UNIVERSITY OF MINNESOTA

International Conference on PRT & Other Emerging Transportation Systems

People-Powered PRT – Preliminary Concepts

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November 18-20, 1996
Marriot Hotel, Minneapolis, Minnesota, USA

Sponsored by
University of Minnesota
- Center for Transportation Studies
- Institute for Intelligent Transportation Systems

In Cooperation with
University of Minnesota
- University College
- Office of Research and Technology Transfer Administration

Advanced Transit Association

Abstract

Bicycles and other human-powered vehicles have been an important element in surface transportation for over 125 years. With the development of the bicycle, inventors began to devise human-powered vehicles for operation on railway tracks, monorails, and other guideways. More recently several human powered, guideway based systems have been proposed. Human power transportation – cycling and walking – has gained new attention, and increased funding, thanks to changes in Federal transport legislation. The shortcoming of existing auto and truck transportation, which dominate urban transport, are becoming increasingly apparent. In NYC an old concept is returning with renewed vigor. Pedicabs are once again appearing on NYC streets. Pedicabs, some with hybrid human and electric power, offer some interesting lessons for developing people powered PRT (PPPRT) systems. Pure PPPRT systems are possible, but a key factor is providing energy storage devices (probably flywheels) so that passengers can provide sufficient energy for their own trip, and for the PRT cars to be recycled for additional trips. One approach to PRT – Supracar – is, in concept, a system that could ultimately replace most auto and truck travel in dense urban areas. Some of the attributes of a human-powered version of such a PRT system are described. Some practical initial development steps could include using PPPRT as a backyard toy, or for short crossings of freeways and rail lines. Human-powered PRT may be a useful instructional tool and research technique. Ultimately, some combination of human and mechanical power may be more practical for real world applications.

I. Why consider people-powered PRT?

Non-motorized transportation is getting a second look as urban planners seek a more humane and livable urban environment. There is growing public concern about the ill effects of our auto-dominated transport system – excessive energy consumption, unacceptable levels of air and noise pollution, the awesome toll of deaths and injuries and the preemption of a large share of scarce urban space. After years of neglect, transportation professionals are again considering walking and cycling as legitimated forms of urban circulation, either as primary modes or as feeders to public transportation. The landmark Federal transport legislation of 1991 (the Intermodal Surface Transportation Efficiency Act – ISTEA) allows a substantial share of Federal transport dollars to be invested in pedestrian and bicycle facilities.

Arguable the greatest achievement in the development of human-powered transportation technology occurred near the close of the 19th Century with the invention of the "safety" bicycle (Ref. 1). This design, which differ little from modern bicycles in use today, replaced the high wheel cycle design of the mid-nineteenth century, shown in Figure 1, and transformed what was mostly a toy for agile young men into a device that could be used with ease by a very wide range of individuals. The invention of the bicycle provided an enormous energy savings for human-powered transportation, tripling the energy efficiency over walking (Ref. 2). This transportation device gained enormous popularity in the U.S. and Europe and created a strong political movement that successfully advocated for paved roads. But human power for wheeled transportation did not remain dominant for long in the U.S. With advances in the technology of electric motors and batteries, and more importantly of internal combustion engines, many of the pioneering manufacturers of bicycles quickly discovered the advantages of mechanical power over human power. Henry Ford's mass production of motor vehicles, and the growing U.S. economy in the early 1900s, quickly took over the paved roads so effectively promoted by cyclists. In Europe, where per capital income levels lagged behind those in the U.S., the bicycle remained an important, economical transport mode. Great efforts were made in Europe to accommodate bicycles in urban settings. Separate lanes, and ample parking facilities allowed bicycles even today to remain a useful, cost effective mode in European cities and even in the countryside.

In contrast, few U.S. cities are well suited to human-powered transportation. Through the years, to accommodate the ever increasing demand for cars and trucks on city streets, traffic engineers made steady gains in improving pavements for movement of cars and trucks. But little space remains for cyclists who must share road space with fast moving motor vehicles. Pedestrians are rarely treated well in cities, and sidewalks scarcely exist at all in outlying suburbs. In New York City, cycling accounts for less than one percent of these conditions cycling is growing in popularity and cycle advocates again are becoming a significant political force. Because of its density and great diversity New York remains a great city for walkers. As the link between exercise and health becomes better understood human powered devices are gaining ground – not only in health clubs with stationary bikes and treadmills for joggers – but on urban streets as well.

But for human powered transportation, especially cycling, to become a significant travel mode in U.S. cities a network of separate veloways or guideways must be constructed. Not only would a separate system be very attractive for existing cyclists, who would avoid the hazards of riding in mixed traffic, it would add to the energy efficiency of cycle travel by offering a purpose-built rolling surface that would allow replacement of pneumatic tires with steel wheels.

This paper, which is a collaboration of a civil engineer and urban planner – George Haikalis, and a human-powered vehicle designer and hot to NYC's largest pedicab business – George Bliss, will attempt to out line the key parameters and characteristics of one such system. One fundamental concept for personal rapid transit (PRT) developed by Haikalis in the 1960s – Supracar – projected that PRT could become a total successor to motor vehicular travel in dense urban areas (Ref. 4). That concept will serve as the baseline for our analysis of people-powered PRT.

II. Early concepts – Guided Bicycles

The marriage of bicycles and railways caught the attention of inventors soon after these technologies emerged in the early 19th Century. A wide variety of human-powered track maintenance and inspection vehicles were developed to help sustain the railway's basic mission of carry people and goods using mechanical power. Perhaps the most familiar was the handcar, where several trackmen would pump levers that propelled the car forward. Conventional bicycles with flanged wheels riding one rail and stabilizing wheels riding on the opposite rail were useful for higher speed track inspection.

But some inventor saw the advantage of creating their own separate guideway and cycle systems. One well documented example was the Hotchkiss Bicycle Railway of Smithville, NJ (Ref. 1). Specially-built cycles would straddle what looked like a farm fence, shown in Figure 2, carrying workers from a company town to a bicycle factory. Several other bicycle railways were built and tested. One was a cycle from a monorail and others had monorails above and beneath the vehicle. Many of these devices became amusement park curiosities. A very limited search of patent files shows a host of proposals for human powered railway devices. A more comprehensive exploration is warranted.

III. More Recent Proposals

In 1973 researchers at Syracuse University proposed "Crusway" – an enclosed elevated veloway (Ref. 5). Bikes would be equipped with masts that would engage a moving steel belt. The bikes would be pulled up a steep ramp, where they would disengage the belt and coast downhill as freewheeling vehicles in the tube. At regular intervals bike masts would re-engage the belt for another uphill climb. To smooth the transition to and from belt power a unique clutch design was developed. The designers also proposed that very small battery-electric vehicles (equipped with masts) could also use the guideway.

More recently Jim Kor, editor of HPV News, proposed a human powered vehicle system that would allow vehicles to operate on tracks in an enclosed tube (Ref. 6). This dual-mode system – the Skyway Transportation System – would have lightweight, low slung enclosed vehicles operate on regular city streets under human power, as shown in Figure 3. The four-wheel vehicles would enter the guideway following slots that engaged the vehicle's wheels. A 10 mph tail wind would give the human-powered vehicles a propulsion assist. The guideway would consist of several lanes, so that more energetic drivers could pedal faster in express lanes. Fortunately, Jim Kor is at this conference and is presenting an updated version of his proposal – Solos Micro Metro.

Also recognizing the importance of air resistance as a force to be overcome by cyclists Milnor Senior recently proposed "Transglide 2000 Bicycle Transit System" (Ref. 7) shown in Figure 4. He proposes an enclosed veloway with a substantial tailwind to make it easier for cyclists to move.

All three of these systems are hybrid devices, combining human power and mechanical power.

IV. Some Lessons from the Pedicab Business

Pedicabs developed almost concurrently with the invention of the bicycle. A pedicab is essentially a tricycle with one person pedaling and typically with capacity for two passengers to ride, without pedaling. Most often the driver is in front and the passengers in the rear, although in some Asian countries the drivers are in the rear as shown in Figure 5.

While pedicabs remain an important mode of transport in many third world cities their use in the U.S. virtually disappeared after the introduction of the automobile and the taxi. Recently they have enjoyed somewhat of a renaissance as a vehicle for recreational travel in tourist areas. George Bliss brought a fleet of pedicabs from Florida to NYC and began Pedicabs of New York (PONY). Pedicabs are leased out to drivers for a fixed period of time. Drivers then negotiate a fee with potential riders, typically 50 centers per minute. NYC, with its relatively mild weather and great number of visitors, many from overseas, is an ideal location for the pedicab business. This summer was especially attractive because of unusually good weather.

There are several significant limitations to pedicabs for urban transportation. The most obvious is that they are very labor-intensive. For many persons, pedicabs symbolize the exploitation of human beings – with one individual exerting a great deal of effort, while others are left to enjoy the ride. While in colonial times, in the third world, this may well have been the case, this is certainly not the situation today. Many jobs require “muscle power” including many well-paying jobs in organized sports. In NYC pedicabs are often hired by persons who lack the stamina or the skill to maneuver human-powered vehicles through Manhattan’s fabled traffic jams.

Pedicabs do require a lot of muscle power. While a typical bicycle in use in the U.S. may weigh about 25 lbs a pedicab weights nearly 200 lbs. Assuming an average weight of a passenger and belongings at 175 lbs, a pedicab driver with two passengers must maneuver 725 lbs of weight through the city’s streets. Driver effort expended may reach a half a horsepower to attain a cruise speed of 15 mph. Recently, PONY has experimented with hybrid electric and human-powered pedicabs. A 2.5 hp motor and a battery pack have been added to one vehicle. This adds 230 lbs, 200 for the batteries. Needless-to-say pedicab drivers appreciate this assist. This may well be the next phase of the pedicab business in NYC. Interestingly, pedicabs in Asian and African cities are being motorized. Small motor scooter-sized gasoline engines augment human power. A number of cities are insisting that small electric motors be used instead, to reduce noise and pollution. Over 100,000 electric pedicabs are in use overseas. The experimental PONY vehicle is only the second one in use in the U.S.

Hybrid bicycles with electric power assists are also becoming popular. A half-horsepower electric bike motor, with batter pack, can add 20 to 50 pounds to the weight of a bike. But it makes long rides and sustained grades more tolerable. Likewise disabled persons are finding hybrid vehicles more suitable. Lightweight wheel chairs propelled by the hand motion of the operator may weigh 20 to 30 lbs. Electrically propelled versions may weigh 70 pounds or more. One popular model of a wheelchair-like “scooter” for the more mildly disabled weighs 163.5 lbs.

V. Limitations of Human Power

Human-powered vehicle systems would be much more attractive as modes of travel in cities if they had their own guideways. Without the ferocious competition for street space in urban traffic a fully enclosed human-powered vehicle operating from origin to destination on its own guideway – a people-powered PRT (PPPRT) – would be an ideal transportation device. Such a system could replace virtually all motor vehicular traffic in dense urban areas. Pedestrians could have the full use of the ground level of streets. People/motor vehicle conflicts would be eliminated. Even bike/pedestrian conflicts, a major source of irritation for older pedestrians in NYC, could be eliminated if human-powered enthusiasts would confine their travel to the PPPRT.

But there are some considerable limitations to a pure people-powered PRT. Some of these limitations can be overcome by using hybrid power, or dual-mode vehicles that can leave the guideway. A true PRT system with captive vehicles and relying only on human power would require consideration of a number of factors.

Perhaps the greatest concern would be the imbalance of supply and demand for vehicles. PRT systems assume that empty vehicles would be recirculated to stations where passengers are waiting for service. For a pure human-powered-only system this would work if an on-board energy storage device, such as a flywheel, were provided. Passengers would be expected to provide enough human power not only for their own trips but to recirculate their empty vehicles as well. The experience in NYC, where an at grade, non-automated PRT system – the Yellow (medallion) Taxicabs – exists, might be useful. Cabbies are under great pressure to find revenue passengers to offset taxi leasing fees and make a profit. Their recirculation strategy is by instinct and experience. The result is three quarters as many miles of empty taxis, as occupied taxis, are traveled on Manhattan streets. While an "intelligent" PRT control system should do considerably better, passengers might still have to pump up a flywheel for perhaps as much as 25% more than the energy consumed for their own trips. The alternative, storing empty cars at destinations, until new users arrive, greatly increases the fleet size of PRT and duplicates the inefficiency of the auto, with its sizeable car parks, and poor utilization.

Travel for the disabled must clearly be accommodated on the PPPRT system. While there is a growing interest in making taxicabs wheel chair accessible in the U.S., few cities have done so thus far. Instead, elaborate and costly van services are maintained. For the PPPRT wheel chair users could be accommodated by having a relatively modest number of drivers available to provide the human power when needed. Alternatively, of course, disabled persons could use hybrid vehicles that are not fully human-powered.

PPPRT systems could be very useful for transporting goods in urban areas. Even now a surprisingly large amount of goods are transported on bicycles and work tricycles in large U.S. cities. Goods loaded onto hand carts, and then rolled into PRT vehicles, would be a big improvement over deliveries now made by cyclists in mixed traffic. But PRT systems would be much more useful if they could carry unattended goods. For pure PPPRT unattended goods would be loaded into a PRT vehicle, and then that car's flywheel would be pumped up to have enough energy to move the goods to their destination. Remarkably little attention has been given to the goods movement requirements of PRT systems. At present urban truck delivery systems are labor intensive and extraordinarily costly. The economies of scale from using large trucks are diminished by the hand labor needed to load and unload them. Large trucks are a particular nuisance in dense urban area. A PPPRT would be competitive for a sizeable fraction of these movements.

A conventional bicycle is a remarkably energy efficient device. On a straight, level, well paved road with no head wind most persons could cruise at 15 mph, exerting less than 0.1 hp. On a PPPRT, with a hard rolling surface that would avoid the need for pneumatic tires this would become even more energy efficient. But weather conditions vary greatly. One of the pioneers of PRT, Donn Fichter, proposed a lightweight one-person electric-propelled PRT system (Ref. 8) sand shown is Figures 6 and 7. His extensive analysis suggested that each of his PRT cars would need a 7.5 hp motor to maintain a guideway cruise speed of 18 mph in the face of headwinds of 35 mph. A baseline PPPRT system would need to have fully enclosed vehicles for all weather use. Even with extensive streamlining any significant headwind becomes a challenge for human power. While freeway speed limits are often reduced during periods of heavy winds, lowering PPPRT mainline speeds may not be enough. Many individual may to have the strength to propel the vehicle forward at all, in the face of strong headwinds, and braking would be needed to prevent the vehicle from rolling backwards. During severe weather PPPRT travel would be restricted. (If the direction of travel can be modified to greater than 45 degrees off wind *sailing* along the guideway may be possible and a rigid microprocessor-trimmed sail could provide the first step toward an automated solution and potential speeds comparable to those of ice boats. fj)

Another concern for PPPRT is climate control within a vehicle. A mechanical ventilation system geared to the vehicle's wheels could assure fresh air flow when windows could not be opened in bad weather. In cold weather the body heat from human power, plus normal outdoor clothing may be enough to satisfy most PPPRT travelers. But some kind of heater might be needed for sub-zero climates, and in case of system breakdown. Air conditioning in warm weather, other than fans or open windows, may not be achievable in a PPPRT.

Finally, a PPPRT system would entail the same control requirements as an electrically propelled system. Speed would have to be regulated. Merges would be programmed by computer. Routings would be selected in some systematic way. With modern microprocessors, computers take much less energy than in years past. But a reliable, high quality energy supply will be needed. It may be possible to have this energy drawn off the human-powered flywheel energy storage system suggested earlier.

VI. Supracar – the Ultimate PRT

A PRT system that could result in the complete elimination of motor vehicular transportation in dense urban area – Supracar – was mentioned earlier in this paper. Transportation of persons and goods consumes about 20% of the nation's economy. Most of this expenditure goes for motor vehicular transportation, and the major part of that is spent in urban areas. A successor system that could reduce the cost of existing motor vehicle travel and also reduce the societal costs of accommodating cars and trucks in our cities would be worth a great deal. But such a system would have to provide substitute service that came close to matching the personalized, door to door transportation now provided by the auto.

While most PRT systems that have been proposed through the years offer competitive service for many auto trips, they do not go far enough to allow cities to completely ban cars from their streets. Supracar proposes a much finer-grained network than has been typically suggested. Instead of spacing stations at quarter-mile intervals, stops could be as close as 20 feet, and might typically be no further apart than 100 to 200 feet. To do this in an economical way stations must be minimized in design. Supracar proposes that stations be little more than footprints on which PRT cars can land. The columns as well as the beams of elevated guideways would be channels for flow. By bringing the cars down to ground level, costly elevators elevated station platforms are eliminated. The concept is shown in Figures 8 and 9.

To make a PRT grid nearly ubiquitous, guideway design must be simplified and made more affordable. One approach is to focus on the local servi ce network first. Most urban trips are short, and mainline speeds of about 15 mph would be adequate to provide area. At a later stage a hierarchy of guideways would permit entire metropolitan areas to become auto-free. One possibility would be for PRT cars designed for low performance guideways to be transported on pallets, like those shown in Figure 10, on the higher speed guideway (Ref. 9).

Acceleration and deceleration lands add greatly to guideway cost. Supracar proposes that cars berth vertically, getting off the mainline by descending following columns to ground level. This could be accomplished by having a separate vertical movement system, or by devising cars that can traverse a curvilinear path. Mainline capacity is diminished since deceleration is not off line. But with a proliferation of guideways the capacity of a mainline guideway is not necessarily a limiting factor.

By completely replacing surface motor vehicular traffic new urban design possibilities are created. The typical urban streetscape with large numbers of parked and moving cars and trucks changes dramatically. Ground level is reserved for pedestrians. Vehicular movement takes place on guideways above. In a very limited number of instances guideways may be placed below grade to preserve traditional urban vistas.

VII. Some options for a people-powered version of Supracar

Most of the constraints and limitations earlier for PPPRT, in general, apply to Supracar as well. An additional concern is the necessity of raising the vehicle, tracking a column, to reach the elevated mainline on the guideway. Keeping the guideway as low to the ground will help, to start with. While 14 to 16 foot vertical clearances are typically required for overhead structures to avoid damage from trucks Supracar guideways could be lower. While a very limited number of trucks would still be needed to haul large pieces of furniture or outsized structural elements into auto-free districts, these could be specially designed low-profile vehicles. Guideways would need to clear pedestrians and be high enough to minimize vandalism – perhaps 8 to 10 feed above the surface. To minimize human power requirements, vehicles would best be counterbalanced like an elevator cab. For the ascent each passenger would need to provide only enough power to raise himself and to overcome friction and inertia in the system. This would be the equivalent of climbing a short flight of stairs. This might be accomplished by pedaling the vehicle and engaging the equivalent of a vertical cog railway for the climb, but a variety of alternative approaches are possible.

Supracar suggested four-passenger vehicles, two pair of seats facing each other, in its initial concept. Fold up seats would allow access by wheelchairs and for good movement. The people-powered version assumes adding pedals to this configuration. The development of the bicycle clearly showed that using leg muscles was the optimal way to use human power for transportation. Pedal location would require an analysis of trade-offs between optimizing ergonomic factors, convenience, convertibility to goods movement use etc. Smaller vehicles might be desirable, though wheelchair access then becomes difficult.

The earlier discussion suggested that energy storage would be desirable for a workable PPPRT. Flywheels are an obvious possibility. Stationary bicycles, functioning as excercising machines, used flywheels over a century ago, when they were first developed. Long promised advances in flywheel technology continue to appear in the popular press. Carbon fibers that combine high strength with light weight may be soon developed, after all. But most flywheel development is aimed at high power devices for automobile propulsion. For example inventor Jack Bitterly proposed using sixteen of his high tech 90 lb, 25 hp flywheels for a high powered auto (Ref. 10). A flywheel for a PPPRT would have much lower energy requirements. One advantage of flywheels, even in conventional electrically powered PRT, is the cost savings from not providing electric contact rails on guideways. This is especially important for concepts like Supracar where ubiquitous guideways are sought.

A hybrid PRT system that combines human and electric propulsion may be desirable. This combination would allow travelers with greater physical capacity to provide most or all of their energy requirements from human power, while less able travelers could contribute less and rely more on the electric utility system. This could even be built into the price structure for travel on the PRT system. Electric propulsion may be necessary in any event, even for a fully human-powered PRT equipped with flywheels, or other energy storage devices. Converting flywheel power to tractive force automatically, and remotely, may not be possible with current mechanical or hydraulic transmission devices. Recharging flywheels at stations is relatively simple, and would be desirable for emergencies, in any event.

VII. Some practical first steps

Constructing initial full scale working prototypes of PPPRTs could be valuable in a number of respects. They would become educational tools, like the recent engineering school efforts to construct solar cars and human powered airplanes. They would serve as working test beds to facilitate research.

Perhaps the first commercial application of a human-powered version of Supracar could be a backyard toy. A fairly compact guideway loop with a single accessible column could be assembled from a kit. A more permanent installation would be comparable in magnitude to a set of swings. A backyard version would be a useful outdoor exercise device. Adding more links and multiple vehicles would add to its interest as a recreational toy.

Interestingly, several miniature working models of devices that combined the horizontal and vertical motions of Supracar appeared as toys designed in Japan and marketed in the U.S. in the early 1970s. Smaller scale versions of Supracar could be developed into educational toys.

A full scale application might be at a lightly trafficked pedestrian crossing of a railroad or highway, perhaps near a school. A single ground level terminal at each of the overcrossing would be possible. United Technologies' Otis Division proposed such a device several years ago, shown in Figure 11, but chose not to pursue it in detail (Ref. 11). A standard pedestrian crossing requires a substantial structure, designed to handle a large group of pedestrians. A guideway and vehicle system might be more efficient, from a structural standpoint. A human-powered Supracar with flywheel energy storage would permit vehicles to traverse the crossing under human power in one direction, and return empty to make a second trip. Alternatively two vehicles could be linked by a cable, in funicular fashion, and trade places, propelled by human power from one vehicle, if there were no passengers in the return vehicle.

Ultimately, Supracar, whether human-powered or not, would face the same substantial hurdles for development as other PRT systems. Challenging control technology designs are needed. Great attention to a host of human factors, such as sensitivity of door edges, procedures for evacuation, resistance to vandalism etc. must occur.

It's been over thirty years since Supracar was presented at a session of the Transportation (then Highway) Research Board and 21 years since the Third PRT Conference was held in Denver, Co. Perhaps the time for PRT development has finally arrived.

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(10) *Discover* Magazine, August 1996

(11) *TransitPulse*, May/June 1989

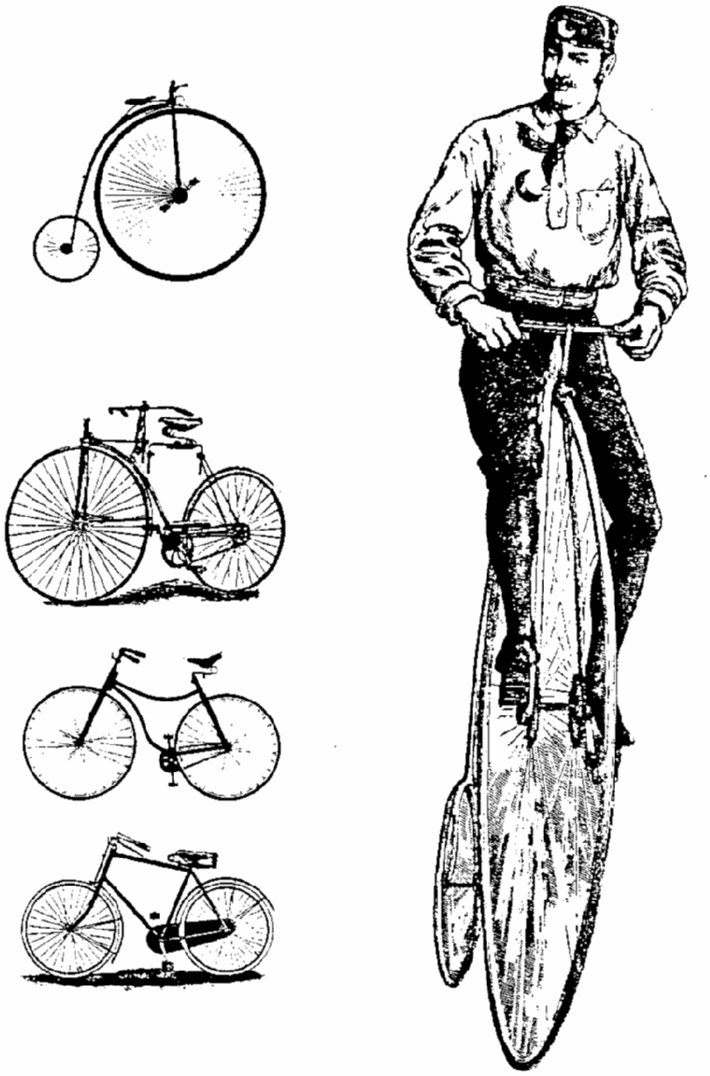

Figure 1 - Highwheelers and "Safety" Bicycles

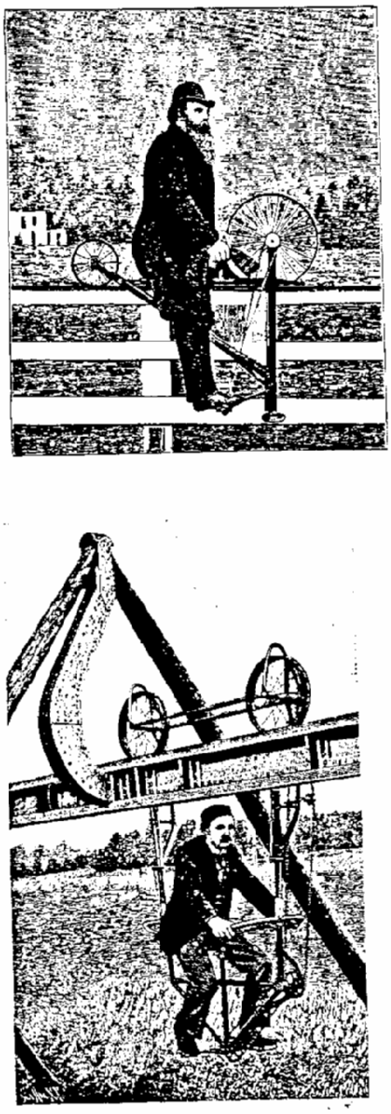

Figure 2 - Hotchkiss Bicycle Railway
Mono-rail Velocipede

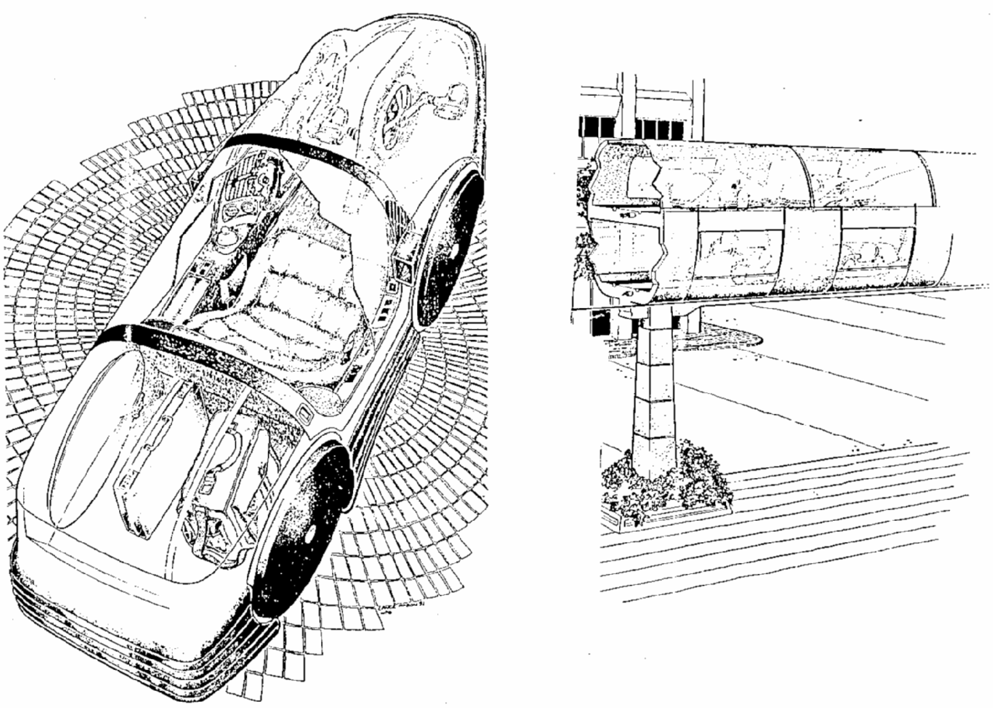

Figure 3 - Skyway Transportation System

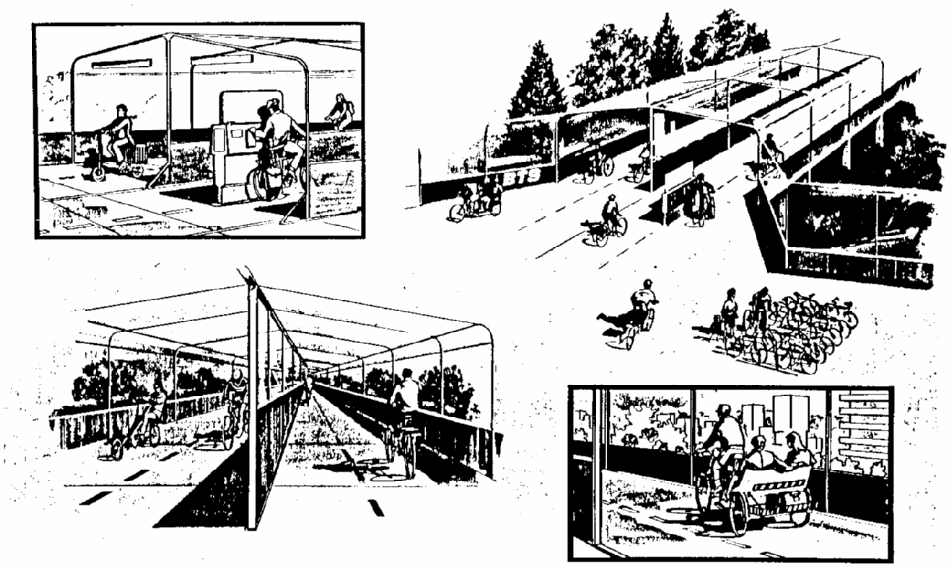

Figure 4 - Transglide 2000 Bicycle Transit System

Figure 5 - Pedicabs

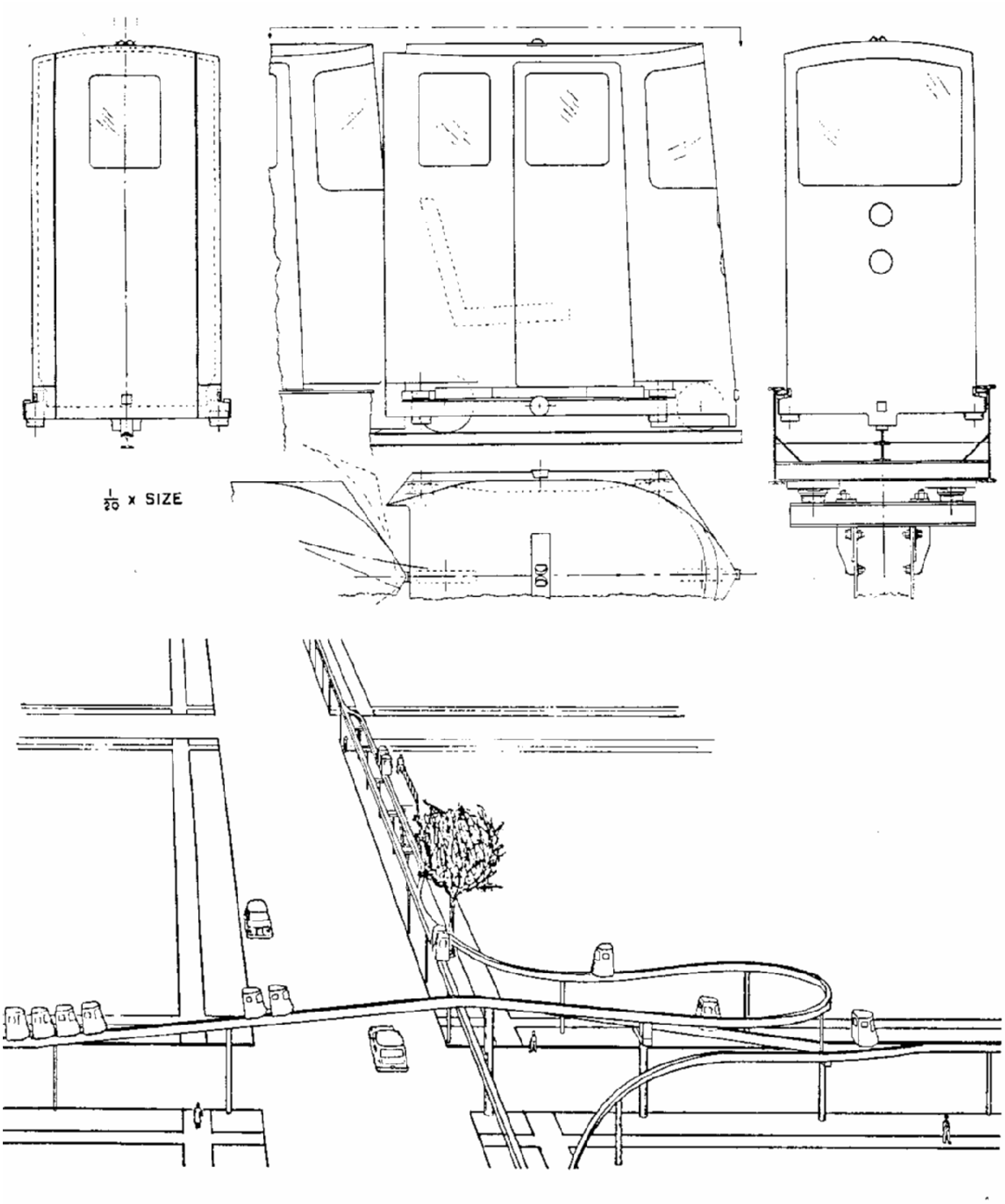

Figure 6 - Fichter's PRT System - one person vehicle, possible guideway layout

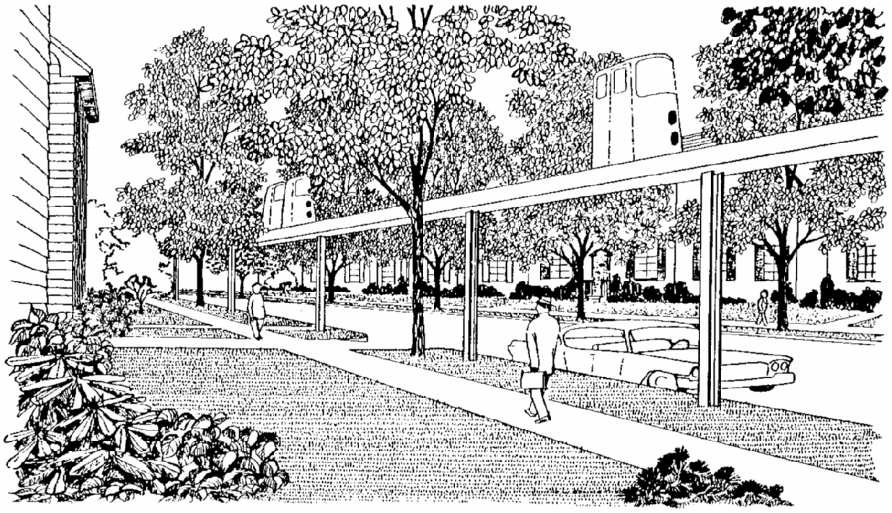

Figure 7 - Fichter's PRT System - on a neighborhood street

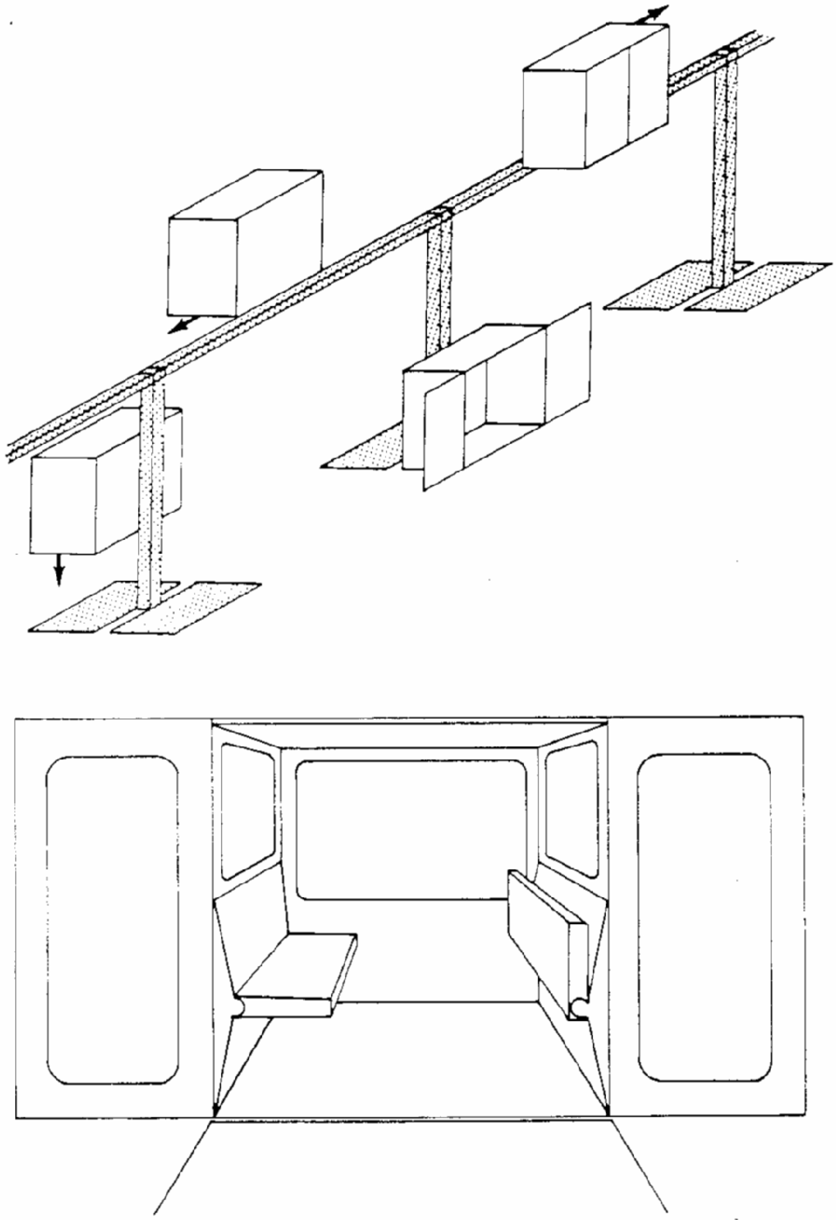

Figure 8 - Supracar - basic concept

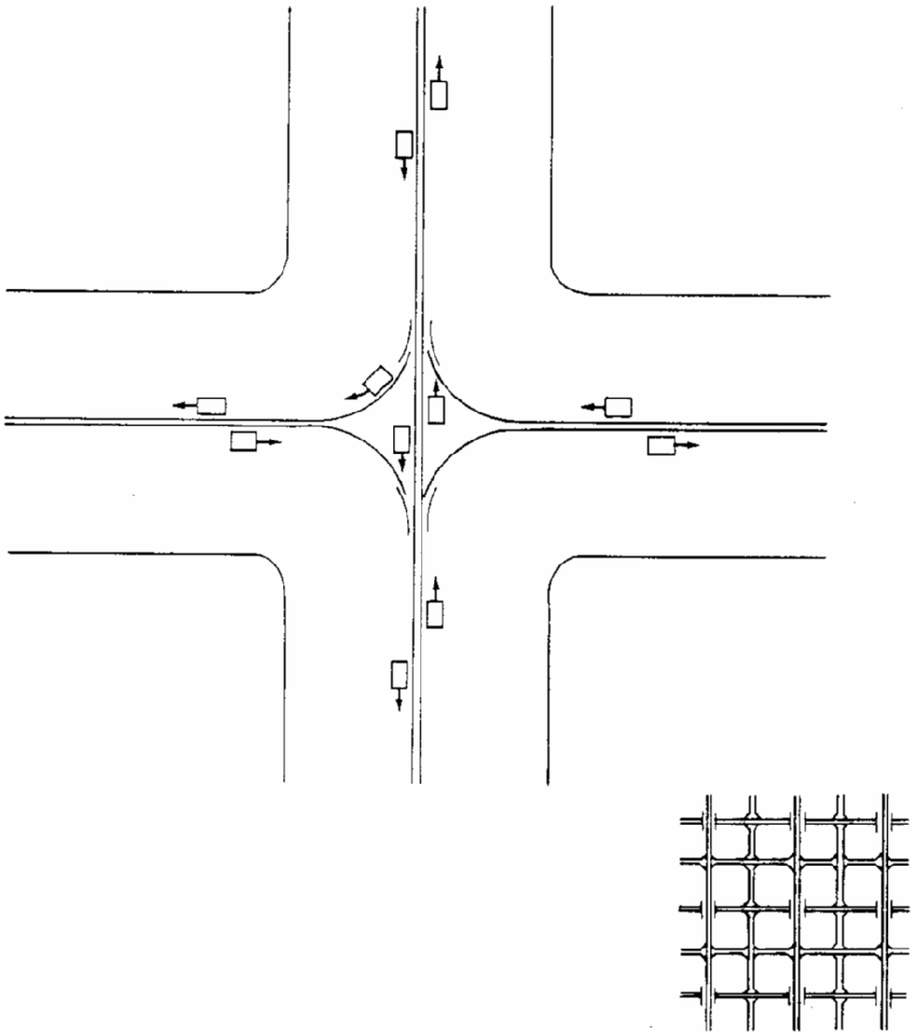

Figure 9 - Supracar - ubiquitous grid

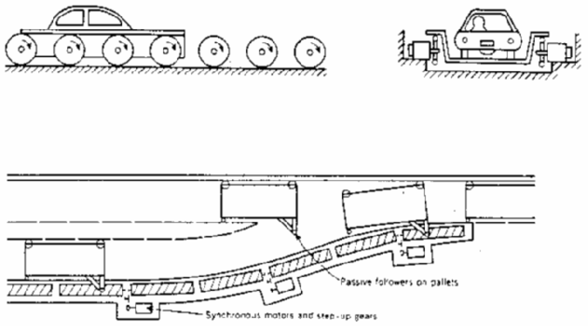

Figure 10 - Pallet Systems

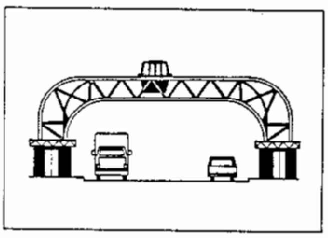

Figure 11 - Otis "Streetlift"