CABLE PROPELLED SYSTEMS IN URBAN ENVIRONMENTS

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INTRODUCTION

The past twenty-five years have witnessed many significant innovations in the evolution of cable-propelled APMs designed for urban and non-ski resort settings. Although urban funicular systems have been in use in Europe and elsewhere since the late 1800's, few urban cable systems appeared in North America after the demise of cable-propelled street railways in the late 1880s' and early 1890's. Cable technology was relegated to ski areas, a few theme parks, and temporary installations at fairs. It was not until the development of Automated People Movers in the 1970's that suppliers in America began to re-evaluate and appreciate the role that cable propulsion could play in moving moderate numbers of people medium distances in urban settings. In this role, cable was perceived by a few visionary transportation engineers as an inexpensive and highly cost-effective alternative to the electric-powered self-propelled vehicles that were being developed and promoted by aircraft and automobile manufacturers and suppliers of conventional rail transit vehicles.

At the time of the construction of the aerial tramway at Roosevelt Island in 1977, only one supplier was marketing and constructing urban cable systems in North America (VSL). There was nothing unique about the technology used for the Roosevelt Island tramway; it consisted of standard hardware of the type that had been used at ski resorts and in alpine settings in Europe. What made the system unique was its location in the heart of North America's largest city, and its role as an element of the public transportation system of New York. Photos of the system illustrated how it could move people over the urban streets and bridges of New York City, and avoid the time delays and congestion being experienced by motorists at street level. Given the transport needs of Roosevelt Island and the constraints of the East River, aerial cable was the logical choice. The Urban Mass Transportation Administration researched the system as part of its program to evaluate the application of innovative transportation technology to solve the congestion problems of urban areas (1). However, within a few years, traditional cable technology would begin to give way to innovative design. This paper describes the innovations that have taken place in three areas of design: type of service, operating speed, and guideway and suspension.

TYPE OF SERVICE

Cable technology can be designed for three different types of operation (2).

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Reversible systems consist of vehicles which shuttle back-and-forth between the two end terminals, though vehicles may also stop at stations located between the terminals. Propulsion is by means of a cable loop which stops and reverses direction when the vehicles reach the terminals. In the case of systems featuring only one vehicle, passengers who arrive on the terminal platform just after a vehicle has departed must wait until the vehicle returns after reaching the opposite terminal. If there are two vehicles which leave the opposite terminals simultaneously, the maximum passenger wait time is approximately half that for a system with a single vehicle. In either case, as system length increases, maximum passenger wait time also increases, which degrades level of service. Thus, for urban applications, where short wait times are desirable, the feasibility of using reversible technology may be limited by alignment length. Table 1 lists reversible systems, other than funiculars, which have been installed or currently are being planned for urban and non-ski resort settings since 1977.

Continuous operation features vehicles which are launched from terminals at equal intervals of time. The haul rope moves continuously. In the case of systems featuring detachable vehicles, the vehicles leaving a station are accelerated to the speed of the haul rope, attached to it, and detached and decelerated at the next station. The gondola is an example of a continuous system. Although the frequency of vehicle launch influences passenger wait time, alignment length does not. Thus, for long alignments, a continuous system provides a superior level of service. Table 2 lists the continuous systems constructed or in the planning stages for urban environments and non-ski resorts.

The third type of operation is pulsed. Pulsed systems feature three or more trains of vehicles equally spaced and permanently attached to the haul rope. The number of trains is equal to the number of stations or a multiple of the number of stations. Stations also are equally spaced. When the haul rope stops, each of the stations has a train positioned in front of it. With pulsed systems it may be possible to reduce maximum waiting time below that of reversible systems; however, it is unlikely that a maximum wait time can be achieved that will be as low as that associated with a continuous system (3). Although reversible and continuous systems have been implemented, no pulsed systems have been built in urban or resort environments

Reversible Systems. The first urban cable systems were of the reversible type. A continuous technology designed specifically for urban environments did not appear on the market until 1986. Between 1977 and 1986, eight reversible systems were opened, including the system at Roosevelt Island. Between 1986 and 1999, nine reversible systems were opened. Two additional systems are expected to open in 1999, and one in 2000. Up until the 1990's all of the urban reversible systems (except for traditional funicular systems constructed in Europe and urban settings outside North America) were produced by VSL and Otis. Additional vendors that have entered the reversible market during the mid-1990's include Doppleymayr and Yantrak.

Individual vehicle capacities for reversible systems range from 180 (Memphis, VSL, suspended vehicle, 1982) down to 32 (Mandalay Bay, Las Vegas, Doppelmayr, bottom-supported, 1999). Train capacities range from 213 (Cincinnati-Northern Kentucky Airport, Otis, 1994) down to 120 (Mirage Resort, Las Vegas, VSL/Lift, 1993; and Bellagio, Las Vegas, Yantrak, 1998). Overall system capacities in terms of passengers per hour per direction range from 8722 (4 independent systems, Narita Airport, Japan, Otis, 1992) down to 550 (Prim, Nevada, VSL, 1990). System lengths range from 1710 m (Sun City, Bophuthatswana, Otis, 1986) down to 140 m (Circus-Circus, Reno, Nevada, VSL, 1985).

Continuous Systems. Although POMA opened a system featuring conventional gondola technology in 1984 to serve the World's Fair being held in New Orleans , and an attempt was made to integrate it into the public transportation system, it subsequently was dismantled (4). Soule opened the first continuous system designed specifically for urban application in 1986 at its Paris-Nord demonstration site near Paris, France. The vehicles were bottom-supported, carried 12 passengers, and operated at a headway of 19 seconds over a 310 m (1017 ft) alignment. Soule subsequently opened two temporary systems at expositions - Vancouver's EXPO86 in 1986 (150 m), and Yokohama's YES89 in 1989 (650 m). Headways were 26 and 19 sec, respectively. The next permanent Soule system was opened in 1993 at Noisy-LeGrand in Paris to connect a RER station with an office center. Vehicles operate at 31 second headways along a 518 m (1700 ft) guideway. The next two systems will open for the new terminals at the Paris-Charles de Gaulle Airport (5). The shorter will eventually be 2800 m (9187 ft) in length and the longer 4500 m (14,765 ft); headways at build-out will be 21 sec. Four or five stations will be served by the shorter system and 6 by the longer system. Vehicles will carry 29 passengers. Soule vehicles do not come to a complete stop in stations, but move at a slow velocity for boarding.

In 1989, POMA opened a 1500 m (4922 ft) system featuring three 50 passenger vehicles in Laon, France (6). Headways can be varied between 60 and 120 seconds. Whereas the Soule system features one continuous haul rope that serves all the stations, the POMA 2000 system features a separate haul rope for each pair of stations. Vehicles are transferred from one haul rope to the next at the stations. In order to prevent a bunching of vehicles in the stations, the haul ropes are run at different speeds.

In the mid-1990's both Doppelmayr and Leitner completed development of continuous technologies and began marketing systems. The Doppelmayr CABLE Liner system has a target headway of 21.5 sec and a maximum length of 5,000 m (16,368 ft) (7). The system also is being marketed for reversible mode operation, and its first North American implementation will be as a shuttle (Mandalay Bay, Las Vegas, 1999). Trains will consist of five 32-passenger vehicles. The Leitner system features headways as low as 60 sec, and vehicle capacities which can range from 20 to 80 passengers (8). Alignments up to 6,000 m (19,686 ft) are reported to be feasible. Leitner indicates that plans are being developed to open a 3871 m (12,700 ft), 11 station system in Perugia, Italy around 2001. Dopplemayr hopes to construct a system in the Donau City Complex in Vienna, Austria. POMA and Otis have teamed to design a system for Zurich International Airport that will feature the POMA 2000 detachable grip and Otis' Hovair suspension (discussed below). Mitsubishi of Japan also has developed a technology featuring detachable vehicles suspended below a rigid guideway (9). The first installation of the technology is in Hiroshima; the system is 1300 m (4265 ft) in length.

Vehicle capacities for continuous technology range from 12 passengers (Paris-Nord, Soule, 1986) up to 92 passengers (Zurich Airport, POMA-Otis, 2002). The number of system vehicles range from 3 (Laon, POMA, 1989) up to 79 (Paris-de Gaulle Airport, Soule, 1999+). Headways range from 19 sec (Paris-Nord, Soule, 1986) up to 120 sec (Laon, POMA, 1989). One-way system capacity ranges from 1200 (Hiroshima, Mitsubishi, 1998) up to approximately 5000-6000 (Laon, POMA, 1989; and Paris-de Gaulle Airport, Soule, 1999+). System lengths range from 150 m (Vancouver EXPO96, Soule, 1986) up to 3871 m (Perugia [proposed], Leitner, 2001+).

OPERATING SPEED

Maximum operating speed also influences level of service. The longer the alignment, the more important speed becomes. This is especially true for reversible systems. Due to problems related to the dynamics of rapidly moving wire rope, the optimum haul rope speed for cable propulsion appears to be in the range of 10 to 12 m/s (33 to 39.4 ft/sec). As speed increases, the engineering problems involved with curved alignments and vibrations in the rope increase the cost of design. For many of the shorter systems, rope speeds are kept fairly low. For example, the early and relatively short VSL systems constructed in Las Vegas and Reno at the Circus-Circus resorts have speeds ranging between 4.1 and 6.1 m/s (13.3 and 20 ft/sec). The slightly longer VSL system constructed later at Prim has an operating velocity of 7 m/s (23 ft/sec), and the most recent VSL system at the Mirage Resort in Las Vegas has an operating speed of 8 m/s (26.4 ft/sec). Otis systems featuring Hovair suspension all have operating speeds in the range of 8.9 to 11.6 m/s (29.3 to 38.1 ft/sec), except for the relatively short Narita Airport system, which has a speed of only 5.6 m/s (18.4 ft/sec). The detachable POMA-Otis system to be installed at the Zurich International Airport is projected to have an operating speed of 13.4 m/s (44 ft/sec). The early Soule systems had operating speeds in the range of 4.2 to 5.6 m/s (13.7 to 18.2 ft/sec), but the most recent systems, which are being installed at Paris-Charles De Gaulle Airport will have operating speeds of 10 m/s (32.8 ft/sec). The more recently developed Doppelmayr and Leitner systems expect operating speeds to be in the range of 8 to 10m/s (26.4 to 32.8 ft/sec) and 6 to 8 m/s (19.7 to 26.4 ft/sec), respectively. Thus, there has been a trend toward increased operating speed.

The need to achieve higher operating speed and accomodate curved horizontal alignments led Yantrak to develop a serpentine belt, rather than an exposed cable, as the means for transmitting propulsive forces to vehicles (!0). The serpentine belt has steel cables embedded within it, and is powered by synchronous motors located on the towers that support the guideway. The Yantrak system operating at the Bellagio resort in Las Vegas is operated at 12.2 m/s (40 ft/sec), but the belt is claimed to be capable of propelling vehicles at operating speeds up to 18 m/s (59 ft/sec).

GUIDEWAY AND SUSPENSION

Concrete Running Surface The Circus-Circus system (VSL) constructed in Las Vegas, NV, in 1981 represented the first noteworthy departure from traditional cable funicular guideway technology. Although the propulsion hardware was standard funicular, the vehicle support was unique. Pneumatic tires and a concrete guideway were used, rather than the steel wheel - steel rail of the classic funicular. The advantage was a lighter vehicle, which reduced guideway loads and provided quieter operation. Concrete guideways had been used successfully by Westinghouse for a number of airport systems featuring independently propelled vehicles. The success of the first Circus-Circus system led to the construction of a second Circus-Circus system in 1985. In that same year, Circus-Circus also constructed two similar systems at its sister casino in Reno, NV. Of these four initial systems, three still operate. The first Circus-Circus system in Las Vegas was dismantled in the mid-1990's to accommodate new construction.

The next effort by VSL to advance the state-of-the-art of concrete guideways can be found in system opened at Prim, Nevada, in 1990. An effort was made to reduce guideway cross-section and produce a less massive structure. The guideway is only 1.52 m by 0.30 m (5 ft by 3 ft), and carries a single 60 passenger vehicle. The most recent cable system constructed by VSL (1993) is the 305 m (1000 ft) single-train system which connects the Mirage and Treasure Island resorts in Las Vegas. The choice of a concrete guideway for all of these systems may have been influenced by VSL’s expertise in pre-cast, post-tensioned concrete construction.

Between the time of construction of the first and second Las Vegas systems, a second new cable technology appeared. Otis developed and successfully marketed a system featuring air suspension. Instead of supporting the vehicle on tires, vehicles are supported by “Hovair” suspension, and float over a concrete guideway. Cushions of air are generated by circular rubber air pads mounted beneath the vehicles. The rationale was to eliminate point loads on the guideway, thereby lowering guideway construction and maintenance costs, as well as to lower vehicle weight and eliminate surface wear since the vehicle does not touch the guideway while in motion. The first installation opened in Serfaus, Austria in 1984. A second system opened in Tampa, FL in 1985, and a third system opened in Sun City, Bophuthatswana in 1986. Subsequently, Otis systems featuring Hovair suspension were opened at Narita Airport in Japan in 1992, Cincinnati Airport in 1994, and the J. Paul Getty Center near Los Angeles in 1997. The next scheduled Otis system will open at Minneapolis Airport in 2000.

Steel Beam Running Surface Aside from the VSL and Otis Hovair systems, and the traditional steel wheel on steel rail funicular systems, other suppliers of cable-propelled APMs have employed a hard rubber tire running on the top surface of a steel I-beam.

Soule, Doppelmayr, Leitner, Yantrak, and the POMA 2000 all employ the hard wheel and steel I-beam. These systems appeared after VSL and Otis had developed concrete guideways. The advantages of steel construction are a lighter and less massive guideway, which allows more light to penetrate to ground level, and rapid construction. Also, guideway super-elevation can be achieved more easily. Super-elevation on the Yantrak system is achieved by outrigger wheels which tip the vehicle. The outrigger wheels ride on the top of a rail which is attached to the guideway. The elevation at which the rail is attached to the guideway determines the amount of tilt given to the vehicle. Thus, the guideway surface itself does not need to be sloped. Curve radii as low as 30 m (98.4 ft) are feasible with the Soule, Doppelmayr, Leitner, and Mitsubishi systems.

Suspended Vehicles In general, technologies featuring suspended vehicles have not been selected for urban and non-ski resort systems. Although suspended vehicle systems have been studied and proposed for a number of cities in North America, only the aerial tramway at Roosevelt Island and a VSL system constructed in 1982 in Memphis, TN have utilize suspended vehicles. However, the POMA 2000 is offered as a suspended system under the name TRASSE (11), and the Mitsubishi system is suspended. The TRASSE utilizes track ropes for vehicle support, but the Mitsubishi system utilizes two parallel steel I-beams closed at the bottom.

CONCLUSIONS

In 1981, only one firm had successfully implemented a cable propelled technology designed specifically for urban and non-ski resort applications, and reversible operation was the only mode of service available. By 1999, seven independent suppliers and one consortium were marketing thirteen different technologies. This number of technologies was arrived at by considering Doppelmayr to be offering two systems since the CABLE Liner is being marketed in both reversible and continuous modes, and by considering Soule to be offering its technology in two different versions, the smaller SK 4000 and the larger SK 6000. Also, the POMA 2000 is offered in a configuration featuring both bottom supported and suspended vehicles. Seven of these technologies offer continuous service.

Suppliers have worked to increase operating speed and reduce the bulkiness and cost of the guideway. They also have found ways to achieve small radius horizontal curvature, which is essential for many urban applications. These improvements have increased the size of the potential market for cable propelled systems, and make them increasingly competitive with the more costly APM technologies which feature self-propelled vehicles. It is noted that cable systems are being installed in airports, a market which previously had been dominated exclusively by suppliers offering systems with self-propelled vehicles. If the market for APMs continues to grow, cable technology should be able to capture an increasing percentage of new contracts. Hopefully, there will be sufficient demand for cable systems to encourage the present suppliers to remain active in the market and expend resources on R&D activity to find ways to continue to improve the performance of cable systems and reduce construction costs.

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Year	Supplier	Location	Length, m (ft)	Capacity, Pass/hr/dir	Vehicle Capacity	Vehicles per TU	Number of TU's	V m/s (ft/sec)	Stations	Comments
1977	Von Roll/VSL	New York, NY	361 (958)	1500	126	1	2	7.3 (24)	2	Aerial Tram
1981	VSL	Circus I, Las Vegas, NV	401 (1315)	1639	50	1	2	6.1 (20)	2	Dismantled
1982	VSL	Memphis, TN	457 (1500)	3600	180	1	2	8.1 (26.7)	2	Suspended
1984	Otis	Serfaus, Austria	1300 (4265)	2000	135	1	2	11.1 (36.7)	4	
1985	VSL	Circus II, Las Vegas, NV	209 (686)	1250	54	1	1	6.1 (20)	2	
1985	VSL	Circus South, Reno, NV	213 (700)	1250	50	1	1	6.1 (20)	2	
1985	VSL	Circus North, Reno, NV	140 (460)	1363	50	1	1	4.1 (13.3)	2	
1985	Otis	Harbour Island,Tampa, FL	762 (2500)	3000	100	1	2	11.1 (36.7)	2	
1986	Otis	Sun City, South Africa	1710 (5610)	2400	100	1	2	11.1 (36.7)	3	
1990	VSL	Primm, NV	550 (1740)	550	60	1	1	7 (23)	2	
1992	Otis	Narita Airport, Japan	319 (1047)	8722	150	1	4	5.6 (18.4)	2	4 independent systems
1993	VSL/Lift	Mirage, Las Vegas, NV	305 (1000)	1800	60	2	1	8 (26.4)	2	
1994	Otis	Cincinnati Airport, OH	358 (1174)	5600	71	3	2	11.6 (38.1)	3	
1994	Yantrak	Mammoth Mountain., CA	1219 (4000)	na	28	2	1	10 (33)	3	Not operating
1997	Otis	Getty Museum, Los Angeles, CA	1200 (3960)	1200	35	3	2	8.9 (29.3)	2	
1998	Otis	Mystic, Boston, MA	235 (770)	1600	45	1	2	8.9 (29.3)	2	
1998	Yantrak	Bellagio, Las Vegas, NV	750 (2460)	3085	40	3	2	12.2 (40)	2	
1999	Doppelmayr	Mandalay Bay I, Las Vegas, NV	838 (2749)	1900	32	5	1	10 (32.9)	2	
1999	Doppelmayr	Mandalay Bay II, Las Vegas,NV	838 (2749)	1300	32	5	1	10 (32.9)	4	
2000	Otis	Minneapolis Airport, MN	335 (1100)	2600	65	1	2	8.9 (29.3)	2	

TABLE 1. Reversible Systems

Year	Supplier	Location	Length, m (ft)	Capacity, Pass/hr/dir	Vehicle Capacity	Number of Vehicles	Headway, s	V m/s (ft/sec)	Stations	Comments
1984	POMA	New Orleans, LA	1067 (3500)	1800	6	58	12	5 (16.4)	2	Dismantled
1986	Soule	Paris-Nord	310 (1017)	2300	12	16	19	5.6 (18.2)	2	
1986	Soule	Vanncouver EXPO86	150 (492)	1800	12	12	26	4.2 (13.7)	2	Dismantled
1989	Soule	Yokohama YES89	650 (2133)	2800	15	25	19	5.5 (18)	2	Dismantled
1989	POMA	Laon, FR	1500 (4922)	2000 - 6000	50	3	60 - 120	7 - 9.7 (23 - 26.2)	3	
1993	Soule	Noisy-LeGrand, FR	518 (1700)	1800	15	12	31	5.5 (18)	2	
1999	Soule	de Gaulle I, phase 1	3524 (11,562)	2900	29	38	36	10 (32.8)	5	
	Soule	de Gaulle I, phase 2	4500 (14,765)	5000	29	79	21	10 (32.8)	6	
1999	Soule	de Gaulle II, phase 1	865 (2838)	2900	29	19	27	10 (32.8)	3	
	Soule	de Gaulle II, phase 2	2800 (9187)	5000	29	70	21	10 (32.8)	4 - 5	
1998	Mitsubishi	Hiroshima	1300 (4265)	1200	25	69+	75	5 (16.4)	3	Suspended
2001	Leitner	Perugia, IT, phase 1	2500 (8202)	na	na	na	na	6 - 8 (19.7 - 26.4)	na	
	Leitner	Perugia, IT, phase 2	3871 (12,700)	3000	na	22	na	6 - 8 (19.7 - 26.4)	11	
2002	POMA-Otis	Zurich Airport	1200 (3937)	4000 - 6000	92 X 2	3	154	13.4 (44)	2	

na - (not available)

TABLE 2. Continuous Systems