ADVANCED FUNICULAR TECHNOLOGY OITAF SAN FRANCISCO

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1. How did funicular technology originate?

1804 The railway age began with the development of the first working steam locomotive.With the construction of the first railways various problems arose. Particularly hilly and mountainous terrain prevented the application of pure adhesion trains. At that time surmountable grades were limited at about ½ %. This of course triggered the ingenuity of the engineers.

1842 A first cog railway for industrial purposes was built. In due course a large variety of developments took place to overcome steeper grades.

1830 - 1840 Among other the rope pull was invented using hemp ropes and horses.

1834 Invention of the steel wire rope. This was another major step towards more sophisticated rope pulls.

2. What technology was applied for the first ”funiculars”?

1840 With the invention of the wire ropes the first steams engine propelled inclines were developed.
Quite a variety of such real funicular forerunners came and disappeared, e.g.
- A steam locomotive fitted with a steam winch was uncoupled from the train at the bottom of an incline, drove uphill alone, unspooling the winch rope, on top was clamped to the track, hauled up the train by rope and continued its course in normal adhesion operation.
- Rope haulage to assist steam locomotives on steeper gradients was further achieved by stationary steam engines alongside the track driving tail end or endless ropes to which the train was hooked.

Most wide spread was the application of successive sections with a looped haul rope counterweight tensioned, and top driven by a friction drive and propelled by a steam engine.

1842 Probably the first double reversible system was built in Ashley Pennsylvania for coal transport. A steam engine driven drum with winding one haul rope and unwinding the other rope was applied.
Its basic concept actually was reapplied just recently for the modernized Hong Kong Peak Tram.

1872 Another technology actually was also developed in the USA with the Cable Car in San Francisco at Clay Street, using continuous running haul ropes and detachable cars.
Actually from 1870 to 1890 such cable cars were constructed in 28 cities in the USA.
As you all know some systems are still in operation right here.
All the mentioned cable cars and inclines were designed for rather moderate grades of between 1 and 15 %.

It is interesting to know that all the systems have been equipped with some kind of a track brake, either gripping on the rails are some wedge system.

3. **Passenger funiculars single reversible or double reversible (2 track system) on steeper grades**

1860 The first passenger funicular 1622 ft long with a max. grade of 16 %, speed 400 fpm was built in Lyon France in 1860.

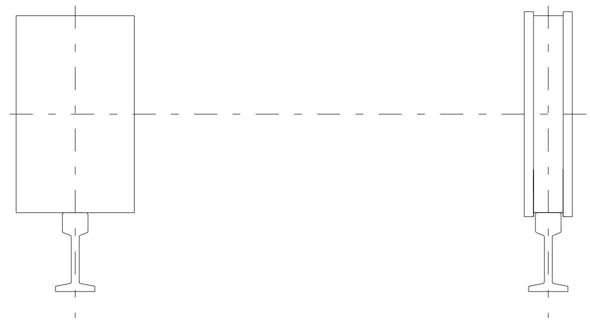
1870 The first steep funiculars were built in the USA, starting with Monongahela incline in Pittsburgh 1870, 640 ft long with an elevation difference of 375 ft (72 % grade).

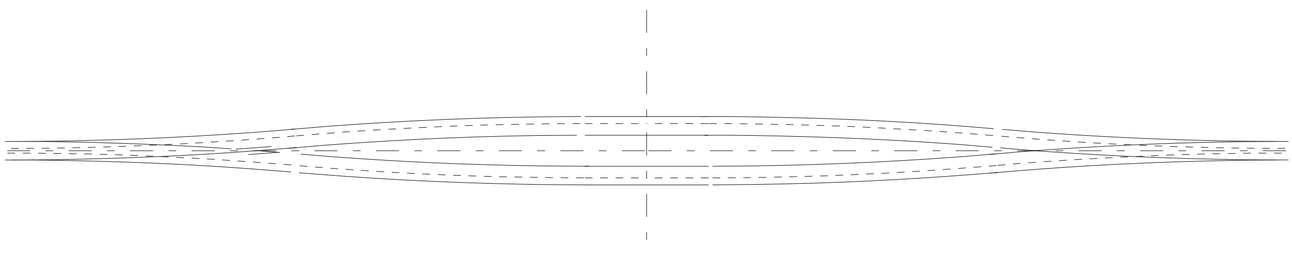
The real funicular boom started after the invention of the Abt passing loop.

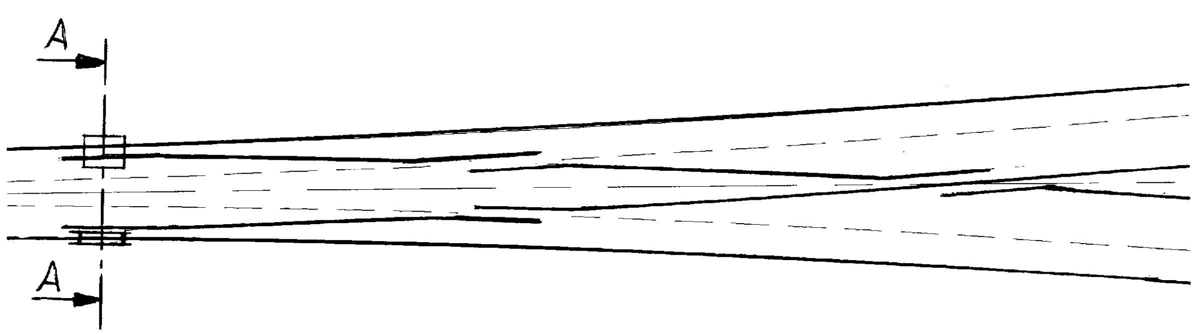
4. What is the Abt passing loop?

Its invention goes back to 1879 and its purpose was creating a single track system with a double track only at the car passing point.

Section A-A







The funicular design was adopted accordingly with the guide wheel and a flat wheel.

5. First funicular with Abt passing loop

1879 In Switzerland the first double reversible, single track funicular with Abt-passing loop was commissioned.

What was the technology applied?

Drive: The water-ballast system
At the time, in Europe water was available in abundance and consequently this system was most economical. In each car is a large water tank, which is filled when the vehicle is at the top station, the tank of the opposite car being emptied automatically and simultaneously while in the bottom station. An adequate storage basin or reservoir at the top is refilled automatically when the minimum allowable level is reached.

Water capacity was based on a loaded car at the lower terminal incl. friction. Hence brakes were required, since the driving force was always excessive. Due to low friction coefficient, brakes on the wheels would not work.

The problem was solved with a rack and pinion system. A rack centered to the rails driving a pinion with brake gear on the car. The car attendant controlled the car speed manually by his hand actuated brake.

The existing rack and pinion facilitated the track brake problem. Overspeed and rope failure both could mechanically actuate an independent brake at the pinion and subsequently achieve positive emergency braking.

Just a couple of years ago we had to upgrade the last waterdriven system in Switzerland and retain the old mechanics for nostalgic reasons. We have had to relearn again what the engineers did 100 years ago.

Even though all the drawing were available, we did not discover all the little engineering tricks applied and it took quite an effort to duplicate the system.

The technical data of the Fribourg funicular are the following:

Originally installed	1899	
System	double reversible	
Length	415	ft
Difference in elevation	185	ft
Grade constant	55	%
Rail gage	4	ft
Haul rope dia.	1	inch
Travel speed	240	fpm
Car capacity	20	persons
One way capacity	240	pph

6. Funicular, big time

Von Rolls first funicular in Berne Switzerland, built in 1885, started a funicular boom all over the world that lasted until World War I.

Funicular building was resumed again after the World War and continued to about 1938. World War II again caused an interruption

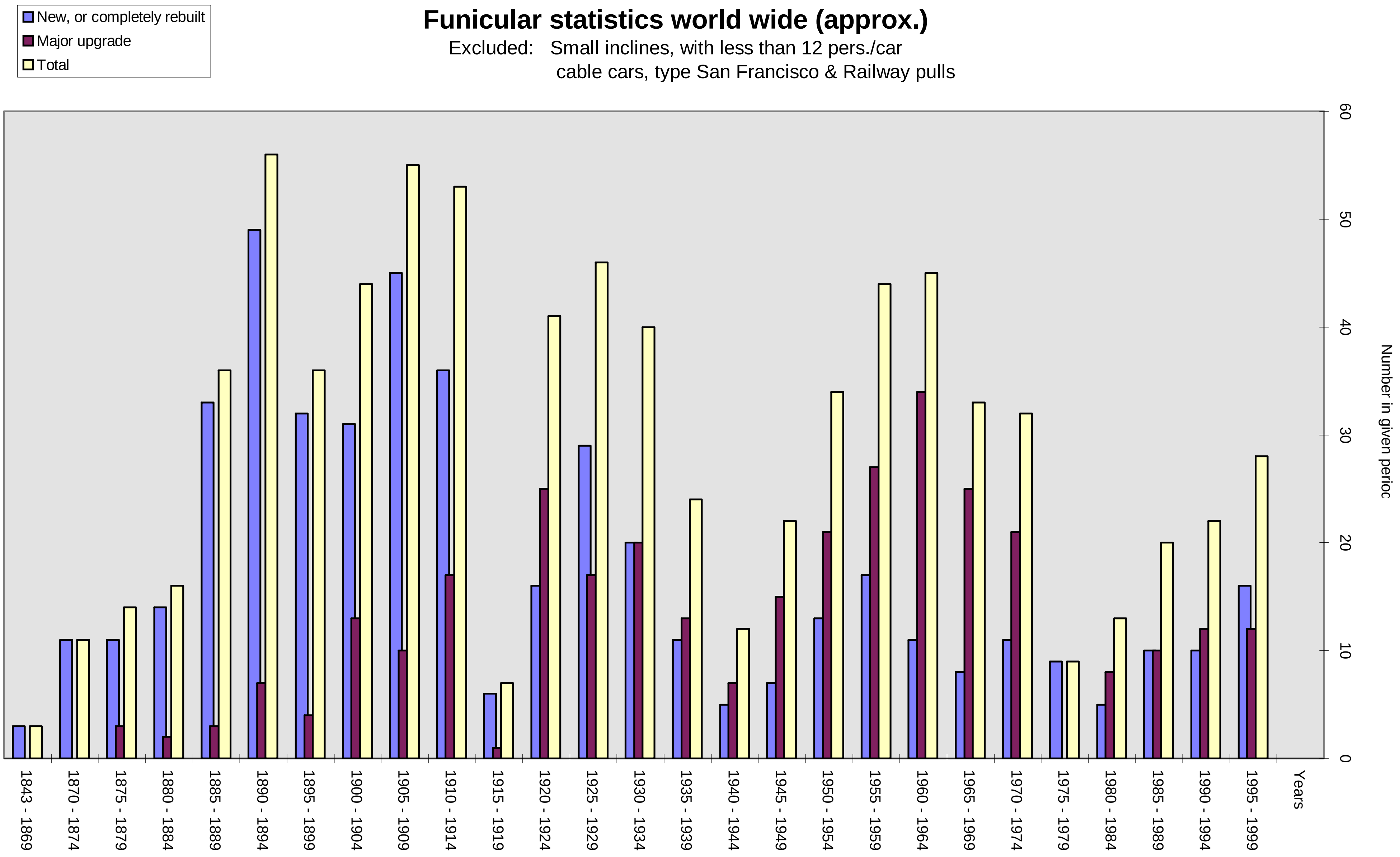
The business was resumed again in the fifties and lasted to somewhere in the seventies.

After a number of ”slow” years the demand for the systems picked up again. Within the last couple of years Von Roll alone was awarded 9 funiculars contracts.

The following statistics give some idea what has been built world wide excluding the cable trams and train haulage systems.

Funicular statistics world wide (approx.)

Excluded: Small inclines, with less than 12 pers./car
cable cars, type San Francisco & Railway pulls



6. **Evolution of funicular technology up to the present standard** (rough outline)

- Drives

  - As the funiculars built in the late 1880this were predominantly water ballast driven in Europe and steam engine driven in North America, electrification of new and existing installations started in the early years of the 20th century. The friction drive was applied at the beginning of funiculars, but was improved over the years by developing various high friction bull wheel liners.

  - Mechanical drive: small gear boxes with open pinion gear drives to the bull wheel were applied until about 1960. Only since than the fully enclosed drives (motor, gear box bull wheel) have been standard.

- Electrical Equipment

  In the early days of aerial tramways electrical controls were limited to the main drive motor in slip-ring technology and several hand-wheel operated switches controlling the resistors. Control and supervision was strictly in the hands of the operator.
  Malfunctions in the electrical system were immediately indicated by a bang or smoke marking the faulty part.
  Increased speed and capacity asked for more subtile controls and better supervisions. DC motors in Ward-Leonard systems have been introduced. Magnetic amplifiers together with simple semiconductors (Selenium!) allowed regulated speed controls and jerk-free acceleration and deceleration. With the industrial use of transistors the world of electronics started in the late 1960s. It became possible to design voltage or current sensors, which replaced slowly the magnetically balanced relays. Supervision systems to detect grounded ropes and soon remote control was possible.
  Due to the fact that remote control and higher speeds have been demanded more and more functions had to be introduced in the tramway controls.
  Fortunately the semiconductor industry produced better devices, diodes and thyristors for 100 amps and integrated circuits containing up tp 50 transistors!
  Wow, what features became now possible! Automatic speed control with smooth acceleration and deceleration and very effective supervision functions replaced the man at the control desk. One next big step in the electrical controls was the introduction of the static converter drive (or SCR). Steady improvement of the electronics with integrated circuits and operational amplifiers mounted on printed circuits allowed very complex functions. With the birth of the microprocessor the electronic world again received a big push, now the chip could perform certain functions or calculations and the sequence could be stored in a memory. As now the same device could perform hundreds of different tasks the PLC (programmable logic controller) was only a natural continuation of the electronic controls. The same hardware can be adapted to perform almost any function.
  In the world of power electronic faster and bigger devices are leading to variable speed drives using the sturdy ac motor: variable frequency drives.
  The use of personal computers and LCD screens are now a must for a modern tramway control giving the operator all the information to run and trouble shoot his equipment effectively.

One thing must be said though: a 1980 funicular will definitely run on the first of January 2000 whereas a 1998 funicular with all the latest gadgets may not...!

- Track brakes changed from rack and pinion brakes to the present hydraulically opened and spring applied rail brakes.

- Drive brakes

  A similar development occurred on the drive brakes, going from weight actuation and electro hydraulic thrusters to the present spring applied hydraulically open systems.

  Whereas on many early funiculars the emergency- as well as the service brake were drum brakes mounted on the high speed motor/gear shaft, now the emergency brake directly grips the drive bullwheel (bullwheel brake) and the service or hold brake is a disc brake mounted on the h.s. gear shaft.

- Cars

  The cars which in a way are the calling card or the figurehead of a funicular underwent a tremendous evolution from the light wooden car body sitting on a heavy unsprung underframe with two rigid axles to a modern self-supporting monocoque vehicle fitted with spring cushioned bogies. These chassisless cars were first introduced by Von Roll already back in 1960, but continuously developed further.

  Car design and styling may best be visualized by the following pictures.

(Showing pictures)

- <u>Track</u>

  The track of funiculars generally is formed by standard railroad TEE rails supported at or near ground level by substructures which may be ballast beds, concrete slabs or beams, bridgelike structures in steel or concrete etc.

  Whenever technically feasible, rail joints are welded. Wooden-, steel- or concrete ties may be used whatever suits best the local conditions.

  Between rail fixation base plates and support vibration damping pads are inserted.

  Actually funicular track evolution closely followed that of modern railroads but always took into account the special requirements of funicular engineering such as steep gradient, rail braking, rail/wheel combination (flat and double flange wheels), travel speed etc.

  In terrain of heavy snowfall elevated tracks are preferred to avoid snow accumulation and to facilitate snow removal, which generally is done by snowplow and/or blower.

  Track sheaves – haul rope supporting means:

  Up-to-date sheaves, with antifriction bearings, boltless light alloy flanges, rubber liners for the straight ones and special liners for the inclined ones (curves) superseded the old cast iron pulleys with plain bearings.

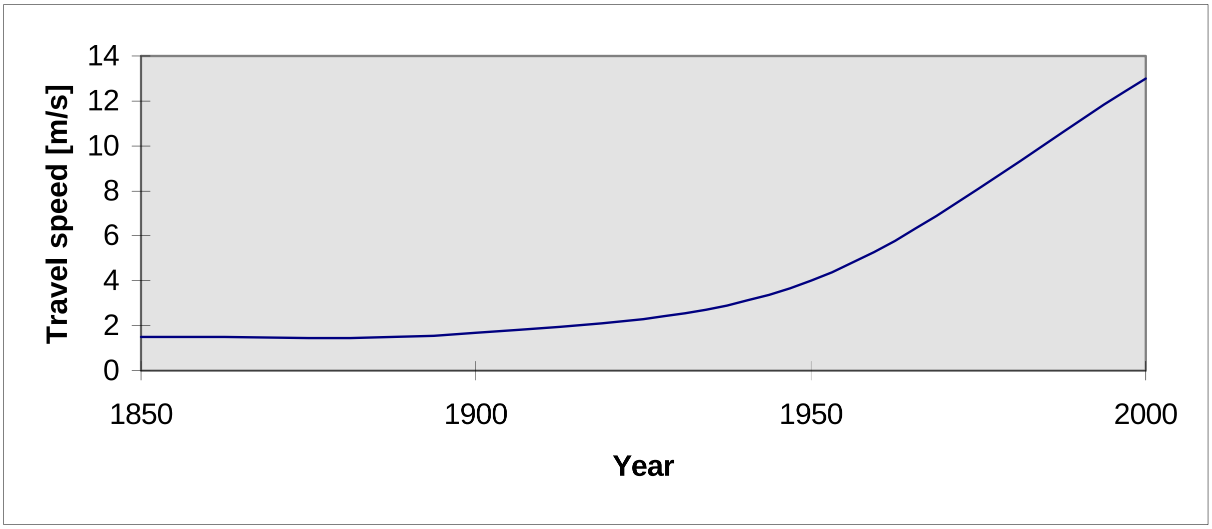
  Hold down sheaves for difficult concave track sections were also developed.

  Haul ropes:

  Rope evolution kept up with the progress in funicular engineering. Many construction types are used, depending on size, environmental conditions, winch or friction drive and other exigencies. In recent years compacted and deform ropes were adopted and performed quite satisfactory. Locked coil haul ropes are the exception.

- <u>Speed</u>

  Looking at travel speeds of funiculars and checking the statistics we find the following:



7. State of the art

Funicular railway engineering is in the favorable position that it can profit by and base on the highly advanced state of the art both of aerial tram drives and controls and of railroad track- and car design. Nonetheless quite a number of specific funicular items and problems require continuing attention and development.

Rather than to go to much into design details I would like to discuss following aspects:

Main criteria:
. Safety
. Automation
. Travel comfort
. Acoustics
. Capacity
. Costs

Safety:	Funiculars statically have been and are the safest ropeway system. With respect to safety the effort was confined to further reduce the possibility of derailment (in view of higher speed) and also various other safety precautions have been developed parallel to the automation. For the case of failure within power supply or main drive equipment an auxiliary drive can be provided if deemed necessary, depending on line characteristics. Rescue procedures from stranded trains are also line related but generally easy and fast.
Automation:	Funiculars now a days can be designed as the most automated system of any ropeway. Many funiculars operate without any personnel in analogy to an elevator. Remotely located monitoring stations are now a days standard.
Electrical:	A state of the art modern tramway is driven by a variable frequency converter, has a PLC control system, a microprocessor based remote control system and is monitored through a network with access from any point. It’s top station camera with weather instrumentation can be accessed on the Internet! Touch screens serve as a very effective man machine interface. On site information for trouble shooting (if there is any!) will help to get the tramway back into operation in no time. Remote trouble shooting from the manufacturers office will lead to minimum downtime!

Of course even with the all perfect PLC's and PC's the electricians will have to fight with the ghost's of the electronic world: operating system bugs, software hick-ups and with the mechanical and physical world which does not always follow the parameters on paper.

Travel comfort: Improvement of rail alignments and bogie design on the cars resulted is a high travel comfort.
Boarding: cars at standstill, car floor level closely matches platform level for boarding and alighting. Moving of handicapped people with wheel chairs is practical.
Depending on profiles adjustable automatic level controls are more and more incorporated to improve travel comfort and to comply to ADA requirements.

Acoustics: Improvement also as a result of better rail alignment rail attachment, substructure and improved car and bogie designs. Further reduction of the travel noise level inside the cars and outside along the funicular line in some places may be desirable. There is still potential for improvement and substantial development and research is continuing.

Capacity: For long funiculars, there is an effort to increase speed, hence capacity can be maintained with smaller trains.
The purpose of speed increase is more a matter of cost savings, than capacity increase.
Rope sizes in comparison to reversible trams of the same capacity are usually small. Using let's say a 70 to 75 mm dia. haul rope very large trains can be moved, and satisfying the demand in capacity is rarely a problem.
We know just of one example where we had to design towards equipment limits. That was Bourg-St-Maurice in France using a 70 mm haul rope. However this was an installation also requiring a tail rope.

Costs: Due to the track, especially the substructure, funiculars require the largest investment to build. However considering operation and maintenance cost the system is very competitive, if the profile is suitable. Additionally with the revival of funiculars it was possible to cut investment costs substantially. A number of elements could be standardized such us bogies, drives etc.

In the following we like to show you some pictures and characteristics of a couple of our new systems.

(showing pictures)

Moléson Funicular

Put in operation	1998	
System	double reversible	
Length	4500	ft
Difference in elevation	1500	ft
Max. gradient	51,8	%
Rail gage	4	ft
Haul rope dia.	1 ½	inch
Tail rope dia.	¾	inch
Travel speed	2000	fpm
Car capacity	90	passengers
Drive power	600/1235	kW
Tensioning tail rope	hydraulic	
Degree of automation	no car attendants,	
		one operator at lower or upper terminal
		video supervision of terminals
One way capacity	1200	pers/h

What are the features of the Moléson funicular?

Safety:
. Insulated haul rope
. Track gage according to max. wind exposure
. Bogies guaranteeing equal distribution of wheel loads
. Electric dual approach system fail safe circuits
. Automatic rail brakes
. Emergency brake on drive bull wheel
. Deceleration controlled service brake
. Entire line is supervised against falling trees
. Easy rescue compared to other ropeway systems

Comfort:
. Well aligned rails
. Clothoidal transmission of straight rails to curves
. Vibration absorbing rail attachments
. Spring suspended bogies
. Noise absorbing design of car body wheel interface
. Exact stopping positions at upper and lower terminal

Bad Herrenalp funicular

Put in operation	1998	
System	single reversible winch driven	
Length	385	ft
Difference in elevation	150	ft
Max. gradient	64	%
Min. gradient	27	%
Rail gage	3,3	ft
Haul rope dia.	¾	inch
Travel speed	315	fpm
Car capacity	22	persons
Drive power rated	56	kW
One way capacity	300	pph

As per picture this is a rather small funicular but it shows the automatic leveling system. Depending on funicular size there are various methods such as the leveling per picture, hydraulic or per screw jack, automatic adjustment of car floors in the car or automatic adjustment of car segments. This is becoming more and more important to comply to the present ADA requirements.

(showing pictures)

(showing video approx. 10 min.)

9. **Why are funicular selected more and more for public transportation in competition with other ropeway system?**

The funicular railway is a well proven, reliable and safe form of transport especially for any point to point connection even on steep gradients. The potential range of application is substantial: access to mountain resorts and ski areas, urban transportation tasks such as traffic jam-free links between high activity points, e.g. parking lots and Downtown areas and many many more.

Funicular features are quite impressive:

- Operation on steep inclines at high traveling speed
- Substantial one way transportation capacity of goods and passengers depending on length and steepness of line
- Double reversible shuttle operation on single track with fail safe crossing loop – track: straight, in curves, on ground level, elevated and/or underground (tunnel)
- Programmed trips even with intermediate stations
- Fully automatic unattended operation for smaller installations
- High safety standard thanks to many redundant electronic monitoring systems and three independent brake system including the automatically released rail brake
- Easiest evacuation
- Statistically safest ropeway system
- Comfort such as easy loading and unloading (car not moving)
- Freight transportation either in separate compartments or trailer car
- Complies to ADA requirements
- Short travel time (high speed)
- Excellent travel comfort
- Possible heating, air-conditioning, lighting
- Alignment with curves

- Availability, reliability:
  Least sensitivity to wind. Can be operated at higher wind speeds than any other system. High technical availability due to advanced design and simplicity

- Maintenance and operating costs
  - By far the most automated ropeway system
  - Low energy consumption
  - Low mechanical and electrical maintenance

- Esthetic fits in the environment as well as any system. No high towers and ropes in the air

- Lowest long time costs of any system if the profile is reasonably suitable

- Acceptability of passengers.
  Best acceptable system, since similar to railways. Many people are afraid to travel on rope suspended systems.

Same top scenic places for tourist, skiing and mountaineering activities would never have been developed without access by underground funicular, as any form of ropeway above ground was rejected for reasons of environment protection and preservation of natural beauty.