AERIAL ROPEWAY SYSTEMS ADVANTAGES AND DISADVANTAGES

By Hazem El Jouzou

Editor's note: The following article was excerpted from the much longer article "A Comparative Study of Aerial Ropeway Transit (ART) Systems" published in Issue 22.4, February 2017, which in turn was based on the author's Master's thesis of 2016. Although some of the data and findings can undoubtedly be updated, we believe this basic summary of the main advantages of aerial ropeway transit systems has value.

HISTORICAL OVERVIEW

Aerial Ropeway Transit or in its simple form "ropeway" is one of the oldest modes of transport used by humanity to overcome obstacles. Some drawings of this transport mode date back to the year 250 BC in the south China area (Hoffmann, 2006, p. 1). Because it is a transport mode with a long history, this old mode of transport is simple, cheap, and tested through centuries of human use.

In the modern era, there were only seldom examples of ART used in urban environments. One of the few countries who utilized this technology for public transport in that era was the city of Algiers in Algeria. In 1956 it constructed the first aerial tramway line "El Madania" to link two neighborhoods that were 83m (272 ft.) above one another; the system had a distance of 215m (705 ft). (Bergerhoff & Perschon, 2012, p. 4) (Alshalalfah, et al., 2012, p. 260)

The second attempt was the Cologne Rhine cableway. Constructed in 1957, with a cost of 1.5 million Deutschmark, the cableway was initially an attraction to the Federal Garden Show held on the right side of the Rhine (where the park now lays). The service was so popular that the people of Cologne did not want it to be removed afterwards. It was temporarily dismantled in 1963 because its supports overlapped with the construction plans of the zoo on the right side of the Rhine (Herwig, 2013, p. 49). Further to that period, the cableway was reopened in 1966 after changing its path and moving it southward.

Photo credit: Chris Barbalis, New York, 2017. https://unsplash.com/photos/red-and-white-cable-car-above-grey-roads-at-daytime-sMZN6XJP-aE

The system has 41 four-seat small cabins which result in a 1,600 passengers per hour per direction (pphpd) on a total distance of 935 m (3067 ft). (Herwig, 2013, p. 49)

The third attempt was the Roosevelt Island Tramway (New York City). This system was built in the USA linking the Roosevelt Island to Manhattan. In 1976, and in the efforts to accommodate and to link the new middle- and low-income housing units being built in the island, an aerial tramway system was commissioned. This aerial tramway was intended to replace the old and deteriorated trolley system that was there since 1909. (Alshalalfah, et al., 2012, p. 259) (CUP, 2016).

ART began first to catch steam in 2004, when the city of Medellin in Colombia opened its first monocable detachable gondola (MDG) system (Line K) to connect the informal settlements (the Communes) in the hilly area of Santo Domingo to the metro transport system in Medellin city. After the installation of the aerial system, the residents of Santo Domingo could—in less than 30 minutes—cover the distance that took busses 2 to 2.5 hours (Bergerhoff & Perschon, 2012, p. 4) (Herwig, 2013, p. 52) (Alshalalfah, et al., 2012, p. 259). After the success of the Medellin ART system, many countries, especially in South America, adopted ART systems and integrated them into their public transport systems. The most interesting of these systems were: Caracas (Venezuela), Koblenz (Germany), and La Paz (Bolivia). The timeline of these systems also demonstrates the evolution of ART systems and technologies.

COMPARISONS WITH CONVENTIONAL TRANSIT SYSTEMS:

Table 1 shows a comparison between ART transit modes and conventional transit modes. These comparisons are made mainly in terms of system capacity (pphpd), speed, and construction cost per km length; it also contains many other relevant comparisons. This table shows that ART (3S) systems lay in the same band of Bus Rapid Transit (BRT) semi rapid transit systems in terms of speed, capacity in pphpd, and cost.

What this table also shows is how misleading some numbers in isolation might be. For example, although aerial trams (Editor: i.e. reversible cable car) have cabins that carry up to 200 passengers, and have a speed up to 43 km/h (26.7 mph), they actually have a less line capacity than the MDG and BDG (mono and bicable detachable gondola) systems with small cabins (up to 15 passengers) and speed only up to 21.6 km/h (13.4 mph). That is because aerial trams only have 2 cabins while the others have many. Also, and most importantly, that is because MDGs and BDGs have a very high frequency and a short headway of 12 seconds. It has to be mentioned also that the costs of the detached gondolas, which are relatively low, are mainly to build the two stations, since the remaining costs for the towers of cable systems are relatively very low. These stations also remove the need to build maintenance hangars since they contain the areas for repair and maintenance. (STRMTG & CEREMA, 2011, p. 5) (Alshalalfah, et al., 2012, p. 254)

	Transport Mode		Investment Cost ($Million/km)	Line Capacity (PPHPD)	Vehicle Capacity (Passenger)	Operational Speed (km/h)	Cars / TU
Conventional Transit Systems	Street Transit	Bus	0.5-0.6	3,000-6,000	80-125	15-25	1
		Tram	5-10	10,000-20,000	100-300	12-20	1-3
	Semirapid Transit	BRT	5-40	6,000-24,000	80-180	20-40	1
		LRT	10-50	10,000-24,000	100-720	20-45	1-4
	Rapid Transit	Metro	40-100	40,000-70,000	720-2,500	25-80	4-10
		Regional	50-120	25,000-40,000	150-1,800	40-80	1-10
ART Transit Systems	Aerial Tram		15-25	500-2,800	20-200	43.2 Max.	1
	Dual-haul		20-25	2,000 Max.	100 Max.	27 Max.	1
	MDG		5-10	3,600 Max.	4-15	21.6 Max.	1
	BDG		10-20	4,000 Max.	4-17	25.2 Max.	1
	TDG		15-25	7,000 Max.	35 Max.	30.6 Max.	1

Table 1: Service Characteristics of ART and Conventional Public Transit Systems.
pphpd: passengers per hour per direction
Source: Author
Data source: Alshalalfah, et al. 2012; Winter, 2016; CUP, 2016

ART SYSTEMS - ADVANTAGES AND DISADVANTAGES

To be able to understand the main advantages and disadvantages of ART systems, the study (Editor: the Masters thesis) created a list of factors that seem important to identify the Strengths, Weaknesses, Opportunities, and Threats (SWOT).

These factors can be summed in the following keywords:

- Comfort
- Availability /Frequency - Headway
- Reliability
- Environment (noise, visual, carbon footprint)
- Capacity
- Safety
- Construction Time
- Land take / footprint
- Cost (investment; Maintenance and Operational Cost)
- Energy efficiency
- Accessibility

(Editor: The comparisons in the following discussion are primarily to the case studies discussed in the full article in Issue 22.4 and in the author's Masters thesis)

Comfort

Gondolas offer sitting and standing areas in their cabins. The cabins (as well as the stations) can be provided with air conditioning systems which cool or heat their atmosphere depending on the weather necessities (Winter, 2016) (O 'Connor & Dale, 2011, p. 18) (CUP, 2016) (Alshalalfah, et al., 2015). In addition, and since those cabins pass relatively higher than the urban topography, weather conditions in these heights tend to be less humid and less hot than that on the urban surface. This in return reduces the need for air conditioning in summer where the cabins in this case can rely on natural ventilation (The Don Valley Cable Car Community, 2016). Furthermore, newer ART systems (e.g.: La Paz, Bolivia) have even introduced WIFI powered by solar panels on the roofs of the cabins to give even more comfort and connectivity (AJ+, 2016, p. Sec:42).

Availability (Frequency and Headway)

The factor of availability is dependent on many other factors like the cabin size, number of cabins in the system, size of embark/disembark area, and speed of the system. Yet since the cabins in ART systems are in continuous loop movement between two stations, waiting time to board these system often does not exceed one minute. This in return removes the need for schedules (CUP, 2016) and thus gives ART system a large advantage over busses and trains and challenges the supremacy of private transport automobiles in terms of freedom and independence from fixed and sometimes unsuitable schedules (of public transport systems). While some ART systems have a very short headway of 12 seconds (Medellin) (STRMTG & CEREMA, 2011, p. 5), other MDG systems *(choose to)* have a longer waiting time (e.g. 34 seconds, Koblenz) (Dale, 2010); this number is not due to the number of cabins but to operational managerial measures to give enough time gap to separate the passengers getting in from those getting out of the cabins (STRMTG & CEREMA, 2011, p. 5). *(Editor's note: reversible trams typically have longer headways e.g. 7 minutes (peak) to 15 minutes (off peak) for Roosevelt Island aerial tram).*

Reliability

Usually reliability factors in transport systems are deduced from measuring the rates of on-time performance, vehicle failures, maintenance procedures, and other factors like number of stops and distances the vehicles run, (American Public Transportation Association, 2012, p. 5) yet those other factors do not affect ART systems which are on continuous rotation. On the other hand, wind speed is an additional factor to be taken into consideration when measuring ART systems reliability, since the cabins are hung in the air and are subjected to tilting due to wind pressure.

In terms of reliability, ART systems have a big advantage over other transport systems, with a remarkably high reliability rate of 99.3% to 99.9%. This high rate is maintained through strict preventive maintenance guidelines, and through innovative technologies that allow the cabins to resist winds up to 110 km/h (68.3 mph) (e.g.. tricable detachable gondolas (TDG/3S)) (CUP, 2016).

Environment

Visual Pollution: visual impact and visual intrusion remains a major challenge for ART. Since historically ART systems were rarely used as a transport system in urban environments, it is often perceived as unfamiliar to the urban environment and thus sometimes receives opposition from residents (STRMTG & CEREMA, 2011, p. 10). This opposition could largely increase when ART systems pass over the skyline of historic cities. The other factor is visual intrusion, residents and land owners around the area where the ART lines will be installed may have worries of what the cabin passengers can see and intrusions on their privacy, and potential impacts on property values (STRMTG & CEREMA, 2011, p. 10).

In that regard, new technologies have widely reduced the possible negative effects that might appear with regards to urban environment or visual intrusion. In terms of being unfamiliar or unsuitable, for instance in historic cities, the good design of the 3S ART system in Koblenz resulted in UNESCO approval even though Koblenz is a world heritage city (Georgi, 2013). In terms of visual intrusion, new glass technologies (Smart Glass) which are already used in public transport systems (Singapore) allow the glass panels of the cabins to become opaque when passing near houses, blocking any form of intrusion (Dale, 2011).

Photo credit: Jacek Dylag, Smog and heavy trafić at night, Kraków, Poland, 2020. https://unsplash.com/photos/a-foggy-city-street-filled-with-lots-of-traffic-mmar_Xs8_mk

Noise Pollution: Since the cabins in ART systems do not contain any motor, the system is considered a very low noise producer. Gondolas therefore, are a very quiet transport unit in comparison to other transport systems (Winter, 2016). The noise they generate will be in most cases indistinguishable from ambient noises produced by other transport systems (traffic for instance) (The Don Valley Cable Car Community, 2016). The minimal noises that come out of this system are in the station where the large motor is situated and in the intermediate tower while the cabins overpass them. Yet even those are barely heard (CUP, 2016).

Carbon Footprint: The carbon footprint is a measurement which shows how much carbon a certain system will produce directly or indirectly. The results of such tests deduce how green the subject system is in terms of energy. The calculation is either done directly when the system produces greenhouse gasses, or indirectly by calculating for example how much carbon emissions would be produced to supply a certain system with electricity.

In terms of carbon footprint, many countries like France consider ART systems by law as an alternative system that could (when used in a general policy) reduce pollution and greenhouse emissions. Many projects are under research in French local authorities under that topic. (STRMTG & CEREMA, 2011, p. 1)

In order to explain in numbers the small footprint ART systems produce, the strategy consulting firm *ClimatePartner Austria* conducted a study in 2009 regarding the carbon footprint of ART systems in comparison to cars, busses, and trains. This study showed that when cable cars utilizing 50% capacity and above have the lowest greenhouse emissions of all these systems. This makes ART systems the world's greenest transport system. Table 2 shows the findings of this study.

Table 2: Carbon Emissions by Mode.

Transport mode	CO2 Emissions in g/pkm
Petrol-Powered motor vehicles	248
Diesel-Powered Busses	38.5
Electric Locomotive Trains	30
Cable Cars	27

gpkm=grams per passenger kilometer
Data source: Herwig, 2013

To put this advantage into physical benefit, the city of Medellin used the UN concept of climate protection by "Carbon trading" to sell its share of carbon to other cities and use the money to further develop its transportation systems (Herwig, 2013, p. 52). In numbers, the city of Medellin, like other cities that used ART systems, saw a drop in its greenhouse emissions, and also in their carbon footprint. **Table 3 and Figure 1** show this drop in emissions in the city of Medellin, from 30+ tCO2 to 10+ tCO2 per year (Bergerhoff & Perschon, 2012).

On average, Medellin saves around 20,000 Tons CO2 each year and sells the corresponding emission certificates. This is, in the minds of many, an environmental benefit for all (Herwig, 2013, p. 52).

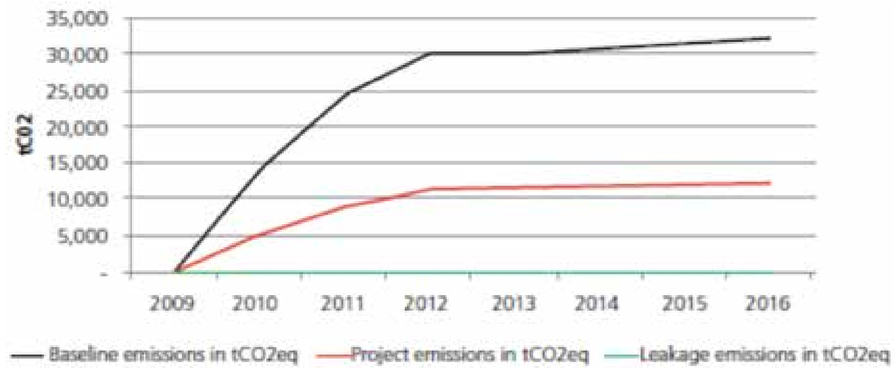

Figure 1: *Medellin projected emission reduction from six aerial cable cars, UN - HABITAT, 2012.*

Table 3: Medellin projected emission reduction from six aerial cable cars								
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
Baseline Emissions in tCO2eq	14,005	24,434	30,103	30,382	31,189	31,458	32,311	193,881
Project Emissions in tCO2eq	5,135	9,083	11,208	11,450	11,724	11,980	12,274	72,853
Emissions reduction in tCO2eq	8,870	15,350	18,895	18,932	19,465	19,478	20,038	121,029
Data Source: UN - HABITAT, 2012								

Capacity

The capacity of ART systems depends on the capacity of the cabins, the spacing between the cabins, the speed of the traction cable, and thus the number of cables used. Because ART systems operate on their own dedicated space, and do not mix with other transport modes, and because they are in continuous automated movement, this allows for a consistent journey time, and a thus a consistent capacity with a consistent passenger throughput (STRMTG & CEREMA, 2011, p. 7).

The capacity of ART systems is in continuous increase. In comparison to other transport modes, the MDGs and BDGs have a capacity nearly equivalent to a small rail-based tram, whereas the TDGs with a capacity of 7,000 pphpd (Winter, 2016) show the potential of overcoming rail-based tramways with cars as large as 43mx2.65m (141 feet by 8.5 feet). **Figure 2** shows a relatively new yet outdated table from 2011 showing a comparison between the capacities of several transport systems including ART. The table was edited to include the capacities of ART systems described by newer sources like Seilbahn Koblenz. As a result, one can see that TDG/3S systems reach a higher capacity than rail-based tramways with cars as large as 43mx2.65m (141 feet by 8.5 feet).

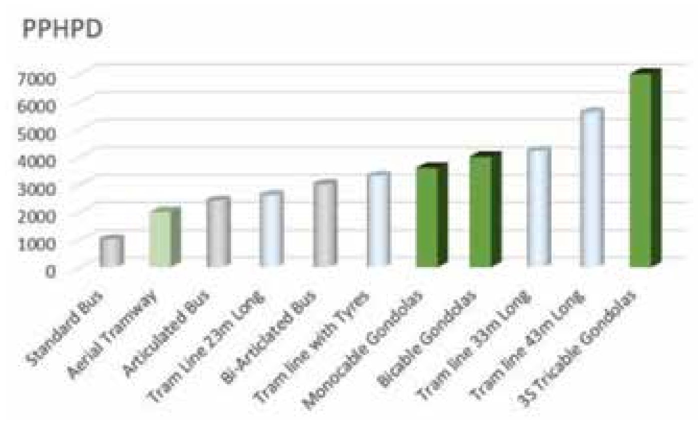

Figure 2: *Capacity in PPHPD of urban transport systems. Source: Author (Figure 5, El Jouzou, WTPP: 22.4). Data source: STRMTG & CEREMA; Winter, 2016.*

Safety

ART systems are systems that operate continuously in loops, without a motor on board and without a driver. This makes the possibility of accidents incredibly low. Therefore, many urban planners and transport engineers call ART systems the safest means of transport in the world. This is based on the ratio of the number of accidents to the number of people transported per kilometer (STRMTG & CEREMA, 2011, p. 6) (Herwig, 2013, p. 51).

Construction Time

ART systems require a relatively short building time. While other modes of transport require 10 to 15 years to build their lines (metros for example), (Herwig, 2013, p. 49) the total building time for these systems has been 13 months in Koblenz (Alshalalfah, et al., 2014, p. 260) (Seilbahn Koblenz, 2011) and two years in La Paz (LAPAZLIFE, 2014). This huge reduction in construction time proves essential to cope with the rapid expansions of some metropolises and the rapid pressure increase on available infrastructures.

Land Take (Footprint)

ART systems can overcome obstacles and topography levels. Their land take on ground level therefore is very limited, and is only confined to that of the station and pylons. The land under the cables can be utilized for other purposes, and thus is not considered as land take. (STRMTG & CEREMA, 2011, p. 8) The standard area of the main stations is usually 250 SQM (2690 sq. ft.) (25mx10m) and 50 SQM (538 sq. ft.) for intermediate stations. These areas are also subjective to the architectural design of the station. Stations that have the embark/disembark area on the ground floor need to have a sufficient clearance area for the cabins that are in this case lowered to the station. Thus, stations which allow embark/disembark on upper floors require less land, and can utilize the extra floors in creating shops or storage areas for the system (STRMTG & CEREMA, 2011, p. 8).

However, ART systems always move in a straight line between stations or at least between pylons. This in addition to the cable length having a preferable limit of 6 kms (3.7 miles) (Winter, 2016), can be a negative aspect in connecting urban environments. Hence, even though ART systems require small land take, integrating stations in urban environments can be problematic. In addition, regulation in countries require safety margins along the path of the gondolas not to be affected in case of fire in a building that the cabins overpass. Furthermore, any passage of a cable line over private ownership requires compulsory purchase, or negotiation with the owners regarding those lands (STRMTG & CEREMA, 2011, p. 9).

Investment Cost

It is a difficult matter to acquire investment costs data regarding ART systems in urban environments. That is because that data is considered commercial data for manufacturers and prime contractors. Yet to have a general figure, CETE Lyon came up with figures of those systems in mountainous environments. Table 4 shows figures and costs of ART systems in mountainous environments. Comparing those numbers to known costs of ART systems built in urban environments (like Koblenz) prove those numbers could be even smaller in urban context.

Table 4: Breakdown of investment costs in mountain area

System Component	Cost	
	Monocable Gondola	3S Tricable Gondola
Start/End Station	€2.5 to 3M	€4M to 5M
Intermediate Station	€1.2 to 1.5M	-
Pylon	€0.1M	€0.5M
Cabins	4 to 15 Seats	35 Seats
	30,000€	300,000€

Data source: STRMTG & CEREMA, 2011
M=million

Maintenance and Operational Cost

In ART systems, operating the system typically requires only four personnel. These four personnel provide assistance in boarding and un-boarding the cabins, overlook the system, and do the necessary maintenance. The operational cost is thus related to the overhead cost of those employees and that of the spare parts for the system. As an example, a simple MDG system requires an annual operational cost of 1.5 M€ on a 7000-operating hour basis (STRMTG & CEREMA, 2011, p. 9). These running costs and life cycle costs are drastically smaller than those of individually motorized vehicles such as busses. This is because the whole system has a single stationary motor that runs the whole system. This criterion therefore, gives advantages for ART systems over other motorized modes of transport (STRMTG & CEREMA, 2011, p. 9).

What makes ART systems even more feasible and gives them the upper hand over conventional UPT (urban public transport) is that unlike trams and busses, the increase in capacity in ART systems has a minimal effect on the operational cost of the system. **Figure 3** compares the increase in the running (operational) cost of buses, trams and ART systems with respect to the increase in capacity. The cost increase is rather very small during the expansion of the ART systems and the increase of passengers per hour rate. This is contrary to bus and or rail systems which push the costs dramatically with the increase of capacity. The relatively low operational cost and low building cost show great potential for a wider implementation of ART systems in urban context, and so does the evolution in ART specification and design. **Figure 3** shows a comparison of operational cost with respect to capacity increase, over the same route between road-based modes of transport and ART systems taken from the city of Grenoble, France.

Energy Efficiency

Cable cars are considered highly efficient in terms of energy consumption. Although the whole system has to be activated even if one passenger is riding it, at a 50% load it is considered a very energy efficient transport system that produces the least carbon footprint in the world (Herwig, 2013, p. 49). That is due to the following criteria as explained by Joachim Bergerhoff and Jurgen Perschon (Bergerhoff & Perschon, 2012) and also by CERTU (STRMTG & CEREMA, 2011, p. 11):

Figure 3: *Comparison between operational costs of Buses, Trams and ART systems. Source: Author (Figure 6, El Jouzou, WTPP: 22.4). Data source: Bergerhoff & Perschon, 2012; Dopplemayr Urban Solutions, 2015*

- A single stationary electric engine moves the entire system at a steady, efficient pace.
- The gondolas do not have to carry engines, fuel, wheels, suspensions, reinforced chassis and thus are of relatively low weight and drag.
- Descending gondolas help pulling up ascending gondolas; hardly any additional energy is required for acceleration of individual cabins or is lost when slowing down cabins in (rare) stations.
- Apparently, the aerial ropeway does not suffer rolling resistance.
- Load and changes in level have a limited impact overall.

Accessibility

Both the station design and cabin design allow the system to be a barrier-free, which allows transport for people with disabilities and even bicycles.

CONCLUSION

ART proves to be an old yet innovative transport method which, in light of its latest innovations, can be proposed not just as a feeder or a touristic element in a ski resort, but as a transport mode that holds very significant potential. This relatively new urban transport mode shows a rapid pace in innovation and upgrades in the last decade. These innovations and this rate of upgrade prove the mode has a promising future and bigger role in future city transportation systems. In comparison to traditional transport modes, the advantages of the ART systems can be seen in various aspects. Those aspects are ones of comfort, availability, reliability, safety, construction time, land take, cost, environment, and energy efficiency. In all of those areas, ART systems have the upper hand on conventional transport modes. It is in light of those advantages that the research finds potential in implementing ART systems as full urban public transport systems that can function as a backbone, yet also complement other existing systems.

Photo credit: Bess Gaby, Baja California Sur, MX, 2018.

Author Details:

Hazem El Jouzou is architect, urban planner, and BIM-specialist, who is currently working as a BIM-developer in a construction company that highly values sustainability.

He wrote about aerial ropeways for his 2016 thesis for a Master of Science in Urban Agglomerations from Frankfurt University of Applied Sciences, available at: https://www.researchgate.net/publication/310888600_A_Comparative_Study_of_Aerial_Ropeway_Transit_ART_Systems_Advantages_and_Possibilities

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