THE INHERENT ECONOMIC AND ENVIRONMENTAL ADVANTAGES OF AEROMOVEL TECHNOLOGY

Banning Garrett

Aeromovel offers superior automated transit system technology now and in the future compared with other existing and planned systems. Aeromovel makes possible an elevated system that is substantially more energy efficient, is less expensive to build, operate, and maintain, and has a lower profile with a smaller footprint, thus requiring less land and disruption in the construction process than any other elevated system.

Aeromovel's advantages lie in the nature of the technology itself. It is Aeromovel's patented pneumatic propulsion system that makes possible an automated people mover that is inherently more environmentally and economically sustainable. Moreover, Aeromovel, like the electric car and the hyperloop, is the realization of a better idea from the 19^{th} Century that only now has become technologically practical and economically cost effective.

Back to the Future

Aeromovel's pneumatic technology follows a pattern of ideas that are born before a time when they can be effectively realized. These are brilliant inventions, but the existing technology to realize the idea is immature or non-existent. The first experiments or products are promising, but disappointing as practical systems. These systems are overtaken in practice by systems that are less advanced in technological concept but more practical based on the existing technology. But eventually the more advanced technological solution matures and makes possible realization of the earlier idea. Finally, the new technology challenges and eventually replaces the interim solution.

We have seen this pattern with the electric car. The first electric cars were built in the early 19th Century and by the early 20th Century, they were more popular than internal combustion (ICE) engine cars, with 38% of the market compared to 22% for ICE and 40% steam driven. The first vehicle of any kind to break the 100 km/hour speed barrier was electric. But these cars had heavy lead batteries with poor range, and were twice as expensive as automobiles with internal combustion engines, which by the 1910s were made affordable by Henry Ford with the Model T assembly lines and by the emergence of the petroleum industry to provide cheap fuel. By the 1930s, production of electric cars had ceased.

Source: boereport.com

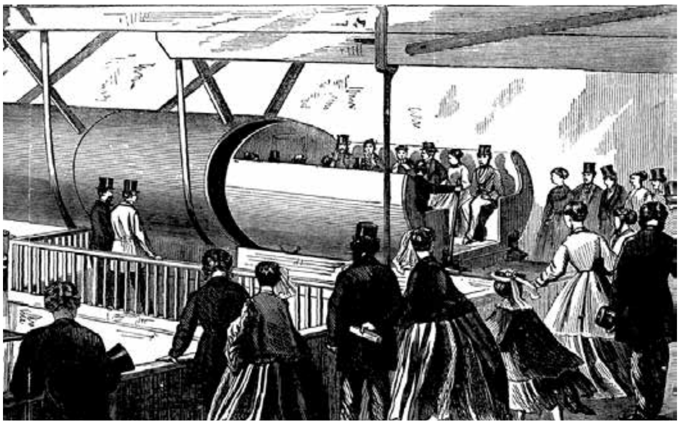
Source: www.flickr.com/photos/automobileitalia/44751575205

Photo of an electric car built by Thomas Parker in England, 1895, and a Tesla Model 3

The ICE has been the dominant technology for cars and trucks for the last century, despite being very complicated, expensive to build, highly inefficient, and a heavy power system requiring a similarly heavy and complicated transmission. The ICE has been engineered to be increasingly fuel efficient, but the technology has nearly reached its limit with only incremental gains possible. Meanwhile, technological developments have made electric cars increasingly viable. The main drawback has been the cost and range of batteries to power electric cars, but battery technology is improving rapidly and dropping in cost. Ultimately, electric cars are simpler, with fewer moving parts and lighter drive trains. They will be cheaper to build, to operate, and to maintain. Moreover, electric cars are becoming iPhones with wheels, building on all the extraordinary advances in digital technologies and sensors of the last several decades, from microchips to the Internet to the GPS system, to become self-driving vehicles.

The ICE will not disappear overnight, but it is an interim technology that likely will eventually become a novelty. As The Economist put it in August 2017, "the internal combustion engine had a good run. But the end is in sight ...." The internal combustion engine car can be likened to the Cathode Ray Tube (CRT) television or computer monitor that is heavy, large, and expensive to build and ship. Once the flat screen became good enough and cheap enough, it was clearly superior to the CRT, which has virtually disappeared – and now flat screens are far superior to CRTs in performance and cost. The same is likely to happen with ICE cars that will be "obsolesced" by electric vehicles.

The "Hyperloop" similarly is a technology with 19th Century roots. Inventors built experimental systems to send trains through large pipes using pneumatic air pressure. Although a number of such systems were built up through the end of the 19th century, including in New York City, the technology was not mature enough for these systems to be practical. Subway transit systems were built with more conventional technology, first with steam engines and then electric motors, as continues to be the case. Now, however, the technology is maturing to bring back the pneumatic tube for transporting people. The race is on to build the first hyperloop system that will transport people and cargo over hundreds of miles at up to 700 miles per hour.

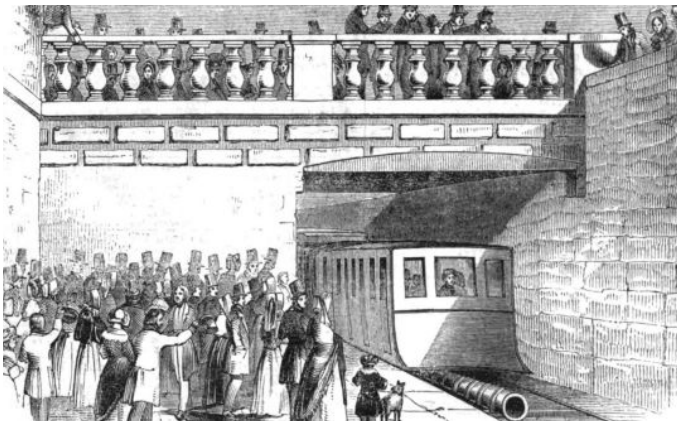


Source: slate.com

Source: shutterstock.com

An illustration of the short-lived Beach Pneumatic Tube transport system in New York City, 1867, and an artist's vision of a Hyperloop pneumatic train in the near future

Aeromovel also has roots in the 19th Century with a superior idea but immature technology. In the early 1800s, a number of inventors proposed a pneumatic transportation system that had many potential advantages over steam engine-powered trains. The rail car was much lighter and required less energy to operat since there was no engine in the car itself, which traveled on rails above a pipe through which compressed air pushed or pulled the vehicle forward by pressure on a "piston" through a slot along the pipe at the bottom of the rail car. The system was safer since it was held on the track and could not derail. It could also negotiate higher grades and sharper turns. Various attempts to build a viable system were deployed in the middle of the 19th Century, including the Dalkey Atmospheric Railway, the first commercial system, which operated from 1843-1855. While the pneumatic railway concept was theoretically superior to the steam engine, the technology of the times was too primitive to build a competitive system. Pneumatic-powered trains were abandoned until Aeromovel capitalized on new technology that made the superior idea of the previous century a viable and superior alternative to other systems. Aeromovel introduced electric blowers, an elevated guideway that is also the pneumatic tube, and the concept of using low pressure. The system was patented in five countries including UK, where the first patent was awarded in 1979.



Source: irishtimes.com

Source: Aeromovel pictures database

An illustration of the Dalkey Atmospheric Railway in Ireland from the London News, January 6, 1844, and Aeromovel's pneumatic automated people mover in Porto Alegre, Brazil (Aeromovel 2.0)

It's in the Technology and System Design

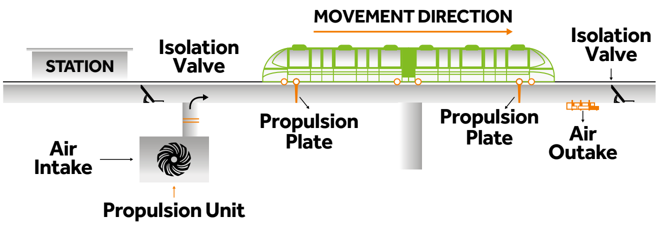
Aeromovel is the technology of the future. It makes obsolete the costly, complex, inefficient, and environmentally and economically less sustainable "interim technologies" that have been employed in conventional APMs. The Aeromovel system can contribute significantly to efforts by cities around the world to meet the UN's Sustainable Development Goals (SDGs), especially SDG 11, on sustainable cities and communities, SDG 13 on climate action, and SDG 9, on industry, innovation, and infrastructure.

This pneumatic technology makes Aeromovel's system inherently more economically and environmentally sustainable compared to other automated people mover (APM) systems and other mass transit alternatives. Aeromovel has been adapting technological developments to constantly improve its APM system, the first iteration of which was built 30 years ago in Jakarta (Aeromovel 1.0) and is still operating. The Aeromovel platform has room for continued improvement. Aeromovel 2.0, which was built in Porto Alegre in 2013, has many improvements from the first system. The current Aeromovel system, 3.0, has many significant, patented improvements over 2.0 to further enhance performance. Future iterations for 4.0 will capitalize on new materials like carbon fiber and CO2-sequestering concrete, manufacturing techniques such as 3D printing, advanced sensors of the Internet of Things, and artificial intelligence to further reduce energy requirements, improve efficiency of operations and maintenance, and enhance environmental sustainability.

Conventional APM systems designs are based on onboard electric motors and powered by high-voltage lines along the guides. The cars are inherently heavy as a result of the large electric motors powering the train and the floorboard reinforcement to protect passengers from motor malfunction. The weight is a primary factor in the energy consumption of the system, which has a high dead-weight to passenger ratio. The heavy weight of the cars also is a critical factor in the size and strength requirements for the piers and trackway supporting the system.

The Aeromovel system takes the revolutionary step of eliminating the need for onboard motors. This step has profound implications for the entire system. Firstly, it reduces the weight of the cars by nearly 50%. Secondly, the lighter cars substantially reduce the energy requirements of the entire system. Thirdly, the lighter cars reduce required strength (and bulk) of the elevated system on which they ride, which reduces cost and time in construction and the footprint and profile of the elevated system.

The key is that the cars are powered by air blown through a concrete box girder that forms an air duct under the running rail. Each car is attached to a square plate — a "piston"— within the duct that is connected by a mast running through a longitudinal slot that is sealed with rubber flaps. Stationary electric air blowers are located along the line to either blow air into the duct to create positive pressure or to exhaust air from the duct to create a partial vacuum. Very simple - the pressure differential acting on the piston plate causes the vehicle to move or stop (with stopping augmented by onboard friction brakes).



Source: Aeromovel database

Illustrative image of the Aeromovel's working principle

The propulsion system of blowers (about every passenger station) reduces electricity consumption per passenger by 2 or 3 times compared with conventional systems. Propulsion by air also has the advantage of eliminating the need for traction by the wheels to move the system. This allows for the use of steel wheels on steel tracks instead of rubber tires on concrete, which have five times more friction. Unlike the steel wheels and rails which last for years, the rubber tires have to be replaced frequently (at significant cost) and the pressure on the concrete guiderails can wear the concrete surface requiring expensive and time-consuming overhaul of the guidewas. While most APM systems ride on rubber tires along concrete guideways, there are some APMs that, like Aeromovel, ride on steel wheels on steel rails. But the systems with steel wheels and rails also rely on friction and traction for movement, their wheels and rails also require expensive and complicated repair and replacement. Since the Aeromovel cars are pushed by air and don't require traction, their wheels last far longer and the rails last indefinitely (they have not been replaced in Jakarta even after 30 years of operation). Moreover, both types of APMs with on-board engines are very limited in ability to climb gradients, while the Aeromovel trains, since they are pushed by air rather than propelled by traction, can climb gradients of 7.5% or greater.

In addition, the Aeromovel wheels are independently mounted rather than on a rigid axel used in cars with electric motors and thus the trains can make much sharper turns. This makes possible designing a system that weaves around pre-existing obstacles, as was done with the Aeromovel system in Porto Alegre, which was built to circumvent pre-existing freeways and bridges, none of which had to be shut down or modified during the system's construction.

Overall, the Aeromovel's inherently superior technology and design makes possible a system that is superior to all other APM systems on the most critical environmental concerns and on cost of construction, operation and maintenance. The system is superior or comparable to all other systems on a long list of system requirements and technical specifications. Moreover, the Aeromovel platform can be continually upgraded by new advances in technology.

	Aeromovel 1.0 Jakarta (1989)	**Aeromovel 2.0** Porto Alegre (2013)	**Aeromovel 3.0** Current design	**Aeromovel 4.0** 2020 design
Transportation Capacity	Low to medium-capacity loop system	Low-capacity single shuttle system	Medium to high-capacity pinched-loop system	High-capacity integrated network
Top Speed	70 km/h	80 km/h	80 km/h	120 km/h
Blower Speed	Fixed	Variable	Variable, feed-back control	Variable, feed-forward control
Operation	Semi-automatic, attended	Automatic, attended	Automatic, unattended	A.I. automatic, unattended
Vehicle carbody	Riveted aluminum plates on steel frame	Fiberglass	Adherent aluminum plates on steel frame	Ultralight carbon fiber monocoque
Guideway	Isostatic single-web concrete beams	Isostatic single-web concrete beams	Hyperstatic doubleweb concrete beams	Spatial steel-truss beams
Switch	No switch	Low-cycling switch	High-cycling standard crossover	Double slip and scissor-type crossovers
Rail Fastener	Rigid	Elastic	Elastic low-noise and anti-vibration	Advanced low-noise and anti-vibration

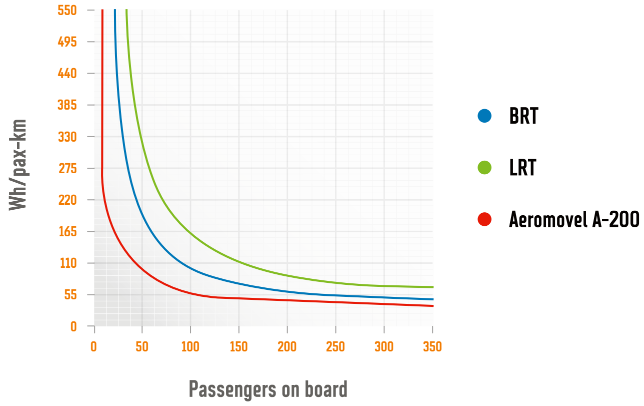
Technological Superiority Reduces Cost and Environmental Impact

Land acquisition costs: Land acquisition for a transit system can easily cost up to $50 million per kilometer and can complicate a transit project with legal variables and right-of-way challenges. Aeromovel can bring enormous advantages in land requirements compared to street cars, light rail, and even other elevated technologies, including monorails and conventional people movers. Due to its elevated design, low-profile, and sharp turning radius, Aeromovel can significantly reduce land acquisition costs and in some cases virtually eliminate them by using existing right-of-ways. The system can negotiate sharp curves (20 meters compared with 100 meters for other systems) and gradients of 7.5% or more since the rail cars are pushed up grades by air and thus do not need traction, which limits other systems. The pillars holding up the elevated guide rails have a substantially smaller foot print that other systems due to the lighter transit cars. All of these characteristics of the system reduce its environmental impact relative to comparable transit system options.

Construction costs of guideways and stations: Due to the ultra-light weight of the rail cars, Aeromovel elevated structures are significantly less expensive to build than elevated structures for other APMs. They require between 20% and 60% less concrete for the guideways, pillars and stations, substantially reducing construction costs and environmental impact. Moreover, the systems design allows the distance between pillars and structural foundations to be varied to enable the system to bypass obstacles in city undergrounds, which often require time-consuming and expensive relocation. In addition, the pillars and guideways can be prefabricated to order at a nearby site and installed rapidly with minimum time and city disruption compared with other systems.

Equipment costs: Since most of the propulsion and electric equipment are on the ground or in the guideway, they do not require the special and expensive onboard design and equipment necessary for on-board electric motors. The blowers and other electric equipment required are standard industrial equipment that is extremely reliable, produced in large quantities, and relatively inexpensive to maintain or replace. In addition, unlike on-board propulsion systems, this equipment does not suffer constant shock, vibrations, water showers, abrupt temperature changes, and dust. Instead, the propulsion system is installed in protected shelters on the ground or in compartments along the system guideway. Since the propulsion system is not in the rail cars, the cars are far less expensive to build. They also can be made with lighter materials, including carbon fiber, since they do not require heavy weight to ensure they do not derail as they are secured to the guideways by the "sail" providing propulsion.

Operating costs: Aeromovel, like other APMs, has a comparable operating cost advantage over light rail and BRT systems that require on-board operators. Unlike other APMs, however, Aeromovel also has a huge advantage in energy efficiency due to its light weight and pneumatic propulsion system. Aeromovel uses at least 30% less energy than other electric rail or people mover technologies. In off-peak operation when the vehicles run with few passengers, that difference grows to 70% (or more) less energy required compared to other, heavy systems, depending on the system. This sharp reduction in energy consumption has significant environmental as well as cost benefits even with conventional electric power sources. If the system is powered by renewable energy sources, Aeromovel provides zero-emissions transportation.



Source: Serguey Nogueira da Silva - PhD, 2013

Energy Consumption by Transit Mode

Maintenance costs: With minimum moving parts onboard and long-lasting industrial blowers for propulsion, Aeromovel demands very limited and low-cost maintenance. Moreover, since the industrial equipment is "off-the-shelf" rather than custom and proprietary, any replacement or parts repair is significantly less expensive than systems with proprietary on-board electric motors. The rolling system also requires very little repair or replacement since it uses steel wheels with steel rails without the friction wear of traction on the wheels. The rails of the Aeromovel system are expected to last for more than 100 years without replacement. Other APMs with rubber tires and friction for traction require frequent and expensive tire replacements as well as more massive and expensive concrete guideways that, unlike steel rails, can deteriorate over time and require costly overhaul. Aeromovel's longitudinal air sealing system is designed to be replaced every 10-15 years when subject to high-frequency operations.

Safety: Not only is Aeromovel fully comparable to other automated people mover and monorails safety standards, its design provides inherent safety features unavailable in these other systems. The "sail" attached to the bottom of the rail cars inside the guiderail ducts holds the cars to the track and ensures that they cannot derail except under catastrophic circumstances. The air propulsion system provides an "air pocket" between cars (or sets of attached cars) that makes collisions impossible. Moreover, if power is lost to the blowers, the cars simply stop. Safety is further enhanced by the design of the system since control is primarily provided by controlling the air pressure inside the guiderail duct, not by control of electric motors in the rail cars. The control system primarily consists of controlling the stationary blowers and control valves and uses safe and highly reliable industrial equipment that is similar to equipment used in gas pipelines, refineries, and nuclear power plants. There are also on-board friction breaks for precision braking that provide additional safety for the system.

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