Image 4: Never-Stop Railway at the British Empire Exhibition, 1925 [7]

Pneumatic or "Atmospheric Railway": The atmospheric railway uses air pressure for propulsion. Depending on the model, it either runs on a tube between the rails connected to the train via a suspended piston, or the car itself acts as the piston with the tunnel acting as the tube. Engines set up along the train's route left a partial vacuum just ahead of the car while pumping air behind the car, causing atmospheric pressure to boost the train. As the name suggests, atmospheric railways eliminated friction and jerkiness, and were nearly silent

Since the mid-1800's, several pneumatic systems have been designed and developed, with varying results. In 1846 the 20-mile (32 km) section from Exeter to Newton of the South Devon railway (now Newton Abbot) employed vacuum through a pneumatic tube laid between the rails, which propelled a piston running in it (Image 5). It had stationary engines at around 3 mi (5 km) intervals. Trains ran at speeds of up to 70 miles per hour (113 km/h), but service speeds were usually around 40 mph (64 km/h). The slots were sealed with leather strips kept supple by the regular application of beef tallow. Unfortunately, the tallow covered leather strips were appealing to rats, making the system difficult to maintain. To further complicate operations, the engines had to be run longer than expected, as they were not initially connected to the telegraph. Pumps were operated according to the railway timetable until the train passed. Consistently late train arrivals (a frequent occurence) increased pumping costs. The pneumatic system was abandoned in 1847 and replaced with steam powered engines at a significantly lower operating cost per mile. [8][9]

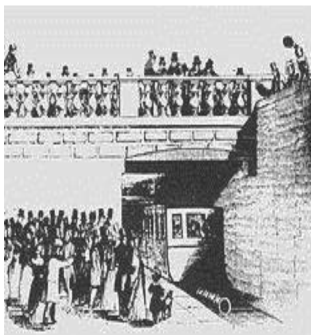


Image 5: South Devon Atmospheric Railway end of line, 1844 [10]

Image 6: Brunel's Atmospheric Railway [11]

Through the work of companies such as Aeromovel and Flight Rail Corporation, pneumatic systems have been staging a comeback, facilitated greatly through the use of modern materials and control technologies. Time will tell if these advancements will make pneumatically powered systems commercially viable.

The three propulsion systems identified above, despite benefits, had limited viability for a variety of reasons. Table 1 identifies the pros and cons of each method.

Table 1: Pros and Cons of Early People Movers

Name	Vehicle Type	Propulsion Method	Pros	Cons
Der Resizug	Funicular	human or animal	low cost	low power, low capacity, low speed
Festungbahn	Funicular	water weight	simplicity, low cost	seasonal operation
Never Stop Railway	rail mounted tram	variable pitch screw	smooth, quiet	initial cost, safety

People Movers since these early beginnings have largely been powered with a system of electrified bars made of various materials later dubbed "Power Rails". While the concept is fairly straight forward, there are technical issues involved with making these systems efficient and reliable. Let's take a closer look at power rail design.

Composition of a Power Rail System

Power rail systems consist of 8 primary components:

- Conductor Rail: The conductors may be covered or bare and must satisfy the electrical and mechanical requirements of the application.
- Collector Assembly: Attached to the vehicle, the collector must maintain contact with and draw power from the conductor rail. The collector shoe part of the assembly can be made of various materials, but are usually a copper and graphite composite. Shoes need to have good wear properties as well as the right electrical properties.
- Splice Assembly: The splice is a mechanical and electrical connection which matches the conductor in strength and conductivity.
- Hanger: These both support and insulate the conductors from earth and other conductors while allowing thermal expansion of the conductors over the operating temperature range.
- Power Feed: This provides a connection point from the source of power supply to the conductor rails.
- Expansion Assembly: This takes up thermal expansion of the conductors while maintaining conductivity and a continuous contact surface for the collectors.
- Anchor Clamps: Anchors secure the conductor to hangers at specified intervals to direct thermal movement toward the expansion assemblies.
- Transfer Caps or Ramps: These manage the collector shoes across switch gaps or other discontinuities in the power rail.

Historical Background of Power Rails for APM's

In 1958 Conductix (formerly Insul-8) modified one of their existing crane electrification conductor systems to power a non-automated people mover, a children's ride. Since those early beginnings, power rails have evolved to satisfy a wide range of requirements through a multitude of profiles, configurations and features. Here's look at a few early applications of power rail to people movers.

Santa's Village, Big Bear, CA – 1962

This system used a 300A 8-Bar power rail developed and patented by Insul-8 Corporation in the early 1950's. The vehicles traveled at 8 mph around the 6000' route. Still produced today in profiles ranging from 100A to 350A, the conductor consists of strips of steel or copper roll-formed into a figure-8 and covered with an extruded PVC cover. As shown in Image 8 below, an opening in the PVC cover provides access for the collector shoe. While a simple design and quite adequate for straight-running overhead cranes, guiding the collector shoe with the PVC cover requires periodic replacement of the cover in high duty cycle applications such as amusement rides and people movers.

Image 7: Santa's Village Bumble Bee monorail [12]

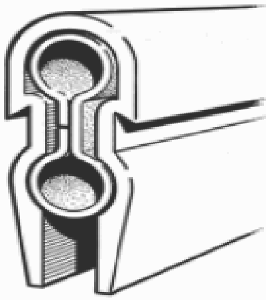


Image 8: 8 Bar conductor**,** Conductix Inc.

Texas Hemisfair – San Antonio, TX – 1968

This 11,000' long top-running monorail, with a design speed of 12mph used Insul-8's 300A 8-Bar power rail. One person was killed and 47 were injured when two trains collided. Driver error was suspected as the cause of this accident.

Image 9: Texas Hemisfair **'68** monorail [13]

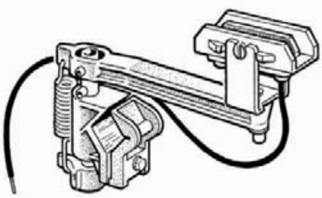


Image 10: 8 Bar collector, Conductix, Inc.

Rohr Aerotrain Tracked Air-Cushioned Vehicle (TACV), Pueblo, CO 1974

This DOT test vehicle traveled at 147 mph on a 29,400' track and was the fastest wayside powered vehicle at the time. Power was delivered by 1600A, three-phase conductors at 4160V designed and manufactured by Conductix (previously Insul-8 Corp.) The test project proved the viability of aluminum/stainless steel v-contact power rails in high speed applications.

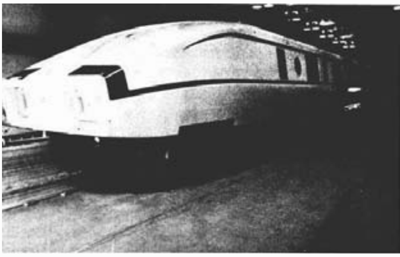


Image 11: Rohr TACV vehicle 1974, Conductix, Inc.

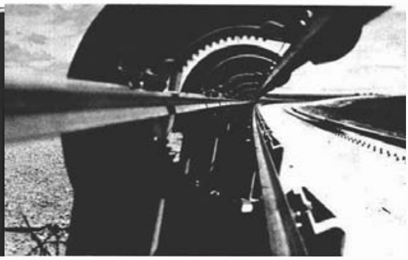


Image 12: 3-phase, al/ss v-contact power rails for TACV, Conductix Inc.

Bay Area Rapid Transit (Bart) – 1978

In 1978, BART installed 3000A aluminum/stainless steel conductors for mainline operation. This 2mm capped conductor design has been used in hundreds of miles of transit systems throughout the world since the late 1970s.

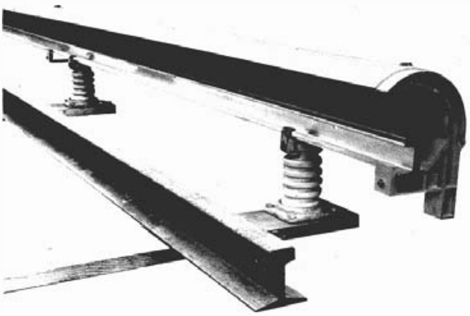
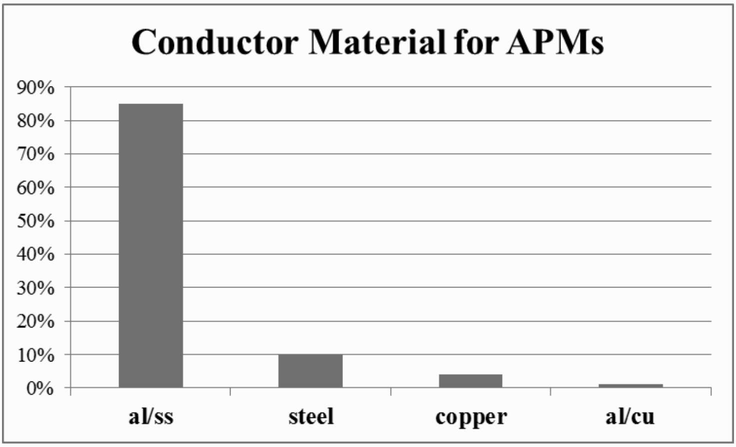


Image 13: BART 3rd rail system with conductor close-up, Conductix, Inc.

Aluminum/Stainless Steel: The state of the art in Power Rail Systems

There are approximately 140 operating APM's worldwide, with the oldest dating back to the mid-1960s. Over 95% of these employ power rail technology. Power rail types currently in use include steel, 10% (such as Chicago O'Hare, Paris Meteor), Copper, 4% (e.g. Circus-Circus in Reno & Las Vegas and Hersheypark, PA,) aluminum-stainless steel, 85% (like Morgantown PRT, Kuala Lumpur LRT) and aluminum-copper 1% (Palm Jumeirah, Dubai). (See Graph 1, below)



Graph 1. Distribution of conductor materials for APMs by type

The most prevalent and cost-effective among these is aluminum conductors with stainless steel contact surface (al/ss). The aluminum provides sufficiently low resistance (55% of copper by volume), excellent strength and stiffness, light weight, and good corrosion resistance. The stainless steel contact surface protects the aluminum from mechanical wear of the collector shoe and provides improved resistance to electrical arcing. This combination of materials provides a durable, cost-effective & electrically efficient conductor that is rigid enough to minimize the distance between supports. The relatively low cost of aluminum extrusion dies makes this an easily adaptable material to a wide variety of conductor profiles and configurations **Table 2** shows the cost advantage of aluminum over copper to be nearly a factor of 7. **Image 14** illustrates that AL/SS power rails can be made is a wide variety of shapes and sizes to suit the application.

Table 2. Cost Comparison of Aluminum and Copper as conductors

	Density (lb/ft^3)	IACS (1)	Cost ($/lb) (2)	Comparison
Copper	559	100%	$ 3.70	$ 2,068.30
Aluminum (55% IACS)	169	55%	$ 1.00	$ 307.27
				6.7

(1) IACS = percent volume conductivity compared to copper

(2) based on Dec 2012 material prices, does not include manufacturing processes

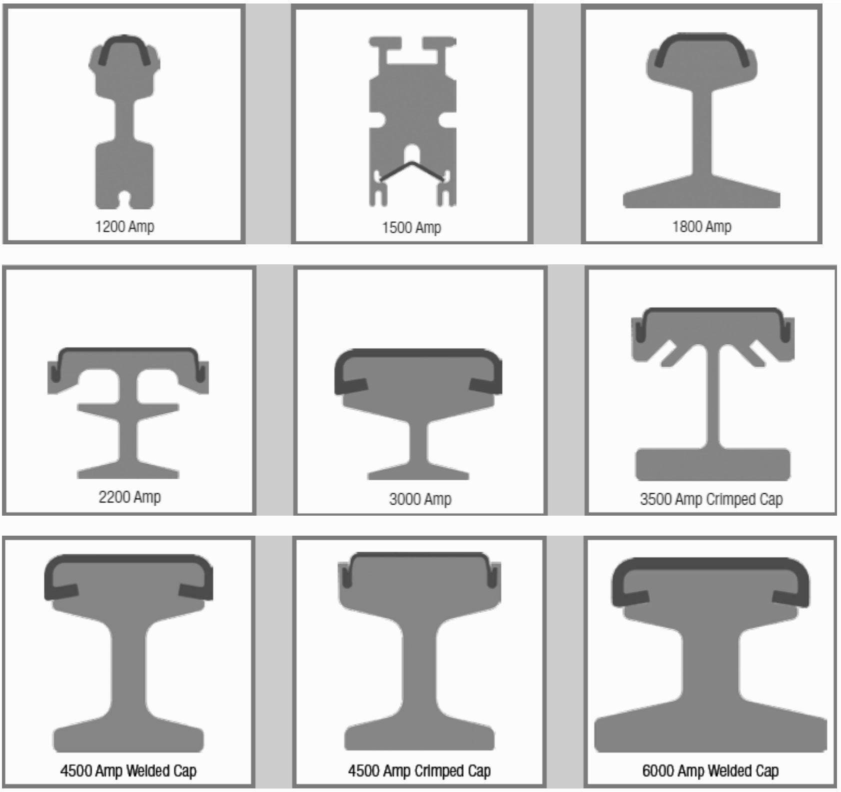


Image 14: Aluminum/Stainless Steel conductors can be produced in a range of shapes and sizes, Conductix Inc.

Extensive wear testing of al/ss power rails indicates exceptionally long life: from .21mm of wear over 93 million shoe passes with a cast iron shoe (Insul-8 Corp, 1977) to 1.43 mm of wear over 73 million shoe passes with a carbon shoe. (Conductix Corp, 2012) While performance varies among the several grades of stainless steel most commonly used, al/ss conductors provide significantly better life than copper or steel conductors. Image 15 shows a conductor wear test device developed by Conductix to evaluate conductor wear under speed and current load.

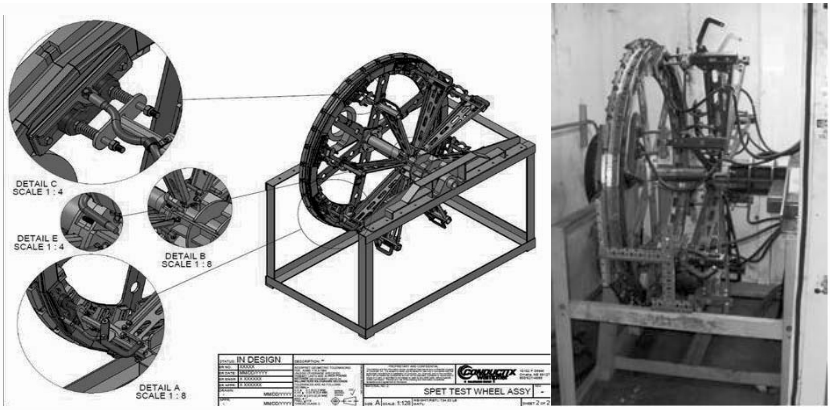
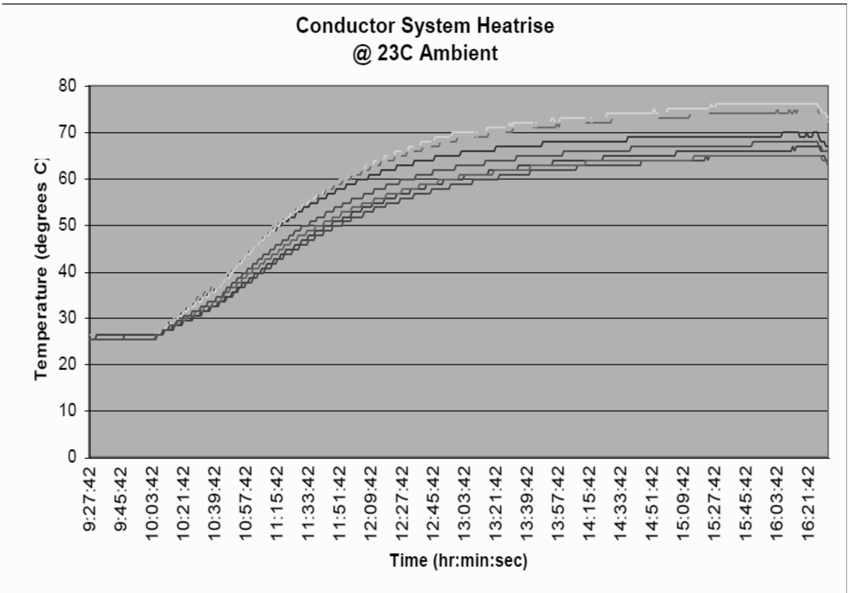


Image 15: Conductor wear test device, Conductix, Inc.

Design Variables to Power Rail Selection

Let's look at the design variables to be considered for power rail applications in APM systems. These variables are the characteristics which may vary from system to system and which may need to be accounted for through differences in design, materials and configuration.

Electrical: Understanding and meeting electrical current requirements is critical to proper power rail selection. Resistance (ohms per unit length) and vehicle current demand are the two most essential specifications for determining voltage drop and available power along the system. Although power rails are typically described in terms of their maximum steady-state current in amps, e.g. 1200A conductor, 99% of APM systems are limited by conductor resistance, rather than current rating. Therefore, the most helpful specification to the conductor rail supplier is resistance per unit length. To illustrate the arbitrary specification of current rating, the following graph shows that conductor rail temperature only stabilizes after more than 5 hours at rated current (Graph 2). This is typical of most conductor rail systems.



Graph 2. Conductor temperature vs. time at rated current, Conductix, Inc.

Where power requirements may vary widely along a given system, it is possible to use different conductors sized for specific current needs along the guideway. For example, the Jacksonville Automated Skyway Express uses a 700A power rail throughout except along the Acosta Bridge where it crosses the St John's River. Here a 1050A conductor was installed to provide sufficient power to the vehicles to climb the relatively steep grade. The different profiles can be spliced one to another and are interchangeable. This provides economy by using the same insulating cover, hangers and splice covers for both profiles (Image 16.) A similar approach was applied for the Kuala Lumpur LRT2 system where 4500A conductors were used for mainline power with 3500A conductors in the depot areas (Image 17.) By keeping the bottom flanges of the two conductors identical, only one insulator design was needed for the system.

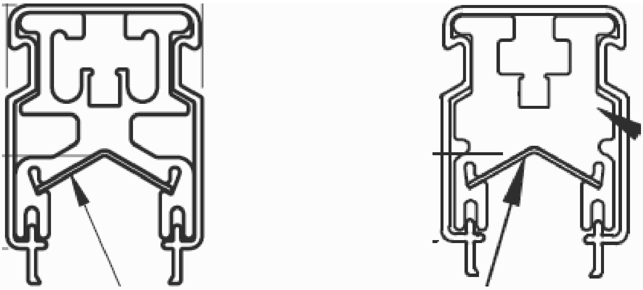


Image 16: 700A and 1050A profiles from the Jacksonville Automated Skyway Express are interchangeable, Conductix, Inc.

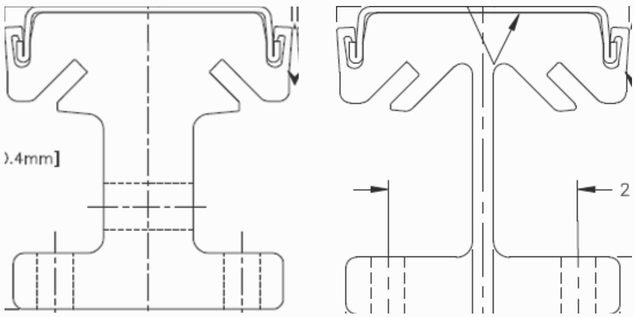


Image 17: 4500A and 3500A profiles from Kuala Lumpur LRT2, Conductix Inc.

Voltage, typically 600 or 750VDC or 480VAC, is the primary driver of insulating levels and creep distances for insulating materials. Environmental conditions (e.g. UV exposure, moisture, pollution levels, etc.) have a significant impact on the effectiveness of insulating materials and should be included in the system specification. Insulators must be designed with the necessary geometry and materials to meet system requirements. Image 18 shows a 750VDC insulator.