Aerial People Movers

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1. Introduction

This paper will address the use of ropeways to create a network of aerial linked transportation hubs within an urban environment. Multiple ropeways would share common hub terminals where passengers load, unload or remain in the carriers to be transported to their destination hub. Carriers are circulated within the network independent of the ropeway link that they currently travel and are transferred between links within the hub terminal or returned to its originating hub. Carrier spacing would be variable.

All carrier movement within terminals is controlled by linear synchronous motors (LSM) that are mounted above the carrier path. A permanent magnet is located on each grip assembly in the same location as the current friction plate. The electromagnetic interaction between the LSM and the carrier magnet controls individual carrier movement within the system.

The carrier destination is determined by the control system. Control decisions are based on historic records, expected events and on current system demands. Carriers circulate in high demand areas for maximum utilization during high demand times. During lower demand periods, carriers are positioned in parking structures and are ready to respond to the next demand period. Carrier spacing is variable as long as the number of carriers within each hub remains below the maximum allowable capacity. The control system monitors carrier positions in real time and enforces system parameters. Excess carrier path length within the hub creates buffer zones and increase system flexibility.

Aerial People Mover systems have the potential for having a positive impact on urban life by providing transportation within walking distance that is cost and energy efficient. Aerial systems are very high capacity with minimal headway time due to the systems continual cycle. The

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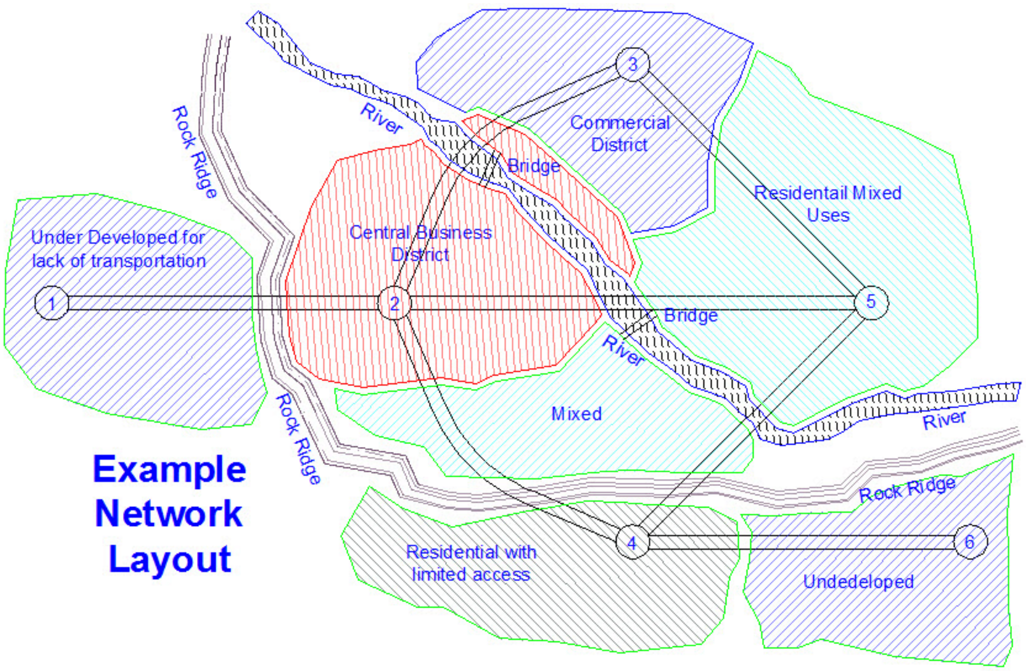
system does not emit any local pollution (dependent upon the means of power generation, this form of transportation could be emission free). Because of the system's 3S configuration it can be operated in all but the most inclement weather conditions. This paper will discuss the benefits of aerial transportation, how it functions and a social model that may fund the creation of a network within the next decade.

2. Physical Layout of Network

The initial layout of the network is critical to its success. If properly designed, it will meet established needs and provide opportunities for economic development and growth. Network hubs are selected based on a number of often competing physical, social and economic factors. Logical locations for hubs include:



1. High volume demand areas that are presently inadequately served by surface transportation such as town centers with retail and offices (Hub 2).
2. Manufacturing areas that rely upon workers during business hours, but are not located near a transit system (Hub 3).
3. Both high and low density residential areas that require vehicles to get to the main transit system station and then parked for the balance of the day. This distance can be as short as ¾ mile.
4. Mixed residential and commercial areas with high population density (Hub 5).
5. Areas that are physically isolated from the main part of the city by topography. Physical blockages may include rivers, railroad yards, highway systems, etc. (Hub 4).

6. Areas of high population density that are underserved by the current transportation system (Hub 5).
7. Land that has major development potential, but lacks transit access for a variety of reasons (Hub 6).
8. Land near major surface transportation links that provide efficient commercial access for product transfer stations. The network is capable of transporting material. Pallets could be loaded on freight carriers and be delivered to small businesses near hubs.

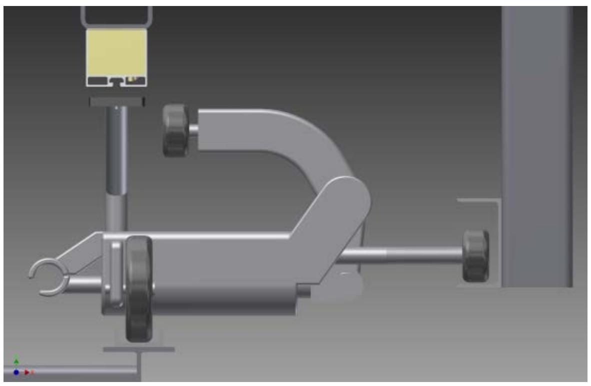
The process of developing the network will be controversial. Planning for the ultimate network is important because each hub is designed for a specific number of links. Unless anticipated, adding links into an existing hub would require extensive modifications. In addition, the rotation of travel on each link (clockwise or counter-clockwise) must be consistent for the entire network. Early decisions include the width and load capacity of the standard carrier to ensure consistent hub design for both passenger and freight carriers.

A primary goal of the network's design is to space a hub within comfortable walking distance from any point within the network. Studies have shown that passengers are more willing to walk a reasonable distance (typically ¾ of a mile) to a transportation system that meets their needs.

3. Linear Synchronous Motors

A linear motor is an electric motor that has had its stator and rotor "unrolled" so that instead of producing a torque (rotation) it produces a linear force along its length by creating a moving magnetic field. In a Linear Synchronous Motor (LSM) the rate of movement of the magnetic field is controlled (usually electronically) to position the object within the field. For cost and space reasons the linear synchronous motor rotor is often a permanent magnet.

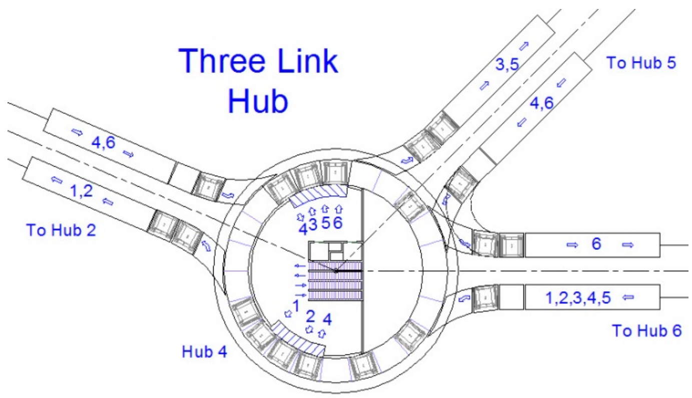
The LSM was first investigated around 1840, but was very inefficient. By 1935 there was a working model for propelling trains. The technology has now advanced to the point that LSMs are the primary form of propulsion for high speed trains and new subway systems. New roller coasters are often propelled by LSMs that launch the carrier up the lift hill. LSMs along the track have the ability to enforce speed and carrier spacing. In addition, LSMs along the track can continue to add energy to the carrier and increase the effective height of the lift hill. LSMs are used for heavy lift applications, air craft carrier launching, high speed elevators and automated pallet movement in warehouses.



The use of LSM technology replaces the current rotating tire propulsion system with a continuous line of stationary electric stators. The firing of each stator is controlled by the system and therefore is the control for each carrier within the network. The rotors are permanent magnets that are mounted on the carrier in the same place as the current friction plate. With current technology, the permanent magnet is only slightly longer than the current friction plate. The grip and the opening/closing mechanism remain unchanged from today's current chairlift design. There are no moving parts or mechanical contact within the carrier propulsion system.

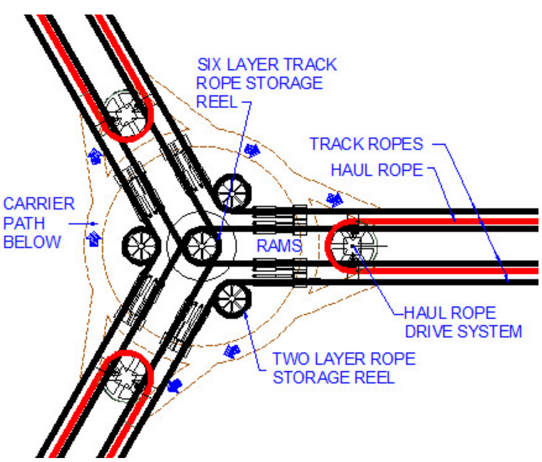
4. Terminals

The APM terminal function is similar to the current detachable terminal in that the carrier is decelerated, conveyed and accelerated back to line speed. In an APM terminal, there is a continuous line of LSM stators along all of the carrier paths. Each individual carrier is under total control of the LSMs from the time it enters the terminal until it is propelled back to line speed and reattached to the haul rope.



The APM terminal layout is similar to a traffic circle. The incoming links are like roads. Unlike a traffic circle, the APM controls carrier movement and overhead switch rails position traffic within the hub based on system demands. Because there is excess carrier capacity within the circle and link constant speed conveyance, the control system continually adjusts spacing to create the maximum amount of system flexibility. Carrier movement within the hub is affected by demand. During lightly loaded times, a carrier may move through the terminal in a matter of seconds, while during peak demand periods carriers may remain in the terminal slightly longer while carriers load ahead.

The loading platforms for terminals are typically above ground level to eliminate the need for major elevation changes as carriers exit the hub. These elevated loading platforms allow access to be tightly controlled. Only passengers who the system determines have an incoming carrier with excess capacity to their destination hub are allowed access to the escalator or stairs to the platform. This level of control allows for efficient loading/unloading of carriers as they move slowly through the door open area. Door open time may be reduced to less than 10 seconds. Once the doors are closed, the carrier can be quickly positioned for exit from the hub.



Hubs are designed to take advantage of the tension forces. All links intersect to a common point in each hub. Horizontal forces are partially resolved in each terminal by the nature of the design. The intersection of multiple links into a common point allows the track rope bollards to be shared between links. Common bollards within the hub would have independent unspooling on a common spool to allow for track rope repositioning on each individual link. The use of hydraulic rams allows for active repositioning of track ropes as needed.

5. Systems Control

Fundamental to the APM system is the ability for carriers to freely move throughout the system allowing it to meet ever changing demands. The system controls the circulation based on historic records, planned events, predicted events and the current demand at each hub. The system's intelligence allows for operational flexibility in the event of a failure within a specific link.

Much of the system's intelligence and flexibility is integrated in a manner that allows the passengers to flow through the system without ever recognizing the complexities of the network. As passengers enter a station, they select their destination hub on an automated ticketing station. The station recognizes their RFID transit pass, notes their selected station and displays the time their carrier will be entering station and the time they can enter the upper platform. Due to the continuous nature of system and its high capacity, passengers can typically enter the upper platform immediately. If traffic volumes are unusually high and there is a wait, the passengers wait in the lower terminal until the time they were given when they purchased their ticket. Only after that time will the turnstiles to the upper loading platform allow them to enter (by reading the RFID card). Once on the upper platform passengers are directed to cabins traveling to their destination hub with color coded lights and text on the individual carriers. As they enter the carrier their RFID card is again read. This allows the system to monitor when a passenger's commute begins and how full each cabin is.

Passengers may pass through several hubs before arriving at their destination hub. At the intermediate hubs, other passengers may load as the carrier moves through the terminal. If no passengers are waiting at the hub, the carrier doors do not open and the carrier is positioned for launching to the next hub.

By design, the system optimizes the number of passengers in each carrier. Hubs with decreasing demand are assigned fewer carriers. The operation of the system is based on historic records and anticipated events, but is influenced by the current demand of passengers waiting to be loaded. Over time the system will anticipate changing demands based on historic records and rules established by the programmer.

As a carrier approaches its destination hub, the color marking and destination name on the outside of the carrier change to reflect it's the next destination hub. All passengers get off at their destination hub at the time predicted on their tickets while the waiting passengers only see an incoming carrier that is marked with the new destination. While exiting the hub, the passengers RFID card is read, they are charged for the trip and the data is stored in the system's records.

The information of each passenger trip is stored in the system for analysis and software control refinement. The accumulated information in the database largely determines each carriers new destination hub after has reached its previously assigned hub.

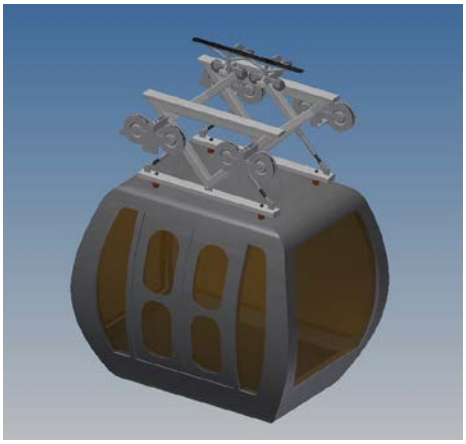
In addition to RFID passenger tracking, each carrier has an RFID tag as well. There are RFID readers at the hub entrances and exits, in the carrier buffer zones and in the hub circle. As a carrier passes a sensor, the data is analyzed and recorded in the system. If the carrier is not in its predicted location, the system analyses the situation and selects an appropriate action.

During operation, the control system knows the exact location of each carrier, its destination hub and the number of passengers in the carrier. For security purposes a digital image of each carrier may be captured as they pass through hub stations. These images may be shown on control station monitors as they enter subsequent stations. In the event of a distress call or another emergency situation, transit staff and security could retrieve the image prior to the carrier entering the terminal to be more prepared for the given situation.

A key component to a successful transportation network is operational flexibility. Even with a fully automated control system there are unexpected operational delays: failed switches, carriers stopped for handicap access, mechanical breakdowns, etc. The APM system increases flexibility by not fully populating the network with carriers at any time. By operating the network at slightly below its maximum capacity even during peak demand periods, the terminal buffer spacing allows for the system to respond to operational delays without slowing either a link or the entire network.

To increase operational flexibility, carriers that are not needed to meet the current or anticipated demand are removed from the network and parked in structures. If needed, carriers can be fed into the network to temporarily increase capacity on high volume links. As anticipated traffic demand changes, some carriers circulate on higher volume links while others are repositioned into parking structures near the next anticipated demand hub. As an example, carriers are prepositioned after the evening rush in parking structures near historic morning demand areas in preparation for the next demand period.

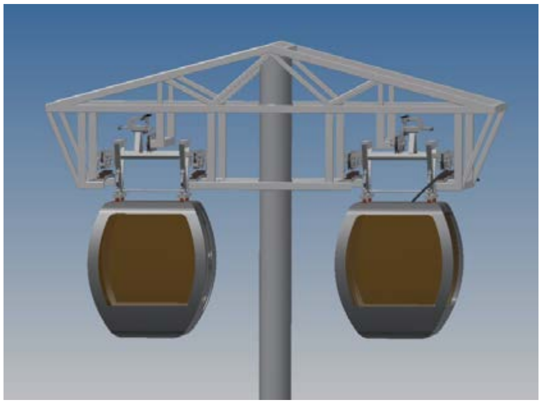
6. Carriers



APM carriers would come in a variety of passenger configurations and would be sized dependent on the networks anticipated demand. Cabins could have a seated capacity of ten around the three sided perimeter with five additional standing passengers if needed. At an arbitrary six second carrier interval, the system's hourly capacity would be 9,000 passengers on each link in each direction. The carrier design would be optimized into a rectangular shape to ease walk-in loading and allow for wider doorways. Dependent upon the environment the system is operating in, carriers could have many of the amenities of a small bus. Air-conditioning, heating, LED lighting, two-way voice communication and Wi-Fi could all be provided within the cabin. All of these systems would be powered with the carriers' battery system. The batteries are constantly recharged in each hub or in parking structures through a hot rail.

7. Line

The ropeway design uses dual track ropes and a single haul rope to maximize system stability. The carrier is supported on four double articulating two wheel bogies. Future advanced hanger designs may use a GPS controlled suspension system that super elevates carriers around long radius horizontal curves. This future level of suspension control would allow for rope speeds to be increased and decrease network travel times even further.



The system benefits from using high tension track cables. With the proper tensioning, passengers would feel minimal vertical acceleration between support towers and across long radius saddles as they pass through towers. Eventually, the use of ultra high tension fiber cables will create the equivalent of two rigid rails. With high tension, long length horizontal saddles and real time system adjusted carrier suspension system, the line speed could be dramatically increased.

8. Freight

In certain situations, an APM system may serve dual roles as both passenger and freight transit. If large carriers are used, the interior dimensions are large enough to transport slide-in containers. The system could be used during lower traffic times to effectively distribute material throughout the system. The use of the system for delivery has the potential to reduce traffic and pollution in the high density areas the hubs serve. Elevators would be used to move the containers to lower levels where they are transferred to ground transportation for distribution.

9. Operations

The operation of the APM system differs from all other transportation systems. With the APM, the location of every carrier and passenger is known. The system controls all link rope speeds, carrier destinations, carrier spacing, traffic in the hub, buffers and switches. Operational personnel have a minimal role in passenger control. Ticketing at the hubs is automated. Passengers do not rely upon any operational personnel to get to their destination. Most hubs need only one or two operator/security/maintenance personnel on duty. Their role is to monitor the loading platform and to respond to the unexpected issues.

The APM is controlled at the master control center. In this center, the system operations monitor the entire network for unusual occurrences such as mechanical breakdown, medical emergencies, unlawful activities and unexpected volumes. Video cameras at the waiting areas, loading platforms and machine rooms are constantly monitored. All machinery is monitored by sensors that continually verify that all components are operating within acceptable ranges. Redundancy is provided on all critical components. Response to unusual conditions is primarily controlled by software. Under certain conditions, operators can over-ride the system for security issues such as intentionally stalling a carrier where suspected activity has occurred until proper security has been established at the next hub.

10. Maintenance

Maintenance of the APM is less than for other transportation systems. The biggest difference between other traditional systems is that each carrier is not powered by its own engine. The passenger to vehicle weight ratio is very high. The driving force for the entire system is electric motors that power each link. All links have multiple drives available if the primary drive is inoperative or being maintained.

The use of LSMs instead of a conventional terminal belt/pulley system to move the carriers eliminates most of the moving parts and drastically reduces maintenance.

11. Financial Model

Ropeways are rarely used for mass transportation in urban environments. Mono-cable ropeway are weather sensitive, have low capacity and slow speeds. The initial construction cost along with limited applications for a simple circulating system ropeways have made it difficult to financially justify.

Although there is a continual demand for additional urban transportation throughout the world, few new systems are being built. The cost of conventional systems is so great that it is difficult to obtain enough government funding. Private/Public business partnerships have been used to construct toll roads, but this cooperation is rarely seen in other forms of transportation.

One model that has proven to be successful is the subway/bus network in Hong Kong. MTR Corp. is responsible for designing, funding, constructing and operating these vital links in Hong Kong. The company is a major land developer with shopping malls, high rise housing mega-projects, office building etc. MTR's transportation network is so effective and vast that it transports 5.1 million passengers every weekday.

The key to the MTR's success is the special relationship it has with the Hong Kong government. The government is responsible for designing the master transportation system in concert with MTR. The transportation network analysis identifies area of high demand with low existing system capacity. Once a transit site is defined the government condemns the property. MTR is granted exclusive development rights in exchange for funding the construction of the subway. Their development of the site with multi-story, mixed use buildings along with the increased traffic brought by the subway system increases the previously underdeveloped site's value. Daily transportation fares fund system maintenance. The citizens of Hong Kong are majority owner of MTR's stock and benefit from both its success as a developer and the transportation network it's constructed.

Recent subway construction costs range between $150 and $300 million per kilometer. The average cost of a light rail system in the United States is $109 million per kilometer. The price per kilometer of a new six passenger monocable gondola is about $12 million (including terminals). Using current technology, the same ropeway could be constructed using LSM technology for about $14 million per kilometer. Assuming additional money for system control, software development and track cable system, the cost per kilometer would likely be below $35 million per kilometer even in an urban environment.

The economic model outlined above is very attractive in applications around the world that have urban growth and densification without access to transportation. The development of a low cost reliable mass transportation system is a key component to economic growth. Growth patterns in many urban areas have large areas of single or two story residential units. The APM network alignment has more freedom of design in these areas because they pass above existing structures.

Of greater importance, the APM hub becomes an epicenter for development due to larger volumes of pedestrian traffic. As seen in the Hong Kong model, the increase of land development potential on property surrounding the hubs can generate the capital for construction of the APM.

The Hong Kong model demonstrates that there must be a strong tie between the local government and the corporate interest that is responsible for the systems development and operation. The corporation has great potential for being very profitable and rewarding investors with solid returns. The people of the community, who own a controlling interest in the corporation are rewarded with economic growth and given a reliable transportation system.

12. Summary and Conclusions

A well designed and operated APM network would have a significant impact on the lives of millions of people around the world who live in crowded conditions without access to transportation. There are very few options for providing expanded transportation for urban dwellers that live in high density urban areas. Currently these residences must rely on private vehicles, local transportation or travel by foot or bike. The result is not only excessive traffic on streets, but a loss of economic development potential along with air, noise and lifestyle pollution that affects all people.

The utilization of a high capacity aerial urban transportation system has not been successful because there has not been the synergism of the technology until recently. The key component is the recent development of computer software (i.e. Watson in Jeopardy) that can analyze large amounts of data and within defined rules modify its own code to match observed condition. The larger the amount of data to analyze the more likely the system will accurately predict the proper operation of the network and respond to predictable, but unscheduled events.

The second key to the development of the APM is the use of computer controlled LSM to control the movement of each carrier within the network when it is not attached to the haul rope. Although LSM technology is well established, the ropeway industry has not recognized the benefits of the system nor is it currently developing a working system for circulating mono-cable systems.

The future is quite clear. Within the next decade, an APM system will be developed and installed. There are no other options. We can’t afford to build subways and more highways. Traffic will continue to increase for lack of any other option. Aerial network systems can be developed with current technology and data driven software to create an urban transportation system that can overlay existing established surface systems to widen the direct access corridor for walking passengers. The APM can be constructed at a small fraction of the cost of any alternatives. With the proper collaboration between the citizens and corporations, the APM can be built and operated for the benefit of all.