of the top car to make it heavier than the car at the bottom of the hill. Once a sufficient imbalance is achieved, the brakes are released, and the funicular is set into motion solely by gravity. At the end of the ride, the water is drained from the descending car. The process is repeated. A few examples of water-power funiculars still operating are the Lynton and Lynmouth Cliff Railway, in North Devon (UK) (operating since 1890, Figure 2a), the Bom Jesus do Monte Funicular in Braga (Portugal) (operating since 1882, Figure 2b), the Leas Lift in Kent, England (UK) (operating

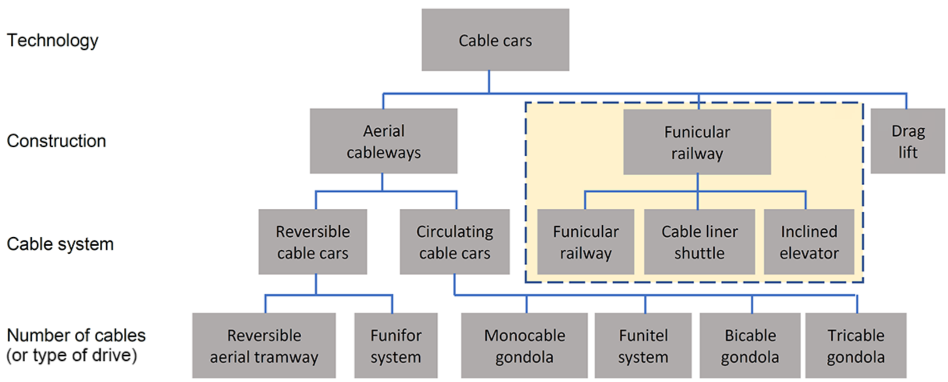

Figure 1. Classification of cable cars (adapted from (Hofer *et al.* 2018; Kremer 2015)

since 1885, Figure 2c), the Nerobergbahn in Wiesbaden (Germany) (operating since 1888), the Saltburn Cliff Lift in North Yorkshire, England (UK) (operating since 1884), and the Funiculaire Neuveville – St. Pierre in Fribourg (Switzerland) (operating since 1899, Figure 2d). The last one is of particular interest as it utilizes wastewater coming from a sewage plant to power the funicular. The Lynton and Lynmouth Cliff Railway is also unique. To fill the water tanks of the cars in the upper station, many funiculars need to pump water uphill. The Lynton and Lynmouth Cliff Railway funicular draws its water from the nearby river and there is no need for pumping. The Lynton and Lynmouth Cliff Railway, the Bom Jesus do Monte Funicular in Braga and the Funiculaire Neuveville – St. Pierre in Fribourg are fully water-powered railways in the world (Patowary 2019).

One of the oldest and most beautiful, as well as the shortest in Europe and the world, is the funicular in Zagreb (Croatia) (Figure 3a). It is 66 metres in length. The little funicular was built in 1890 and became the first public transport in Zagreb. The funicular ride takes just 1 min. Passengers do not have to climb steep steps. It is said that the funicular used to break down frequently. Passengers were then asked to push it. Castle Hill funicular in Budapest (Hungary) (Figure 3b) was opened in 1870. It ascends to the Buda Castle. The railway track is 95 metres long. Spectacular views of Budapest open from the funicular. During World War II on 20 December 1944, the funicular was hit by a bomb. It was restored only in 1986.The funicular has an electric drive. The passenger cars, named Gellért and Margit, have 3-tiered cabins. Each cabin can accommodate 24 passengers. Operational safety is ensured by spring brakes, which stop the vehicle in the event of a cable break. In 1987, the funicular was added to the UNESCO World Heritage List (BKK 2024). The funicular in Lugano (Switzerland) was built in 1886 (Figure 3c). It is popular with locals and tourists. The Lugano funicular carries more than 2 million passengers every year. It runs through 2 tunnels. It has a rail track length of just 206 m (CK Travels 2024).

Lisbon (Portugal) has 3 funiculars, called Lavra, Bica and Gloria. The most famous of these is Gloria (Figure 4a). It is because of its lovely name and also it is the best way to reach Restauradores Square. The funiculars date back to the late 1800s. The Peak Tram in Hong Kong (Figure 4b) is one of the most spectacular funiculars in the world. The funicular was constructed in 1888 to allow residents of Victoria Peak and guests at the Peak Hotel to get to the top of the 1811-foot-tall Mount Austin, where they could enjoy stunning views. The funicular is more comfortable than the portable chairs previously used (Lemmin-Woolfrey 2023). Prague Funicular railway (Figure 4c), also known as *Lanovka* (in Czech), goes from Ujezd in Lesser Town to the top of Petrin Hill with one middle stop, Nebozizek, in between. It started working in 1891 and is the easiest way to get to Petrin Gardens and its famous Petrin Lookout Tower nicknamed Eifel Tower of Prague (Zahradnikova, Zahradnik 2024). The funicular was water-powered until 1914. In 1932, an electric drive was installed. The Funicular ran until 1965 when a part of under flooding Petřín Hill broke away and deformed a railway. The costly reconstruc-

Figure 2. Water-power funiculars: (a) – the Lynton and Lynmouth Cliff Railway funicular, North Devon (UK) (Patowary 2019); (b) – the Bom Jesus do Monte funicular in Braga (Portugal) (Rosa 2023); (c) – Leas Lift in Kent, England (UK) (Patowary 2019); (d) – the Funicular Neuveville – St. Pierre in Fribourg (Switzerland) (Fribourg Tourisme et Région 2024)

Figure 3. European short funiculars: a – the Zagreb funicular (Croatia) (EBD 2023); b – Budapest Castle Hill funicular (Hungary) (CK Travels 2024); c – Lugano Città – Stazione funicular (Switzerland) (CK Travels 2024)

Figure 4. The former funiculars: a – Lisbon funicular Gloria (Portugal) (CK Travels 2024); b – Peak Tram funicular in Hong Kong (Lemmin-Woolfrey 2023); c – Petřín funicular (Czechia) (Guide of Prague 2023)

tion took place between 1983 and 1985. It was then put back into operation. The funicular can carry 1400 people per hour. The drive up the hill takes about 3 min (Guide of Prague 2023).

Kyiv funicular railway (Ukraine) is one of the city most important symbols (Figure 5). It has a long history. Kyiv is located on hills. There is a joke that the best way to describe the city is as follows: "<...> if you think you have already climbed the hill in Kyiv, no, not yet <...>" (Grigaliūnaitė 2018). The idea of a funicular railway in Kyiv originated in 1902, when it was necessary to connect Podolia with the so-called Upper Town. Construction began in 1903, and by 1905 the citizens were able to use a new and original means of transport. Originally, the length of the funicular was 200 m. In 1928 the line was extended by 38 m (Mikul'onok, Andrejev 2017). The funicular carriages are marked in relation to the upper station – left "Л" (in Ukrainian: *лівий*) and right "П" (in Ukrainian: *правий*). The invasion of Ukraine by Russia and the desire of occupants to seize Kyiv have led to the consideration that the funicular should serve both as a means of public transport and as a memorial. The stained-glass windows created by Ukrainian artists Valentin Zadorozhniy and Nikolai Shkaraputa are of great value. As the war started, the stained-glass windows were covered with wooden shields and reinforced with fire-resistant tarpaulins and galvanised iron sheeting. The funicular is currently closed for maintenance works (Magdyk 2022).

Figure 5. Kyiv funicular (Ukraine) (Tockij 2017)

For centuries funiculars have been transporting passengers to hard-to-reach places. They are many and varied around the world. The article mentions just a few of them.

3. Funiculars in Lithuania

Not only the history of Lithuanian railways is interesting (Maskeliūnaitė 2021), but also that of funiculars. There are 3 funiculars in Lithuania – 2 in Kaunas and 1 in Vilnius. Kaunas funiculars are a unique means of transport and an integral part of the city history, architecture, and technical heritage. The Žaliakalnis (Figure 6a) and Aleksotas (Figure 6b) funiculars are among the oldest in Europe. They have been designated as technical monuments. Still intact in their original purpose, appearance, and equipment, they provide authentic information on inter-war engineering and blend well with the environment (Tamoliūnienė 2009). The museum installation located in the village of Saliai (Kaunas district municipality) in the private resistance-time printing house "AB" should also be added to the list of Lithuanian funiculars (Morkūnas 2013). It is the only shelter of its kind in Lithuania that was not detected by the Soviet security services. The rooms are located at a depth of 7 m (Jacytė 2016). A self-made funicular railway for lifting loads operates in this printing house (Smolienė 2018). Technical characteristics of the funiculars in Lithuania are shown in Table 1.

The funicular, also known as the rope tram, was supposed to connect the fast-growing upper part of the city, Žaliakalnis, with the city centre below (Pamatyk Lietuvoje 2023). In Kaunas, the Žaliakalnis funicular was the 1st motor vehicle powered by electricity. Trolleybuses started running the city streets much later, on the last day of 1965. Similarities can be found between funiculars and horse-drawn carriages (in Lithuanian: *konkė*) (Vanagas 2017), but in the horse-drawn carriages the horsepower was essential, while in the funiculars the mechanical devices were essential. Initially, only one carriage was reserved for passengers, while the second carriage was loaded with stones as a counterweight. The number of passengers increased rapidly. They could no longer fit in one carriage, so a second carriage was adapted to carry people. The carriages meet halfway: one goes up, the other goes down (Javaitytė 2017).

The main reason for the emergence of Kaunas funiculars is that after the restoration of Lithuania independence, Kaunas went from being a city of the Russian Empire to the temporary capital of Lithuania. This led to the development of the city. The city population was growing. People settled in the upper part of the city – Žaliakalnis. However, it was difficult for Žaliakalnis residents to get to jobs in the city centre and Old Town. As early as 1921, residents wrote to the City Council asking for a tramway to be built to improve connections between the upper and lower parts of the city. In 1927, the Kaunas city Burmistrz asked the Railway Board to build a railway from Palemonas to Vilijampolė via Žaliakalnis. The Railway Board rejected this idea due to the high costs. It was decided to build a funicular from the Aušra Path to Kalnų Street. Several European

Figure 6. Kaunas funiculars (Lithuania):
a – Žaliakalnis funicular (Činga 2019);
b – Aleksotas funicular (KA 2024)

Table 1. Technical characteristics of funiculars in Lithuania

Technical characteristic of funicular	Name of funicular		
	Žaliakalnis funicular	Aleksotas funicular	Gediminas Hill funicular
Location	Kaunas	Kaunas	Vilnius
Built in	1931	1935	2003
Track length	142 m	132.9 m	71 m
Track number	single track, with a fork in the middle of the track for passing cars	single track, with a fork in the middle of the track for passing cars	single track
Track gauge width	1200 mm	1200 mm	1200 mm
Track gradient	26°	29.5°	37°
Lifting power	1875 kg	2000 kg	1200 kg
Number of cars	2	2	1
Car capacity	36 passengers	25 passengers	16 passengers
Breaks	special automatic	special automatic	–
Number of stations (lower – upper)	2 (V. Putvinskio g. – Aušros g.)	2 (Veiverių g. – Amerikos lietuvių g.)	2 (Arsenalo g. – Gediminas Hill)
Ride duration	1 min 38 s	1 min 8 s	35 s (with passenger boarding and disembarking – 1 min)

companies were consulted about the construction of the funicular. They included Austrian, German, Swiss and British companies. To investigate potential passenger flows, the Municipal Economy Directorate hired unemployed people to count all those going up and down the stairs. In 1930, a contract was signed with the German company *Curt Rodolph* (Dresden, Germany). On 6 August 1931, the funicular was officially opened. The opening ceremony was attended by the President of Lithuania (Antanas Smetona), and the then Burmistrz of the city (Jonas Vileišis). They initiated the construction of this funicular. During the first week of operation, the Žaliakalnis funicular lifted passengers for free. Later, the service cost 10 cents for an adult to ascend and 5 cents to descend. The deck for Žaliakalnis Lower Station was built later. When a passenger fell into the lower car descending pit, a safety fence was erected on the Putvinskio Street side. In response to a complaint from the funicular conductor to the city Burmistrz that the tickets and money being sold were getting wet in bad weather, a shelter was built in 1935 at the lower stop. It has survived to this day. During the 1937 reconstruction, 2 completely new cars were designed and built on new longer chassis made by Swiss company *Theodor Bell*. They were made by Lithuanian engineer Napoleonas Dobkevičius, who won a tender (Morkūnas 2013). The funicular was serviced by 9 employees: a driver, 4 cashiers, 4 conductor-carriage attendants, who were also ticket controllers (Javaitytė 2017).

The upper stop of the Žaliakalnis funicular has a basement. It is equipped with lifting mechanisms. Reliable lift safety systems are in place: the cars have special automatic brakes that prevent the cars from rolling downwards in the event of a cable break. The funicular track is a single pair of rails. In the middle of the track there is a passing loop – for a car going up and a car coming down to pass each other. The control panel is located at the top stop. The rope pulley wheels operate here, which are turned one way or the other by an electric motor at the push of a special lever. The cars stop automatically when they reach the end of the track. The start-up and operation of the funicular is controlled by the driver working at the stop. The cars have special automatic brakes that prevent the cars from rolling downwards in the event of a cable break. The lift ropes are routed between the rails. They are held in place by special roller bearings (Ąžuolyno biblioteka 2024).

There are all sorts of stories about the Žaliakalnis funicular. One of them is about how the famous Lithuanian tenor singer Kipras Petrauskas used to entertain his guests in this funicular (Masiokaitė 2011). He would ask the funicular driver to stop in the middle of the track and used to sing "Funiculi, Funicula". The song echoed down the slopes of the hill, so everyone knew who was coming up the funicular. A funny story is about a young man who asked the funicular staff to hide flowers in the car, while he was waiting for his girlfriend at the lower station and they both got on the funicular car. As agreed, the funicular driver stopped it in the middle of the track, the young man knelt and asked his sweetheart to marry him. It is not uncommon for marrying couples and wedding guests to take the funicular. Foreign tourists also admire the funicular ride. Employees of the German company AEG are surprised that their equipment is still working (Javaitytė 2017).

The funicular quickly gained popularity. The inter-war press wrote: "<…> And so quickly the funicular became a common thing that it seems to have been constructed in the times of Vytautas the Great <…>" (Pamatyk Lietuvoje 2023). Since the construction of the Žaliakalnis funicular in Kaunas, 3 more funiculars to Žaliakalnis have been planned and under design. However, to promote the development of Linksmadvaris (currently Aleksotas), the construction of a funicular on the left bank of the Nemunas was chosen. The contract was signed with *Theodor Bell*, the Swiss company that reconstructed the Žaliakalnis funicular. Equipment and chassis were purchased from the company *Theodor Bell*. The works were planned and carried out by Lithuanian engineers and construction workers. The Aleksotas funicular was officially opened on 6 December 1935 (Morkūnas 2013). Today, the funicular continues to serve as public transport, taking passengers up and down Aleksotas Hill. The original appearance and equipment of the funicular has been preserved (Figure 6b) and is still in perfect working condition today.

In 2003, the Žaliakalnis funicular was declared a cultural monument, and in 2004 a postage stamp was issued in its honour (artist Giedrė Luzinienė). Kaunas funiculars are easily distinguishable by colour: The carriages of the Žaliakalnis funicular are yellow, while those of the Aleksotas funicular are cherry coloured. It was in 1970 that the biggest number of passengers was carried by the Žaliakalnis funicular. At that time, there was the Radio factory "Banga" on the Green Hill (in Lithuanian: *Žaliakalnis*), which employed around 14 thousand people. The funicular was mainly used by employees of this factory. Children were particularly fond of the funicular rides. It was one of the few entertainments of that time (Javaitytė 2017). Lithuanian journalist and publicist Andrius Užkalnis wrote: "<…> The most modest and at the same time the most amazing transport in the city, which has remained a part of my life since my childhood, is the Kaunas Žaliakalnis funicular <…>". The Žaliakalnis funicular embodies what urban transport is all about, and it is exactly what urban transport should be. It has cosy – oak-panelled inside, with wooden benches. It's beautiful – red and yellow on the outside, like a sunset. It reminds of a warm summer all year round. It has big windows – you can see the city in the distance and the houses of the people who live on the hillside (and I envied them, too – some of them could watch the funicular from their balconies any time they wanted). And most importantly, the Kaunas funicular clearly, quickly, and conveniently does what all city transport must do: it connects 2 lives in the same city – the sleepy Žaliakalnis, with its tranquillity and quiet streets, with its houses and old trees, and the centre of Kaunas, the Liberty Avenue, with its people and its hustle and bustle, "<…> It binds them together with a strong and reliable thread that has been stretched in the twentieth century and still holds today <…>" (Užkalnis 2010). German state television has made a short film about the Žaliakalnis funicular. The funicular has been used in Donatas Ulvydas's feature film "Emilija from Laisvės avenue" (in Lithuanian: *Emilija iš Laisvės alėjos*) and Kristijonas Vildžiūnas's film "When I'll Embrace You" (in Lithuanian: *Kai apkabinsiu Tave*) (Javaitytė 2017).

The only funicular railway in Vilnius started operating on Gediminas Hill in 2003 (Figure 7). Gediminas Hill is a slope of erosive origin that was turned into a castle fortification more than 5 centuries ago. The legend has it that the Grand Duke Gediminas dreamt of the Iron Wolf howling on this very hill, foretelling of the rise of a great city in the area. It was on this hill that the Duke built a wooden castle in the 14th century. Later, Vytautas the Great built a stone castle here, the remains of which can be seen to this day (Go Vilnius 2024).

The Vilnius Gediminas Hill funicular is a short railway with a cable pulley system. It is installed on the steep slope of Gediminas Hill to take visitors up to Gediminas Tower. The funicular was built in 2002 by the Austrian company *ABS Transportbahnen*. The construction of the funicular was supported by the Government, and the decision was motivated by survey data showing that only one in ten Vilnius residents has climbed Gediminas Hill. There were opinions that the lifting of visitors to Gediminas Hill should be abandoned because of visual pollution. In the words of Birutė Kulnytė, former director of the Lithuanian National Museum, "<…> a house for a lift on Gediminas Hill is too much honour <…>". On several occasions, the funicular has been closed due to the threat of landslides and repairs. Studies have not shown that it has a negative impact on the condition of Gediminas Hill, so it has been operating successfully ever since (Lrytas 2019). When the historical trail is closed in the event of a landslide due to rainfall or other reasons, the only way to get to Gediminas Hill is funicular railway (BNS ir Lrytas 2022).

Figure 7. Gediminas Hill funicular (Lrytas 2019)

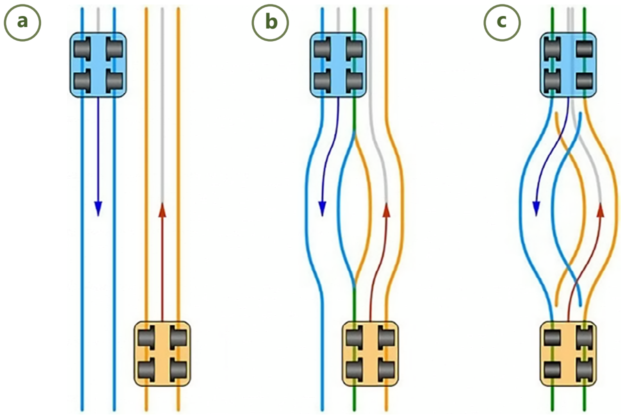

Figure 8. Track superstructure configurations of funiculars (Kak jeto sdelano 2016):
(a) – 4-rail superstructure configuration;
(b) – 3-rail superstructure configuration with passing loop;
(c) – 2-rail superstructure configuration with passing loop (both cars run on green rails)

4. Design features of funiculars

Funiculars have been transporting people and goods on steep inclines for almost 500 years. The technology has hardly changed in that time. Funiculars remain relevant because of their efficiency and simplicity of design. By using a counterweight pulley system, the funicular uses the kinetic energy of the descending car to raise the ascending car in a manner similar to that of an elevator. Additional energy is needed to overcome frictional losses in the system, but this is a sustainable method of transport because no fuel is used. Instead, funiculars harness the energy inherent in the motion of the cars. These railways demonstrate the lasting value of simple solutions and are a testament to engineering ingenuity) (Harley-Trochimczyk 2009).

Funicular tracks are of various widths. Regarding the number of rails used to form the track superstructure, funiculars can be classified into 3 categories (Pyrgidis 2016):

- *4-rail superstructure configuration* (Figure 8a). In some 4-rail funiculars, the upper and lower sections are interlaced while having a single platform at each station;
- *3-rail superstructure configuration with passing loop* (Figure 8b). In superstructure layouts using 3 rails, the middle rail (green colour) is shared by both cars;
- *2-rail superstructure configuration with passing loop* (Figure 8c). This type of superstructure does not require switches and crossings. The vehicles feature specially arranged wheels. More specifically, only the wheels of one side of the wheelset feature a flange, which is in fact double. The intersecting vehicles have their wheels with a flange at opposite sides, and this allows them to follow different tracks. This configuration significantly reduces costs.

There are several types of funiculars. Usually, these are 2 motorless cars firmly connected by a cable thrown over a pulley. The pulley and the stationary motor that turns it are located at the upper end of the track. The motor drives a cable thrown over a pulley and routed between the frame rails. Funicular cars are attached to the ends of the cable.

The cars pass at the half-way point. Such a funicular is cost-effective because the energy is not used to raise and lower the cars, but to balance the different weights of the cars. Also, to overcome frictional and braking forces.

In a funicular, both cars are permanently connected to the opposite ends of the same cable, known as a "haul rope". This haul rope runs through a system of pulleys at the upper end of the line. If the railway track is not perfectly straight, the cable is guided along the track using sheaves – unpowered pulleys that simply allow the cable to change direction. While one car is pulled upwards by one end of the haul rope, the other car descends the slope at the other end. Since the weight of the 2 cars is counterbalanced (except for the weight of passengers), no lifting force is required to move them – the engine only has to lift the cable itself and the excess passengers, and supply the energy lost to friction by the cars' wheels and the pulleys (Hofmann 1999).

Most modern funiculars do not have a motor. The driving force is an electric motor installed in the engine room (usually in the top station) (Figure 9a). The motor links to a substantial pulley, referred to as the drive bullwheel, through a gearbox that reduces speed. This bullwheel controls the movement of the haul rope through friction. In earlier times, some funiculars utilized steam engines or other types of motors in a similar configuration. The bullwheel typically includes 2 grooves, and the cable returns via an auxiliary pulley after completing the 1st half-turn around it. This design offers the advantage of doubling the contact area between the cable and the groove, ensuring that the downward-moving cable aligns with the upward-moving one. Modern installations frequently integrate high friction liners to enhance the friction between the bullwheel grooves and the cable. For emergency and maintenance purposes, the engine room employs 2 sets of brakes: the emergency brake directly engages the bullwheel, and the service brake is positioned at the high-speed shaft of the gear. Additionally, the cars are equipped with spring-applied rail brakes that are hydraulically opened for emergency situations (Hofmann 1999; Neumann 1992).

In certain setups, the cars are connected to a second cable, referred to as the bottom towrope (Figure 9b), which travels through a pulley located at the base of the incline. In these configurations, one of the pulleys must be designed as a tensioning wheel to prevent slack in the ropes. A notable advantage of such installations is that the weight of the rope is evenly distributed between the carriages. Consequently, the engine no longer requires additional power to lift the cable itself. This approach is commonly employed in funiculars with slopes below 6%, those utilizing sledges instead of carriages, or any situation where it cannot be guaranteed that the descending car always has the capability to pull the cable out from the pulley at the top station of the incline (Hefti 1975).

Safety is at the heart of every engineering project. Funicular developers use several different measures to reduce the likelihood of system failure. The steel cables of the funicular shall be tensile resistant. The system design provides for a maximum capacity of the cars to prevent cable breakage. In the event of an emergency (including overspeed or a slack haul rope), each funicular is equipped with an emergency rail brake in the form of clips. They automatically tighten the rail to bring the car to a safe stop. The funiculars are simple in design, so there is a low probability of failure and the existing safety features can adequately protect passengers (Harley-Trochimczyk 2009).

A funicular usually has 2 stations, an upper and a lower station. In this case, the cars move without stopping. However, there are funiculars with intermediate stops (Prague Funicular, Czechia). There can also be stops on request of passengers (Karlovy Vary Funicular, Czechia). Funicular cars are designed individually for each track, considering the slope gradient. Not only individual funicular cars can run, but the whole train as well (Istanbul Cable Car, Turkey).

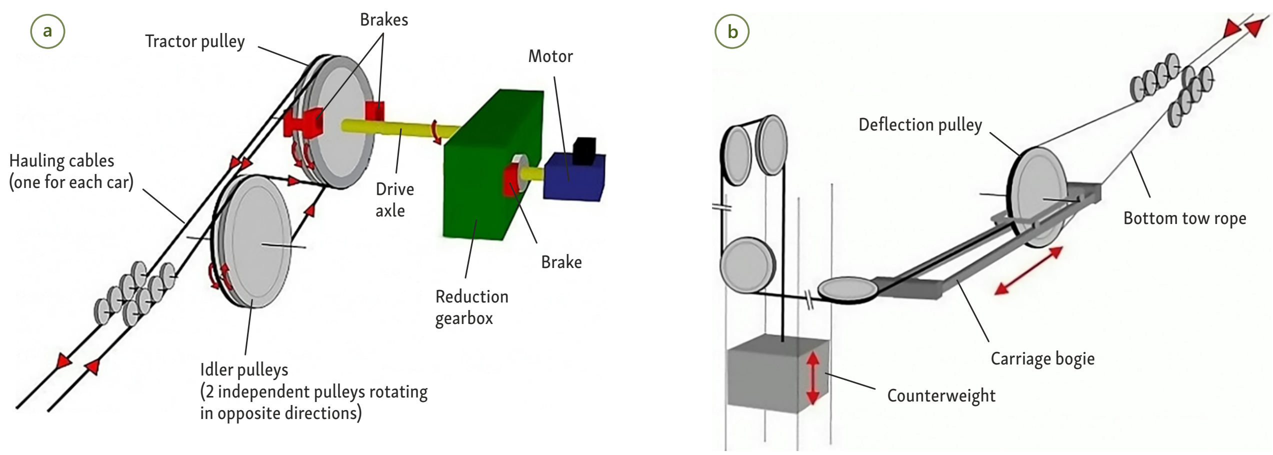

Figure 9. Funicular station facilities: (a) – top station facilities; (b) – bottom station facilities (Wikipedia 2024a, 2024b)

5. Influence of the mountainous nature of the country on the number of funiculars

The number of funiculars in a country is likely to depend on its mountainous nature. Funiculars are installed on slopes with an angle of inclination of less than 35^0. The largest number of funiculars in operation is in Switzerland (49), Italy (26) and Japan (20) (Table 2).

The study has been carried out to establish the relationship between the number of funiculars (N) and the country mountainousness index (M). A correlation analysis of these variables was carried out using the data in Table 2. The dependence of N on M was tested using 3 types of regression models. The regression models were used to draw straight lines and curves. The resulting regression equations, coefficients of determination R^2 and correlation coefficients R are shown in Figure 10. The N and M relationship with outliers for 36 countries (Table 2, Figure 10a) and without outliers for 15 economically advanced and tourism-developing countries (Table 2, Figure 10b) was examined.

Table 2. Number of funiculars per continent and per country (adapted from (Pyrgidis 2016)

Continent	Country	International country codes	Number of funiculars, N	Mountainousness index, M [%]
Europe	Austria	AT	13	73.4
	Azerbaijan	AZ	1	45.7
	Czechia	CZ	4	32.3
	Croatia	HR	1	30.5
	France	FR	16	22.3
	Georgia	GE	1	79.2
	Germany	DE	12	14.7
	Greece	GR	1	77.9
	Hungary	HU	1	4.7
	Italy	IT	26	60.1
	Lithuania	LT	3	0.0
	Norway	NO	2	91.3
	Poland	PL	3	5.2
	Portugal	PT	8	39.1
	Romania	RO	1	37.9
	Slovakia	SK	1	62.0
	Spain	ES	11	55.7
	Sweden	SE	2	50.6
	Switzerland	CH	49	90.7
	Turkey	TR	4	70.0
	Ukraine	UA	2	3.5
	United Kingdom	UK	18	25.5
	Bosnia and Herzegovina	BA	1	72.6
North America	Canada	CA	2	24.0
	United States	US	14	–
South and Central America	Argentina	AR	1	48.0
	Brazil	BR	8	–
	Chile	CL	9	52.0
	Colombia	CO	1	25.9
	Mexico	MX	1	-
Asia	China	CN	1	52.2
	India	IN	1	16.9
	Israel	IL	1	16.0
	Japan	JP	20	75.0
	Malaysia	MY	1	–
	Thailand	TH	3	20.0
	Hong Kong	HK	2	91.9
	Lebanon	LB	1	81.1
Africa	South Africa	ZA	1	26.0
Oceania	New Zealand	NZ	1	60.0
Total		–	249	–

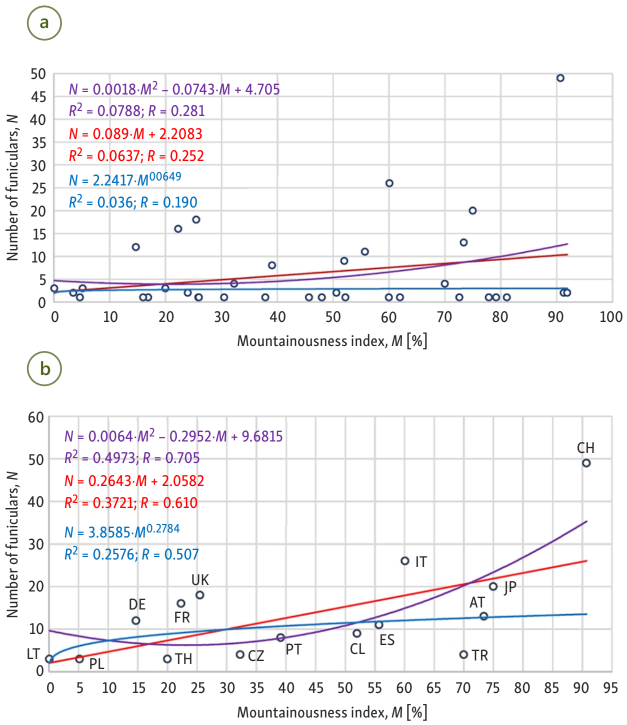

Figure 10. Dependence of the number of funiculars on the mountainous terrain of the country:
(a) – all countries (with outliers);
(b) – countries with a strong economy and developed tourism (without outliers)

When deciding on the correlation between variables N and M, it is necessary to compare the values of the calculated correlation coefficients R with their smallest (critical) values R_{min}. When R is greater than R_{min}, which depends on the number of degrees of freedom $\nu = m - 2$ and the significance level α, it is reasonable to assume that variables N and M are correlated.

When testing the statistical hypothesis that the estimated correlation coefficient is zero, the Student criterion of the statistical significance is calculated from the formula (Bertulienė *et al.* 2019):

$$t = R \cdot \sqrt{\frac{m-2}{1-R^2}}, \tag{1}$$

where: m is the number of countries with funiculars (i = 1, 2, ..., m); R is the estimated pairwise correlation coefficient.

After rearranging the Equation (1), the smallest value of the pairwise correlation coefficient R_{min} is calculated, which shows that with the significance level α and the number of degrees of freedom $\nu = m - 2$, it can be considered that the variables are correlated (Podvezko, Sivilevičius 2013):

$$R_{min} = \frac{t_{\alpha,\nu}}{\sqrt{m-2+t^2_{\alpha,\nu}}}, \tag{2}$$

where: $t_{\alpha,\nu}$ is Student's statistic (percentage points of the t distribution) that depends on ν and α, found in the mathematical statistics table (Montgomery 2019).

In practice, the significance level α = 0.05 is usually taken. When the correlation of 36 variables is investigated, the number of degrees of freedom is $\nu = m - 2 = 36 - 2 = 34$. Interpolating the values $t_{\alpha,\nu}$ between ν = 30 and ν = 40 (t = 1.697 and t = 1.684) from the mathematical statistics table gives $t_{0.05,\,34}$ = 1.6918. The minimum threshold value of the correlation coefficient R_{min} = 0.2786. It shows that the variables N and M (Figure 10a) are correlated only in the quadratic regression model.

When studying the correlation of variables N and M of 15 economically advanced and developed tourism countries, without outliers, the degree of freedom $\nu = m - 2 = 15 - 2 = 13$. The value of statistic $t_{0.05,\,13}$ is equal to 1.771. Threshold (minimum) value of correlation coefficient R_{min} = 0.4409. The data show that according to all regression models (Figure 10b), N and M are correlated.

6. Discussion and conclusions

It is sometimes wrongly assumed that the funicular is a historical rather than a practical means of transport for modern society. The review shows that this type of railway is still successfully used in public transport systems in cities around the world. Similar technologies are being installed in residential and commercial properties, ski resorts and golf courses. Although the use of funiculars is limited to a narrow range of transport – transporting passengers up and down steep slopes it is efficient. The unique combination of the funicular counterweight pulley system and the rails ensures minimal energy consumption. The funiculars are simple in design and therefore have a low probability of failure. It is also an environmentally friendly means of transport. Funiculars are often historic heritage sites that represent the country. A funicular ride is also a great emotion that comes from looking at the beautiful panorama, which opens. The funicular is thus a remarkable example of engineering ingenuity, proving that a long-established and simple technology can be successfully used to this day.

Urban funiculars are an increasingly frequent subject of scientific research. Cable car installation projects are underway across Europe. They aim to complement the local public transport system. For this purpose, the characteristics of rope hoists, modern trends and their implementation possibilities are examined. The focus is on aerial funiculars, which are increasingly used for urban mobility, rather than alternative ones such as railway funiculars. The economic aspects of funiculars are also examined). Since funiculars do not require the construction of a depot, as is the case with buses and streetcars, the investment costs for urban funiculars are very low. A particularly short construction period of 12 to 18 months is also a great benefit, especially when compared to such projects as underground railways with a construction period of 5 to 10 years. The fact that funiculars produce virtually no harmful emissions during operation means that they can help improve air quality in cities. However, the installation of funiculars is not without its challenges. Before construction, a detailed assessment must be made of how ropeways running over residential areas will affect residents. The possibility of using the cable cars in the city must be evaluated taking into account specific circumstances (Graser 2022).

The year 2030 will be the global turning point for sustainable mobility in the world's largest cities, due to the fact that travel in private vehicles will decrease 10% on a global scale in the next decade. Car-sharing, multimodality, and autonomous vehicles, along with the world's aging population, will reduce the need to own a car, which will be offset by increased use of public transport, cycling, and walking as citizens opt for more functional, safer, and environmentally friendly ways to travel. However, there is another crucial aspect when it comes to public transport: safety. In this respect, ropeways, or funiculars, are among the safest public passenger transport systems in the world. To achieve this, many elements are involved, among them the right of way, since the aerial route does not interfere with other means of transport, eliminating the possibility of accidents due to impact. This in turn increases its effectiveness, as it is not affected by traffic congestion, with the numerous associated benefits that this entails. Modern funiculars feature unique rope position detection systems. Constant monitoring of the rope position through the use of state-of-the-art technology guarantees cableway operators high cost-effectiveness and, for users, maximum safety along the entire route, from the lower station to the upper station and back. The future of ropeway mobility is based on autonomous driving (Panagiotou 2022).

The correlation analysis between the number of funiculars per country and the country mountainousness variables N and M shows that for all 36 countries, the correlation between the number of funiculars N and the country mountainousness variable M, as expressed in the 3 regression models, is weaker than it is for the 15 advanced economies and developed tourism countries. Empirical correlation coefficients calculated from statistical data, compared to their critical values, show that the number of funiculars is still low in some mountainous countries. In countries with very high mountains, it is likely that aerial funiculars, rather than railway funiculars, are used to transport passengers. The significance of the quality parameters of the funicular can be investigated in the future by means of expert research methods.

References

Ąžuolyno biblioteka. 2024. *Kauno entuziastų virtualios parodos*: *Kauno funikulieriai*. Ąžuolyno biblioteka, Kaunas, Lietuva. Available from Internet: https://azuolynobiblioteka.lt/paslaugos/kauno-entuziastams/kauno-entuziastu-virtualios-parodos/ (in Lithuanian).

Bertulienė, L.; Juknevičiūtė-Žilinskienė, L.; Sivilevičius, H.; Laurinavičius, A. 2019. Evaluation of frost blanket layer strength using different devices, *Građevinar* 71(2): 95–104. Available from Internet: http://casopis-gradjevinar.hr/archive/article/2139

BKK. 2024. *Funicular*. Budapesti Közlekedési Központ (BKK), Budapest, Hungary. Available from Internet: https://bkk.hu/en/travel-information/special-and-heritage-transport-services/funicular/funicular.12121/

BNS ir Lrytas. 2022. Į Gedimino kalną patekti bus galima tik keltuvu, *Lietuvos rytas*, 2022-06-28. Available from Internet: https://www.lrytas.lt/gamta/keliones/2022/06/28/news/i-gedimino-kalna-patekti-bus-galima-tik-keltuvu-23807898 (in Lithuanian).

Celik, E.; Aydin, N.; Taskin Gumus, A. 2014. A multiattribute customer satisfaction evaluation approach for rail transit network: a real case study for Istanbul, Turkey, *Transport Policy* 36: 283–293. https://doi.org/10.1016/j.tranpol.2014.09.005

CK Travels. 2024. *13 of the World's Most Spectacular Funicular Railways*. Available from Internet: https://www.cktravels.com/worlds-best-funicular-railways/

Činga, E. 2019. *Kaune vėl veikia Žaliakalnio funikulierius*. Available from Internet: https://welovelithuania.com/kaune-vel-veikia-zaliakalnio-funikulierius/ (in Lithuanian).

EBD. 2023. *Top Funiculars that Bring You to the Most Beautiful Places in Europe*. European Best Destinations (EBD). Available from Internet: https://www.europeanbestdestinations.com/top/best-funiculars-in-europe/

Escobar, D. A. G.; Sarache, W.; Jiménez-Riaño, E. 2022. The impact of a new aerial cable-car project on accessibility and CO_2 emissions considering socioeconomic stratum. A case study in Colombia, *Journal of Cleaner Production* 340: 130802. https://doi.org/10.1016/j.jclepro.2022.130802

Flesser, M.; Friedrich, B. 2022. Are we taking off? A critical review of urban aerial cable cars as an integrated part of sustainable transport, *Sustainability* 14(20): 13560. https://doi.org/10.3390/su142013560

Fribourg Tourisme et Région. 2024. *Funiculaire de Fribourg*. Fribourg Tourisme et Région (FTR), Switzerland. Available from Internet: https://fribourg.ch/fr/fribourg/trains-transports-touristiques/funiculaire-de-fribourg/

Graser, J. 2022. Cable cars: urban transport of the future, *Seilbahnen International*, 24 August 2022. Available from Internet: https://www.simagazin.com/en/si-urban-en/topics-urban/urban/seilbahnen-stadtverkehr-der-zukunft/

Go Vilnius. 2024. *Gediminas' Hill*. Go Vilnius, Vilnius, Lithuania. Available from Internet: https://www.govilnius.lt/visit-vilnius/places/mount-gediminas

Grigaliūnaitė, V. 2018. 5 dalykai Kijeve: paglostyti, pamatyti, pajusti, išgirsti, išmėginti, *15 min*, 2018-11-25. Available from Internet: https://www.15min.lt/gyvenimas/naujiena/keliones/5-dalykai-kijeve-paglostyti-pamatyti-pajusti-isgirsti-ismeginti-1630-1064498 (in Lithuanian).

Grigelis, A.; Jankauskas, R.; Jovaiša, E.; Juodkazis, V.; Kulvietis, G.; Motuza-Matuzevičius, G.; Naujalis, J.; Ruzgas, V. 2016. *Gedimino pilies kalno šlaitų būklės ir jų tvarkymo programos vertinimo ataskaita*. Lietuvos mokslų akademija, Vilnius. 25 p. (in Lithuanian).

Guide of Prague. 2023. *Petřín Funicular*. Guide of Prague, Czechia. Available from Internet: https://guide-prague.net/tourist-attractions/the-petrin-funicular/

Guzman, L. A.; Cantillo-Garcia, V. A.; Arellana, J.; Sarmiento, O. L. 2023. User expectations and perceptions towards new public transport infrastructure: evaluating a cable car in Bogotá, *Transportation* 50(3): 751–771. https://doi.org/10.1007/s11116-021-10260-x

Harley-Trochimczyk, A. 2009. The fun of funiculars, *Illumin Magazine*: *a Review of Engineering in Everyday Life*, 7 July 2009. Available from Internet: https://illumin.usc.edu/the-fun-of-funiculars/

Hefti, W. 1975. *Schienenseilbahnen in aller Welt*: *Schiefe Seilebenen Standseilbahnen Kabelbahnen*. Springer Basel AG. 321 p. https://doi.org/10.1007/978-3-0348-6568-5 (in German).

Hofer, K.; Haberl, M.; Fellendorf, M.; Huber, G.; Fallast, K. 2018. Travel demand estimation for cable car transport in the urban areas shown for the moderate-sized city of Graz, Austria, in *Proceedings of 7th Transport Research Arena TRA 2018*, 16–19 April 2018, Vienna, Austria. 1–10. https://doi.org/10.5281/zenodo.1483240

Hofmann, G. 1999. *Advanced Funicular Technology*. Colorado School of Mines, Golden, CO, US. 15 p. Available from Internet: https://repository.mines.edu/handle/11124/70549

Ishvetsov.ru. 2023. *Kak vygljadit funikuler*. *Chto takoe funikuler i kakova ego rol' v sovremennom mire*. Available from Internet: https://ishvetsov.ru/kak-vyglyadit-funikuler-chto-takoe-funikuler-i-kakova-ego-rol-v/ (in Russian).

Jacytė, V. 2016. *Pogrindinė spaustuvė „AB"*. VšĮ „Tautos atmintis", Vilnius, Lietuva. Available from Internet: https://tautosatmintis.weebly.com/straipsniai/vikte-jacyte-pogrindine-spaustuve-ab (in Lithuanian).

Javaitytė, S. 2017. Kauno funikulieriai: miesto tapatybės ir unikalumo simboliai, *Kas vyksta Kaune*, 2017-07-23. Available from Internet: https://kaunas.kasvyksta.lt/2017/07/23/kultura/kauno-funikulieriai-miesto-tapatybes-ir-unikalumo-simboliai/ (in Lithuanian).

KA. 2024. *Aleksoto funikulierius*. UAB „Kauno autobusai" (KA), Kaunas, Lietuva. Available from Internet: https://kaunoautobusai.lt/paslaugos/aleksoto-funikulierius/ (in Lithuania).

Kak jeto sdelano. 2016. *Funikuljor – kak sredstvo peredvizhenija*. Kak jeto sdelano. Available from Internet: https://kak-eto-sdelano.ru/funikulyor-kak-sredstvo-peredvizheniya/ (in Russian).

Karkee, R.; Khadka, S.; Gautam, S. 2015. Introducing a modified water powered funicular technology and its prospective in Nepal, *International Journal of Science and Technology* 4(8): 412–419.

Kayaoğlu, E.; Candaş, A.; Kocabal, Y. Z.; İmrak, C. E. 2014. Early application of underground funicular 'tunnel' in Istanbul, in *ELEVCON 2014 – the 20th International Congress on Vertical Transportation Technologies*, 8–10 July 2014, Paris, France, 103–113.

Kremer, F. 2015. *Innovation Seilbahn*: *Potentiale für den urbanen Personennahverkehr und Positionen der beteiligten Akteure*. Universitätsverlag der TU Berlin, Deutschland. 86 s. https://doi.org/10.14279/depositonce-4371 (in Germany).

Lemmin-Woolfrey, U. 2023. *12 Thrilling Places that Put the 'Fun' in Funicular*. Travel Awaits. Available from Internet: https://www.travelawaits.com/2555886/best-funiculars-in-the-world/

Liu, H.-L.; Hsu, W.-L. 2015. Framework for assessing cable car construction investment projects: examining investment projects in Taiwan, *Advances in Mechanical Engineering* 7(11): 15620087. https://doi.org/10.1177/1687814015620087

Lrytas. 2019. Brangus, neišvaizdus, bet reikalingas – keltuvas į Gedimino kalną jau veikia, *Lietuvos rytas*, 2019-09-24. Available from Internet: https://www.lrytas.lt/bustas/architektura/2019/09/24/news/brangus-neisvaizdus-bet-reikalingas-keltuvas-i-gedimino-kalna-jau-veikia-11902827 (in Lithuanian).

Magdyk, N. 2022. U Kyjevi vyrishyly zakryty funikuler – nazvano prychynu, *S'ogodni*, 3 chervnja 2022. Available from Internet: https://kiev.segodnya.ua/kiev/ktransport/v-kieve-reshili-zakryt-funikuler-nazvana-prichina-1623913.html (in Ukrainian).

Masiokaitė, A. 2011. 80 metų jubiliejų švenčiantis Kauno funikulierius mena ir K. Petrausko dainas, *Lietuvos rytas*, 2011-08-06. Available from Internet: https://www.lrytas.lt/kultura/istorija/2011/08/06/news/80-metu-jubilieju-svenciantis-kauno-funikulierius-mena-ir-k-petrausko-dainas-5505432 (in Lithuanian).

Maskeliūnaitė, L. 2021. Railways in Lithuania: from tsarist Russia to *Rail Baltica*, *Transport* 36(4): 364–375. https://doi.org/10.3846/transport.2021.16086

Mbereyaho, L.; Dushimimana, A.; Nzapfakumunsi, A. 2018. Proposal of aerial cable car as an alternative means of public transport in Kigali city, *International Journal of Applied Engineering Research* 13(8): 6216–6224. Available from Internet: https://www.ripublication.com/ijaer18/ijaerv13n8_84.pdf

Mikul'onok, I. O.; Andrejev, I. A. 2017. Istorija stvorennja kyi'vs'kogo funikulera, *Storinky istorii'* 45: 29–44. https://doi.org/10.20535/2307-5244.45.2017.117739 (in Ukrainian).

Miravet, D.; Domènech, A.; Gutiérrez, A. 2021. What prompts tourists to become public transportation users at their destination? The case of a Mediterranean city, *Travel Behaviour and Society* 24: 10–21. https://doi.org/10.1016/j.tbs.2021.01.007

Montgomery, D. C. 2019. *Introduction to Statistical Quality Control*. 8th Edition. Wiley. 768 p.

Morkūnas, E. J. (red.). 2013. *Įdomiausi Lietuvos technikos paminklai*. Kaunas: Terra Publica. 266 p. (in Lithuanian).

Moscariello, G.; Niola, V.; Rossi, C. 2005. Law of motion influence on the start-stop transients of funicular railways, in *ISCGAV'05*: *Proceedings of the 5th WSEAS International Conference on Signal Processing*, *Computational Geometry* & *Artificial Vision*, 15–17 September 2005, Malta, 260–265.

Neumann, E. S. 1992. Cable-propelled people movers in urban environments, *Transportation Research Record* 1349: 125–132. Available from Internet: https://onlinepubs.trb.org/Onlinepubs/trr/1992/1349/1349-017.pdf

Otamendi, J. 2009. Cost analysis of a funicular-type train service via simulation, in *2009 11th International Conference on Computer Modelling and Simulation*, 25–27 March 2009, Cambridge, UK, 322–327. https://doi.org/10.1109/UKSIM.2009.51

Pamatyk Lietuvoje. 2023. *Prezidentinis maršrutas*. Available from Internet: https://www.pamatyklietuvoje.lt/keliones/marsrutai-pesciomis/prezidentinis-marsrutas/261 (in Lithuanian).

Panagiotou, K. 2022. *Cable Cars a Safe and Sustainable Option for Urban Mobility*. Available from Internet: https://mexicobusiness.news/infrastructure/news/cable-cars-safe-and-sustainable-option-urban-mobility

Patowary, K. 2019. *Water Powered Funiculars*. Available from Internet: https://www.amusingplanet.com/2019/02/water-powered-funiculars.html

Podvezko, V.; Sivilevičius, H. 2013. The use of AHP and rank correlation methods for determining the significance of the interaction between the elements of a transport system having a strong influence on traffic safety, *Transport* 28(4): 389–403. https://doi.org/10.3846/16484142.2013.866980

Pyrgidis, C. N. 2016. *Railway Transportation Systems*: *Design*, *Construction and Operation*. CRC Press. 511 p. https://doi.org/10.1201/b19472

Roberts, M. S. 2020. 'Funiculì, Funiculà': what are the original and English lyrics to the Neapolitan song? Available from Internet: https://www.classicfm.com/discover-music/funiculi-funicula-neapolitan-english-song-lyrics/

Rosa, G. P. 2023. O elevador do Bom Jesus de Braga, único no mundo, *National Geographic Portugal*, 20 de Dezembro de 2023. Available from Internet: https://www.nationalgeographic.pt/historia/o-elevador-do-bom-jesus-braga-unico-no-mundo_2782 (in Portuguese).

Schwartz, H. 2021. Funicular, in *Designing Buildings*: *the Construction Wiki*. Available from Internet: https://www.designingbuildings.co.uk/wiki/Funicular

Skuodis, Š.; Kelevišius, K.; Žaržojus, G. 2017. Vibrations measurement of the funicular generated vibrations on Gediminas Hill north part slope, in *Environmental Engineering*: *10th International Conference*, 27–28 April 2017, Vilnius, Lithuania. 1–8. https://doi.org/10.3846/enviro.2017.120

Smolienė, A. 2018. Žaliakalnio funikulierius mena ir dar vieną nelaimę, *Kauno diena*, 2018-06-17. Available from Internet: https://kauno.diena.lt/naujienos/kaunas/miesto-pulsas/alekso-to-funikulieriu-atgaivinti-galetu-kavine-868618 (in Lithuanian).

Tamoliūnienė, R. (red.). 2009. *Kauno savasties ženklai*. Kaunas: Kauno apskrities viešoji biblioteka, 166 p. (in Lithuanian).

Težak, S.; Lep, M. 2019. New technological approach to cable car boarding, *Sustainability* 11(15): 4017. https://doi.org/10.3390/su11154017

Težak, S.; Sever, D.; Lep, M. 2016. Increasing the capacities of cable cars for use in public transport, *Journal of Public Transportation* 19(1): 1–16. https://doi.org/10.5038/2375-0901.19.1.1

Tockij, O. 2017. Chto nahoditsja v jetom zhurnale?, *Livejournal*, 1 ijunja 2017. Available from Internet: https://tov-tob.livejournal.com/ (in Russian).

Uletova, J. 2010. Puteshestvie k krateru Vezuvija: istorija funikulera, *Livejournal*, 1 sentjabrja 2010. Available from Internet: https://ulli-u.livejournal.com/122796.html (in Russian).

Užkalnis, A. 2010. Miesto transportas: civilizacijos siūlai skruzdėlyne, *Bernardinai*, 2010-12-10. Available from Internet: https://www.bernardinai.lt/2010-12-10-andrius-uzkalnis-miesto-transportas-civilizacijos-siulai-skruzdelyne/ (in Lithuanian).

Vaitkevičiūtė, V. 1999. *Tarptautinių žodžių žodynas*. 1 dalis: A–K. Vilnius: Žodynas. 707 p. (in Lithuanian).

Vanagas, J. 2017. Konkė: the first public transport in Vilnius, *Transport* 32(1): 94–100. https://doi.org/10.3846/16484142.2016.1167124

Wikipedia. 2024a. *Funicular*. Available from Internet: https://en.wikipedia.org/wiki/Funicular

Wikipedia. 2024b. *List of Funicular Railways*. Available from Internet: https://en.wikipedia.org/wiki/List_of_funicular_railways

Zahradnikova, V.; Zahradnik, V. 2024. *Funicular Railway on Petrin Hill*. Prague Free Tour (PFT). Available from Internet: https://www.tours-prague.eu/prague-funicular.phtml