CABLEWAYS FOR URBAN TRANSPORTATION: HISTORY, STATE OF THE ART AND FUTURE DEVELOPMENTS

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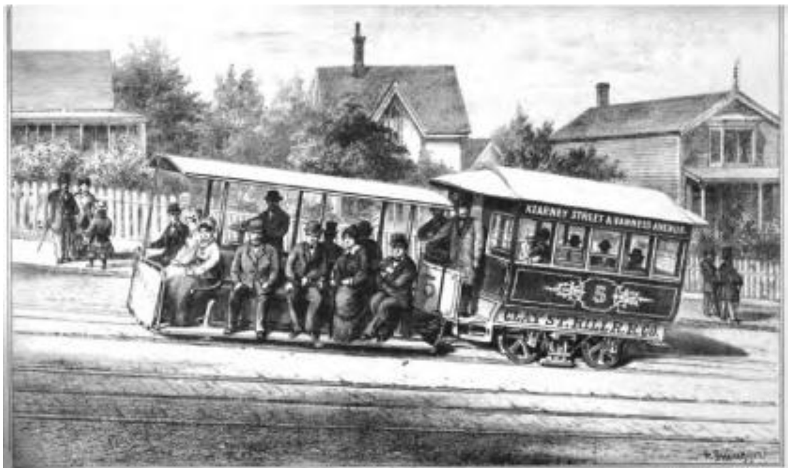
The use of haul ropes in the urban transportation technology started in the IXX Century, but this option was quite put in oblivion by the private car and oil civilization.
The big cities, with their heavy traffic, focused the specialists' attention on tramways and classic underground and light railways systems; where the vertical drop was large and in the marginal areas the connections were often left to buses and private cars.
Even for wider areas, the intermodal transportation concept based on public transportation never found the followers it deserved, since there was poor sensitivity to energy saving, to global warming and air pollution; furthermore, the oil price was low.
In Italy, for instance, the orography and the urbanistic situation is really fit to the use of the rope technology as an alternate means of transportation to roads, to connect the city center to the surrounding villages, but, even though many transportation scholars proposed that way on the theory point of view, there were not so many practical examples.

I remember that in 1976 I proposed, during the *"Mountain problems Convention"* in Turin, to use the rope system as part of an intermodal public transportation system; those were the years when you could see that Italy has widespread mountain areas and the distance between the seacoast and the mountains over 1000 m high is often only few kilometers and that a large part of the inhabitants has to surmount large vertical drops every day.
Mountain and vertical drop do not mean just skiing, ski areas and snow, it is the everyday life of people who live far away from the Alps too.

2. THE RISE AND FALL OF THE URBAN TRANSPORTATION BY CABLE

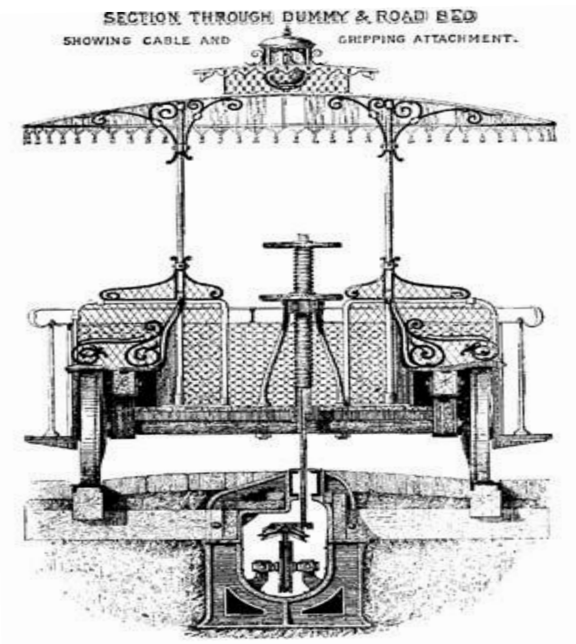
Recently there has been a *renaissance* of the urban cableway based technology and we can find many typical ski areas cableways used as APM and new kind of cableways, using the funicular or gondolalift basic concepts.
In any case, towns with up and downhill are not just an Italian peculiarity, but it is necessary to cross the Ocean and the USA to find a really ingenuous urban cableway: the San Francisco cable car.



CLAY STREET HILL WIRE ROPE RAIL ROAD.
ASCENDING AN INCLINE OF ONE FOOT IN SIX. — THE FIRST CABLE ROAD CONSTRUCTED.

Andrew Smith Hallidie, a Scot born, took the cable car idea by Benjamin H. Brooks, who could not accomplish it because of lack of capitals; on the contrary Hallidie, the first steel cable manufacturer in the USA and supplier of many enterprises, mine and forestry for instance, which used his patented steel ropes, was able to propose the Municipality his system, based on a former patent of his and on his experience in closed loop ropes.

William E. Eppelsheimer, a graduated engineer from Germany, was put in charge of the system line and grips.
On the 1st of September 1873 the first leg started its operation on a part of Clay Street making real Hallidie's idea to solve by means of a rope the inclination problem, that caused so many accidents to the horse-cars.
All the carriers had a man operated grip, that was closed on the haul rope, always running, to start the carrier and was opened to allow the stop of the carrier.
The rope loop was able to haul many carriers, that run independently; soon the system was extended to the whole city and it is still in operation.
The Hallidie's system has a central drive station and all of the haul rope loops are driven from there; the original system had steam motors and the drive sheave has about 2.4 m diameter.
The haul rope runs inside a trench, to avoid any interference with the other vehicles, on 279 mm rollers mounted at a 12 m. pitch; the carrier and a track brake, the carrier brakes and an anti-rollback device.



THE CABLE STREET RAILWAYS OF SAN FRANCISCO.

The first carriers was designed for 16 passengers on the grip carrier and 14 on its trailer, but, during the rush hours, they could carry respectively 26 and 24 passengers with no problem; the daily operation lasted 17.5 hr at 2.6 m/s, about 10 km/h, and the ticket cost the not small amount of 5 cents; now it costs about 5 dollars! The operator controlled grip allows even now to stop the car at the lights and to run in abide of the traffic requirements. The fact that the rope runs in a trench and the acceleration by friction between the rope and the grip causes wear and frequent rope replacement, but that was not a problem, at least for Mr. Hallidie, since he was the first American rope manufacturer.
Nowadays, an updated acceleration system and a rope running higher than the cable and not in the wet environment of the trench or between the rails, could properly solve that too.
From the historical point of view, the San Francisco Cable Car was second to the London and Blackwall Railway, 3 and a half miles long (about 5 km and 600 m) , built in 1840, but it had fiber and not steel ropes and collars to connect the grip to the rope; because of ropes wear and other technical problems, the line was transformed by means of steam vehicles in 1848.
This British system had two drive stations and the cable was winded on a drum and released by the drum of the opposite station and vice-versa running in the other direction; each station had 8 steamship motors, four in use and four in stand-by, with 75 HP in Blackwell and 110 in Minories, because of the line inclination.
The carriers left the station as a single train, but the last one was stopped at its destination station along the line, opening the grip; returning back, the carriers started at the same time and rejoined at the last station.
This is the same philosophy of the new Chinese train, seen as a new ingenuous concept, because crossing the stations, it leaves there one of its carriers and goes on, with no stop, until it arrives at the terminal station.
In 1868 the West Side and Yonkers Patent Railway was open to operation, but it was transformed in a classic steam railway within two years; that system had two steel rope loops, 1.6 miles (2.56 km) each, driven by steam motors, and the carriers were transferred by the former to the latter loop with a

complicated lifting system; in this case too the grip problems caused the dismiss of the cable as haul system.
The multiple rope loops concept has been resumed by the Poma 2000 and by the Doppelmayr Oakland APM.
At the end, I think it is fair to consider the San Francisco cable car, still working, as the first effective cable urban transportation technology.
In the following years many further systems entered in operation: in New Zeeland in 1881, in Chicago in 1882, where the grip equipped car had three towed passenger cars, to increase the capacity; in 1883 they opened the really interesting New York Brooklyn Bridge Railway, hauled by a rope along the line, but fitted with a small on board motor for the short station displacements (today we could resume this concept to cut out the acceleration-deceleration beams and the always complicated links between different rope loops), and in 1884 the Archway-Highgate, a North London suburb, with 9% max. inclination, at the time not viable with natural adherence railcars, that is to say with standard trams (now in Switzerland a tram line can reach 11% inclination).
In the following years almost 55 urban transportation cableways were built.
The rope based systems had the advantage to confine the heavy motor of the time in a drive station and to get light carriers along the line; there was an energy saving feature not only because of a rational power house, but often because of the "counterweight effect", if some carriers were on the uphill and others on the downhill section of the line.
Later, because of the technological evolution, the electric and diesel motors became able to give high power with little weigh and over all dimensions and to need small volumes for the energy reservoir, oil in place of coal; furthermore the oil is brought to the motor by an automatic system and not by a fireman's shovel.
The second problem was the speed: the San Francisco technology cable cars run slightly slower than 10 km/h and, since they were bound to the street traffic, their overall speed resulted quite slow; furthermore they were by far less agile than a bus. The cable system infrastructure is expensive, the bus is flexible and uses the existing roads: there were many good reasons to dismiss the cable and switch to the buses and cars.

3. THE CABLE STRIKES BACK

But everything changes and that too changed: an oil barrel is sold for few dollars no more and the air pollution is an economic development symbol no more, but of lack of environmental awareness.
In the meantime, funiculars became able to run at 40 km/h and more, a standard gondola lift runs faster than 20 km/h, more than twice the Hallidie system speed: the cableway is topical again!
The advantages are the same as always:

- *Electric drive in a main drive station*
- *Lightweight carriers*
- *High safety*
- *Reduced operator number*
- *No influence of the carrier – runway friction coefficient*
- *Intrinsic safety against carrier collision along the line.*

The drawbacks are now really few, because in any case a dedicated runway, independent by the urban traffic, is necessary to grant acceptable ride time and capacity; the overall speed is faster than the bus one, even if the bus has a dedicated lane.
In urban transportation the rope is back! Since there are many systems in use, it is possible to find which one fits the local requirements better; to be clear, let's look at some examples.

4. FUNICULARS AND INCLINED LIFTS

Since it is not possible to run a steep line because of the wheel-rail friction coefficient, often spiral sections are used, for instance in the St. Gotthard line, that makes the line longer and normally needs expensive civil works, like tunnels and bridges.
The widely accepted inclination limit is 3.5%, even if in many cases that is not much, if we speak of a hill: for instance the *Ferrovia Retica del Bernina* runs on a line where the inclination is twice and a Geneva tram runs on the amazing 11% gradient. Today a funicular railway can overcome a 100% gradient slope and have multiple carriers, up to 300 passengers per train or more and run over 40 km/h.
Basically a funicular railway has two carriers, connected to the opposite sides of a steel haul rope loop, so that, as soon as a carrier runs uphill, the other runs downhill; during the following ride, the rope loop rotation sense reverses; because of this alternate motion, this lift also is called "jig-back".
The system is not really rigid and there are funicular railways with a single carrier and the haul rope, not closed in a loop that winds on a drum; now automatic funiculars with a single operator are allowed in many countries.
The modern funiculars, for instance the new Innsbruck one, can run on concave and convex lines as well and they can run left and right corners; the car can be suspended or controlled by devices that keep the car floor horizontal, even if there are wide changes in the line inclination.
The system limit is the line length, because the jig-back system capacity decreases when the line gets longer: it is critical a line longer than 2 or 3 km.
The necessary energy is variable along the line, but, in any case, the efficiency is better than a bus system one, connecting the same points with the same capacity, even if the traffic conditions are not severe.
The **inclined lift** is actually a light funicular manufactured using lift components, request by button included, like a usual elevator.
The Flaine, France, and the Sansicario, Italy, inclined lifts were among the first systems using that technology to be designed with a large car.
The inclined lift features are limited by the European Community Standard, now in progress, since it relates the lift speed and the carrier capacity; for instance a 100 passengers carrier is allowed to run at 3.6 km/h, a 75 passengers one at 9 km/h and a 40 passengers one at 14.4 km/h; these are not overall speed, but just the maximum allowed speed: taking into account the acceleration and deceleration phases at each station, the average speed is by far slower, especially if the lift is short and has many stops.
This proposed European Standard (prEU81-22), setting a speed limit, as a result limits the lift capacity and the line length that fits the inclined lift technology; furthermore, a discussion is open about the possibility to use Lift certified safety components when the lift does not serve different building levels, since this is in the Directive 95/167EC scope.
Another limit is that, because of the standard above, the line cannot have corners and it is difficult to manage large line inclination changes.
From the point of view of transportation engineering and political decision, there is no difference between a funicular and an inclined lift, but, if the line is short and the requested capacity low, the inclined lift initial and operating costs are by far lower.
Lifts are produced everywhere in the world in millions of units and there are dozens of components manufacturers: that means low cost and high reliability, granted by such a widespread technology.
The lift spare parts are more cost effective and easy to find on the market; on the opposite the funicular ones are often built on demand.
Since there are many specialized lift maintenance companies everywhere, the inclined lifts do not need the intervention of customer service centers, often very far away, since there are only two or three funicular manufacturers in the world.

Since these two systems are often interchangeable, I put together some examples of lifts and funiculars not used by skiers only.
I will first mention the well known funiculars in Naples, Italy, and the one in Lugano, Switzerland, used to connect the railway station to the city center, which is a noteworthy intermodal transportation example.
Another quite striking example is the renewed **Mondovì (Piedmont, Northern Italy), funicular** that sports 80 passengers carriers, designed by Giorgietto Giugiaro Italdesign: the new line is about 540 m long with 137 m vertical drop; the machinery is installed inside the cellars of a historic palace, built in the XVII century, after an accurate study to limit noise and the vibrations that could damage the old structures.
The funicular first version, water driven, entered in operation on the 12th of October 1886 and was modified switching to an electric drive; the funicular was in operation until the 24th of December 1975 and remained out of operation until the building of the new, updated funicular, that started its operation on the 16th of December 2006.

The cableway connection between the Breo district to the old Mondovì Place is used by thousands of passengers with a shorter than 2.5 minutes ride, about one quart of the same run by bus, with no pollution and traffic problems.
A classic urban example is also the **Osimo inclined lift**, built in a historic environment, with III century Roman walls and surrounded by Medieval and Renaissance buildings; the line crosses an old landfill site, where the materials resulting from the demolition of older buildings were dumped throughout the history of Osimo ; that is the reason why the line is founded on long end bearing piles.
The Osimo inclined lift has two 40 passengers carriers, moved by two independent drives, to grant the operation in case of failures or maintenance of one line.
At the valley station there is an intermodal traffic knot with urban and intercity bus station and a multi-store parking, connected to the lifts platform by means of a tunnel crossing the road.

The ride up ends at a small place, connected to the historic city center by means of an escalator; this solution makes the station structure not visible and leaves the ski line uncorrupted.
The line is 100 m long, has 45 m vertical drop, runs at 2.5 m/s and the total capacity is 1600 p/h; the lift operates in full automation, under remote security control located in the multi-store parking ; in case of power failure an automatic diesel generator allows the operation.
The Osimo inclined lift has transported million of passengers with no problem or accident and helped to lighten the private car pressure on the narrow medieval streets of the historic center of Osimo.

Giorgetto Giugiaro designed the Mondovì carrier, but some lift cars were designed by well known designers and architects: sir Norman Foster, Renzo Piano e Pininfarina, who designed the San Sicario 20 passengers carrier, driven by standard lift machinery; that inclined lift connects the village three levels running on a steel girders line, supported by concrete towers.
It is interesting to know that the San Sicario village is connected to Cesana, the main village, by means of an 8 passengers gondola lift, designed with urban transportation features, disabled person facilities included; alas, the two transportation systems are poorly integrated.

5. GONDOLA LIFTS

The gondola lift is a transport originally born to be used in ski-areas, but it can fit the urban transportation requests properly; the simplest system is the **pulsée** one, born in France, with groups of carriers attached to the same rope; the carrier group, when the carrier is full, accelerates up to max. speed and then slows down to enter the opposite station; if there are only two groups, the system works as a classic jig-back aerial tramway, with the only difference that the carriers run through the station, so that the haul rope loop has always the same sense of rotation.
If there are four carrier groups, as the first enters the mountain station, the second one is close to the middle of the line, the third enters the valley station and the fourth is close to the middle of the line, but on coming down rope; the second and the fourth carrier groups stand or run at a very low speed in the middle of the line while the first group stands or runs at a very low speed in the mountain station and the third in the valley one, to allow the passengers to get out and to get in the carriers.
If there is an intermediate station in the middle of the line, the passengers can use it and they are not aware that the carrier had stopped there even if there were no station; if there is no station, they can spend their waiting time looking at the landscape.
The more the carriers groups, the more the stops, but, if it is possible to have intermediate stations at a constant pitch, the system is a very effective urban transportation mean.
A well known pulsée gondola lift is in Grenoble, to connect the city to the Bastille; since it started to operate in 1934, it is one of the oldest urban transportation aerial cableways and it has transported more than 13 millions of passengers since; in 2009 alone, it transported 290.000 passengers.

The operations last about 4000 hours per year.
Now the carrier capacity is 6 passengers and each group has 5 carriers or 30 passengers per group; the line is 700 m long and it has 276 m vertical drop ; the max. rope speed is 6 m/s. about 22 km/h, but the average speed, this is inherent in pulsée technology, is by far slower.

The pulsée system is manufactured in two versions, the bicable, with a track and a haul rope, as in Grenoble, and the monocable one, as in Cogne, with three 12-passengers carriers.
What follows about the capacity and travel time is based on the gondola lift experience, but it can be used without changes to systems running on tracks (rails, steel profiles, concrete).
In any case, the pulsée system solves problems with reduced capacity on short lines and its energetic efficiency is lower than other cableways one, because of the continuous acc-deceleration cycles; for instance, a 1725 long system, with 6 groups made of 2 carriers with twelve passengers per carrier, reaches the non impressive capacity of 500 p/h running at a 5 m/s maximum speed, but a short system, for instance 600 m long, could carry 899 passengers per hour and its ride could last less than 5 minutes.
Increasing the cableways speed, on the 1725 m long line, up to 8 m/s, very close to the physical limit because of the distance between the stops, the capacity would be increased to only 578 p/h, a very small improvement.
A system 600 m long, with an intermediate station in its middle and with 4 groups of two carriers 12 passengers with 12 passengers per carrier, had a 758 p/h capacity and could ride the whole line in a little less than 4 minutes, a quite interesting time, if the station vertical drop is 100 m or more: these examples can well show the speed and capacity where this system gives its best.
In urban transportation the loading and unloading phases shall be with the carrier standing, at least if there are disabled passenger or on request, increasing the stop time and decreasing the system hourly capacity.
To better clarify the stop time influence, the same 600 m long system above, increasing the stop time to 40 s and decreasing the acceleration to 0.1 m/s2, gets its capacity reduced from 758 to 579 p/h; it is clear that a larger carrier running on a track could have a by far larger capacity.
The pulsée system actual capacity calculation is complicated, since it has many variables, but usually this

- *The line is short enough to get an acceptable ride last;*
- *The carriers have a large capacity, that means, in the order, rail , bicable and monocable systems;*
- *The stops have a constant distance and it is the same between two carriers groups.*

Trains with many passengers mean a jig-back system with multiple rope loops and to detach the grips at each station or to use modular vehicles small enough to make a U turn in the terminal stations.
If the stations distance is variable, the system can have only 2 carrier groups or design sequential rope loops, to open the grip at each stop like in a Poma 2000 system, and to run the loops at different speeds, calculated to keep the time between the station constant.
With some simulation, if the legs length is not too different, there is an acceptable capacity decrease between that and a constant distance system; for instance, a system with 200 passengers carriers in each leg and a 400 m leg lengths (or between 300 and 400 m for the variable station distance version), with a line 2462 m long, has 5520 p/h capacity and 13 min transfer time if the station distance is constant, and 5210 p/h and about 1 min more transfer time if the station distance is variable.
In theory, the constant distance system could have just one haul rope loop and save the change of haul rope loop in each station, but, if the cableway is long, it is in any case useful to divide it in many haul rope loops to contain the machinery and ropes sizes.

A **detachable gondola** lift instead, has capacity independent from the station number and the line length, it grants high overall speed along the line, since it is coincident with the maximum rope speed, and it can be designed without complications to embark the passengers with standing carriers and to be used by disabled persons, by means of a *"stop at the point"* feature, that makes a carrier to stop within few centimeters around the point where the disabled person is waiting for the carrier.
In this case too, the general concepts stands for aerial detachable and for system running on a track.
The Turin winter Olympic gondola lift Cesana-Ski Lodge, designed as urban transportation to connect Cesana to its Sansicario village, has the features above and it showed that it is not necessary to use the previous discriminating ways (different color of the carrier, bells and flashing lights) to transport disabled passengers; designing the stations, these aspects were token in account and, for instance , the lifts connecting the boarding level to the parking lot are designed to be used by anyone willing to avoid a flight of stairs and not reserved to the disabled passengers.
The monocable gondola lift ride at about 22 km/h and it can run even faster if it is a bicable one, with an haul rope and one or more track rope or rails.
The aerial gondola lift can overcome natural obstacles, rivers for instance, with no expensive civil works and it can run with no interference with the road traffic with no need of dedicated causeways; on the other side, the visual impact of a cableway is heavy, because the carriers have to run high over the ground, higher as the span between two towers get longer; taking in account of the necessary height over a road and 100 m span, the tower height at the roller assemblies is 15-16 m.
Another problem is that it is necessary to detach the carriers if the line is not straight; this means to have a station at each line corner.
The gondola lift has cost and operational advantages, if it has few stations and few corners.
Prof Pierre Jassaud of Grenoble has published an interesting study to compare the gondolalift and other transportation means cost; it is evident that the urban and suburban transportation by cableways is effective, when the systems can be used, from the energy and environmental point of view and from the costs and offer to the passengers one as well.
In another case the weak and strong points of the different transportation means are compared on the same inclined line, as results from the following table:

Transportation mean	Cost (M€)	+	-
car	14.4 (2 lanes road, veichles included)	comfort	Pollution, traffic jams, investment
bus	16.5 (Autobus and road lanes, 2 ways)	acessibility, flexibility	Slow overall speed, noise e investment
tram	22 (track and veichles)	noisless, clean, good frequence	high investment, limited gradient
funicular	10 (track and stations)	Fluid, noiseless and clean	Investment and waiting time between the rides
Gondola lift	3.5÷5	Fluid, noiseless and clean short waiting time	Visual impact

Further data can be found on the Jassaud urban transportation internet site, where there are the following table data:

Connection between two points 540 m vertical drop and 30% gradient	**Energy used (KJ/KWH)**	**Energy per passenger**
pedestrian	0.12 KWh	0.12 KWh renowable
8 passengers gondola	3.4 KWh	0.43 KWh

Tram (street car) 300 passengers	32KWH	1 KWH
Bus+driver+60 passengers – 35 l/100 km, 20 km ride	81.2 Kwh	1.35 KWh
Car + 4 passengers	17.3 KWh	4.7 KWh
Car + driver (Clio 7CV gasoline) 8.5l /100km	13.1 KWh	13.1 KWh

In a study he compares a gondola lift, bus and bridge for bikers and pedestrians between the Brignod (F) rail station and a mall, about 1 km long and crossing the river Isère, the railway and a highway; more can be found on the original text, but the interesting conclusions are in the following table, calculated on the base of 15 years amortization for bus and 20 for the bridge and the cableway.

Mode	investment	operation	total
8 pass.gondola lift	0,32M€	0,33M€	0,65M€
bridge	0,75M€	0,075M€	0,825M€
bus	0,06M€	1,2M€	1,26M€

	BUS	car	Street car (tram)	cableway
Mass ratio	50%	30%	21%	40%
Fiction factor	0.3 –0.6	0.3 –0.6	0.12-0.2	0.03
Energetic efficency	83-166	50-100	105-175	1333

Furthermore, the bus line generates 620 CO_2 tons per year; a further table compares the energetic efficiency of different transportation systems, that, in the French scientific literature is defined as the ratio between the passengers percentage of the total weight and the system friction factor.

In the international literature there are also very interesting data about the air pollution, the energetic cost and the waiting and ride times, always favorable to cableways.

The Climate Partner Austria, a consulting firm, studied, by appointment of Doppelmayr, the CO2 pollution of different transportation means; in conclusion, an 8 passengers gondola lift pollutes less than a train, a car and bus, provided that the fill-factor is almost 50%; the study proposes the following table:

Mode	Grams CO_2/pers.km
Gasoline car	248
Diesel bus	38,5
Electric train	30
8 passengers gondola	27

As written above, the gondola lift can use monocable or bicable technology; the monocable has a single loop closed cable, that supports and hauls the carriers, the bicable has one or two track ropes (2S or 3S), that are the trolley “rails “ and one or more haul ropes, that are used to haul the carriers on the track ropes; the bicable system is more expensive, but usually has lower friction and runs faster over longer spans.

6. MINIMETRO

The Minimetro is nothing more than a bicable gondola lift running on a track in place of cables; the tracks support the vehicle and the haul rope, that runs between the tracks, therefore under the vehicle; a noteworthy Minimetro is the one Leitner built in Perugia.

Like in a gondolalift, it is necessary to detach the carrier entering the stations, decelerate it and run at low speed inside the station or also to stop the carrier to allow the passengers to get in and out and, at the end, to accelerate it up to the rope speed and to connect the grip to the rope; this is made by means of belt moved tires rotating at increasing (or decreasing) speed, so that the carriers acceleration is quite constant.
The Perugia system has 25 carriers, it is about 5 meters long with 20 passengers capacity, that ride between the terminal stations with 5 intermediate stops; unlike from a classic gondola, where the carrier makes a U turn and is launched on the opposite side, the Perugia Leitner system has a railway like rotating table to invert the vehicles direction; then the carriers get out the terminal station on a track parallel to the entering one and run in the opposite sense until the other terminal station, where the run sense is inverted again.
The track is on a bridge and the carriers run on tires; the line speed is about 25 km/h, quite interesting, since the track has no interference with the road traffic.
The standard time between the carriers is about 2.5 minutes, but the Minimetro limit is about 60 s; this technology can fit its capacity to the traffic demand changing the number of carriers in line and decreasing the friction.

7. SHUTTLE

The shuttle is a small gradient funicular railway, like the Leitner serving the S. Raffaele Hospital in Milan or the Doppelmayr-Garaventa, installed in Venice.
The Venice system is about 800 m long and operates as a jig-back, with 200 passengers trains running a little slower than 30 km/h on a causeway with two bridges, one of them 180 m long, the first crosses the Canale del Tronchetto and the second the Canale di Santa Chiara, two Venice canals; since the line is short enough the capacity is high as 3000 p/h.

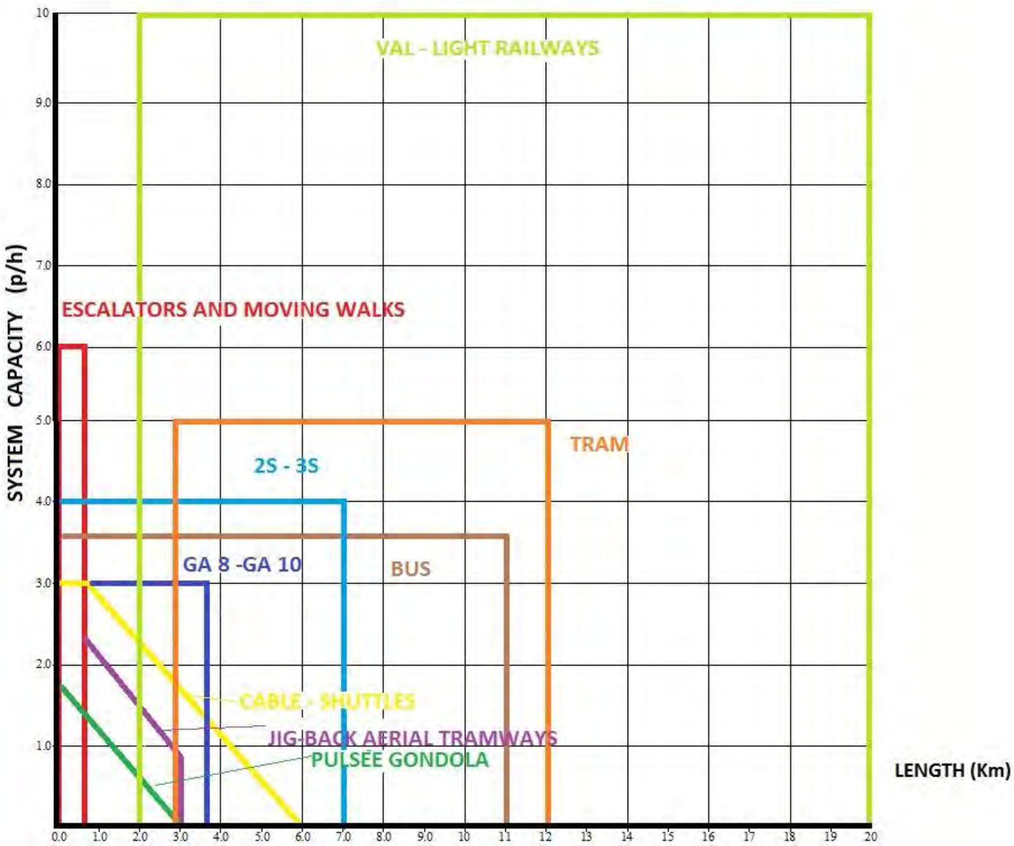
The line has an intermediate station, obviously in the middle of the ride, and a very little max gradient, the 6.2% on the Tronchetto Bridge, and 0.58 m vertical drop between the stations.
In the image you can see the train coming out the Tronchetto Station.
If the line were longer, it should be divided in two legs and the train should be transferred from the first to the second haul rope loop at the intermediate station; this way the system had 4 trains, like in Oakland, in place of 2; it is to remember that the coupling of the

grips to the rope happens when the haul rope is standing; unlike other hectometric systems, the haul rope has an alternate motion and not an acceleration deceleration cycle with constant rotation sense.
As written above, the multiple haul rope loop based systems, even if the loop is changed when the rope is standing, anyway need a carrier translation systems at each intermediate station, even if it is by far simpler than an acceleration-deceleration beam; these systems make their best if the distance between the stations is constant; if not, it is possible to design a system where each leg has a different speed so that any leg ride time is the same and the vehicles displacement is congruent; it is clear that a really short leg causes an overall speed decrease and there are the limits that the presence of only one carrier per leg involves.
In any case the constant rotation sense version allows just one carrier per leg to avoid a deceleration –stop-acceleration cycle during the ride.
Coming back to the shuttles, this transportation system, like the mini-metro, needs a dedicated track and this increases the costs; the Venice system cost 22.7 millions Euros, also because of the foundation and underground utilities, whereas the initial evaluation was 16.3 millions, and a large part of the difference is because of civil works.
The bridge has a noteworthy weight, specially where it crosses the Canale del Tronchetto, 180 m divided in three spans, how is shown by the following image.

The ride lasts about 3 minutes, in place of the 20 minutes it takes walking; usually a train leaves the station every 7 minutes.

8. TRANSPORTATION SYSTEM SELECTION

Since the choice among the transportation systems depends on many local factors and on the technological evolution, it is not possible to give a rule that always works and that can be used in any situation.
The choice will come from a transportation demand serious study, from the local situation and from each solution costs-benefits analysis.



As rule of thumb, the following figure gives a first suggestion about the possible choices, taking into account non cableways solution too, for instance escalators and moving walkways for short distances and VAL and light railways if the distance and requested capacity are larger.
Under the name CABLE SHUTTLES are the fixed grip shuttles, the shuttles that change haul rope loop when the rope is standing with trains up to 200 passengers and the pulsée systems running on a track.
The jig-back aerial tramways features are calculated with carriers up to 120 passengers.
The inclined lifts are in the fixed grip cableways running on a track; actually, there is no difference between those lifts and the funiculars, but that they are manufactured using some lift components and that, in Europe, they have some speed and carriers capacity limits.

9. THE FUTURE

How is the cable-APM future? Certainly promising, because it is necessary to decrease air pollution and transportation costs, but it is necessary to consider the different cable-APM features, because, as mentioned above, they fit different needs and can solve different transportation requirements.
The following is a cable system possible classification:

a) *Ski area cableways, with some stations, carriers and control system modifications.*
b) *Shuttles running on a dedicated track with fixed grips or with haul rope loop switching at the stations, with standing or very slowly running cable and with no acceleration deceleration device.*
c) *Systems running on a dedicated track with detachable carriers and acceleration-deceleration devices in each station.*

The **ski area cableways technology** is used when the vertical drop is large and the systems have to run along the max inclination line, or there are obstacles, lakes or rivers for instance, to cross; the limit is that it

is difficult to have lines with many corners and stations, and the visual pollution of the towers, specially inside an urban tissue.
The **shuttle systems** involve a heavy bridge, particularly if the span between the towers is wide; long lines and many intermediate stops mean a severe capacity decrease or compel to very large carriers.
The **mini-metro** has a lighter track, because the carriers are smaller and can run corners, but there is a limit of line gradient; many changes in the line inclination ask for complicated systems to keep the floor horizontal, but the real problem is the stations number, because, using the existing technology, there is a high number of tires to accelerate and decelerate the carriers and belts or gears to drive them.
Some deflated tires or loosen belts can stop the system until the maintenance crew arrives.
The acc-dec beams is the detachable systems big problem, because those beams have a large number of components and control systems: this reduces the transportation system reliability, because, as everybody knows, stands the formula:

$$R = R_1 * R_2 ... * R_i ... * R_n$$

Where R_i is the component "***i*** " reliability: it is clear that, when the components number in series layout rises, the reliability decreases, even if each component reliability is very close to 1.
In Hiroshima, Japan, the Mitsubishi Electric used a linear motor for the acc-dec beams, to decrease the number of the mechanical components that have to work properly at the same time to grant the system operation, a very interesting cableway with rail and rope over the carriers.
The track over the carriers has some advantages on the rope under the carrier layout, because it has no interference with the road traffic and the towers supporting the bridge can be placed in the traffic islands between the lanes; furthermore the ropes run in open air and not in a trench, where humidity and dirt usually reduce the rope life.
A 4 km long detachable line with a stop every 400 m would have 11 stations, terminal ones included, with two acceleration and two deceleration beams for station and therefore 44 beam sections, each of them with tires, belts, anti-collision devices, grip coupling test devices and anything needed to grant safe operations.
A description and interesting data about urban transportation by cable can be found in Anton Seeber's book "*The Renaissance of the Cableways*", and in the cableways manufacturers informative material.

10. THE COMPETITORS

The most redoubtable competitor is an electric driven vehicles system, under an informatics system control, based on the Heathrow airport, England, **pod-car** concept; at the moment the system is expensive, but the technological evolution forecasts an amazing cost reduction in the future.
The Heathrow system entered in operation in April 2011 and fully operates, 22 hours per day, since the 7th of May, with very good customer satisfaction, as

proved by an independent poll; the previous shuttle bus was discontinued and now all the passengers of that leg use the Pod.
The cars are driven by a battery powered electric motor, they run at 40 km/h, each carrying 6 passengers and their luggage; the system capacity is 656 passengers per hour, since this figure is adequate at Heathrow, but the system theoretical capacity is by far higher
The Pod-Car system is complicated because it offers the passengers to ask for transportation request from any station and to choose a custom path.
If a fixed path meets the local necessities, as it happens for the mini-metro or a cable shuttle, the designer task would become by far simpler and really few system components would be not "on the counter".
The drive system, the electric motor and controls are the same used by electric cars, and their cost, since in future the quantity of produced components will be larger and larger, can just decrease while the reliability will increase.
The exact carrier position along the line is easy to know on a fixed path, by combining a GPS positioning and a very simple and cost effective control based on signals on the track; the carrier positioning can be managed by an on board control system and verified in the central control room by means of a wireless system.
The cableway has the advantage that it is inherently protected against the carrier collision, one of the railway great risks, and this stands for fixed grips systems and for the detachable ones, at least along the line.
In the detachable systems stations, there is the risk of acc-dec device failure; for instance an 8 passengers gondola, luckily empty, because of the failure of the acceleration beam drive roller, arrived at a really low speed on the haul rope still running at almost 4 m/s.
In case of self propelled vehicles, at urban transportation speed, the anti-collision system can be borrowed from the automotive components, since there are reliable sensors able to brake, or, in this case, to start the deceleration ramp, when there is the risk of rear end collision; the central carriers control gives a second anti-collision check.
Another problem is the tire to track friction coefficient in case of ice, since the tire-wet road (or steel wheel-rail), friction coefficient is enough to grant a comfortable carrier deceleration; a theoretical safer, but expensive, solution is to use special devices to grant the adhesion in the acceleration-deceleration areas, in addition to automatic de-icing systems and technologies to prevent the "leaf on the rail" condition.
The artificial adhesion system can allow very steep legs along the line.
The emergency braking distance, as everybody knows, is a strong limit to the line capacity, because it sets the time interval between the carriers depending on the max. speed.; in any case, as a simple formula application shows, using a friction factor as low as 0.15, 5 as safety factor on the braking distance and 20 passengers carrier to compare with the mini-metro features, the capacity is still higher than the cableway one.
Since an automotive mechanical braking system is ready in case of electric braking failure, the safety is the same as a cableway, where a grip can fail or the acc-dec device drive roller lining can explode and so on; it is not useful to repeat here a well known risk analysis.
The batteries used to store the electric energy to power the motors are now, as we know from the electric and hybrid car technology, the most expensive and heavy components; as an alternative, a supercapacitor could supply power and be recharged at each station, if the designer is willing not to use a rail to supply power; for instance, many transportation systems (subways, the Torino Superga cog railway), use aluminum rails with a stainless steel plate as contact surface, but it is expensive to buy and mount it and it involves risks that can be eliminated by means of further expensive devices.
A simplified self propelled system, designed to follow a fixed path and not a custom path on passengers' request, would have about the same mini-metro bridge, the same or a lower cost and it could be more reliable, because it would be enough to take out of order the faulty carrier to keep the system in operation; on the contrary a detachable system is put out of operation by just one failure in any station.

The control software of a simplified self propelled system is not too complicated and can be found on the market in Italy too.
Weighing the pros and cons, it is possible that, if the line gradient is limited and there are not large obstacles, the electric drive system could soon be a strong competitor and it could be developed at affordable cost.
The shuttle system pro and cons are under exam too; two independent reports compare the Oakland shuttle cost and features to a PRT system and to a really simple solution: a further road lane for the bus; this report, since it is about a system to be manufactured now and not in the close future, does not take into account the amazing developments of the road vehicles automatic drive, that could reduce the most expensive chapter of a classic bus line: the drivers salary.
To write this does not make me happy, because cableways are and have been my family's job and hobby; I spent my life in the cableways field.
I have the greatest respect for the cable-APM Companies (I worked in the past with both of them and the happy memories overcome the difficulties and the problems that any work involves), and for the colleagues who designed the now used systems: I am not criticizing the design or the manufacturing process.
What I am afraid of is that past history repeats itself; to see again, as in the past, the cableways leading public urban transportation at first and then being pushed into oblivion because of the technological development of other drive: that is why I am trying to suggest some criteria to make the cable-APM niche stronger.
Now the situation is similar to the IX century one, when the steam motor became light enough to be mounted onboard rather that in a drive station and when the Diesel motor further improved the power to weight ratio: *to day a wheel mounted electric motor weight is comparable with a detachable grip one*.
It is interesting to check some power to weight ratios:

motor or vehicle type	**Power/Weight ratio (KW/Kg)**
Steam naval motor about 1850 (Blackwall railway)	0,007
Stephenson locomotive The Roket (1829)	0,035
Steam locomotive motors (power at the motor)	0.016 ÷ 0.024
Modern naval diesel motor	0,03
Modern diesel car motor	0.65 ÷ 1.15
Industrial electric motor (drive, gearbox and pfc not included)	0.15
Wheel mounted automotive electric motor (super capacitor or batteries not included)	0.8 ÷1
Professional biker (Tour de France – Alberto Contador - Verbier year 2009)	0,0035

Using the IX century technology, the self powered vehicle and the cable hauled one as well, needed operators on the carrier, but now the cable-APM needs by far less operators than a classic bus line, specially if the APM stations have remotely-controlled automatic doors.
On the other point of view, modern technology can solve, with reliable and cost effective devices, the safety problems inherently solved by the cable and, since it allows full automation controlled vehicles, for instance the VAL in Turin, Italy, or the Pod-cars, it clears the operating cost advantage of the cable-APM.
Another comparison: once, all of the shops had tools powered by belts and pulleys, but at the end electricity proved more effective to transfer energy; if the rope use is just to haul the carrier, it risks becoming a loser, as the belt transmission was.

11- WHICH FUTURE FOR THE CABLES?

The cables future is.. to go on being a cable!
There are so many types of cable-APM and so many technical solutions used that the following data and considerations are just a rule of thumb; in any case I took them from project I worked at or I know well and

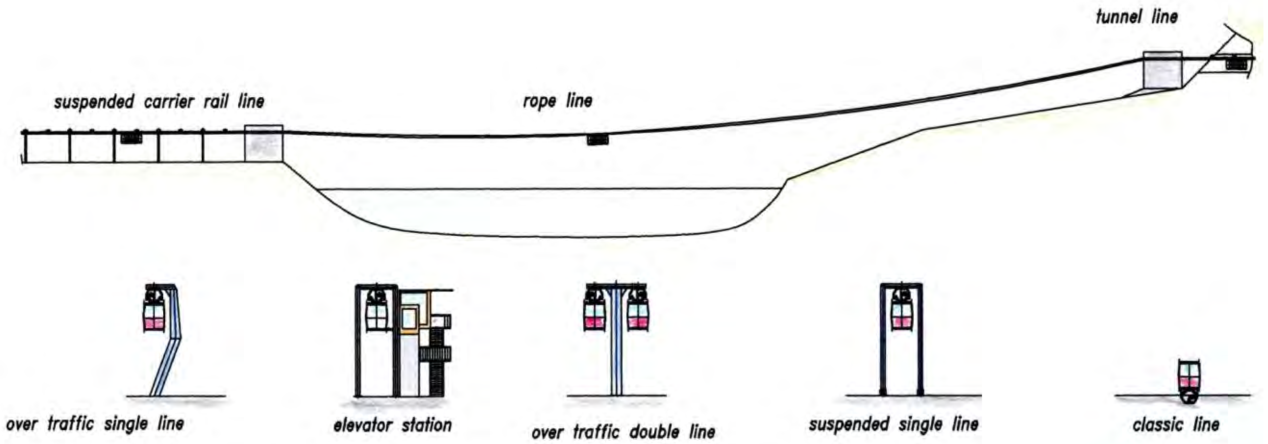
I compared the “steel weight” of a rope supported and hauled cableway and of a steel bridge on steel towers one.
Since the structure is function of the local conditions, seismic effects, wind and snow loads, the results are in the field of magnitude order; furthermore, the structure cost is not automatically proportional to its weight: for instance a steel rope costs by far more than a steel profile per unit of weight. A complete analysis should take into account the foundations and the ancillary works, but anyway, since this is not the report for a tender, the results are accurate enough to suggest something useful.
In both cases, the steel weight is from steelworks, because the steel rope weight is a small percentage of the total one and the ratio between the steelworks and the steel rope cost per weight unit is 0.25÷035.
For instance, if the line runs over a road and therefore shall be designed in abide of the necessary clearance, it is possible to use long spans and high towers, to compensate for the rope sag, or to choose low towers and short spans, to decrease the rope sag; furthermore it is possible to decrease the rope sag by means of higher rope tension (and rope diameter), but this increases the rollers and sheaves size and the civil work cost.
If the cableway towers are very high, as for the Alta Via concept, to give an example, it is necessary to lift the passengers up to the station or lower the line at the station by means of big hold down towers, but this way the friction increases a lot.
Even if the line has no vertical drop, since the rope configuration is a catenatry curve, there are a rising and a falling part; if the system layout has conditions when all the carriers are on the rising part of the catenaries at the same time, there are high instantaneous torques; this does not happen with a steel bridge supported APM.
It is clear that in some situations, the rope fits better, but in other cases the bridge or a “pendular” structure, like the Doppelmayr-Garaventa funicular Deer Crest (USA) are a better choice; the “pendular” bridge allows to save a large amount of steel without increasing the foundations, if used on flat profiles and the tower height is about constant.

Line type	**Steel weight (t/m)**
Simple pendular line, 11 m span, 40 passengers carriers	0,50
Double pendular line, 11 m span, 40 passengers carriers	0.74
Steel bridge, single line , 18 m span, 80 passengers carriers	0,81
Steel bridge, double line, 18 m span, 80 passengers carrier	1.4
Bicable gondola lift	0.04
Monocable gondola lift	0.05

The table above shows, even if the values are indicative, that it is worth to use the rope, if the system main features allow it.
Assuming 3000 p/h capacity for monocable gondola lifts and 4000 p/h for 2S and 3S, the system cost is, as a magnitude order:

System type	**cost (mil. €/ km)**
8/10 passengers monocable gondola lift – 3000 p/h	5.42
2S gondola lift – 4000 p/h	8.57
3S gondola lift – 4000 p/h	10
Shuttle on bridge - 2700 p/h	34
Light railway	41

The cableway are calculated on the basis of 3 km length at least, with no intermediate stations, and the cable powered shuttle on a 5.6 km long line, with an intermediate station, two rope loops and 200 passengers trains.
The rope choice is well motivated by a high line gradient and by its possibility to fly over obstacles , even if they are really large: *in this niche the rope has no competitors*.
At the end, according to many studies and to what the manufacturers propose, the right solution is to use, as cable-APM, as far as possible the cableways in their classical version as an aerial system, and to improve reliability and rescue procedures, since the rescue is the public administrators main concern; this peculiar aspect will be studied by the CEN working group in charge of the rescue European Standard revision.
Obviously, it is not always possible or acceptable on the landscape and environmental point of view to fly high over a town and it can be worth to find a way to make the cableway able to run close to the ground, where height of the carriers is a problem, but without losing the possibility to manage obstacles and inclination.
On the basis of standard gondola lift materials, it is not so difficult to develop a system able to run on rail and track ropes as well with the same carriers and able to run on right and left corners and support and hold down towers too, without detaching the grip from the haul rope.
Running on the streets, the upper rail is the best solution, because that overcomes the carrier floor inclination problems and, since the rope, running over the carriers, is less sensitive to humidity and dirt; this way, rope and roller are supported by a structure that, where necessary, could be closed and soundproof, to avoid the noise that has been source of criticism against previous steel rope powered APM.
If the system has to cross a river or step up a hill, or when this can be made with no landscape or environmental problems, the carrier, always hauled by the same rope, rides two parallel track cables in



place of the rails, while the passengers ride the same carrier running on the ropes and on the rails as well.
A standard detachable grip can be mounted in a special assembly to make it able to run any corner, hold down and support rollers, so that it can manage non straight lines with strong convexities and concavities, as seen in an American provisional patent.
A similar system could be extended to monocable lifts, with some modification to the classic grip and carrier connection, if no rail supported leg is necessary.
Such lift features could hardly be matched by electric self powered vehicles and could rule its market niche.
The second cableways used as APM limit is that they fit the point to point transportation well, if the line has no corner or eventually one or two intermediate stations where the corners are; the pulsée and the hectometric system can fit a multi-stop station a bit better, if the stations are at a constant distance; the detachable systems is effective if there are not many stations, because of the complicated station machinery.
To be competitive with the electric self propelled systems on any line, it is necessary to find the way of working with no acceleration – deceleration beams.

A detachable APM shall have a station in aforethought points of the line and, there, it needs heavy devices; this means many components per station and a really rigid layout, since it is really difficult to change the stations position in a second time.
The two limits, corners at the station only and the acceleration deceleration device, can be well overcome with the old San Francisco cable car, unfortunately that system was not an automatic one and allowed really slow rope speeds.
Today technology could easily solve the grip automation, but to cope with the rope speed and wear is a bit less easy.
There is more than one proposal about that, but there is, on what I know, no published or patented system able to win that challenge.
Among the proposals under development there is a system with on board sheaves; the haul rope engages them and if the sheave turns idle, the carrier can stop and if the shave is fixed, the carriers run at the rope speed.
Another, perhaps more promising system, has a grip controlled in full automation, able to use the carriers length to control the accelerations and decelerations: we will see what happens in the future.

12 - CONCLUSIONS

The cable APM already solves some urban transportation problems by means of the classic or slightly modified ski area technologies.
If the cableway gets out of its special niche, that is where there are obstacles or high vertical drops, its current success could be jeopardized by electric self propelled systems, based on automotive components and therefore reliable and cost effective.
Further cable powered APMs developments, with carriers able to run on track and on rope as well and to ride lines with corners, convexities and concavities, could generate really competitive systems, that could be able to solve transportation problems until now unresolved without passengers trans-shipment; a system able, like the San Francisco one, to connect itself to the haul rope in any point of the line without complicated stations and able to grant acceptable ropes life and speed, could open really new possibilities.
The development of the cable powered APMs asks for a strong research commitment, but the interesting results could pay well for that.