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BATTERY CARS ON SUPERCONDUCTING MAGNETICALLY LEVITATED CARRIERS--ONE COMMUTING SOLUTION

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ABSTRACT

Commuting to work in an urban-suburban metropolitan environment is becoming an unpleasant time-wasting process. If paid $15 an hour, a million people by moonlighting instead of commuting two hours to and from work each day, could earn $6 billion per year. That income in 10 years, invested at 10 percent compounded interest, would pay off a $100 billion bond debt by the municipality. However, saving the commuters' time rarely enters into municipal planning.

Today's embedded metropolitan commuting routes can be traced to radiating street-car tracks that brought workers from trackside villages to downtown factories. Now the urban workplaces are dispersed, and commuters drive to work on freeways which are too often choked with traffic jams. Subways and light rail have the same flaws--inconvenience, lost time, and low passenger productivity--that bankrupted the interurban trains in the 1930's.

To this commuting problem we applied the technology of communication management, a system-engineering tool that produced today's efficient telephone network. The resulting best commuting option is magnetically levitated carriers of two-passenger, battery-powered, personally-owned local-travel cars. A commuter drives his car to a nearby station, selects a destination, drives on a waiting carrier, and enters an accelerating ramp. A central computer selects his optimum 100 miles-per-hour trunk route, considering existing and forecast traffic; assigns him a travel slot, and subsequently orders switching-station actions. The commuter uses the expensive facilities for only a few minutes during each trip. His cost of travel could be less than 6 cents per mile.

BACKGROUND--HISTORY OF LIGHT RAIL

Light rail, the proposed solution to today's clogged freeways, has a basic flaw. We illustrate this flaw with Southern Pacific's "Red Electric" trains which by the early 1900's connected Portland, Oregon with Salem, Oregon. In the morning these trains collected workers along its 40-mile route and delivered them to Portland where they rode streetcars to their job sites.

Consider the four-car train operated by Conductor Kimmel and his crew, consisting of an engineman and three brakemen. No fireman was needed because the train was electrically propelled and heated. When carrying 150 people at 30 miles per hour, this crew delivered 600

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passenger miles per employee hour. In comparison, one crew member on a 747 airplane creates 37,500 passenger miles per crew-member hour. Dietrich Koelle illustrated the contribution of high speed to the productivity of labor in flying a hypersonic airplane. Koelle's hypersonic airplane would cost twice as much as a Boeing 747. The liquid-hydrogen fuel cost 10 times as much as the kerosene for Luftansa's 747. Yet, because of the tremendous passenger-mile-per hour productivity from flying at Mach 4.2, the cost per seat km of the two airplanes would be the same (1).

Crew cost, which was included in the passenger's ticket, was not what drove the "Red Electric" and other electric interurban trains into bankruptcy in the 1930's. The real cause was lack of passenger convenience. The typical commuter walked from his home to the depot in the morning, arriving 10 minutes early to be sure he wouldn't miss the scheduled train. On the train he sat patiently as the train stopped at depots along the way to pick up more passengers. In Portland he got off the train and waited for a streetcar which slowly carried him to near his workplace, stopping at every intersection along the way. He then walked several blocks to his workplace. The return ride could be even worse if it rained while he waited for the streetcar and then the train.

The result was that our commuter bought a car as soon as he could afford its cost. Then he drove straight to work from his garage. He could also make side trips on his way home, and haul bulky packages. This feature of commuting transportation we call "passenger convenience."

We can ask, "With today's jammed freeways, will a commuter give up his car and ride the new and beautiful light-rail train?" Portland's new "MAX" tells one answer. The trains, tracks, and right-of-way cost $214 million. Passenger volume was forecast to be 42,500 happy commuters per day by 1990 (2). However, the initial ridership of 24,000 dropped to 19,000 by 1988. The 19,000 trips per day (8500 commuters) contrasts with four million automobile trips per day in the Portland area. It would seem that each voter who supports the light-rail projects hopes that he will be able to enjoy a clear freeway after the other commuters ride the train.

IMPORTANT FEATURES OF COMMUTER TRANSPORTATION

In considering alternatives to freeways and light rail, we evaluate in Figure 1 the quality of past and present commuting options. Here the filled dots represent desired features. For example, the walking commuter enjoys unsurpassed route flexibility. Joseph Jenks started, in 1643 at Lynn, MA, the first manufacturing plant in America. He commuted by walking across his back yard. A later development was the New England mill town, where workers living in houses around the mill also walked to work.

The larger steel mills and electrical factories needed more workers. In 1880 Edison and Villard introduced the electric streetcar. Streetcar lines soon radiated from the factories in city

Trasportation option	ERA	Factors determining commuter desirability for use						
		Time	Route flexibility	Multi functional	Security	Cost/mi	Convenience	Safety
Walk	< 1900	Very undesirable	Very desirable	Very undesirable	Very undesirable	Very desirable	Very undesirable	Very desirable
Horse	< 1900	Undesirable	Very desirable	Very undesirable	Marginal	Very desirable	Very undesirable	Very undesirable
Street car	1900-30	Marginal	Marginal	Undesirable	Undesirable	Desirable	Very undesirable	Marginal
Bus	> 1925	Desirable	Desirable	Marginal	Undesirable	Marginal	Desirable	Desirable
Bicycle	< 1910	Undesirable	Desirable	Very undesirable	Marginal	Undesirable	Undesirable	Undesirable
Automobile	> 1918	Very desirable	Very desirable	Very desirable	Very desirable	Very undesirable	Very desirable	Undesirable
Freeway	> 1945	Very desirable	Very desirable	Desirable	Desirable	Very undesirable	Very desirable	Undesirable
Subway		Desirable	Marginal	Undesirable	Undesirable	Desirable	Marginal	Very desirable
Light rail		Desirable	Marginal	Undesirable	Undesirable	Desirable	Marginal	Very desirable

Legend: ● Very desirable; ◍ Desirable; ◒ Marginal; ⊖ Undesirable; ○ Very undesirable

Figure 1. The automobile's commuter-convenience advantage over alternative commuter transportation is being eroded by freeway traffic congestion.

centers to the suburbs where the workers lived. Riding the streetcar was more comfortable than walking. However the streetcar could travel only where the tracks were laid. Buses replaced street cars in the 1930's, and bus routes could be easily changed.

In the modern metropolitan area people live in one suburb and work in another. For example a person living in Pasadena may work in Long Beach. A hub-and-spoke rail network extending from downtown Los Angeles would require the commuter to travel to the downtown center and out again on each trip. Driving a car is much quicker. Having a bus going from every home to every workplace is not practical.

PRODUCTIVITY OF COMMUTING RESOURCES.

The bicyclist, whose personal capital cost is trivial, illustrates an important limit in the productivity of a community's capital investment. Bicycling commuters help solve our trade unbalance and the carbon-dioxide problems, besides contributing to longevity and physical well-being of their own population. The United States trade unbalance could be eliminated by not importing oil, most of which goes into propelling our automobile fleet.

The bicyclist generates 1200 passenger miles per food-equivalent of a gallon of diesel fuel. The food that he eats has its ultimate source of energy in sunlight falling on plants, and the plants consume the carbon dioxide that the bicyclist releases. However, bicycling commuters occupy space. The streets of Beijing, which are packed with bicycling commuters in the morning and evening, illustrate the first principle in moving commuters:

- The productivity of capital investment in the transportation of people is directly proportional to the throughput, measured in passenger-miles generated per hour.

For example, a bicyclist with a reasonable headway of 15 feet and a 4-foot clearance on each side, occupies 176 square feet of pavement. Delivering in one hour a million bicyclists traveling at 7.5 miles per hour would require a street 4500 feet wide!

On the other hand, assume that the bicyclists could be parked on a 100-miles-per-hour moving belt. Now they can be packed closely together so that each cyclist occupies only 13 square feet of belt space. To deliver a million cycling commuters with this impractical method would require a belt only 25 feet wide. A more feasible arrangement might have the cyclists enter a magnetically levitated carrier which delivers them over a dedicated guideway to destinations from which each one can cycle to his workplace.

We generally increase freeway capacity by adding lanes, which occupy more land. Ultimate increases in capacity will have to come from multi-level freeways. Higher speed limits do not help because the faster-driving motorists want more headway, which is then unoccupied. The Highway Capacity Manual, TRB SR 209 1985, shows that a freeway's traffic-flow peaks at 2000 cars per hour per lane at a speed of 34 miles per hour. At 60 miles per hour the flow is down to 1000 cars per hour per lane (Figure 2).

At a rate of 2000 cars per hour per lane, delivering a million commuters in 4-person cars requires a freeway that is 125 lanes wide.

APPLICATION OF COMMUNICATION MANAGEMENT TO MOVING PEOPLE

Communication management is a well-developed tool for moving messages. For example, when you dial a number on your telephone, a computer determines the best unused route for the call and commands switches to make this connection. Federal Express delivers parcels the next day because, within minutes after the driver picks up the parcel, the computer knows where it must go, and has planned its entire overnight movement. The U.S. Post Office once performed equivalent functions with clerks working in its railway mail cars.

Applying communication-management technology into commuting practice requires these elements:

- Each commuter must be an entity to be transported, as on a bicycle or in an electric car.

- He must be picked up quickly when he arrives at a station near his origin, and transported at high speed, like 100 miles per hour, to a point near his destination.

- His movement over branch lines and main loops must be computer-controlled to place him in the best routing when considering existing traffic.

CONCEPT FOR HIGH-SPEED, HIGH PRODUCTIVITY COMMUTING

The commuter transportation system in Figure 3 could meet these requirements. The commuter drives his own standardized electric car through an entry where the computer's optical sensor identifies him for future billing, and ascertains his destination. He drives to a magnetically levitated carrier which accelerates him at a rate which achieves 100 miles per hour at the next available slot on the main line. Subsequent computer-controlled switching and off-ramping operations deliver the commuter within a few km of his destination in a few minutes (Figure 4).

We have calculated that the travel cost, including amortization of capital, need be only 6 cents a passenger mile, which is a fraction of the cost of driving a car (Figure 5).

STATUS OF AVAILABLE TECHNOLOGY

Available today are the components for building and operating the magnetically levitated and propelled commuter transportation system. For example, for aircraft flight control we are developing quad-redundant components so that an airplane can be dispatched with

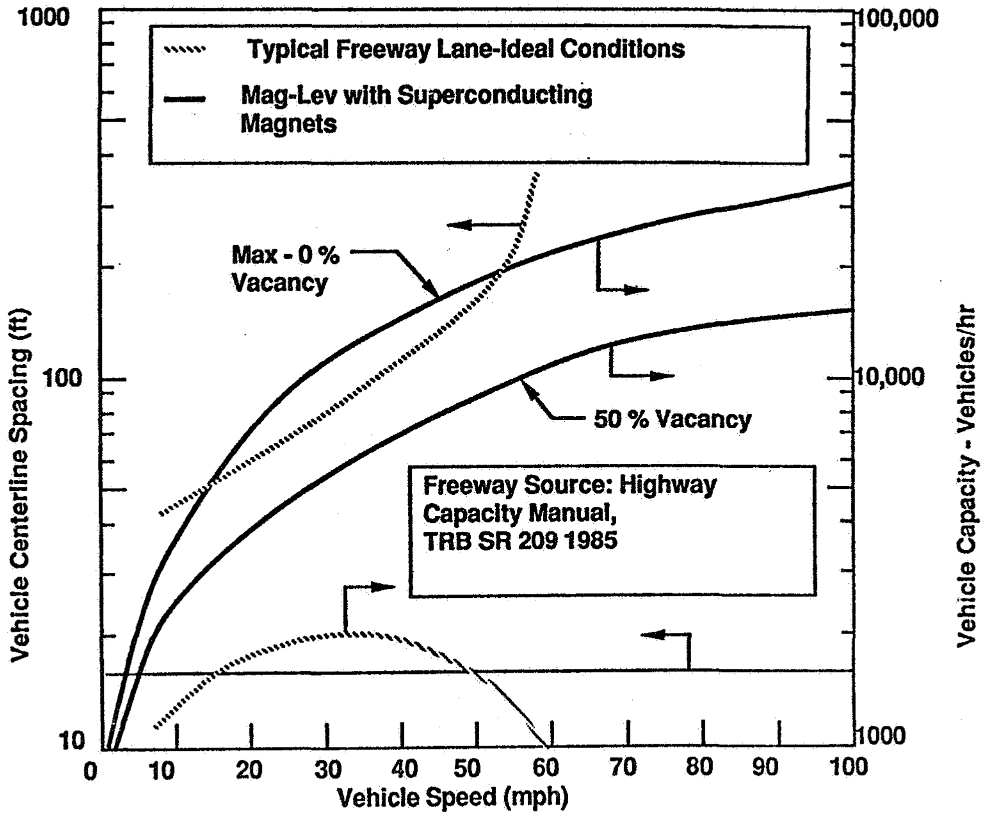


Figure 2. Freeway-lane capacity drops at speeds above 35 miles per hour because drivers need more forward clearance.

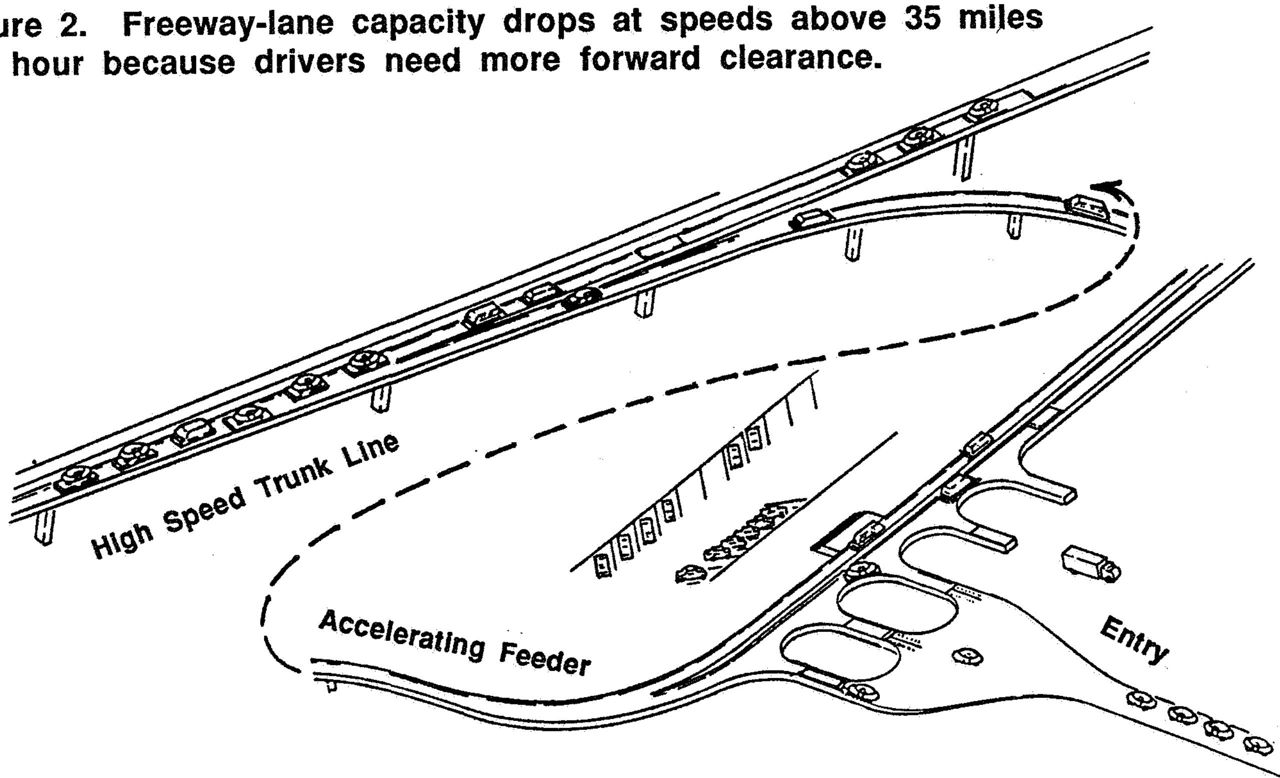
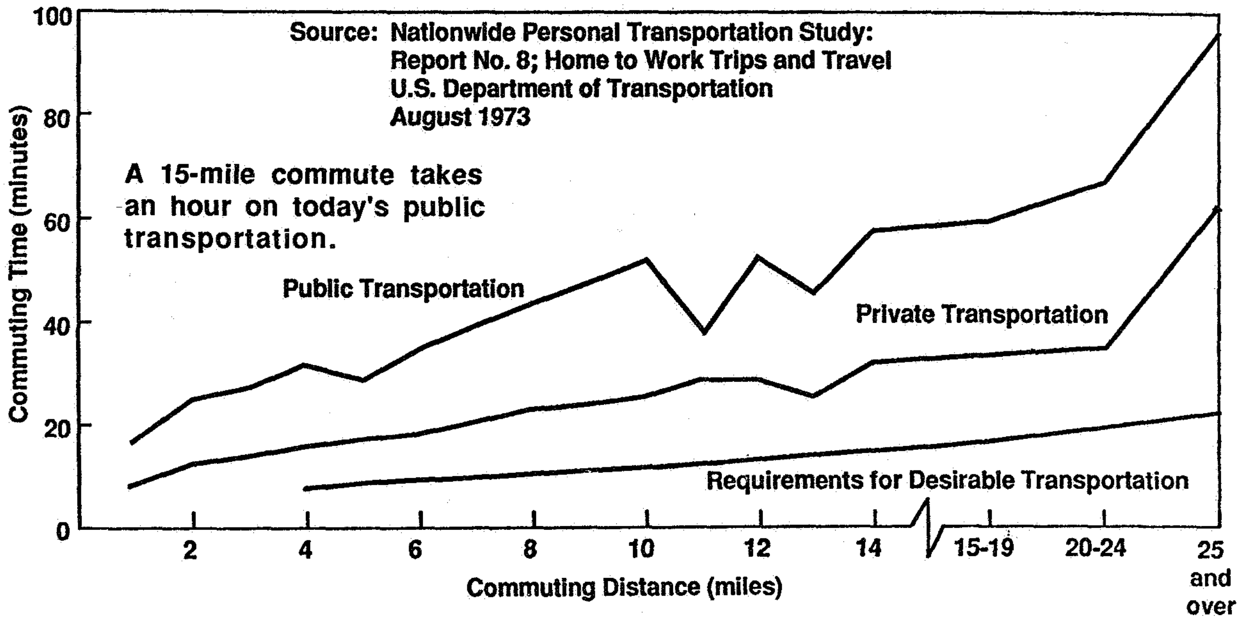


Figure 3. A commuter drives his battery-powered car onto a carrier at the entry. His car is accelerated to trunkline speed on the feeder line.



Commuting Elements	Time (minutes)			Distance (miles)			Average Speed Allocation		
	7 mi trip	15 mi trip	25 mi trip	7 mi trip	15 mi trip	25 mi trip	7 mi trip	15 mi trip	25 mi trip
Board Electric Car	0.5	0.5	0.5	0	0	0	0	0	0
Drive to system on-ramp	1.5	2.0	2.0	0.5	1.0	1.0	20	30	30
Board Mag-lev Carrier	0.5	0.5	0.5	0	0	0	0	0	0
Lower Speed Feeder Line	0.5	1.0	2.0	0.5	1.0	2.0	60	60	60
High Speed Trunk Line	3.0	7.2	12.6	5.0	12.0	21.0	100	100	100
Lower Speed Feeder Line	0.5	0.5	0.5	0.5	0.5	0.5	60	60	60
Deboard Mag-lev Carrier	0.5	0.5	0.5	0	0	0	0	0	0
Drive to Parking Lot	1.0	1.0	1.0	0.5	0.5	0.5	30	30	30
Deboard Electric Car	0.5	0.5	0.5	0	0	0	0	0	0
Total Time & Distance and Average Trip Speed	8.5	13.7	20.1	7	15	25	49	65	75

Figure 4. A 25-mile commute takes only 20.1 minutes with optimized transportation if there are no choke points.

Assumptions:	Guideway is installed on existing freeways, with no real-estate purchase. Vehicles occupy 15-foot slots and travel 100 miles per hour on trunk lines. Armature power consumed by each vehicle is 50 kW. Commuting network has 400 miles of guideways. Each day guideway is loaded to 50% capacity 4 hours, 20% capacity 12 hours, and is empty 8 hours.	
Capital Cost:	Guideways: 400 miles X $ 2.0 million/mile	$ 800 M
	Armature windings: 400 miles X $0.5 million/mile	200 M
	On-off ramps, carriages	350 M
	Communications, computers, and programming	100 M
	TOTAL	$ 1450 M
	Annual cost at 15% capitalization	$ 217 M
	Hourly ownership cost, 0.67 X 8760 hours/ year	$37,000
	Hourly ownership cost, per mile	$ 100
Cost per Mile per Vehicle:	Vehicle miles/hour generated on one mile of trunk	17,600
	Ownership cost per hour per mile per vehicle	$ 0.016
	Power cost per vehicle per mile, 50 kW , $0.07/kW	0.035
	Personnel cost, 1000 employees, $30/hour 8 hours/day	0.006
	TOTAL COST, PER MILE PER VEHICLE	$ 0.057

Figure 5. To the user the per-mile cost of propulsion power is twice the cost of using the high-productivity guideway.

triple redundancy even if one computer fails while passengers are being loaded. Other developed components include:

- o Magnetic-levitation and propulsion. The Japanese are building a $2.5 billion 40-km a track, 70 percent underground, for testing 500-km-per-hour magnetically levitated trains. The track will ultimately be part of a line connecting Tokyo with Osaka.

- o Small compact one-tesla helium-cooled superconducting magnets are being mass-produced for magnetic-resonance-imaging machines.

- o A variety of battery-powered electric cars with ranges up to 100 miles are being built in the United States and Japan.

- o Solid-state control is used to regulate the speed of ship-propulsion synchronous motors and large rolling-mill motors in steel-making plants.

Problems requiring further analysis are these:

- o Response to power failure. All vehicles must decelerate smoothly and come to a safe emergency-stop, followed by an orderly start-up.

- o Fail-safe design. Any accident or sabotage event must result in an orderly shutdown, followed by speedy rescue and restoration of service.

- o Carrier-to-guideway interface. The reaction of the levitation forces with the propulsion force is not inherently stable. Dynamic control will probably be required.

- o Carrier power. The carrier requires power for control and refrigeration of its superconducting magnets. Collecting electric power from a trolley would complicate guidway design.

CONCLUSION

Our present population, not having experienced the old interurban trains, enthusiastically supports light-rail as the solution to freeway congestion. Each commuter expects the light-rail trains to attract the other commuters so that he can drive quickly to and from work in his car.

The problem with personalized magnetically levitated commuting is that capital cost for a metropolitan area the size of Seattle could be 1.5 billion dollars. We are unlikely to see this much capital raised for a 10-years-ahead solution to problems. We are more likely to see more park-and-ride lots served by express buses, widening of freeways, and stop-and-go light-rail installations. Such band-aid facilities do not address the need for passenger-convenience.

On the other hand, the cost of real estate is rising, and in metropolitan areas more people commute to work each year. The freeway network will need more lanes, hence more of the expensive real estate. Neither freeway lanes nor light rail offer significantly improved productivity that reduces real-state requirements. The key to productivity is high speed, combined with uninterrupted decentralized routing. For example, in the early 1900's the New York Central railroad built four parallel tracks to carry the passenger traffic between Chicago and New York on its 20th Century Limited and other name trains. The Limited sometimes ran as four sections. That same passenger traffic between these cities could be carried today by one highly-productive 747 airplane, diverted from other routes for part of each day!

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