ANYTHING BUT TRAINS? A COMPARATIVE ANALYSIS OF ALTERNATIVES PROPOSED FOR THE SONOMA MARIN AREA RAIL TRANSIT PROJECT

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ABSTRACT

Changing America's commuting habits may be the most difficult part of becoming a sustainable society, if the struggle to establish passenger rail service in San Francisco's North Bay is representative. Even by California standards the region is heavily automobile-dependent. Highway 101—presently the only north-south transportation option—is the fourth most congested freeway in the Bay Area. Moreover, over sixty percent of the greenhouse gases in the two counties are emitted by highway vehicles. Sonoma-Marin Area Rail Transit (SMART) hopes to begin moving passengers by 2010, using self-propelled diesel-hydraulic rail cars that are bio-diesel capable.

Critics of the project have suggested numerous alternative technologies, which they claim to be less costly or more beneficial than a rail system. Simple NIMBYism cannot explain their opposition; a mindset of technological optimism—even determinism—is manifest. This study was conducted in effort to move the discussion to a more holistic level by incorporating environmental, social, and aesthetic variables in addition to economic ones. The results validate the technology originally chosen for the project, but without precluding new technologies that may become viable in the future. The assessment procedure should be useful for other sustainability projects that generate opposition from lobbyists and self-interest groups.

Keywords: Electrified Rail, Personal Rapid Transit, BART, Bus Rapid Transit, Dual Mode Vehicle, Automated Direct Transit, MagLev, Monorail, Self-propelled Railcars

INTRODUCTION

SMART seeks to begin passenger rail service along 70 miles of dormant track between Cloverdale in Sonoma County and the ferry terminal at Larkspur in Marin County. The most cost-effective approach is to begin service with diesel self-propelled multiple railcars (DMUs). Opponents have raised objections to the project in general and DMUs in particular, advocating a wide array of alternatives. This report compares the nine most feasible proposals by evaluating each one against twenty attributes that collectively comprise the economic, environmental, social, and aesthetic attribute—or impact—categories. Although no alternative matches the service offered by the baseline plan, the baseline SMART plan does not preclude future changes.

The capital cost forecast for the baseline plan is $5.5 million per mile—387 million 2006 dollars—including track and roadbed restoration, rolling stock, stations, signal infrastructure, and a bicycle-pedestrian pathway. Where available, published capital costs of alternatives are utilized; but operation and maintenance costs are not reliable for technologies that are still in development.

ELECTRIFIED OPTIONS

Several proposed alternatives would require electric power. SMART could build and operate its own renewable energy power generation system, but the capital cost would be very high; and as a practical matter the region served by SMART offers only one renewable energy source (the Geysers geothermal field) and that is fully appropriated. Electricity most likely would be purchased from PG&E, which means that the greenhouse gas (GHG) emissions would be whatever PG&E is producing. Losses incurred transmitting electricity to substations must be added to the energy required to propel the vehicles. The good news is that PG&E presently obtains more than 50% of its electricity from nuclear, hydro, and renewable sources that produce no GHGs. As things stand today, the principal environmental advantage of electrification is that the pollutants would be released *elsewhere*.

Electrified Regional Rail

Electrified alternatives that have been proposed include electric standard gauge rail, BART, monorail, and MagLev. Each alternative requires construction of a high-voltage electrical feed system such as an overhead contact system (OCS) or a "third rail." The additional cost would be considerable. Consider the simplest option first—electrification of the existing standard-gauge tracks. Electrifying the double-track CalTrain line between San Francisco and San Jose was originally estimated at $7 million per mile, and the single-track line from San Jose to Gilroy at $3.5 million per mile (both figures in 2003 dollars).[1] By 2007, rising material and labor costs increased those figures nearly 40%.[2] FasTraks (Denver Metro) estimated $2.5 million per mile (in 2006 dollars) to electrify its Northwest Corridor route—a line with many similarities to SMART. To these figures must be added the cost of electrical subsystems and more expensive rolling stock. Even using FasTrak's lower estimate, a twenty-year life cycle cost comparison reveals that electrification of SMART would cost approximately $400 million more than the baseline plan.[3] An increase of this magnitude would have to be justified on the basis of reduced emissions, increased carrying capacity, or energy independence. CalTrain is basing its electrification arguments on faster acceleration and future high-speed trains. Even carrying many times the number of passengers as SMART, CalTrain calculates the pay-back period will be twenty one years.[4] FasTraks calculates more than thirty years to recover the differential cost of electrification vs. operation with DMUs on the Northwest Corridor.[5]

BART

Bringing BART trains to the SMART Corridor would require a Bay crossing, either by adding a second deck to the Golden Gate, Carquinez, or Richmond-San Rafael Bridges, or by constructing trans-bay tubes. No current estimate is available for adding a deck to one of the bridges, but it would be extremely expensive owing to the need to build approaches that would enable the trains to climb from sea level to bridge height, and for the structural changes to accommodate trains. A tube between San Francisco and Marin has been estimated to cost ten billion dollars or more.[6] A tube from Richmond to Novato would probably cost a similar amount.

In addition to the bay crossing, the cost of adding BART tracks plus electrification would be very high. In East Contra Costa County, traffic congestion caused by sprawling development spurred the County and the Metropolitan Transportation Commission to seek solutions.

The first option was a BART extension from Pittsburg to Byron. A cost-benefit analysis revealed that conventional BART was less attractive than other options. Instead of using existing railroad tracks, BART requires special tracks and hardware, which would take twice as long to build as the other options (see below) and would cost $390 million (2004)[7]—$18.6 million per mile. Computer-controlled BART trains can move more passengers in a shorter period of time, resulting in greater potential revenue, ridership forecast for the route was not sufficient to offset the higher capital cost.

Many lessons from the Contra Costa County study are applicable to SMART. Because its 750-volt power is supplied by a third rail that will electrocute anyone who walks on it, the entire line must be fenced and include over- and underpasses at all roadway crossings. Grade separations cost between $100 million and $200 million each—whether for BART or SMART. The $390 million estimate for the Contra Costa extension includes only a portion of the required separations.

Grade separations are often controversial within communities because some people do not want the noise and disruption created by construction. Some feel that grade separations are an important safety and traffic issue and worth the cost; others object to the social and aesthetic impacts of a "great wall" that divides the community. Even if we neglect grade separations, the foregoing figures indicate that installing BART tracks along the SMART corridor would cost over than $1 billion—more than three times the cost for the system proposed in the SMART EIR.

BART trains operate on tracks that are wider than standard railway tracks. A BART line might be laid alongside the existing track—which must remain for freight trains—but that would probably eliminate the bicycle-pedestrian path. Alternatively, the entire line could be elevated, but the cost would balloon to $155 million or more per mile; and the visual impact would be significant (see photo in the section on Monorail.). BART cannot share tracks with freight rail as SMART will be able to do. A three-rail track is technically feasible, but significant hurdles would have to be surmounted. First—as noted above—the high-voltage rail for BART requires fencing and grade separation. Second, BART chose long ago not to permit such shared use anywhere on its system. A major change in operational procedures would be required—a highly unlikely outcome. Finally, shared use with two gauges adds costly complexity to switches and crossovers. In sum, any plan for BART would have to include 1) electrification; 2) a trans-bay crossing; 3) separate tracks; and 4) elevated or grade-separated right-of-way.

Shared Right of Way

A critical variable that must be considered in electrifying SMART is sharing the route with freight trains of the Northwestern Pacific Railroad Company north of Ignacio. Freight operations are scheduled to resume in late 2008, and tourist excursions are also likely. Shared use of tracks—or rights-of-way—by passenger and freight trains is not uncommon, but extra safety measures are required by the Federal Railroad Administration. Sharing can be by temporal separation of freight and passenger trains (e.g. freight at night only); or physically on separate tracks. Utah Transit Authority and Union Pacific Railroad share twelve miles of rail north of Salt Lake City (below left). Notice

Light Rail Terminal at Sandy, Utah

Caltrain Common Corridor, Mountain View, CA

the fence—considerably less substantial than the ones BART requires.[8] The photo on the right shows both "shared corridor" and "shared use." The LRV tracks are built on Caltrain right of way. The Caltrain track in the foreground shares use with UP night freights.[9]

BUS RAPID TRANSIT (BRT)

Contra Costa County also considered bus rapid transit for the Pittsburg-to-Byron extension. BRT would be cheaper

and quicker to build than a BART extension. But it was ranked second in the study because using the existing railroad tracks would be cheaper yet, and BRT was projected to attract fewer riders. Nation wide, studies repeatedly show that passengers prefer trains to buses. BRT presumes a "busway"—a special roadway or lane designed for the exclusive use of buses, with large distances between stops and sometimes traffic controls at roadway crossings. Short stretches of streets designated for exclusive bus use are sometimes also called busways.

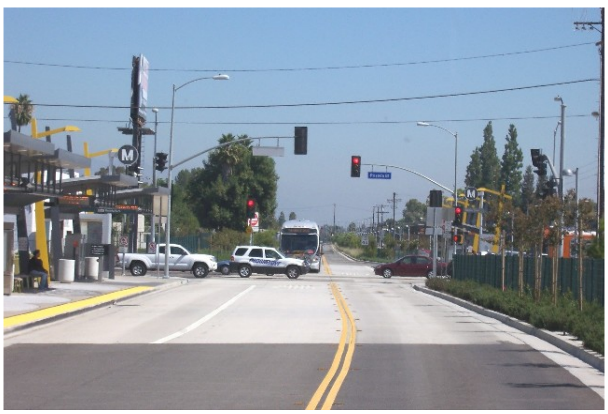
.Busways usually have on-line stations, constructed so that there is room for passing stopped buses. If at-grade signalized intersections are used, traffic signal detectors can be installed to give buses a green signal when they arrive at the intersection. There is a danger that cross traffic will ignore traffic signals if they believe there is little traffic on the busway.[10] The same concern applies to trains.

Sonoma-Marin counties have a bus system (Golden Gate Transit) with rush hour express service. But although the roads are crowded and the rush "hour" just keeps getting longer, GGT has faced a long-term decline in patronage. Meanwhile, ferry patronage from Larkspur enjoys steady increases even with higher fares than the bus. These findings conflict with BRT proponent's "if we build it, they will come" argument. If we pave the SMART right-of-way, they say, and make it into an express busway—then the riders would come. But the SMART right-of-way must be preserved as an operating freight line. A busway might be installed within the SMART right-of-way, alongside the NWP tracks—one lane on each side. But it would be at the expense of the bicycle-pedestrian path. Perhaps a reversible single-lane busway could be constructed on just one side of the tracks, and traversed by buses that travel one way during rush hours and return via HOV lanes on the freeway. But the irregularity of the right-of-way probably would require the busway to cross the railroad tracks periodically; and this one-way BRT concept would seem unattractive for weekend tourist operations. Whether by shared right-of-way or by paving over the tracks, BRT does not provide a separate Bay crossing or reduced noise and traffic impacts—the same deficiencies that critics have levied on SMART.

The claim that BRT is 'just like rail, but cheaper' is counterintuitive. Buses requires more operators per passenger than trains do; and they do not have the inherent low-rolling resistance that is the key to rail's low energy cost and high productivity. Moreover, buses have considerably shorter operating lives than rail cars. So how can BRT proponents claim otherwise? Conflicting claims have proliferated because it is very difficult to find reliable data upon which to make meaningful comparisons.[11] Some lines require acquisition of property, removal of existing structures, and construction of grade separations; some revitalize existing-but-unused infrastructures; and still others include elevated structures along roadways.

Consider the Nation's newest BRT—the "Orange Line" in Western San Fernando Valley. How does the line actually measure up in comparison to light rail and other rail systems? "On the whole, the Orange Line BRT is a major transit improvement in the corridor it serves," says the 'Light Rail Now Project team.' And given applicable legal restrictions, a busway was effectively the only option for implementing rapid public transport service in the former railway alignment. [12] But the Orange Line fares rather poorly compared to the new Gold Line light rail transit system to Pasadena, which offers an 18% faster schedule than the BRT Orange Line. The Gold line has the benefit of the grade separations (overpasses) left over from a former freight railroad, but the Orange Line does have automatic crossing protection. Even though the BRT Line operates in a corridor with far greater population density and serves at least 40% more major activity centers than does the Gold Line, ridership is approximately 24% lower than one would expect from light rail transit in the same corridor. [13]

The photo below of a roadway crossing illustrates the problem, and explains why the buses slow to 10 mph at crossings even when the signal is green.[14] The fact that buses operate more frequently than trains is claimed as a bonus by BRT advocates, but it means not only more frequent interruptions of traffic at crossings, but also higher labor costs. Finally, the positive guidance of rails means that double tracks or passing track can be closer together



than busways—thereby consuming less land than busways. BRT drivers tend to slow down when approaching an opposing vehicle.

The fourteen-mile Orange Line busway cost $330 million to build—$25 million per mile. Absent detailed cost records it is not possible to ascertain the reasons for the high cost. But other BRT systems—in Boston, Los Angeles, Kansas City, Ottawa and Pittsburgh (about 60 [total] miles of exclusive busway)—cost over $50 million per mile in 2007 dollars, not including the buses. By contrast, light rail for 46 miles [total] in Denver, to Portland Airport, Salt Lake City to Sandy, and east of Saint Louis, cost $23 million per mile or less including both cars and shops. And light rail vehicles cars last for 35 or 40 years, compared to fifteen for buses.

Finally, environmental impacts of BRT are worse than impacts from rail transport. Buses consume more energy per passenger per seat mile than passenger trains, and therefore emit more pollutants. Paved busways reduce percolation and increase runoff[15]—a factor of special significance considering the several wetlands that must be traversed. And unlike highways, railways do not serve as a physical barrier to wild animals. BRT can be ruled out *a priroi* in any case, north of Ignacio, because the tracks must be retained for freight trains.

SELF PROPELLED RAIL CARS

The winning option from the Contra Costa BART extension turns out to be—surprise!—*self-propelled railcars* The key reason for this outcome is that dormant standard gauge rails are in place along the right of way—just like they are for SMART. The Contra Costa concept is dubbed "eBART"—for "east BART." Diesel multiple unit trains will start at the Pittsburg/Bay Point station and head east in the State Route 4 median; then switch to the existing, under-used railroad tracks. eBART would be less expensive and completed faster than other options. This is an attractive alternative because: 1) it uses existing rails, 2) it uses diesel propulsion, thereby eliminating the need for investment in an OCS system; 3) the aesthetics are good; and 4) the operating cost per passenger mile is low. Moreover, it does not rule out future electrification.

AUTOTRAM

AutoTram is a is a fixed-guideway system like a railroad, but runs on rubber wheels and for guidance relies on detection of an electrical conductor embedded under the roadway surface. On routes with low passenger volume AutoTram can be operated as a single bus; or up to three units can be assembled in to form a higher-capacity vehicle 36 meters long. AutoTram draws its power from a 180-kW, 258 bhp BMW 740D diesel engine and a flywheel energy storage system (4 kWh/200 kW). The flywheel absorbs part of the braking energy, enabling AutoTram to travel up to two kilometers without the motor. AutoTram's developers claim it to be 30 to 50 percent cheaper than conventional railway—perhaps because it is intended to operate on public roadways. The concept has potential for labor savings compared to conventional buses, but it is a brand-new technology—introduced in 2006 by Fraunhofer Institute for Transportation and Infrastructure Systems in Dresden.[16] AutoTram suffers from roadway congestion just as regular buses do. Basing public transit on a technology still in its concept stage would engender technical and financial risks and would not be prudent for a least-cost project such as SMART.

DUAL-MODE VEHICLES (DMV)

A variant of the self propelled railcar known as a "dual-mode vehicle" looks like a minibus and runs both on conventional railway tracks and paved roads. The main advantage of such a vehicle is that passengers need not transfer from a small capacity van to a large capacity train; the main disadvantage (as with Bus all bus transit) is that small capacity vans have relatively high per-seat labor costs.

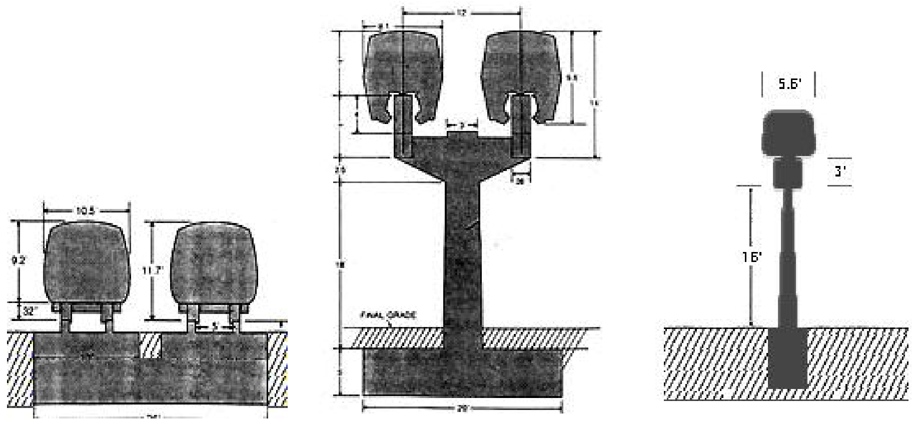
A Japanese dual-mode vehicle was tested in Fuji city in November, 2006. The 28 passenger test vehicle—with a maximum speed of 40 miles per hour—was developed by the Hokkaido Railway Company in a project that began in 2000.[17] Technicians aboard the vehicle evaluated the safety and ride quality during the series of tests on rail and road. After the 3 km railway portion of the test course, the vehicle stopped at a crossing, retracted the railroad wheels and switched to street mode in just 10 seconds. The video reveals that more than a minute is required for the reverse move from road to rail. No information was provided on how long it takes to reach running speed on the track. The latter would be needed to establish safe headways between vehicles.

A number of local governments around Japan have shown interest in DMV because they are forecast to be inexpensive ($145,000 in 2004 dollars) and operate. In April 2007 such vehicles began operating along part of the Kushiro line in eastern Hokkaido. The target market is branch lines which have fewer than 500 riders per day—making the vehicle poorly suited for 5,300 daily SMART riders. The extra set of wheels create a tare-weight penalty; but engineers have attempted to retain as much of the steel-on-steel efficiency as possible. The vehicles are driven by the rubber tires, and the portion of the load carried by the tires is just enough to provide friction on the rails. If operated between Ignacio and the Larkspur Ferry, such vehicles might be able to provide a close connection between rail and ferry service that would be acceptable to the City of Larkspur. Like AutoTram, however, DMV is an unproven technology which engenders risks that are not prudent for SMART. It is unlikely that the Federal Railroad Administration will permit DMVs to share tracks with freight trains.

Speed, acceleration, comfort, and efficiency of the DMV are likely to be less than for the self-powered railcar. If SMART is able to work out integrated timed transfers to local bus and van services, DMU trains very likely have higher ridership potential than DMVs and can deliver the service with less energy and pollution.

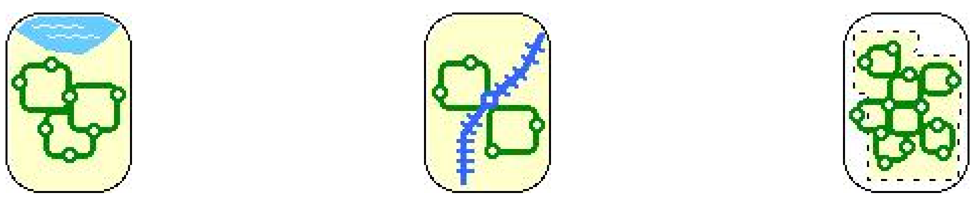
PERSONAL RAPID TRANSIT (PRT)

Personal rapid transit seeks to provide mass transit while retaining the flexibility and spontaneity of the personal automobile. It purports to reduce the mass of personal transport vehicles from today's absurd 2-5 tons per vehicle to one ton or less. Lower vehicle weight means guideways can be lighter and less-intensively engineered than highways, elevated rails, or monorail beams. As shown in the figure below, PRT vehicles and guideways are envisioned to be smaller and lighter than standard rail, BART, or monorail. One reason that the structure appears smaller is that only a single guideway is depicted. Bidirectional service requires an additional track, just like all other modes. Most PRT concepts envision replacing some autos, buses or rail transit; but some advocates argue that PRT can provide complete transportation systems—at least for commuting or shopping. “Portals” must be located within ¼ mile of riders, however, because studies indicate that is as far as potential riders are willing to walk.[18] As a consequence an effective PRT system will require blanketing the urbanized area with a grid of guideways. If the system reduces the need for roadways and parking, PRT has the potential to improve land use.



For a heterogeneous population distribution like Sonoma-Marin, three options are envisioned—as pictured below:[19]

Three PRT layouts



(a) Small networks for local circulator transit, congestion relief, or in anticipation of future density

(b) Transit service to and from rail stations

(c) Circulators linked together, forming a county-wide network

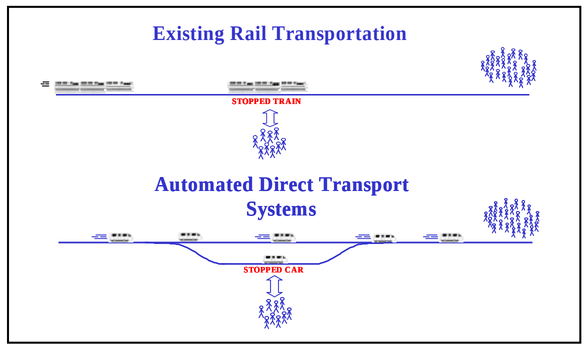
It is hard to imagine that the citizens of Sonoma and Marin Counties would accept the visual impact of a PRT network like the one shown in (c). But as a feeder system, such as from a college campus to SMART, PRT might work—except that cost estimates range from $10 to 15 million per mile.[20] Additional factors that must be considered include:

- The aesthetic impact of a grid of elevated PRT guideways. Advocates posit that the structures would be “lighter than monorail and therefore of less impact.” But unlike monorail, they would be everywhere! And if solar panels are added, the canopy effect would be significant.
- Rather than providing beneficial impact on land use, the opposite may be more likely. The concept could facilitate sprawl because—in contrast to SMART, monorail, or BART—it is a two-dimensional system like automobiles on roadways.
- The guideways are one-way. Travel to a destination could involve roundabout routing, under computer control.
- Small PRT vehicles are likely to prove claustrophobic for long-distance travel.
- PRT experts acknowledge that the concept is more suitable for urban than inter-urban applications.[21] But the question comes to mind as to why the local service could not be achieved simply by encouraging smaller automobiles—like ZAP cars. The way to make that happen is via a gasoline or carbon tax, with the revenue invested in transit.
- The infrastructure for SMART is already in place, needing only to be refurbished.

- PRT requires an entirely additional new infrastructure. The infrastructure must be overlaid upon the existing network of roadways—or if located off roads, new right-of-way must be secured.
- While guideways are envisioned to be non-bulky, PRT requires sophisticated electronic operating systems including radar, microwave communication, servo controllers, and integrated computer control—all of which need to be demonstrated in service so that operation & maintenance data can be generated.

Like Dual-Mode Vehicles and AutoTram, PRT is an unproven technology which increases the technical and financial risks beyond the bounds of prudence as a substitute for SMART.

AUTOMATED DIRECT TRANSPORT SYSTEM (ADTS)
Automated Direct Transport can apply to trains or autos. The term refers to driver-less, computer-controlled single vehicles or trains.[22] The idea involves driverless vehicles—operating on elevated guideways or at ground level—with a passing track at stations. A train control system without an operator in the vehicles reduces labor costs and (according to the proponents) the ability of vehicles to bypass stations permits any number of stations to be established while speeding travelers to their destinations, with demand-driven bypassing of stations" as portrayed in the figure to the right.[23]



Envisioned operating efficiencies include smaller and lighter vehicles with correspondingly smaller and cheaper guideways and stations. But the 'passing track' portrayed in the figure is hardly a new concept. The SMART right of way is sufficient to provide a passing track at most stations without displacing the bicycle-pedestrian trail. SMART could run such express trains, bypassing a number of stations, too. An express could follow an ordinary local train that stopped (for example) at Novato, and express to Santa Rosa.[24] In addition to the intriguing possibility of being able to provide more responsive service (that is, service to rider-specified destinations stations on demand), ADT proponents believe that the concept will reduce construction costs—but the assertion has not been tested. ADT is a variant of PRT, retaining all of its deficiencies while solving a problem that seems not to be of concern to other PRT proponents. With the objective of further reductions in operating costs, Unimodal Skytran Inc. has proposed combining PRT and ADT concepts with maglev.[25]

Neither ADT nor PRT are useful as a system until the two-dimensional grids are in place—and to this analyst that seems very unlikely. A trunk line ADT-PRT system conceivably could be constructed above the SMART right of way, and a supplemental network could function as "branch lines" or feeder systems to SMART from—say—Sonoma State University or Sebastopol. But the cost of construction alone—not to mention land acquisition—is triple the cost of SMART. The cost of land acquisition and legal procedures to obtain new right of way has not even estimated. In the words of the Coalition for a New California Infrastructure (CNCI), "serious commitments to development and deployment are needed if the (ADT) concept is to realize its full potential of providing mass rapid transit-like service to a large population."[26] The technical and financial risks of ADT—like PRT—are imprudent for a least-cost start-up like SMART.

MONORAIL
Saving half of the number of rails—and the job of keeping them level with each other and the right distance apart—has made the idea of monorail a recurring dream. Its problem is that, like the bicycle, it is not "statically stable" unless the "rail" is located above the vehicle's center of gravity.[27] The case for and against monorail can be understood fairly readily by looking at the following photo of the Seattle Monorail system. The monorail is up and out of traffic, such that separate grade separations are not needed (although the widest crossings probably would require additional structural support). Also no separate power rail or overhead power lines are required, because the power supply can be attached to the guideways; and no safety fencing is necessary. But the physical dimensions of monorail for serious, urban-mass-transit have to be large and extensively engineered to support the weight of two-to six-car trains. Along the route, access is convenient only if you are near a station. If not, you are still living with shadows and noise.[28]

Consider these additional points as well:

- Like PRT, monorail fails to exploit the efficiency of steel wheel on steel rail.
- Absence of an effective switching mechanism mandates double tracking.
- Monorail is more expensive than any other alternative except possibly an elevated BART system.
- Monorail introduces another new transit mode, one having no compatibility with existing systems.

In sum, monorail systems are suitable (if anywhere) in dense, urban areas where the restricted availability of land justifies the high capital investment required for this alternative. That justification does not exist in the proposed Smart Train corridor.)

MAGNETIC LEVITATION (MAGLEV)
Maglev trains are operating today between the Shanghai Airport and downtown, as well as on test tracks in Japan and Germany. But capital costs are more than double that of high speed rail, and maglev may never be widely used unless the costs can be brought down.[29] When the Chinese government learned that the proposed 775-mile maglev line from Beijing to Shanghai was going to be $57 to $77 million per mile,[30] they rejected maglev and contracted with Siemens to build a national steel-wheel high-speed-rail network. The Japanese are still considering a Tokyo to Nagaya maglev line to be built by 2025—310 miles at a cost of over $76 billion, or Tokyo-Osaka for $100 billion.

Maglev proponents tout lack of friction, as if friction were a major drawback of conventional rail. But steel-wheel-on-steel-rail trains are operating in regular service at over 300 km/h today and have been demonstrated at 574 km/h (357 mph)—nearly as fast as the maglev record of 360 mph. In either case, when speed rises above about 220 mph most of the energy is being eaten up by overcoming air resistance. High-speed trains may be in the future for travel corridors where cities are over 100 miles apart, such as San Francisco-Los Angeles, Dallas-Houston, Portland-Seattle, and the Northeast Corridor. But maglev trains require a minute and a half to attain operating speed. With the average five-mile distance between SMART stations, the trains would be mostly accelerating or braking. The 80 mph planned for SMART's proposed self-powered railcars are a much better fit than maglev for this corridor.

MAKING COMPARISONS
How do we assess the claims that the proponents of each of these alternatives have made? Quantitative comparison is extremely difficult—perhaps even counterproductive—because the inherent differences among the modes in the nature of services, routes available, and many additional factors mean that significant assumptions must be made in order to develop directly comparable data.[31] Like every sector of the economic system, transportation is a means of using labor, energy, material, and capital to produce goods and services that society values. There are faulty interconnects among the production, economic, and ecosystems. In order to understand these faults—and evaluate ways to correct them—the performance of the various parts of the interlocking sets of systems must be analyzed.[32] Computations of the productivities of various modes of transportation are complex, because highways are used by private vehicles together with government vehicles, emergency vehicles, buses and trucks—and likewise the nation's airways and waterways. This is one of the reasons why it is so difficult to find directly comparable data for the different modes.[33]

Most of the "data" for new technologies is projected, while for mature technologies it is derived from actual operating experience. Moreover, each technology tends to be evaluated by different measures.[34] Advocates make assumptions and draw the boundaries of the analyses in ways that favor their own system. Bus rapid transit proposals reduce O&M costs by presuming that highway departments will maintain the right-of-way; PRT advocates forecast low O&M costs without benefit of operating experience. Electrically powered systems will reduce our dependence upon petroleum but at the cost of increased GHG emissions unless the electricity is generated from renewable sources. But renewable sources would also apply to an electrified SMART system. Biofuels—for BART or SMART—can reduce GHG, but large-scale production of biofuels will compete with the food supply.

Clearly *economic* arguments do not begin to tell the whole story. Productivity measures must include the immense number of lost hours accumulated by commuters stuck or creeping in traffic. Rail travelers can—if they choose—work while commuting. Speed, comfort, and stress reduction also have an economic component. But we have been doing this since the Interstate Highway System began. "With remarkable precision," wrote Barry Commoner in 1976, "the US transportation system has favored those modes of transportation that are thermodynamically inefficient and low in capital productivity." As a result, the US transportation sector consumes much more fuel and capital than it needs to, relative to the relative to the transportation that it produces.[35] With respect to each measure railroads are more productive than alternative modes and the margin is widening. Trains with steel wheels on steel rails easily surpass all other modes nationally with respect to productivity—in passenger- or ton-miles per unit of energy, right-of-way per passenger or ton, or labor per passenger- or ton-mile.

Nevertheless in the decades between 1950 and 1990 rail systems lost their role the foundation of US transportation. Three things accounted for this unfortunate turn of events. First, rail lines are one-dimensional, whereas the roadway network is two-dimensional. Until the national road network was constructed (at enormous public expense), railroads promoted clustering of development near stations and along spokes, or spines. The roadway network permitted autos to go anywhere in two-dimensional space, with the result a dispersion of American society. The process is self-reinforcing. As sprawl progresses more roads are built, walkable places decline in significance and auto dependency rises—which in turn stimulates further dispersion. Transportation and land use are coupled.

The second reason that rail systems lost ground as the primary shaper of transportation and land use is that private automobiles have come to fill important psychological and social needs. Among these needs are *esteem*—a personal statement to self and others of who we are (or want to be); *solitude*—the need to separate oneself into a quiet space in the midst of the rush of contemporary life; *power and control*—for the many who feel powerless and insignificant; and *freedom*—for those who feel trapped by life and circumstances. Much of this is by design, advertisement, and *de facto* public policy. Using autos to meet psychological needs has led to enormous environmental and social problems, from lack of exercise to road rage. Removing just 5% of the cars from a congested road will raise highway speeds by 20 mph,[36] relieving considerable frustration. We need to acknowledge the psychological needs and take deliberate steps to find non-automotive ways for meeting them..

The third reason is *misinformation*. Some of the misinformation arises when apples are compared to oranges—i.e., not placed on a common footing—and some arises as an unintended consequence of a free press in a market economy. In the name of "balance," studied and un-unstudied (or mature and immature) ideas receive equal coverage. Editors and producers know that controversy attracts audiences. Thus well-researched conclusions and off-the-wall ideas are frequently cast as simply opposing viewpoints. Jon Krosnick, professor of communication and political science at Stanford University, calls the process "balance as bias." The process doesn't simply "inform"; in reality it leads to uncertainty and confusion in the mind of the average reader (or listener).[37]

If transportation could be provided as a market commodity, perhaps individuals could choose the optimal solution for their particular needs from among many options. But transportation does not lend itself to commoditization, in spite of attempts to operate the automobile sales and service sector as commodity-based. The reason is because of the enormous economic cost of the requisite infrastructure, and because of the cumulative social and environmental impacts of the hundreds of millions of individual transportation events that take place each day. But the seeds of failure are so inherent to highway-based transportation that inevitably and ultimately, population growth and increased automobile use make the end state unavoidable. Hence rail transportation and mass transit—especially rail—are once again growth industries in the US.

A quantitative comparison that accounts for the diverse array of factors described above does not exist; but the process that follows is a reasonable semi-quantitative step toward that objective. The proposed alternatives to SMART are evaluated in a matrix, according to terms of three kinds of sustainability:

1. Physical (energy consumption, sources and reliability, environmental impacts, land use, renewable energy options).
2. Aesthetic (shadowing from elevated structures, aging facilities, land conversion, urban vs. rural visual).
3. Social and cultural (impacts on spontaneous mobility; productivity—economic, energy, and land; social and psychological needs).

CONCLUSION

The comparisons of the alternatives for SMART are tabulated in the matrix below—which is displayed in two parts for readability. In light of the discussion associated with each alternative, certain of them may be eliminated by inspection. In other words, one or more of the evaluation factors render some alternatives infeasible or unviable, as for example unproven technologies that create unacceptably high technical and financial risk. The SMART solution must consider only those alternatives that have progressed at least through the pilot plant stage, so that performance has been studied and documented and reliable capital cost figures are available. Readers wishing to develop their own quantitative comparisons are referred to the references already provided; many others are available

Positive Attributes of proposed alternatives for SMART		Alternatives										
		Keep driving	CalTrain-like Electrification	BART Extension	Bus Rapid Transit	Dual Mode Vehicle	AutoTram	Personal Rapid Transit	Automated Direct Transit	Monorail	MagLev	Colorado Railcar
Environmental	No new right-of-way required	0	5	5	5	9	0	0	0	5	0	9
	Compatible with bike-ped path	5	9	0	0	5	9	9	9	5	0	9
	Facilitates T-O-D	0	9	9	0	0	0	0	0	9	9	9
	Reduces Greenhouse gases	0	5	5	5	5	5	5	5	5	9	5
	No impermeable surface	0	9	9	0	5	5	5	5	5	0	9
Economic	Compatible with freight	9	9	5	0	0	9	9	9	5	0	9
	Saves commute time	0	9	9	9	9	5	5	5	9	9	9
	Capital cost under $6M/mile	0	0	0	0	9	0	0	0	0	0	9
	Uses existing infrastructure	5	5	0	5	9	0	0	0	0	0	9
	Doesn't preclude other options	0	5	0	0	9	0	0	0	0	0	9
Social	Reduces VMT and VHT	0	9	9	5	5	9	9	9	9	9	9
	Provides choices	0	9	9	9	5	9	9	9	9	9	9
	Operational by 2010	5	5	0	9	9	0	0	0	0	0	9
	Reduces petroleum imports	0	9	9	5	5	9	9	9	9	9	5
	Permits multi-tasking	0	9	9	9	9	9	9	9	9	9	9
	Fits MTC Regional Plan	0	9	5	0	0	0	0	0	0	0	9
	Geographically flexible	9	0	0	5	5	0	0	0	0	0	0
Aesthetic	No overhead structures	5	0	0	9	0	0	0	0	0	0	9
	Minimal land use	0	9	9	5	5	0	0	0	5	5	9
	Reduces smog	0	5	5	5	5	9	9	9	9	9	9
Sum		38	129	97	85	108	78	78	78	93	72	163

9 **Strong—9points** 5 **Moderate—5 points** 0 **None—0 points**

Numerical values assigned to produce spread/ qualitative value not implied

Only the Colorado Railcar emerges as an acceptable near-term solution. Alternative technologies could be implemented in the future, on a schedule that matches the projected needs for mass transit in this corridor and that limits the financial and technical risk to the taxpayers. DMU railcars could be considered as Phase 1, with Phase 2 being conversion to hybrid engines, and electrification as Phase 3. Technologies currently on the drawing boards might become useful for feeder service, but near-term choices must not preclude future options.

ENDNOTES

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