Cable-drawn urban transport systems

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Abstract

Cable-drawn transport systems have been in use for a long time for passenger transportation, mostly in alpine areas. However, in recent years these transport systems have also been increasingly used in urban areas.

In this paper the various structural forms of cable-drawn passenger transportation systems particularly suited for urban transportation solutions are discussed. Particular attention will focus on single- or bicable continuous ropeway systems, funicular railways in continuous or reversible operation and inclined lifts. The function and mode of operation as well as design of these cable railway systems will be described in detail.

The possible incorporation in the urban traffic flow will be demonstrated with several of the solutions at present under construction or already in operation with quite diverse systems.

Apart from the advantages and disadvantages, the summary will describe the current fields of application and operational limits of the individual types of construction regarding travel speed, route lengths and carrying capacity.
Keywords: detachable ropeways, funiculars, inclined lifts, cable cars.

1 Introduction

A ropeway is a system for the transport of passengers or goods whereby the passengers or goods in cars are conveyed or drawn by means of a towing device, which are borne by one or more ropes or a track and movement is controlled by one (or two) rope(s). Lifts are expressly excluded.

The principle of the cable-drawn transport system was known even in ancient times. As early Chinese historical drawings demonstrate, this principle was already in use very early for material transport. But during the course of the Industrial Revolution, the invention of the steel cable by the German mining

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official Albert in 1834 heralded a period of lively development of the various cable-drawn transport systems [1]. While initially development mainly focused on funicular railways (such as the Cable Car Line in San Francisco, 1872) later interest turned to aerial ropeways, which only came into operation for passenger transport shortly after 1900. Various technical systems have evolved over the decades. For example, more recent systems can be classified according to the type of track (carrier) is used. Figure 1 shows an overview of the various systems, which are naturally in use with very diverse frequency. The variations in bold print will subsequently be described in more detail. In addition, inclined lifts will also be examined; these are intrinsically a modified form of funicular railway, but are subject to lift regulations and therefore cannot be directly regarded as aerial ropeways.

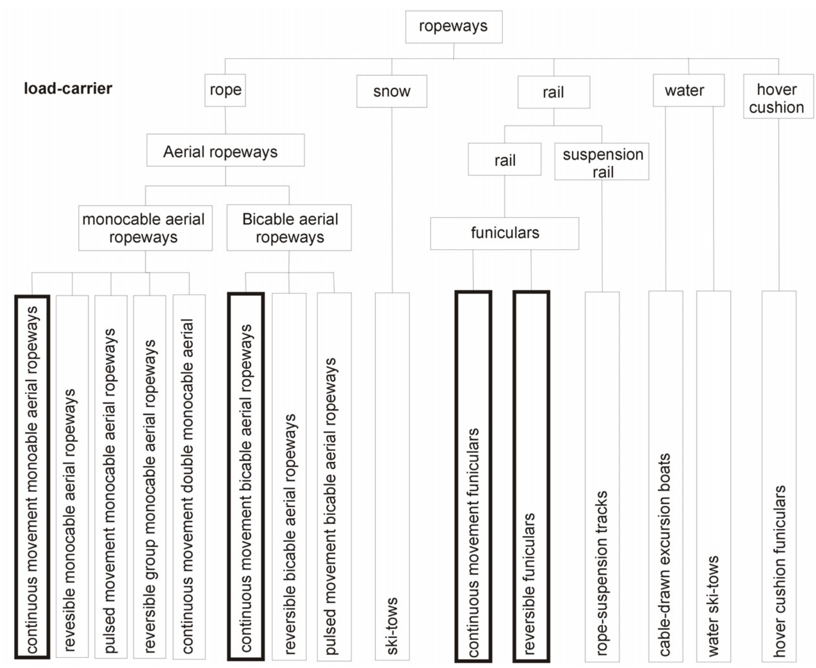

Figure 1: Classification of aerial ropeways.

2 Continuous movement monocable aerial ropeway and bicable aerial ropeway

2.1 Design and mode of operation

In principle, continuous movement monocable aerial ropeways and bicable aerial ropeways only differ in the number of rope systems. While with a bicable aerial ropeway the cars are carried by one or more ropes (track ropes) and moved by a further rope of rope system (haul rope), with a monocable ropeway one or two ropes assume the carrying and hauling function (carry-hauling cable). The continuous movement operation is thus characterised in that moving rope always circulates in the same direction of motion with uniform speed.

With reference to the bicable aerial ropeway, the design and mode of operation of detachable ropeways are as described in Figure 2.

With a detachable continuous movement bicable aerial ropeway the clamping to the haul rope is by means of operationally releasable clamping devices. In the station the cars are separated from the haul rope, decelerated and guided onto an overhead monorail which leads the car at low speed through the embarkation and disembarkation area. The low speed through the station enables easy mounting and dismounting for the passengers. Before the station exit the car is accelerated again to the constant haul rope speed and joined to the haul rope by the closure of the clamp. Thus the clamping device fixed to the car can grip the haul rope at any point and thus enable the setting of various sequential intervals between the individual cars.

Outside the station area the ropes are led over line support structures, the track rope on saddles (track rope saddle), the haul rope on support rollers. At the circulating operation there are two track ropes that are permanently anchored at one end of the track, normally the upper end, and maintained under constant tension by weights at the other end. Each of the two track rope sections serve for just one direction and are linked together in the upper and lower stations by the overhead monorails. The haul rope can be tensioned either by a tension weight or a hydraulic tensioning cylinder. Drive for the haul rope is provided by the electric motor-driven drive pulley.

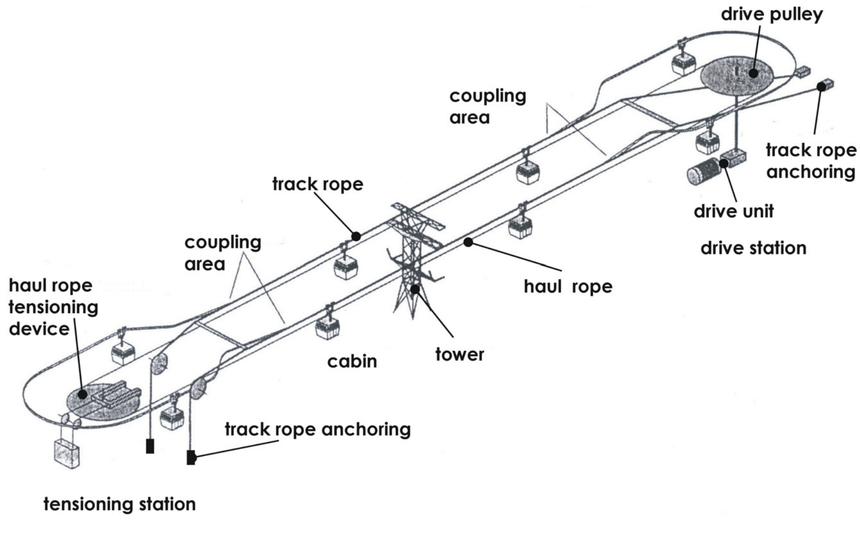

Figure 2: Diagram of a detachable continuous movement bicable aerial ropeway.

2.2 Pros and cons

The advantages of the continuous movement monocable aerial ropeway and bicable aerial ropeway are: safe system, high carrying capacity, long routes can be implemented (approx. 6 km/section), adaptability to the terrain, the continuous passenger flow thanks to the constant movement, low space requirement along the route, nom overlap with other forms of transportation.

Further advantages of the bicable aerial ropeway are: very long rope sections are feasible (up to approx. 1,500 m), high wind stability.

Disadvantages of the monocable aerial ropeway and bicable aerial ropeway include: weather-sensitive system, as safe operation cannot be maintained in the vent of high winds, heat cabins are hardly feasible.

Further disadvantages of the monocable system: low wind stability, and long rope sections can only be implemented with difficulty.

2.3 Application area

As high carrying capacity is dependent on the track length and intermediate stations along the route are easy to implement, this ropeway system is admirably suitable for covering long distances in inner urban areas (up to 6 km for a ropeway section).

2.4 Example: Tung Chung Cable Car

The Tung Chung Cable Car, a detachable continuous movement bicable aerial ropeway, consists of two sections with a total length of 5.7 km. Figure 3 shows the alignment of the Tung Chung Cable Car. The first section begins in conjunction with the public transport system from Hong Kong in Tung Chung. From there is crosses Tung Chung Bay to an angle station on Airport Island. The second section leads from Airport Island via a further angle station at Nei Lak Shan to the terminus in Ngong Ping.

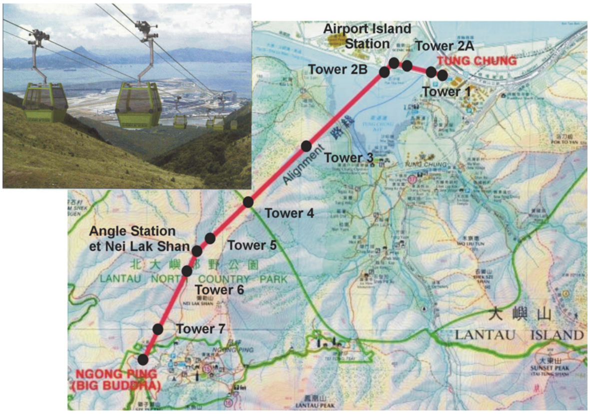

Figure 3: Alignment of the Tung Chung Cable Car [7].

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Next to the Ngong Ping Station there will be a themed village leading all the way to the Ngong Ping plateau, where the world´s largest seated outdoor bronze Buddha Statue is located. The ropeway will be supported by 8 towers. Most of the Tung Chung Cable Car infrastructure will be located in North Lantau Country Park. The ropeway journey will offer an attractive 17-minute aerial alternative to the current one-hour journey by Tung Chung Road. In addition to being a new attraction, the ropeway should also provide a appealing interlude for transit passengers at the airport. The Tung Chung Cable Car is expected to open to the public in early 2006.

3 Inclined lifts

3.1 Design and mode of operation

The inclined lift is a modified form of the funicular railway in shuttle operation with just one car for transporting passengers over a single-track, appropriately short route. But in contract to a conventional lift, the main difference is that with this transport system the route can be adapted to the terrain. An automatic adjustment device for cabin inclination is also feasible, not only for travelling over a constant inclination, but also a route with varying inclinations. Regardless of the track inclination, the cabin floor remains horizontal. The haul rope is driven by a drum winch or a drive pulley. In the latter case a counterweight travelling between the track bearers balances the car weight.

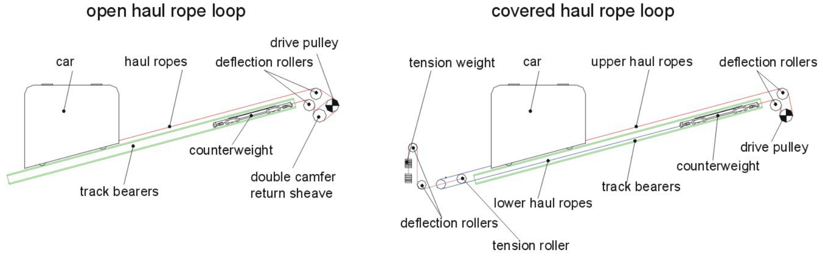

Figure 4: Assemblies of an inclined lift with open haul rope loop (left-hand diagram) and covered haul rope loop (right-hand diagram).

Designs can differ between inclined lifts with open and covered haul rope loops as shown in Figure 4. If the driving capacity of the drive pulley is sufficient, then the inclined lift is implemented with an open haul rope loop. In order to increase the driving power of the drive pulley, an additional tensioning device is provided in the other station, thus achieving a closed haul rope loop. As with the conventional lift, the inclined lift is summoned by a press button.

3.2 Pros and cons

The advantages of this transport system are: low space requirement, safe, comfortable, reliable, energy-saving, low-maintenance, quiet in operation, no operator required, extremely resistant to environmental influences, easy transport of wheelchairs or baby carriages, inclinations up to 60° possible, adaptability to existing terrain conditions.

A disadvantage is the low carrying capacity of this system.

3.3 Application area

This system is widely used particularly in urban areas for ascending short inclines. Thus the inclined lift can easily provide a link between individual hotels, sanatoriums or residential complexes and the main community, parking areas or railway stations.

3.4 Example of an inclined lift, Spa

Figure 5 shows the inclined lift system at Spa, Belgium. This consists of two independent, parallel-aligned inclined lifts, each with a cabin capacity of 25 passengers. The maximum route inclination is 32°, and the minimum route inclination 15°. The system links a public parking area with an hotel as well as a public health facility. With a travel speed of 2 m/s and a route length of 160 m, each of the two inclined lifts has a carrying capacity of 250 persons/hour.

Figure 5: Inclined lift, Spa, Belgium [6].

4 Reversible funiculars

4.1 Design and mode of operation

Figure 6 shows the basic layout of a funicular railway in shuttle operation. Two cars are linked together by a haul rope and this moves them along the route. The cars travel on tracks using steel rollers on tracks. The drive unit for the system is housed in one of the stations. Electric motors propel the drive pulley and thus the haul rope via a gearbox. The service brakes act on the flywheel of the fastmoving shaft of the motor, thus braking the entire system (car and haul rope). Passengers embark and disembark when the car is stationary. Funiculars are normally designed as single-track systems. For this reason a passing point is provided in the middle of the route.

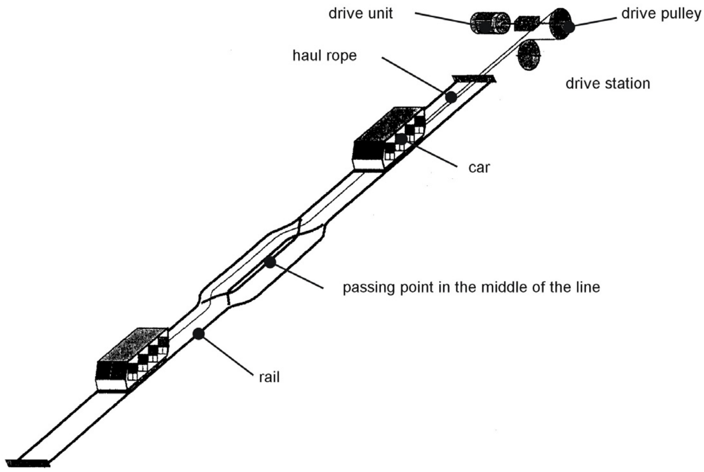

Figure 6: Layout of a reversible funicular.

4.2 Pros and cons

Advantages of this system include: environmentally sound, high availability of the system, low maintenance and service requirements, flexible route planning (horizontal and vertical deviations as well as tunnel negotiation possible), highest travel speed of rope-drawn ropeway systems, operates independent of weather.
Advantages are: carrying capacity heavily dependent on route length, irregular passenger flow due to shuttle operation.

4.3 Application area

This ropeway system is particularly suitable for shorter routes (up to approx. 1 km long) in urban areas, where the requirement is for optimum carrying capacities combined with high safety and availability of the system.

4.4 Example: Montjuic funicular

Figure 7 shows the Montjuic funicular in Barcelona, Spain. This fully automatic funicular was built as part of the transportation system serving the competition facilities located on the Montjuic Hill for the 1992 Summer Olympic Games. It is integrated in the city's public suburban transport network and links the underground line with the tourist attractions and leisure facilities of Montjuic. The carrying capacity is 8,000 persons/hour with a route length of 720 m and a travelling speed of 10 m/s, carrying 400 passengers per car.

Figure 7: Montjuic reversible funicular in Barcelona, Spain [6].

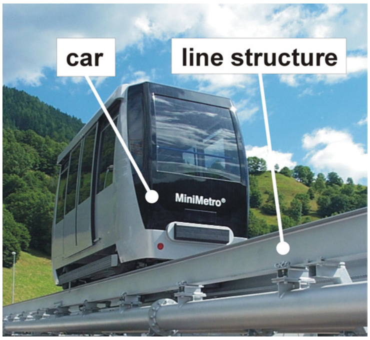

Figure 8: Car of a continuous movement funicular [6].

5 Continuous movement funiculars

5.1 Design and mode of operation

In contrast to shuttle operation, a funicular in circular operation requires two completely separate tracks. The cars are coupled to the haulage rope at specific distances by normal releasable clamping devices. Placement of stations along the line is possible without technical limits according to the local service requirement. Figure 8 shows the Car of a continuous movement funicular.
In the stations the cars are automatically detached from the cable and moved by an independent conveyor system, as in Figure 9 shown. This is realised with lateral wheels which are moved by inverter driven motors and form two sections:
- A deceleration sector where the car is slowed down on approaching the parking position;
- A parking and acceleration sector, which has the function of holding the car in the passenger loading area and accelerating it afterwards to the speed of the cable.

Disadvantages are high production costs, space requirement

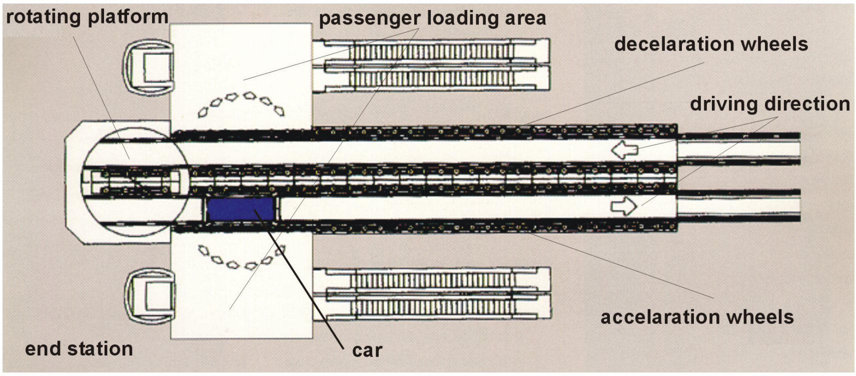

Figure 9: End station of a circulating funicular [6].

5.2 Pros and cons

The advantage of this system are: high availability, environmentally sound thanks to central drive unit, fully automatic operation, high carrying capacity, low noise nuisance, long routes can be implemented, system independent of weather, flexible adaptation to the existing infrastructure.

5.3 Application area

Main transport for small and medium sized cities, Connections from public parking lots to hospitals, universities or commercial centres, Connection between central located train or metro stations and peripheral suburbs.

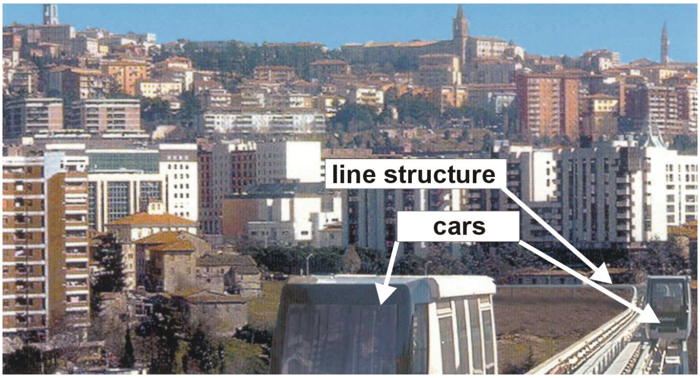

Figure 10: Perugia Minimetro [8].

5.4 Example: Perugia Minimetro

Such a system is under construction in the Italian city of Perugia, linking the Pian di Massiano district with the historic city centre located on a hill. With a difference in elevation of 160 m, the route is 3 km long, of which 1.5 km is on line support structures and more than 1 km passes through tunnels. A planned second section will be implemented at a later point in time. Embarkation can take place seven stations. A total of 25 cars are in service, each with space for 50 passengers. This system can convey up to 3,000 passengers at a maximum speed of 25 km/h. Fig. 10 shows an animation of the lower section of the future system.

6 Limits of cable-drawn urban transport systems

An important parameter for the assessment of a transport system is the carrying capacity. To do this with rope-drawn systems a differentiation must be made between circulating and shuttle operation.

The carrying capacity F_u of funiculars in passengers per hour is given by:

$$F_u = 3600\frac{P}{t} \tag{1}$$

In eqn (1), P is the number of passengers in a car and t the sequence time in seconds. The sequence time is the period of time between two successive cars. The sequence time is given by the space A between two successive cars and the travelling speed v_F of the system:

$$t = \frac{A}{v_F} \tag{2}$$

The carrying capacity F_P of shuttle systems results from:

$$F_P = 3600\frac{P}{t_{ein} + t_b + \frac{L^*_{ges}}{v_F} + t_v + t_{aus}} \tag{3}$$

With t_{ein} as embarkation time and t_{aus} as disembarkation time of passengers in the stations, t_b the time taken for acceleration of the car on leaving the station and t_v the time taken for deceleration of the car on entering the station, L^*_{ges} the route length over which the car travels at constant speed. From equation (3) it can be seen that the carrying capacity of shuttle systems falls with increasing route length. A larger number of passengers increases the carrying capacity, but also increases the embarkation and disembarkation times [2].

Table 1 provides information on the limits of rope-drawn urban transport systems. The limit values take into account currently valid European standards for cableway systems for passenger traffic and those for inclined lifts take into account the European standards for lifts.

With continuous movement monocable aerial ropeways and bicable aerial ropeways there are limits to the reduction of the sequence time for increasing the carrying capacity, as there must still be sufficient safety intervals between the uncoupled cars in the station areas.

The achievable travelling speed of funiculars is essentially limited by the route layout and thus the deflection of the haul rope along the route [3].
The implemented or currently planned route lengths are mainly limited due to the current limited in the production of haul ropes.

Table 1: Limits of cable-drawn urban transport systems.

type	limit acc. to standard	limits of realized or precently planned types			
	driving speed in m/s	driving speed in m/s	route lenght/section in m	capacity in passengers/car	carrying capacity in passengers/hour
continuous movement bicable aerial ropeway	6 to 7 [1]	5 to 7	up to 5,500	up to 17	up to 4,000
continuous movement monocable aerial ropeway	6 to 7 [1]	5 to 7	up to 5,000	up to 15	up to 4,000
continuous movement funicular	12 [1]	10 to 14	up to 5,000	up to 50	up to 5,000
reversible funicular	12 [1]	10 to 14	up to 5,000	up to 450	up to 8,000
inclined lift	undetermined [2]	1.5 to 5	up to 300	up to 30	up to 500

[1] ... according to [5]
[2] ... according to [4]

7 Conclusions

It has been seen that a wide range of variations on rope-drawn transport systems have been operated since ancient times. Many different technical systems described in this paper have since proven themselves well in urban areas. It can be expected that such systems will increasingly come into service in future, particularly in the further development and more effective realisation of existing passenger transport systems. Important aspects here include the reduction of blocked roads, parking problems, noise and air pollution.

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