Appendices

Metropolitan Access, Intercity Rail and Technology

The Vital Role of Metropolitan Access in Intercity Passenger Transportation

From the Traditional Limited-Stop Express to the 21st Century Ring Railroad

Alex Lu, Dalong S. Shi and Carl D. Martland
MIT Center for Transportation Studies (1-235), 77 Massachusetts Avenue, Cambridge MA 02139-4301
lexcie@mit.edu – (617) 776-6547 (617) 253-5326

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1. ABSTRACT

Carriers in intercity passenger transportation markets employ a different set of technologies with diverse characteristics. Potentially, the ease of access is an important competitive advantage for rail carriers. In major metropolises, the downtown business district is physically too large to be served effectively with a single station. Thus, a series of stations are required for effective rail service, just as an urban expressway requires more than a single exit downtown to be effective. The local distribution mechanisms can be an important driver in intercity mode choice, since it affects the utility of the overall "trip experience", especially in a competitive situation where the overall origin-to-destination time for a selection of intermodal itineraries are similar. A loop is an effective layout for servicing the demand and for operational reasons, although in some cities other layouts are more effective. The conventional wisdom of concentrating passenger operations at a union station is misleading since in the typical city of more than two million population, much demand originates from suburban business districts and homes – where the airport is more accessible. Case studies show that effective downtown rail loops may reduce origin-to-destination journey times on the order of 15~20 minutes, which is roughly equivalent to increasing average line-haul speed from 120 to 168 km/h (80mph to 105mph) over a 160-km (100-mile) segment. Effective downtown access may be much more leveraged than increasing maximum permissible speed.

2. INTRODUCTION

Intercity Passenger Transportation is, at best, a limited commodity market. Carriers employ various sets of technologies – railroad, highway, aviation, hovercraft – each with different characteristics and addressing the needs of a different market segment. Besides speed or cost, there are a multitude of performance measures all of which can be turned into a competitive advantage for a given mode or carrier. This paper examines the circumstances under which the accessibility to a given mode can become one such advantage. Specifically, how can the layout of railroads and location of intercity stations within the high-density downtown area contribute towards the railroad's ability to compete for intercity passengers?

Traditionally, intercity trains have departed from a single downtown 'union' station while airplanes have departed from an out-of-town airfield. The inherent technological constraint in aviation is that while they offer low end-to-end journey times, much land is required for a terminal and thus it is impractical to site them in high-density areas. The consolidated downtown terminal offered good access for high-density central business districts in large cities of up to perhaps 1 million in population. However, with the development of suburban business districts and multi-clustered downtown centers in major metropolises such as Tokyo or Los Angeles, the downtown terminal may be unable to realize the full market potential. There is widespread recognition within the industry that access to the city-centre can be an important part of any high-speed rail scheme. In Britain, it is documented *(1)* that upgrades to the "classic" lines which provide access from the downtown to new high-speed cut-offs are an expensive but necessary part of the passenger rail vision. What is not widely recognized is that a large proportion of intercity trips originates from the greater metropolitan area, thus urban distribution can be just as important as downtown access. Traditionally, urban distribution has been left firmly in the domain of local transit authorities and private bus operators. This institutional divide often led to counter intuitive routings by public transportation, making the do-it-yourself private auto approach much more attractive than it otherwise would be.

Already, airports are taking advantage of the sheer size of some cities to provide a distributed service. London's Gatwick, Heathrow and Stansted airports all feature services to Edinburgh, and those residing north of London are more likely to fly via Stansted than those residing in the south. Distributed rail terminals in a congested city may be provided by railroads in a variety of layouts: lines travelling through the city independently, lines joining an inner urban ring, or a combination of both. Ultimately, the constraining geographic features in a city and the distribution of densely populated areas will determine which scheme is the best, although the ring railroad concept offers good performance for relatively low cost. This is not a suburban ring – the ring must have a small radius. The inherent advantage of downtown access to rail terminals disappear if the stations on the ring are not within walking distances of the densely packed city centers. Station amenities are critical – luggage stowage, taxicab services, stores and restaurants are available at most airports. Multiple full-service downtown stations are needed.

In the suburban "non-walkable neighbourhoods", there is insufficient density for effective rail service *(2)*. Thus, strategically-located Park & Rides (parkway stations) are more important. Parkway stations should be located such that they are closer to the demand generators than the airport, even if it means detouring the rail line. Car-hire and car-sharing facilities are needed. Conceivably, an argument could be made that every city with a relatively high urban density and a population of more than two million should have a downtown rail distribution mechanism – a ring railroad, or simply a series of stations on one common trunk route through the city.

Effective local distribution mechanisms are a leveraged area with respect to performance of intercity passenger systems. Experience with the South Shore Line in Indiana demonstrates that decreasing terminal accessibility (elimination of street-running and local drop-off) can have dramatic negative impacts on intercity ridership *(3)*. Conversely, despite longer journey times, the North Shore Line remained competitive against the Hiawathas as it offered much better access to downtown Chicago via the elevated loop *(4)*. As with overnight services, the vehicle costs are insignificant when compared with the infrastructure costs (in many cases the service plan would utilize turn-around times in the existing fleet). Thus, the leveraged technologies are infrastructure related. New construction methods are needed to allow cheaper tunnels and elevated rail lines with lesser environmental impacts, so that infrastructure could be retro-fitted to congested downtown areas. New rolling stock technologies, such as distributed power & brake, higher power-to-weight ratio, and lower emissions from diesel power plants may allow intercity express trains to perform better in start-stop runs and underground. High-performance switches and crossings could allow greater stability and higher speeds in highly constrained geometries, e.g. a novel method of vehicle guidance over turnouts, such as a third contact point or a non-contact system. Cheaper and more reliable train-control technologies will allow increased train-densities on congested downtown distributor lines. Rapid-transit type signalling principles adapted for compatibility with the traditional railroad systems may hold promise.

On the marketing side, enhanced decision-support and data-collection systems can assist service design and analytically determine optimal stopping patterns for local and express trains. Seamless ticketing technology for intermodal trips will allow easier transfers, making high-speed rail an integral part of the wider transportation network. Finally, innovative door designs and luggage handling facilities will minimize station dwell times – which will become increasingly important due to the additional station stops the intercity passenger train would make on a loop.

3. COMPETITIVE UTILITY ANALYSES – HOW TO BEAT 'EM AT THEIR GAME

Before embarking on a detailed utility analysis, it is useful to conduct a strategic analysis for each type of intercity passenger transportation technology. Given a reasonable "high-speed" intercity rail system with average speeds between 144 and 200 km/h (90mph and 125mph), it is clear that in the corridor market (320-960 km, 200-600 miles), the aviation industry will always have a speed advantage, while the private auto will continue to be more accessible. How can rail operators defend its market position?

Table 1 catalogues the historical development of urban railroad layouts throughout the 20th century and beyond, and compares the competitiveness of rail service against the state of the art in other modes. The union station is largely a product of the pre-war era, when the only effective competition was the electric interurban. Against present-day auto and air, it has little advantage. As the railroads progressed towards the parkway station concept, shorter access time for those living near the parkway station resulted, gaining a competitive advantage for a limited market segment.

Technology changes that will reduce the airplane's advantage in journey times are likely to be very expensive, but rail can succeed by attacking the technology's inherent weakness of requiring a large airfield by advancing towards a multi-hub network. The enhanced accessibility for rail also happens to reduce the private auto's strength in offering convenient access. Although the intercity train will never be as convenient as the auto, an intermodal solution based on short-distance feeder limousines can reduce the auto's advantage to virtually nothing. Then, with the interstate highway system (both autos and buses), rail is able to compete on the grounds of lower overall journey time and comfort; while competing on the grounds of cost and accessibility with the aviation industry.

3.1 In Vehicle Time Versus Out-of-Vehicle Time

It has long been known in transit demand modelling that in-vehicle time is preferable to out-of-vehicle time, especially where the terminal amenities are either nonexistent or excessively expensive *(5)*. In an origin-to-destination trip analysis for an intercity traveller, the trip may involve many modes and multiple transfers. If some of these transfers and the associated waiting times can be eliminated, the utility of the intercity trip (and thus the competitiveness of the mode) could be dramatically improved. In addition, allowing the passenger to board the "line-haul" mode closer to the origin reduces the total trip time. Recent professional testimony suggested that the concept of one-seat-ride in Commuter Rail has a dramatic positive impact on ridership *(6)*. In addition, there are intangible effects of providing a sense of presence for the railroad, which can induce changes in trip generation and mode choice *(7)*. In short, better access for intercity trains offers a way for undesirable access time to be converted into more desirable in-vehicle time and reduces overall journey time.

3.1.1 The Base Case

Consider a typical leisure trip from an outer suburban home to an inner suburban destination in a nearby city (160~480 km, or 100~300 miles away). With a traditional, TGV-style point-to-point service, the typical trip would involve a drive (or a transit-ride) to a downtown union station (between 30 minutes to 1½ hours), some buffer time for access unreliability, a point-to-point ride (one to three hours), followed by a cab or transit ride from the rail terminal in the destination city (30 mins to 1½ hours). For trips of less than 300 miles, the extra time required for checking in and security screening offset the higher speed of the airplane. Here, the accessibility of rail and air are roughly equal. The airline has a slight advantage for origins and destinations closer to the airport (and the lesser-congested suburban areas), and the railroad has a slight advantage for origins and destinations closer to downtown (and the more congested city neighbourhoods). Most of the competition takes place on the line-haul leg, and customers make their mode-choice based on line-haul time and amenities offered. In this situation, rail technology is disadvantaged due to the high costs of infrastructure required to attain line-haul speeds competitive with the aircraft. The same argument also applies to a business trip from a suburban business office, even if the destination is close to downtown.

3.1.2 Why is Non-Stop Rail Competitive at All?

Why is rail competitive at all in those circumstances, as demonstrated by such flows as London-Edinburgh and Paris-Lyons? *(8)* The reason lies with different values of time associated with different modes *(9)*. Although rail takes longer, the greater degree of comfort offered by rail and the lower price-per-mile in some cases mean that a number of people will choose rail. In addition, crucially, rail allows the time spent on-board to be used productively; a business traveller can in fact generate value during this time, potentially giving rise to a higher utility despite the longer in-vehicle time. For the leisure traveller, this argument is less compelling, although most passengers ordinarily classified as "leisure" travellers for their lower willingness-to-pay are actually able to utilize the time productively. For instance, a college student may choose to review course materials, and a person visiting a friend may choose to write a letter or read a book en-route. All of the above activities may be preferable to making many transfers, waiting up to half-hour for each transfer, and spending time standing in line to clear security at an airport.

3.2 Parkway Stations and Their Impact

Parkway stations, usually located in the suburbs featuring drop-off drive-thrus and ample parking, was rail's first attempt to capture suburban travellers. Situated conveniently on an interstate beltway, the parkway station enlarges the market reach for rail out towards the suburbs on one side of the city. The parking is easier and cheaper (in terms of opportunity cost of land consumed). Certain parkway stations also serves as interface for the local transit system to reduce journey times for certain trips by allowing an outbound transit connection, rather than forcing everyone to connect through the downtown hub. This is the first step towards a decentralized network of stations to serve a large and congested metropolitan area.

3.2.1 Parkway is Quicker than the Base Case

Reconsider the trip discussed in the base case. Instead of having a difficult and possibly time-consuming drive (or transit ride) downtown, some travellers choose to drive along the beltway to the parkway station, avoiding downtown congestion and utilizing high-performance expressways, resulting in time savings. In addition, the line-haul journey time would be shorter because of reduced distance to travel. For its target market, parkway stations reduce access time, in-vehicle time, and may provide a better quality service on the access leg. (Table 2) It is therefore likely to expand the market reach of the intercity train.

However, from the perspective of utility analyses, the parkway station does the exact opposite of what we want to accomplish. The parkway station (out of town) exchanges comfortable line-haul time in a traincar for uncomfortable driving time. The total journey time is not reduced significantly except for a small sector of the metro area close by. With a taxicab, it can increase out-of-pocket costs considerably, due to increased mileage. The loss of the haul between the city center and the parkway station represents a lost business opportunity for the railroad. Had the railroad been more accessible from the origin, a longer haul and potentially more revenue could be attained (realizable from the decreased length-of-haul in the taxicab or the private auto, and thus less out-of-pocket costs for the traveller). Ideally, from a competitive standpoint, the nearest parkway station to every destination in the city should be more accessible than the nearest airport, to the extent permitted by the railroad alignment. Parkway stations offer airport-type ground access to those low-density parts of the city that could not be effectively served directly by rail. Nonetheless, many parts of megacities besides the downtown can support direct rail service, and this represents a business opportunity for the intercity rail carrier.

3.3 Accessibility of High Speed Rail in the Downtown Area

Many large cities[1], especially those with extensive commuter rail operations, have already realized that a single downtown terminal per line is insufficient to serve the diverse range of possible destinations for travellers. Consolidating rail travel demands at a single union station results in less competitive access times, except for a small market segment whose origins or destinations happen to fall within a relatively small radius of the downtown rail station. On the other hand, by having several downtown rail terminals, not only does the rail operator provide a larger geographic area with direct high speed rail service, it also remove some of the problems traditionally associated with a concentrated terminal – e.g. parking shortages and vehicular access congestion. Instead of merely providing intermodal transportation through connections to the local transit system, high speed rail may remove the transfers altogether and offer near door-to-door service in large cities with high demands. This is particularly important in the "walkable" neighbourhoods in the downtown area *(10)*. Although there are additional costs associated with providing multiple full-service union-style stations, there will also be higher revenues.

In a sense, the idea of making high speed rail more accessible in the downtown by installing additional stations is not new. The basic proposal is to match the supply of rail stations to the demand for rail stations by opening additional stations where the demand is concentrated, and closing stations where the demand isn't significant. The innovation lies with the realization that the conventional wisdom of consolidating demands for intercity travellers can cause more problems than it solves for rail. While the aviation industry is limited by the nature of its technology to consolidate demands from a metro area to an airport and a region to a hub, the railroad is not subject to the same limitations, and rail ought to exploit this competitive edge to the maximum extent possible.

4. THE RING RAILROAD (AND OTHER DOWNTOWN DISTRIBUTORS)

[1] Examples include Boston South Station and Boston Back Bay Station; Edinburgh Waverley Station and Haymarket Station (Scotland), Philadelphia 30th Street, Suburban, and Market East stations.

Why is downtown distribution important? Many transit (and intercity passenger transportation) professionals have come to believe that a consolidating approach to intercity services is a good thing. Many cite the union station's downtown location (an intercity rail "hub") as a great attraction. The downtown location is actually an impediment, not an attraction, to suburban dwellers and suburban business travellers. In contrast, the out-of-town airport offers much better access. Some business trips have non-downtown destinations, e.g. hotels and business parks. Moreover, the originating demands for intercity travel from the suburbs and the non-downtown city neighbourhoods, when integrated across the entire metropolitan area, dwarfs the originating demands within easy walking distance of the downtown station. Although the downtown remains a significant demand generator and requires direct service, it is no longer dominant.

A simple analogy with the interstate highway network demonstrates why more than one downtown station is required. An intercity railroad terminating only at the union station and beltway parkway is akin to an urban interstate expressway with only three exits, requiring the traveller to proceed through the city on slow arterial streets (akin to feeder transit systems or feeder buses). Services designed for shorter-haul passengers using a downtown distributor makes the service much more attractive than a point-to-point, airplane-like service.

The goal of such downtown distributors is to bring the intercity train to within about 10 minutes' walk or taxicab ride of most parts of the city, including suburban business districts and the downtown area. The scale is extremely important. Access time of less than 10 minutes makes a 45-minute taxicab-ride to the airport plus an hours' waiting in line for check-in seem much less attractive. With just one downtown station, the congestion in the downtown could make airport and union station access time similar in a taxicab from most suburban locations and city neighbourhoods.

4.1 The Inner Ring Railroad for Intercity Trains

The inner ring railroad is a particularly efficient layout for providing access to the downtown area. An "inner ring" is a smallish ring with a diameter between two to five miles with up to about six stops, designed to be traversed by a high speed train in less than about 30 minutes (inclusive of the station dwell times). The goal of such a ring is distinct from suburban ring transit schemes which have recently become fashionable. Instead of aiming at transit-dependent neighbourhoods to build ridership, the intercity ring aims at serving commercial and business districts as well as affluent parts of the downtown to maximize convenience for those who are likely to afford intercity travel. The ring will offer station spacing of between one to three miles – within comfortable walking distance for most, and a less-than-10 mins taxicab ride away for everyone in the city center.

The ring provides better access downtown, and serves distant city neighbourhoods and some suburban areas better than other layouts (Figure 1). The relatively small diameter of the ring results in less construction costs and relatively little additional mileage for trains leaving the city. Where many radiating lines converge, the ring offers an alternative to constructing independent "crosstown" tunnels for each line, potentially avoiding a huge expense while offering a better level of service. In addition, the ring is the only layout to guarantee a single cross-platform or same-platform transfer connexions between any lines. It allow departures to virtually any direction from any station, removing the need to navigate to a specific line for suburban auto travellers; they simply traverse the suburb, and board a train to go through the downtown to their intercity destination directly. The most congested and difficult to navigate neighbourhoods for the private auto are often the most pedestrian friendly, encouraging walk-up riderhsip. The railroad, with its exclusive right of way, is much less susceptible to congestion. If travellers are headed "back out" passing their residence, the total trip time would be shorter than a transfer at the union station in the heart of downtown (Table 2). Alternatively, they could elect to use a parkway station. If the travellers are heading in a different direction, the in-vehicle time is lengthened, but this can result in more productive work done compared to driving downtown, and there is still an overall trip-time reduction.

Consider the trip discussed in the base case (3.1.1). With a suitable parkway station, rail becomes competitive for a sector of the metropolitan area. However, with a ring, an auto-rail or cab-rail intermodal trip can potentially become competitive in most of the suburbs, except for the neighbourhoods immediately adjacent to the airport. Those neighbourhoods tend to be lower-income, and not a major originator of intercity travel. Instead of driving 15 to 40 minutes through the downtown or round the beltway, the driving is now no more than twenty minutes from any suburb. The element that varies, is the productive in-vehicle time, depending on the locations of the origin and destination relative to the downtown.

4.2 The London, England Case Study

How can the idea of an inner-ring railroad be applied to an actual situation to benefit local and transfer passengers? To illustrate the concept, a scheme was designed for the City of London to evaluate the potential benefits and feasibility:

- Estimate journey time savings for connecting and terminating passengers.
- Is a double-track ring railroad sufficient to carry all the trains arriving during the off-peak hours?
- Are reasonable turn-around times for intercity trains attainable?

This is purely a hypothetical scheme, intended to demonstrate the concept and illustrate the scale of the ring in question. London is of particular interest because, like Chicago, it is a national transportation hub and a large metropolis. A significant number of intercity travellers arriving in London will need to make a short-haul interurban trip to reach their final destination. Of course, there are many constraints on London's radiating intercity lines which will prevent interlining between them in the short term. However, as a long term proposition, the idea has potential. The proposed route closely mirrors London Underground's Circle line, linking all of London's mainline stations. Importantly, the line will be constructed to mainline railroad standards, and will thus permit intercity through-trains. A key assumption is that the ring replaces all crosstown railroads, current or proposed.

4.2.1 Running Time & Capacity Analysis

The amount of time it takes for an intercity train to travel around the ring was calculated using a formula calibrated from existing run-time data and other infrastructure assumptions. The distance around the ring was estimated and an average speed achieved between any two station-stops was calculated. This running time analysis also determines whether the vehicle time spent traversing the ring results in a saving over the turn-around time at a stub-end terminal.

It was impossible to stop at all BR London Terminals yet maintain a reasonable running time. However, if skip-stop service was introduced, overall time savings are possible and the majority of passengers could still make an effortless transfer to an interurban or commuter service. Most parts of Central London remains directly accessible from the ring. The run-time around the ring in the skip-stop scenario was 30 minutes. Using the existing Train Service Database information maintained by Railtrack and the running times, arrival times for all services was extrapolated to King's Cross station to determine if a capacity shortage would occur on the ring. The result demonstrates that at off-peak times, theoretically, most of the long-distance arrivals at the London terminals could be handled with 20 tph signalling on the ring. During peak hours, some trains would be refused access to the ring and short-turned at their terminal.

4.2.2 Transfer Time Model

To calculate the cross-London tranfer time under different scenarios, the transfer time was broken down into different components, populated using current Railtrack data, and then altered accordingly to reflect the hypothetical ring-railroad. The three components of the transfer time are:

- Walking time to and from the station platform
- Expected waiting time plus running time on the London Underground (the Tube)
- Expected waiting time for the next mainline train to your final destination

The average cross-town transfer time with a London Underground connexion was 58 minutes. The ring-railroad reduces that time to 47 minutes *(11)*. The reduction in access time for certain passengers are much larger (up to 25 minutes is possible), despite London's transit-orientation. Time savings would be even more dramatic in a congested city without transit. Many of these passengers would be likely to choose rail for intercity travel, even without line-haul time reductions. Table 3 shows a typical sample of actual journeys, along with estimated access and in-vehicle times. The majority of journeys show a decreased total trip time, and a greater % of in-vehicle time.

A simple benefit analysis assuming a value-of-time of $15 per hour, a passenger mix of 25% transfer, 55% downtown terminating and 20% metro-area terminating passengers suggest such a scheme would generate $350 million per year of consumer surplus in access time saved alone. There are much external benefits not explicitly accounted for in this model. This case study simply serves as an illustration that the ring-railroad can be a viable option to reduce access time and through journey time for some cities with more than about 2 million population.

4.3 Is an Inner Ring Railroad Always Necessary?

In certain cities, the city neighbourhoods have grown in such a way as not to lend itself easily to the planning of an inner ring route. Local geographical features are usually the reason. In Boston, the densest and most affluent neighbourhoods happened to wind through the city in an U shape, roughly following the banks of the Charles and Mystic Rivers. The lower-income neighbourhoods filled the gap on the South side and the Northeast, and the very low density suburbs are towards the West *(12)*. Thus, a reasonable alternative to an inner ring would be a "trunk distributor" roughly following the U-shape *(11)*, similar to previous proposals *(13)*. Although the journey time for through-trains would be increased due to additional mileage, it is not a major concern as Boston is a stub-end city with most intercity destinations to the South or the West. Also, in Boston, the walkable downtown is not sufficiently large to justify a complete ring, and the more affluent neighbourhoods are already covered by high-quality rail transit with convenient connections. Thus, the trunk distributor may be better than a ring.

In a city such as Cleveland, where the through traffic is as important as the originating traffic, segregation of through and originating/terminating traffic would be necessary. Many passengers are inconvenienced if every through train went around a ring. The segregation can be accomplished with smaller, modular trains. In a hypothetical New York-Cleveland-Chicago corridor, the westbound express trains may call at Cleveland Heights, where it will drop off a small high-speed EMU (e.g. 127-seat Metroliner) before proceeding around a by-pass and continuing towards Chicago. The Metroliner would traverse the ring in Cleveland to distribute local passengers, and continue to Columbus and Cincinnati. Demand-driven fleet allocation models similar to ones used in the aviation industry could benefit operations by calculating optimal fleet size and vehicle schedules.

Critically, with longer in-vehicle time, the on-board amenities becomes comparatively more important than the terminal services. The Pennsylvania Railroad's Metroliner owed much of its success to an unprecedented level of on-board service, despite a moderate service speed *(14)*. The comfort is an important part of the rail advantage. Although terminal amenities are less important, they must remain competitive with airports. An underground island platform is clearly insufficient.

The ring is not for every city. In older cities such as New York, there may be implementation issues arising from local opposition and the lack of suitable space. However, multiple access points remains a central need; unfortunately, the glory days of Penn Station are no more.

5. ARE AIRLINKS ALWAYS A GOOD IDEA?

Airlinks appear to be an extension of airlines to the downtown. Non-stop rail service from downtown is distinct from a transit connection; obviously aimed at the affluent downtown clientele, it is specifically designed to erode point-to-point high-speed rail's downtown advantage. The schemes were often designed with the airport as a goal – a destination in itself, with the associated retail and hotel operations, rather than simply a transit hub where transfers take place. As previously demonstrated, the alleged "downtown advantage" may not be all that significant and is based on the probably mistaken popular notion that high speed rail service has to follow a point-to-point, airplane-like business model. In the context of integrated intercity rail service, airports can be logical stations in some, but not all, circumstances – depending mainly on the competitive threat of air shuttle services.

5.1 High Speed Rail Connection to the Regional Airport

Airport rail links have become increasingly popular, with a variety of different schemes proposed and implemented by cities worldwide. Most schemes had been local in nature *(15)*, built to enhance the airport access from the city center (and sometimes from the metropolitan area). They are often sponsored by the airport authority, and charge a premium to recover the likely loss in revenue from airport parking. In some locations in Europe, such as Amsterdam Schipol and Frankfurt, the airport has indeed become a center of commerce. There, the local transit system would of course connect the airport the same way it would any other centers of activity in the metro area *(16)*. In other cases, despite strong retail developments, the airport remains mainly a transportation facility, e.g. in Chicago and in London Heathrow. Then, the decision to construct a high-speed rail link must be based on commercial considerations, and strict intermodal utility analysis, to create an efficient transportation system with the airport playing an appropriate role.

5.2 The Distinction between Shuttle Airports and Regional Airline Hubs

In a non-hub city airport, where the traffic is predominantly local shuttle flights to airline hubs or nearby destinations, it may not be in the interest of intercity rail carriers to enhance access to the airport. Rail has an inherent advantage in collecting passengers from the metro area; these passengers would generate the most revenue by travelling long-haul. Collecting passenger efficiently then delivering them to a local airport is giving the store away! With a shuttle flight, the passengers would still be saddled with the need to clear security, board the aircraft, and subject to any airside congestion effects at the connecting air hub or a popular shuttle destination. Despite the shorter journey time, the air shuttle may result in higher disutility than travelling by rail directly to destination *(17)*. Here, the intercity rail carrier and the air shuttle operator are in direct competition and better rail-air access should not be promoted. Removal of short-haul passengers from the air carrier's network could increase its overall network revenue by allowing it to focus on longer-haul passengers with the limited airport capacity available. Institutionally, the two operators do not necessarily have to compete – the air shuttle operator and the high speed rail operator could be jointly owned by the same transportation company.

In a regional hub airport, where the traffic is mostly transcontinental and international flights, direct access to the airport from a high-speed rail corridor is vital. Rail cannot generally compete in transcontinental markets, thus it should focus on delivering passengers from the region and the metro area to the hub. More airport capacity could then be released for transcontinental flights. The key is for rail to act as 'spokes' on the regional scale, and not just a metropolitan mass-transit system, delivering passengers to a truly world-class air hub rather than the nearest airport. For the vast majority of passengers making the local city-to-city trip, accessible direct high-speed rail represents a much more attractive option than an auto-air-transit tri-modal trip.

6. WHY EXPAND THE MARKET REACH? (IS HSR REALLY A NICHE PRODUCT?)

There are good reasons for high-speed rail to expand its market reach. Although rail had recently been marketed as a niche product in specialized point-to-point corridors, the fact remains that rail technology enjoys enormous economies of density. The airline industry has long discovered that in a given origin-destination corridor market, the carrier that provides the larger frequency share gains a disproportionately larger market share *(18)*. Since rail often operate in such corridor markets where travel is generally unplanned, it is doubly important for rail to offer extremely frequent service. Rail needs to reach out to the mass market with a Southwest-like business model. Enlarging the competitive areas covered, with trains perhaps as small as 200-seats, can help to justify more frequent service. A critical ridership must be reached before rail will be truly competitive or cost-effective. A seat departed empty is a full-fare revenue loss, and the marginal cost of adding seats by adding vehicles is low. With an effective revenue-management system, rail may stimulate highly elastic discretionary travel demand much better than an air shuttle. Fares competitive with bus carriers could easily be offered on night-time corridor trains, while daytime walk-up fares would be more in line with airline fares. All of these suggest the rail carrier ought to focus much more on better, multi-point metropolitan access rather than the traditional point-to-point approach hereto adopted by the Japanese Shinkensen and the French TGV.

7. CONCLUSIONS

In the past thirty or so years, high-speed rail has pursued a limited-stop express business model. There are good logic behind this:

- Customers prefer not to stop en-route.
- Short point-to-point times are required to compete with the airlines.
- High speed rail is perceived as a niche product serving the downtown-to-downtown business travel market.

Such a business model has not generally proven to be profitable without government subsidies. Some of this must change in future, to ensure a more sustainable basis for intercity passenger rail. Rail technology, by nature, enjoys greater economies of density, scope, and scale (in seats per vehicle, number of stops en-route) than air technology. Thus, it is in the rail advocate's interest to serve the mass-market, recovering capital costs through Ramsey-pricing.

Better downtown distribution is one way to expand rail's market reach and market share, while realizing potentially cost-saving economies. Having multiple rail terminals in the walkable neighbourhoods of large cities is not only a good competitive response to cities with multiple airports, it is also a good way to serve the large suburban population currently in a better position to access the out-of-town airfields. A downtown railroad loop happens to be an effective layout for servicing the demand and for operational reasons, although other layouts are possible. The main emphasis should be matching the supply of rail terminals to the originating travel demands within the immediate locale, enabled by technology changes over the last century (Figure 2). Ideally, the "nearest rail terminal" should always be more accessible in any part of the city except for the communities immediately adjacent to the airport. The rail depot could then once again return as the focus of the community in an urban landscape, in a way that airports simply cannot – in addition to providing good transportation services.

The detailed analysis demonstrates that in principle, a ring-railroad or a semi-circle with multiple stations around the downtown centre can decrease access time for travellers originating from the city and combat congestion at a single downtown union station. The London and Boston case studies show that a practical routing could indeed be designed to give a total journey time reduction. A downtown ring may be less expensive than many through-routes which criss-cross the city, but deliver similar benefits. Thus, a downtown ring railroad is something that the passenger rail industry ought to study closely as an option for enhancing its performance in terms of access time thus the overall customer utility of the journey experience. The rail industry must seize this opportunity to regain its prominence as a part of the passenger transportation system.

8. ACKNOWLEDGEMENTS

The authors are grateful to Andreas E. Aeppli of Reebie Associates for his extremely helpful and knowledgeable comments and other assistance in the preparation of this paper. The authors would also like to thank D. Austin Horowitz and Michael Brotzman for reviewing an early draft.

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Figure 1: Location of an Inner Ring Relative to City Neighbourhoods

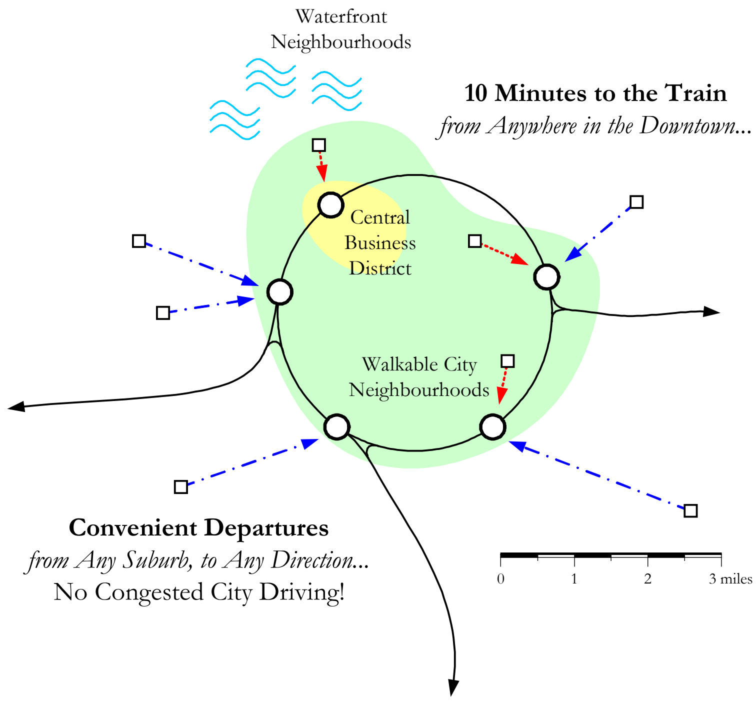


Figure 2: The Evolution from a Supply-Driven to a Commercially Focused, Market-Driven Railroad

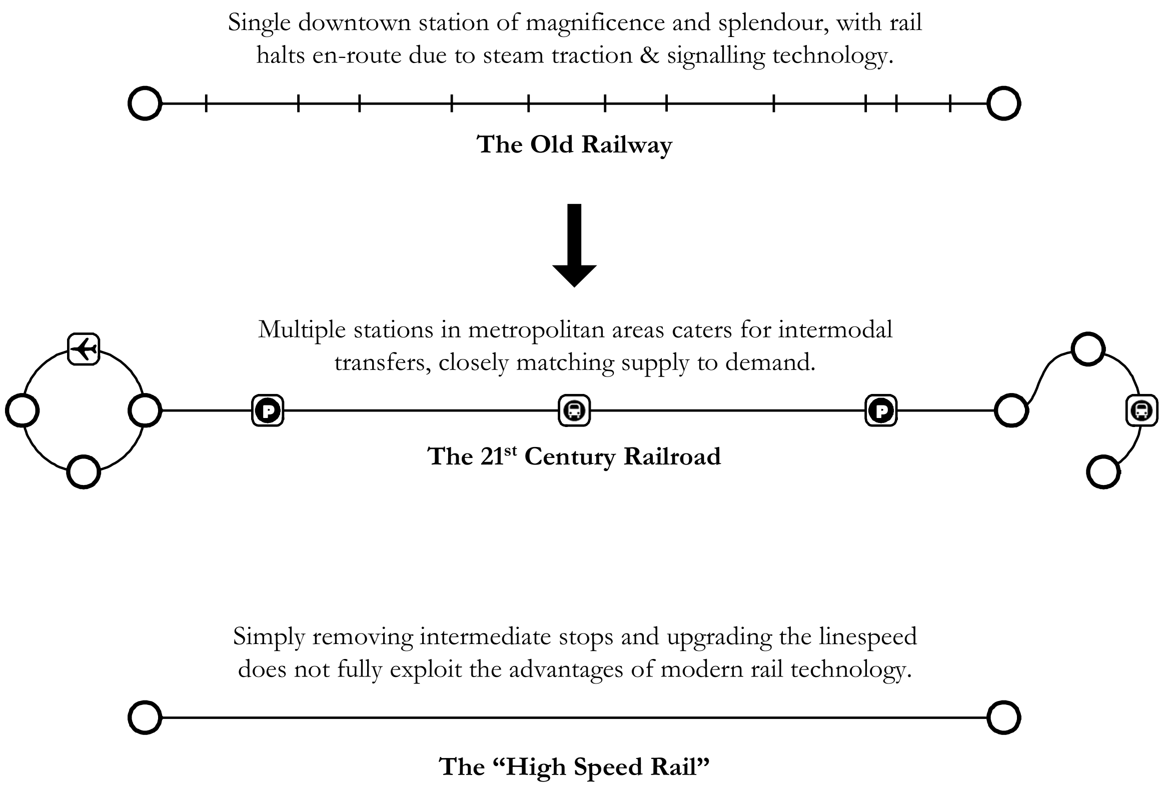


Table 1: Competitive Analysis of the Intercity High Speed Passenger Travel Market

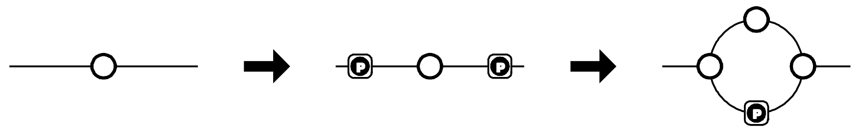
	Market Segment: Intercity Corridor Rail (320~960 km, 200-600 miles)		
Rail Station Type	*Union Station (1900's)*	*Parkway Station (1980's)*	*Multi-hub/Ring (The Future)*
			
Stations per Metro-Area	One	2 to 3	Many
Mode			
Private Auto			
Strength	Easy Access	No Transfer	—
Weakness	Long Journey Time	Long Journey Time	Long Journey Time
Scheduled Air			
Strength	Short Journey Time	Short Journey Time	Short Journey Time
Weakness	—	Longer Access Time (local effect)	Longer Access Time (citywide)
Intercity Bus/Electric Interurban			
Strength	Low Cost	Low Cost	Low Cost
Weakness	Long Journey Time	Long Journey Time	Long Journey Time

Table 2: Typical Journey Time Estimates by Urban Railroad Layout and Market Segment

	Union Station				Parkway				Multi-hub/Ring			
Origin/Market Segment	*Access*	*Buffer*	*En-train*	*Total*	*Access*	*Buffer*	*En-train*	*Total*	*Access*	*Buffer*	*En-train*	*Total*
Urban Dweller												
(Downtown Office)	0:10	0:05	2:00	2:15					0:10	0:05	2:05	2:20
(City Residence, Central Neighbourhood)	0:15	0:05	2:00	2:20	(use Union Station)				0:15	0:05	2:05	2:25
(City Residence, Transit-Accessible Neighbourhood, Right-side)	0:25	0:20	2:00	2:45					0:15	0:15	1:55	2:25
(City Residence, Transit-Accessible Neighbourhood, Wrong-side)	0:25	0:20	2:00	2:45					0:15	0:15	2:15	2:45
Suburbanite, Off-peak												
(Right-side)	0:35	0:10	2:00	2:45	0:15	0:05	1:45	2:00	0:10	0:05	1:55	2:10
(Off-side)	0:35	0:10	2:00	2:45	0:30	0:10	1:45	2:25	0:10	0:05	2:05	2:20
(Wrong-side)	0:35	0:10	2:00	2:45	0:45	0:15	1:45	2:45	0:10	0:05	2:15	2:30
Suburbanite, Rush Hour												
(Right-side)	1:00	0:30	2:00	3:30	0:30	0:15	1:45	2:15	0:20	0:10	1:55	2:25
(Off-side)	1:00	0:30	2:00	3:30	0:45	0:20	1:45	2:50	0:20	0:10	2:05	2:35
(Wrong-side)	1:00	0:30	2:00	3:30	1:05	0:25	1:45	3:15	0:20	0:10	2:15	2:45

Multi-hub structure impacts journey times in the following way:

- Increase journey times by 5-minutes for city-center travellers
- Decrease journey times by 20-minutes for some connecting passengers (from transit)
- Decrease journey times by 5- to 15- minutes for off-side and wrong-side suburbanites in the off-peak
- Decrease journey times by 15- to 30- minutes for off-side and wrong-side suburbanites in the rush hour
- Increase journey times for right-side suburbanites, who may choose to use the parkway station instead

Note: Off-side and wrong-side suburbanites are in fact the majority, compared to the right-side suburbanites. Although some journey times from the city center have become worse, running non-stop expresses from the downtown at periods of peak intercity travel demand can mitigate the impact.

Table 3: Projected Journey Times, Before and After a Ring-Railroad is Constructed around London

	Before						After				
Origin/Destination	*Local Access Time*	*Tube Time*	*Exp. Wait Time*	*Line-haul Time*	*Total Journey Time*	*Routing*	*Access Time*	*Exp. Wait Time*	*Line-haul Time*	*Total Journey Time*	*Routing*
Urban Dwellers											
Big Ben/Westminster to The North East (Newcastle)	0:10	0:38	0:15	2:35	3:38	Circle Line/East Coast Mainline	0:20	0:15	2:50	3:25	Victoria BR/Ring/ East Coast Mainline
Imperial College (Paddington) to Scotland (Edinburgh)	0:20	0:24	0:15	3:59	4:58	Hammersmith & City/East Coast	0:20	0:15	4:11	4:46	Paddington BR/Ring/ East Coast Mainline
Heathrow Airport to The Anglia Region (Cambridge)	0:15	0:59	0:15	0:45	2:14	Piccadilly Line/ Cambridge Flyer	—	—	—	—	—
Heathrow Airport to The Anglia Region (Cambridge)	0:32	0:34	0:15	0:45	2:06	Heathrow Express/ Cambridge Flyer	0:32	0:15	0:57	1:44	Paddington BR/Ring/ Cambridge Flyer
Harrow-on-the-Hill to The South (Southampton)	0:25	0:29	0:15	1:25	2:34	Chiltern/Bakerloo/ South West Trains	0:44	0:15	1:46	2:32	Bakerloo/Ring/ South West Trains
Suburbanite, Off-peak											
Henley-on-Thames to Scotland (Glasgow)	1:24	0:34	0:15	5:15	7:28	Thames Trains/ East Coast	1:24	0:15	5:27	7:06	Thames Trains/Ring/ East Coast
Henley-on-Thames to Scotland (Glasgow)	1:24	0:36	0:20	5:24	7:44	Thames Trains/ Virgin West Coast	1:24	0:20	5:33	7:17	Thames Trains/Ring/ Virgin West Coast
Chelmsford to The South West (Plymouth)	0:47	0:43	0:20	3:54	5:44	Great Eastern/ Great Western	0:47	0:20	4:11	5:18	Great Eastern/Ring/ Great Western
Portsmouth to The North West (Manchester)	1:44	0:33	0:20	2:46	5:23	South Central/ Virgin West Coast	1:44	0:20	3:01	5:05	South Central/Ring/ Virgin West Coast

- **Local Access Time** is the time to get from origin to a London BR Station, including any buffer time, etc required for any transfers.
- **Tube Time** is the time taken to make the cross-London transfer from the inbound London BR Station to the appropriate London BR Station for outbound travel, including the expected wait time for the London Underground train.
- **Expected Wait Time** is half of the headway on the outbound services from the London BR Station. For longer distance journeys with lower headways, this is decreased to reflect some planning.
- **Line-Haul Time** is the advertised trip time between the outbound London BR Station and the final destination.

Geographical Notes:

Westminster is the seat of the British Parliament in Central London, on the banks of the River Thames, at the Big Ben.
Imperial College is a nationally-renowned technical college of the University of London.
Harrow-on-the-Hill is an affluent neighbourhood of Greater London.
Henley-on-Thames is a town in the affluent Berkshire/Buckinghamshire/Oxfordshire suburbs (known as Thames Valley), where an annual regatta takes place on the River Thames.
Chelmsford is a medium-sized city in the industrial Essex suburbs, where many people commute to London.
Portsmouth is a port city on the South Coast of England, within reasonable commuting distance of London.

From the Limiteds and the Zephyrs to the 21st Century MetroFlyer

(or The Vital Role of Metropolitan Access
in Intercity Passenger Transportation)

Alex Lu and *Carl Martland,* Center for Transportation Studies, MIT 1-153,
77 Massachusetts Avenue, Cambridge, MA 02139-4301. *lexcie@mit.edu, martlan@mit.edu*

Presented at the 82nd Annual Meeting of the Transportation Research Board, Washington, D.C., January 2003.

Amended 9-8-03 (Thesis -- version 8.1)

The Modern Day Olympian Hiawatha – a "Limited" – at Glenview, Illinois.
Wouldn't it be wonderful if this train, like the North Shore Line, also made stops on the Loop?

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THESIS

- Enhancing access is more important than reducing journey time.
    - 110mph is a reasonable top speed for most demographics.
    - Three hours of in-vehicle time between major origin-destination pairs is a reasonable trip length.
    - Three hours of access time from door-to-door is unacceptable!
- Carriers can compete more effectively with other modes if it controlled the local access.

OUTLINE

- North America is a suburban sprawl – getting to the train station or airport is more difficult than getting between train stations or airports!
- Customers would rather sit on the train (and relax or work) than fight traffic on urban highways.
- The objective of the carrier is to maximize passenger utility, not to minimize in-vehicle time.
- Modern technology enables track-sharing, making high-cost urban infrastructure more cost-effective.
- Intercity Rail is not a transit! Customers are not captive, and customers want to be happy. Intercity carriers are selling an experience, not just transportation.

ACKNOWLEDGEMENTS

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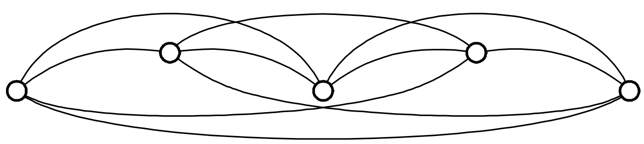
- Some of this research is influenced by materials taught in the MIT Center of Transportation Studies, in courses 1.252 (Fredrick P. Salvucci, Mikel Murga) and 1.258 (Nigel H.M. Wilson).

TRAINS ARE NOT PLANES

Why is a train not a plane? The nature of air technology is such that airports requires large amount of land mass and intensive capital investment to support a limited number of take-offs and landings. Once airbourne, infrastructure requirements are relatively modest. The nature of rail technology is completely different – the terminal footprint is small but infrastructure costs rise approximately linearly with distance. Thus, planes are good for long-haul point-to-point trips, whereas trains are good for pick-ups and drop-offs along a corridor.

Limited Stop Network Design

Lower per-route-mile costs
High terminal costs
Dispersed demand generators
Focused generation at each node



Zone Express Network Design

High per-route-mile costs
Lower terminal costs
Clustered demand generators
Demand generation not focused

The Future of North American Intercity Transportation…

Which would you *choose?*

High line-haul speed compensates for longer access time

Photo: Ryan Tam, MIT Center for Transportation Studies.

Shorter access time compensates for lower line-haul speed

Photo: Lexcie Lu, MIT Center for Transportation Studies.

This Depends on Economic Geography –

Where the Activity Centers are, and How *Clustered* they are.

U.S. ECONOMIC GEOGRAPHY

North America has a Distributed Economy. Some of the major U.S. economic and population centers are separated by more than 600 miles. In such long-distance markets, air will dominate, since the line-haul speed and the resulting shorter door-to-door trip time drives mode choice.

North America is a Suburban Sprawl. However, access to the airport within a metropolitan area will never be particularly efficient. The high cost of the airport means that the densities in most metropolitan areas are insufficient to support separate airports for each neighbourhood. In fact, airports generate significant externalities and are not welcome in most neighbourhoods. Thus, aside from megacities like New York which are able to support multiple airports, the access to the airport will remain poor for most part of the metropolitan area. Consolidation of demands will necessarily occur, leading to long access times for those who do not live near either conventional high-speed rail's downtown "union station" or the airport.

Here lies an *Opportunity* for Rail Carriers…

Activity centers in North American metropolitan areas are sufficiently dispersed that a rail carrier can take advantage of the inherent nature of rail technology to serve many more flows much closer to the point of origin than an air carrier can practically do so without transfer. Since suburb-to-suburb travel is expected to dominate intercity travel in North America in the foreseeable future, it is conceivable that strategically placed rail stations will make high-speed rail service much more auto-competitive on shorter trips (50~150 miles), while making it much more air-competitive on mid-length trips (150~400 miles).

Only large metropolises like Boston, Massachusetts, can support a busy airport with many international and transcontinental flights.

Photo: Ryan Tam, MIT Center for Transportation Studies

Limited Stop

for longer trips (More than 600 miles)

Demand from a large metro area is consolidated to a "high speed access point" such as an airport for the highest possible port-to-port speed.

However, many Americans live in the suburbia like Harpers Ferry, West Virginia, and don't like to go downtown for intercity transportation..

Photo: Lexcie Lu, MIT Center for Transportation Studies

Zone Express

for mid-length trips (150~400 miles)

Demand from a large metro area is consolidated onto the same vehicle, which makes multiple stops, to avoid the long access time required by local transportation.

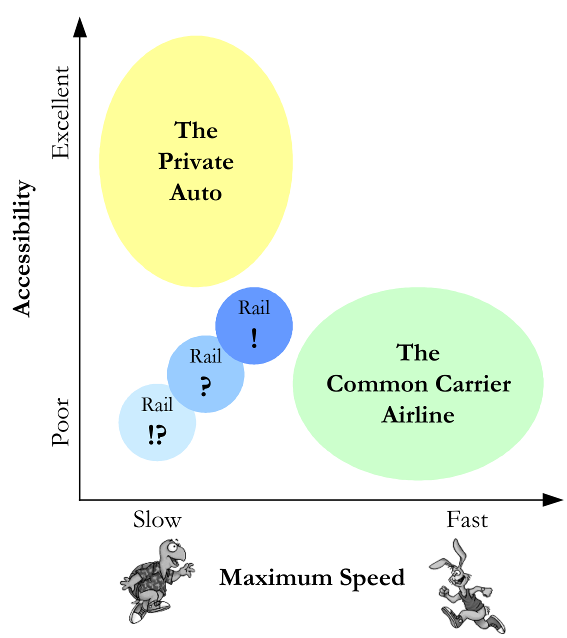
WHY ARE THE LIMITEDS NO MORE?

Today's Urban Areas are Different to ones that existed in the Golden Age of the Railway. The limited-stop express business model is simply not applicable anymore. In the days of the famous Limiteds and Zephyrs, metropolitan areas were much smaller and much more concentrated. Intercity travel were dominated by city-center to city-center flows, and the railroad was the quickest practical way to travel overland. Thus, it made sense for the fastest service to depart from the downtown union station (then a "high-speed access point") and consolidate demand from the smaller metro area with streetcars. The consolidation was relatively efficient since the access portion of the trip remained fairly manageable with smaller cities. Today, the fastest service is the air service, and the "high-speed access point" is the airport; the railroad must find a new niche to survive.

Broadway Limited **Super Chief el Capitan**	**Acela Express** **Virgin 'Pendelino'**
Rail is the fastest	Rail is most comfortable
Small metropolitan areas	Large metropolitan areas
Streetcar suburbs	Automobile suburbs
Travel between city-centers dominates	Travel between suburbs dominates
Auto use not widespread	Small carless population
Interstate Highways not yet built	Interstates free and convenient

But… *What* new niche?

That New Niche, is Comfort and Accessibility. Today, rail faces tough competition from two sides. The automobile is ubiquitous, have very low up-front, incremental costs per passenger and per trip, and have very good access (especially in the suburbs where parking is a-plenty). The leisure air fares are affordable, the service is frequent, has much lower journey times than most modes; despite the difficulty of access, it is nonetheless a formidable competitor even in rail's "home stretch" of 150~400 mile journeys. The intercity coach continues to dominate the low-end of the market with its very low cost of production. Passenger rail will survive and thrive, if it exploits the competitors' weaknesses; passenger rail will remain a curiosity of the bygone era, if it continues to attempt to emulate its competitors and pretend to be the fastest, the most convenient, or the cheapest mode.



WHY IS ACCESS IMPORTANT?

Access for Service. First and foremost, customers would like better access. While seasoned commuters may not find transfers daunting or inconvenient, these are not our target customers when seeking to expand the rail market share. Evidence from the airline industry suggests that direct flights are preferred by non-regulars, especially those new to flying. Evidence from commuter rail suggests customers with high values of time dislike transfers because they interrupt work. Commuters may be willing to pay a premium for facilities that will eliminate transfers – for instance, Pennsylvania's elimination of Manhattan Transfer through the Hudson Tubes.

Access for Ridership. Secondly, public officials who are concerned about airport capacity and the negative externalities that the airports generate understand that short-haul flights are an inefficient use of airport capacity and would like to see more short-haul trips on rail. Providing better rail accessibility would encourage people who would have never considered rail as a viable mode (perhaps because they live far away from downtown) to use rail at least some of the time. This may reduce airport congestion significantly, since short-haul flights are a significant proportion of total take-offs and landings at hub airports in large metropolises.

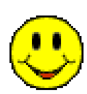
Access for Competitive Advantage. Last but not least, intercity rail carriers in Europe and North America, many of whom struggles to make a profit without subsidies, would love to find a lesser capital-intensive way to expand market share and revenues. Instead of investing in a faster railroad with infrastructure subsidies, perhaps enhanced access would offer a lesser capital-intensive way forward.

Access is a *Win-Win-Win* proposition:

There are no losers.

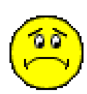
Higher Maximum Speed

Existing Customers
– faster trip, shorter journey time

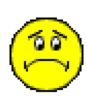


Potential Customers
– service not really much different

Public Officials
– more infrastructure subsidies

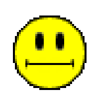


Intercity Passenger Rail Carriers
– more maintenance costs

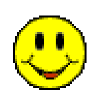


Transferring value from government to consumers is politically popular…

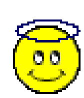
Better Access
Multiple Stations



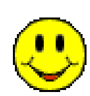
Existing Customers
– service not really much different



Potential Customers
– shorter access time
friendlier local service



Public Officials
– reduced congestion & externalities



Intercity Passenger Rail Carriers
– larger market reach

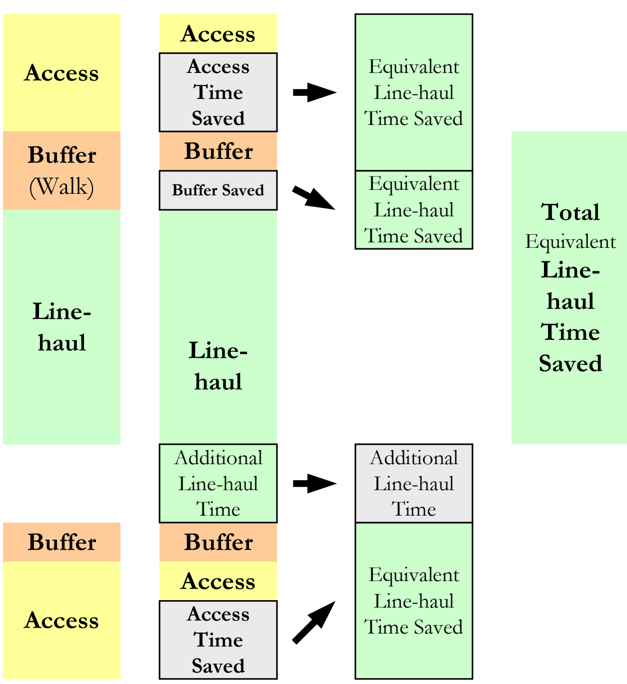
Providing a service for which consumers are willing to pay is good business.

WHY DO CUSTOMERS WANT BETTER ACCESS?
(IS TEN MINUTES REALLY TEN MINUTES EVERYWHERE?)

Rail can Reduce Travel Time through Urbanized Areas. Rail is the most efficient mode with which one could travel through heavily congested urban areas – this is widely confirmed in Japan and Europe. Rail has small right-of-way footprint and high carrying capacity, compared with buses, private auto and airlines. Thus, the leveraged portion of the intercity rail trip is the first ten miles and the last ten miles. By substituting rail for auto or subway for the "access" leg of the trip, externalities (highway or subway congestion at peak hours) are reduced, while the traveller saves valuable time.

Even if Travel Time is the Same, the Passenger is Better Off. Instead of an intermodal trip comprising of a 45-minute subway leg, 15-minute transfer time, 30-minute check-in, 1-hour air leg, 15-minute transfer time, and another 45-minute subway leg, the passenger is able to replace the fragmented idle time with 3 hour 30 minutes' of comfortable and perhaps productive time onboard a train to relax, work, or simply enjoy the scenery. If the subway legs are necessary to reach the downtown rail union station, rail's advantages are lost. In Europe, many high-speed rail riders are captive riders who don't have uncongested roadways to drive on! One study has shown that travel time in the air has a twice the disutility of travel time in a railcar. The accessible rail replaces onerous terminal time and access time with comfortable in-vehicle time – unlike the limited-stop high speed rail, which erodes the in-vehicle time in favour of longer access times.

Customers don't like to Get Up and *Walk!*



Equivalent Line-haul Savings can be Substantial

Because Terminal, Buffer and Access Times are particularly onerous, trying to cut access time is a much better goal than trying to cut in-vehicle time.

Generally access time is valued at twice the equivalent in-vehicle time. Line-haul time is much more comfortable.

Frequent Service will cut *Adjustment Time*
Schedule Coordination will cut *Transfer Time*
Reliable Access will cut *Buffer Time*
Terminal Shuttle will cut *Access Time…*

Enhanced Metropolitan Access
will cut **All Of The Above!**

DO YOU LIKE NEXTBUS?

How does NextBus Work? Nextbus works by exchanging uncomfortable terminal time (waiting at a bus stop) for more comfortable adjustment time (waiting at home, at work, or in a café), so that the passengers may arrive in time to meet the vehicle. The fact that many transit authorities are spending not insignificant amounts of money on this technology suggests that the value of time at a terminal, compared with the value of "adjustment time", is clearly different. When studying intermodal itineraries, it is therefore critically important that the modeller should make clear distinctions between in-vehicle time, terminal time, adjustment time, access time, and access time aboard different modes and different vehicle/service types.

At Davis Sq. in Somerville, Mass., you could grab a coffee while you wait for the bus instead of enjoying the crisp fall air, if you knew when the bus would arrive..

Photo: Lexcie Lu, MIT Center for Transportation Studies.

It's the *Value of Time*, Sir.

How does MetroFlyer Work? MetroFlyer works by exchanging uncomfortable terminal time and access time (taking the subway downtown, then waiting for the intercity train to depart) for more comfortable in-vehicle time (the quiet surroundings of a luxurious intercity train is much more comfortable than a taxicab sitting in traffic or the noisy subway). In many cases, the total trip time is actually reduced. Even in the cases where the trip time is not reduced, the quality of the trip is still much better since a greater proportion of the trip is spent on-board a comfortable intercity train.

NextBus

Stay at Home for Longer
– staying at home is better than standing at the curb

Know your Connexions
– reduces buffer time, since real-time information enables tighter connexions

Know when the Bus will Arrive
– reduces waiting anxiety, disutility of transfer time reduced

MetroFlyer

Stay On-board for Longer
– riding a long-distance train is better than standing in a bus or subway

Know you will Make the Connexion
– reduces buffer time, since access is shorter and subject to less variance

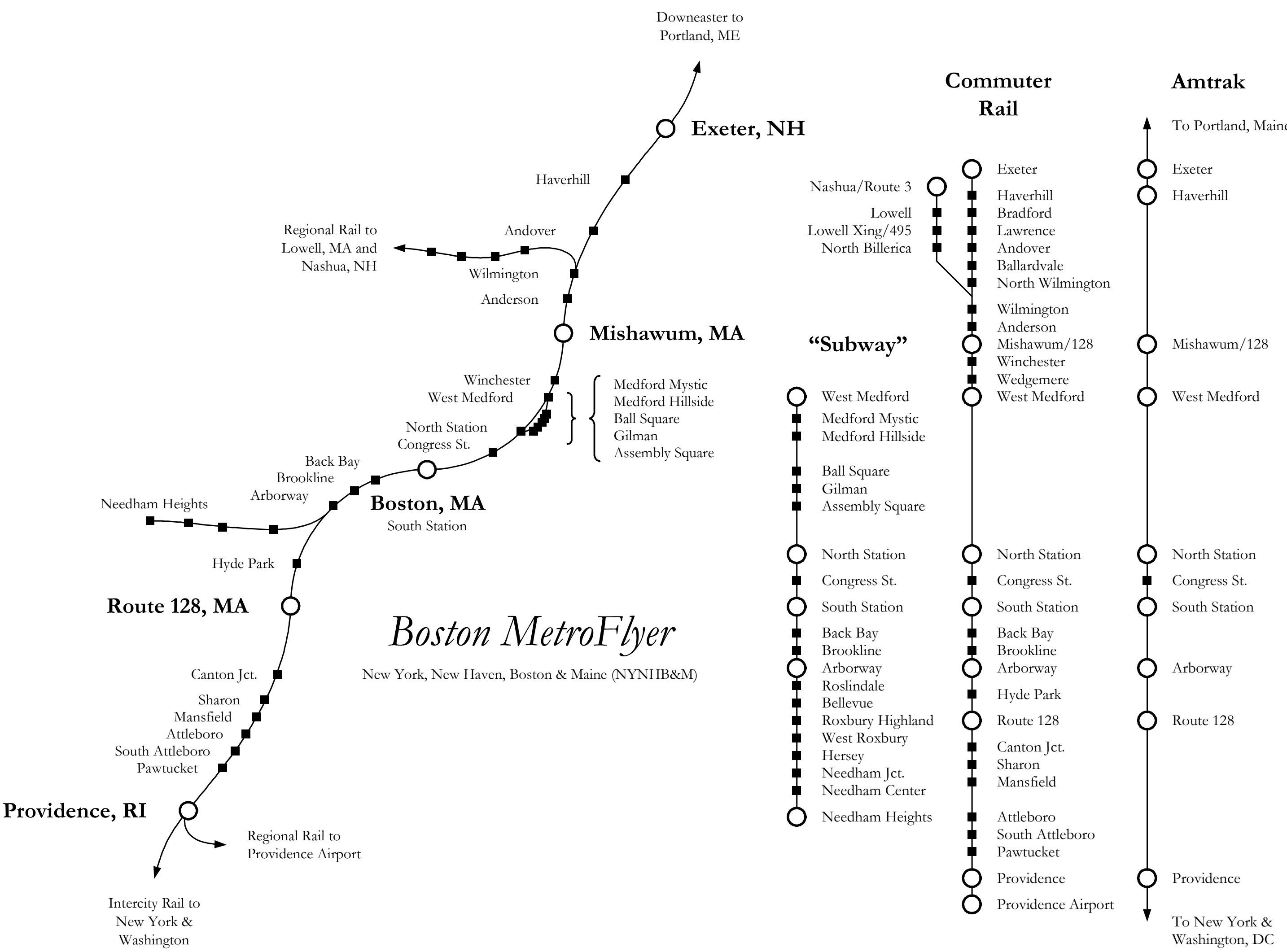
Reduces Transfers
– less need for schedule coordination; shorter adjustment and transfer time

MODERN TECHNOLOGY ENABLES TRACK SHARING

Rail Infrastructure Offers Opportunities for Smart Growth. With today's intercity rail technology, there are little reasons why infrastructure should not be shared between intercity, commuter, and urban rail operations. Creating a dedicated rail right-of-way within the city (or reusing an old right-of-way) for the purposes of intercity rail is not only beneficial for intercity travellers, but for neighbourhoods en-route which will receive an economic boost, and also creates a corridor for urban regeneration. Intercity and Commuter trains, which may depart every 15-minutes, can share tracks with FRA-compliant urban electric trains which will utilize the remaining corridor capacity to deliver a subway-like service. Sharing of the right-of-way in congested areas is critical and will create economies of density in infrastructure utilization otherwise not possible with commuter rail or subway alone. Higher cosmetic standards would be required than a typical subway installation, but such investment will also encourage more choice riders than otherwise possible.

Intercity Rail is an **Opportunity** for *Transit Authorities…*

…to offer **Additional Subway Service** with *Spare Track Capacity*



WHAT SPARE TRACK CAPACITY?

Modern Technology and Disciplined Operations allow High Track Capacity. On many modern transit systems, headways as low as 90-seconds are routinely maintained. Current moving block signalling technology allows headways down to the 75-second range. However, such headways are not routinely sustainable. Instead, most manually operated transit systems regard 24 trains-per-hour (tph) as the maximum practical limit. Using the hypothetical Boston MetroFlyer example, we found that a feasible operating plan could be created to cater for combined operations of a 12tph Subway, a 4tph Commuter Rail, and a 3tph Amtrak over the same double-track right-of-way – with reasonable margins for recovery should a disruption occur. (The signalling system was assumed to allow trains to follow each other every 90 seconds.) Highly disciplined operations, combined with modern signalling technology, will allow urban infrastructure corridors to be used to the maximum extent, and to cater for trains of varying speeds.

Although the operating and maintenance costs of an FRA-compliant subway will be higher, these costs are smaller than the cost of providing separate rights-of-way through congested urban areas.

Assumptions: Sidings for same-direction passing at West Medford (MFDW), Boston South Station (BOSX), and Brookline (BKLN), with four tracks in the immediate vicinity of South Station. Subways trains may have unscheduled delays of up to 72 seconds due to congestion effects. Points can set-and-lock or reset-and-lock within 36 seconds.

Photo: Joe Testagrose, New York City Subway Resources (http://www.nycsubway.org/)

Boston MetroFlyer – **Operating Plan**

	SUBW	R/R	AMTRAK		AMTK-	SUBW	AMTK-	SUBW	RR-HH	SUBW	SUBW	SUBW	RR-NS	SUBW	AMTK-	SUBW	SUBW	RR-HH	SUBW	SUBW	SUBW	RR-NS	SUBW
	S/S+D	S/S+D	S/S+DWELL		xx/00	xx/01	xx/05	xx/06	xx/10	xx/11	xx/16	xx/21	xx/25	xx/26	xx/30	xx/31	xx/36	xx/40	xx/41	xx/46	xx/51	xx/55	xx/56
EXRX																							
HHLX			23		10.87		10.95		10.72						11.37			11.22					
BRFD		2							10.75									11.25					
LWNC		9							10.90									11.40					
ANVR		5							10.98									11.48					
BLVL		4							11.05									11.55					
NWMT		7							11.17									11.67					
WMTC		15							11.42				11.67					11.92				12.17	
ARTC		5							11.50				11.75					12.00				12.25	
M128		1	31		11.38		11.47		11.52				11.77		11.88			12.02				12.27	
WNTR		6							11.62				11.87					12.12				12.37	
WGME		2							11.65				11.90					12.15				12.40	
MFDW		4	11		11.57	11.47	11.65	11.55	11.72	11.63	11.72	11.80	11.97	11.88	12.07	11.97	12.05	12.22	12.13	12.22	12.30	12.47	12.38
MFDM	4					11.53		11.62		11.70	11.78	11.87		11.95		12.03	12.12		12.20	12.28	12.37		12.45
MFDH	4					11.60		11.68		11.77	11.85	11.93		12.02		12.10	12.18		12.27	12.35	12.43		12.52
BALL	5					11.68		11.77		11.85	11.93	12.02		12.10		12.18	12.27		12.35	12.43	12.52		12.60
GLMN	4					11.75		11.83		11.92	12.00	12.08		12.17		12.25	12.33		12.42	12.50	12.58		12.67
ASMB	4					11.82		11.90		11.98	12.07	12.15		12.23		12.32	12.40		12.48	12.57	12.65		12.73
NSTA	4	13	12		11.77	11.88	11.85	11.97	11.93	12.05	12.13	12.22	12.18	12.30	12.27	12.38	12.47	12.43	12.55	12.63	12.72	12.68	12.80
NSTA-DEP	1	5	5		11.85	11.90	11.93	11.98	12.02	12.07	12.15	12.23	12.27	12.32	12.35	12.40	12.48	12.52	12.57	12.65	12.73	12.77	12.82
CSTA	3	2	2		11.88	11.95	11.97	12.03	12.05	12.12	12.20	12.28	12.30	12.37	12.38	12.45	12.53	12.55	12.62	12.70	12.78	12.80	12.87
BOSX	3	2	2		11.92	12.00	12.00	12.08	12.08	12.17	12.25	12.33	12.33	12.42	12.42	12.50	12.58	12.58	12.67	12.75	12.83	12.83	12.92
BOSX-DEP	1	5	5		12.00	12.02	12.08	12.10	12.17	12.18	12.27	12.35	12.42	12.43	12.50	12.52	12.60	12.67	12.68	12.77	12.85	12.92	12.93
BBYX	4	5	5		12.08	12.08	12.17	12.17	12.25	12.25	12.33	12.42	12.50	12.50	12.58	12.58	12.67	12.75	12.75	12.83	12.92	13.00	13.00
BKLN	5	4				12.17		12.25	12.32	12.33	12.42	12.50	12.57	12.58		12.67	12.75	12.82	12.83	12.92	13.00	13.07	13.08
ABWY	7	6				12.28		12.37	12.42	12.45	12.53	12.62	12.67	12.70		12.78	12.87	12.92	12.95	13.03	13.12	13.17	13.20
HDPK		8							12.55				12.80					13.05				13.30	
R128		5	10		12.17		12.25		12.63				12.88		12.67			13.13				13.38	
CNJN		4							12.70									13.20					
SHRN		6							12.80									13.30					
MSFD		8							12.93									13.43					
CATB		8							13.07									13.57					
SATB		7							13.18									13.68					
PTKT		5							13.27									13.77					
PVDX		5	29		12.65		12.73		13.35						13.15			13.85					

HOW TO PROVIDE DOWNTOWN ACCESS & DISTRIBUTION

Multiple Union Stations. The basic idea for enhancing downtown access and distribution for intercity passengers, is to extend the concept of the "union station", invented by North American railroads in the early 20th century to facilitate interline transfers and to reduce costs. The union station was an appropriate concept of its time, since the smaller cities allowed a single terminal to be conveniently sited for most parts of the city. However, as business district expanded, the important economic activities within a metropolitan area are no longer within walking distance of the union station. Providing a number of union stations (where all terminating trains call) within the metropolitan area will dramatically improve the access to high-speed rail services.

Can you resist the *Ubiquitous* railroad?

City Neighbourhooods have Different Character. When designing one of the many "union stations", it is important to consider how it would be used. In the walkable downtown, business travellers are likely to walk to the station, thus station spacing should be no more than about 1½ miles. In the suburban areas, where densities are too low to justify a "union station" for every neighbourhood, the stations should be designed as intermodal transfer facilities featuring parking and mass-transit access. In many cases, one single union station with Park & Rides on the beltway may be the correct answer. For some cities, a number of downtown access points are clearly needed, especially where the walkable areas of downtown is more than about 1½ mile in diameter.

It is also extremely important to pay close attention to both the needs of the locals and the through-travellers. If the number of stations required to adequately serve the originating local riders is too high, a through by-pass should be considered.

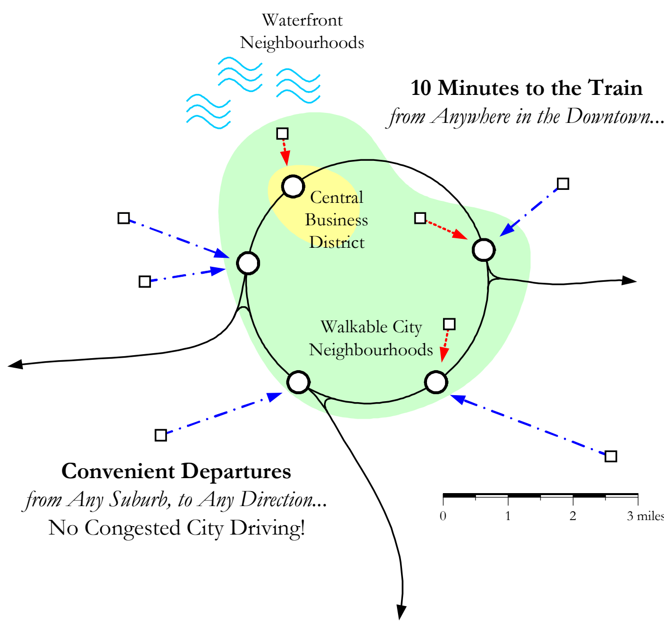
Ten Minutes to the Train

– the ubiquitous railroad

Multiple Union Stations
– allows convenient access from all parts of the downtown

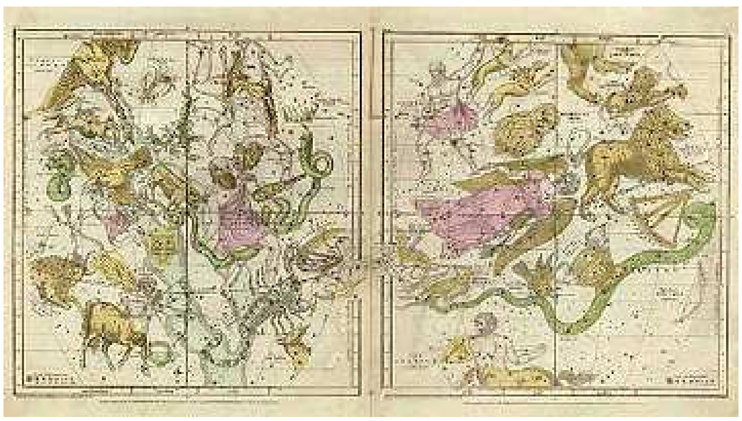
Multi-Purpose Neighbourhood Stations
– by putting some of the union stations close to the edge of the walkable downtown, they could become multimodal access points for the inner suburbs

Park & Rides
– provide accessibility for the outer suburbs and edge cities, but these will not be union stations since the time penalty of detour for all trains would be significant



CONNECTING THE DOTS

Different Layouts are Possible. Having determined the number of stations, these stations would need to be linked such that as many of the terminating trains as possible call at as many of the stations as possible, while minimizing the amount of new infrastructure required. In some cities, this is simply a question of changing the service design using existing infrastructure. In other cities, perhaps new spurs or wyes would be required, or "missing links" (because of historical oversight) would have to be built from scratch. Evaluation would be required on a case-by-case basis, where project evaluation techniques could be used to calculate the expected costs and benefits. Popular layouts to consider include: (1) East and West Park & Ride with Union Station, (2) Trunk Distributor, (3) The Inner Ring Railroad. Other layouts are possible, depending on the local situation.

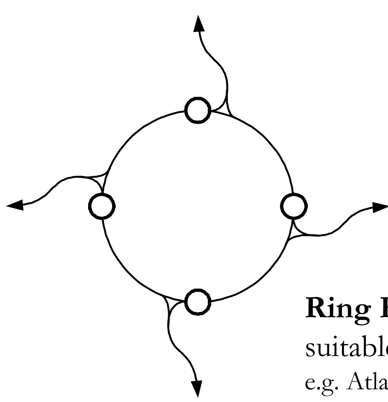


There are many ways of connecting stars to form constellations – and many ways to connect urban stations to form a metropolitan access network. Constellations are constrained by ancient Greek mythology, while urban rail networks are constrained by existing infrastructure, available funds, and planning mythology(?).

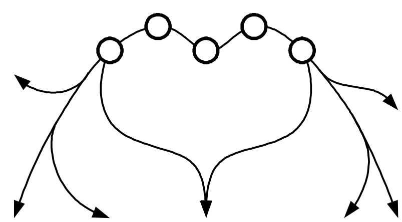
Photo: Celestial map of the constellations from Elijah Burritt's *Celestial Atlas* (1835).

As a counterexample, consider the Penn Station in Baltimore, Maryland. The station never realized its full potential since it was sited on the edge of the downtown and not particularly accessible. The single union station downtown is as accessible to the affluent suburbs as Baltimore Penn Station is to the city!

In Tokyo, a former suburban ring railroad has been adapted as a downtown distributor for commuter and regional interurban rail arrivals as the central business district grew larger and became distributed over a large area. Some Shinkensen is already making edge city stops to facility transfers to these distribution facilities.



Ring Railroad Layout
suitable for inland hub cities,
e.g. Atlanta, London, Montreal

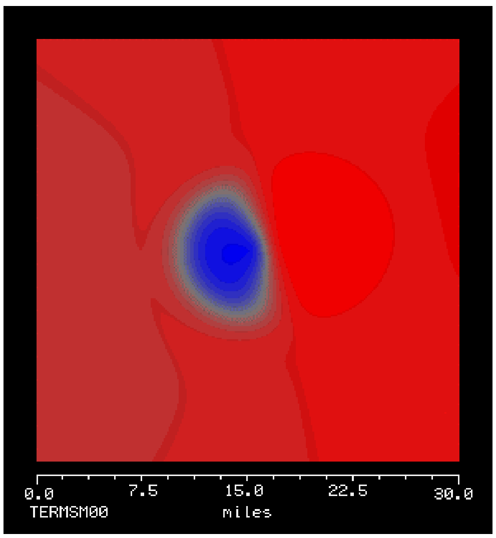


Trunk Distributor Layout
suitable for riverfront or seaboard cities,
e.g. Halifax, Miami, Rotterdam

The ring is theoretically most efficient, in terms of ratio of catchment area to track mileage required. However, there are operational issues associated with the ring, and most cities do not have downtown rights-of-way which can be readily connected to form a ring. Thus, a ring can be a good alternative in a city in the early stages of its development (perhaps in the developing world), whereas trunk distributors may be more realistic in busy cities where new construction is difficult and expensive.

DEMAND & MODE SHARE STUDIES

More than a One-Seat Ride. The purpose of enhanced access to intercity rail is not merely to provide a one-seat ride for intercity riders. Most intercity riders would still need to transfer to a different mode to connect the office or the home to the neighbourhood union station – those who are downtown would need to walk or take a cab, and those in the suburbs would need to drive. The most important aspect of enhancing access is its eefect on mode split. To illustrate this, we used a very simple utility model, based on the methodology discussed in the Performance-Based Technology Scan paper (TRB 03-2545), to show that adding terminals will in fact give intercity rail a big advantage over airlines – possibly more so than spending equivalent amount of money on upgrading the right-of-way and increasing line-haul speed. The mode share projected is based on a decision rule.



Before – *Single Union Station*

Rail Dominates in the City Center
– rail has a significant advantage in the region coloured blue.

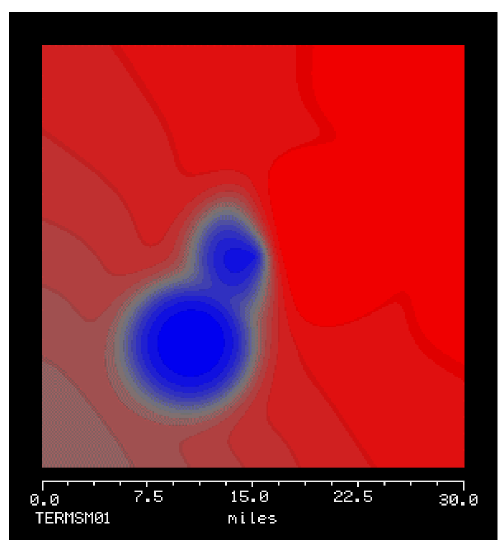
Airlines Dominates the Rest of the Metropolitan Area
– more than about two miles from the union station, the rail advantage disappears. Throughout the metro area, air is the preferred mode because the shorter line-haul time compensates for the access time, which become more similar as the origin moves further away from the union station.

New stations *Significantly* affects local mode share…

After – *Multiple Access Points*

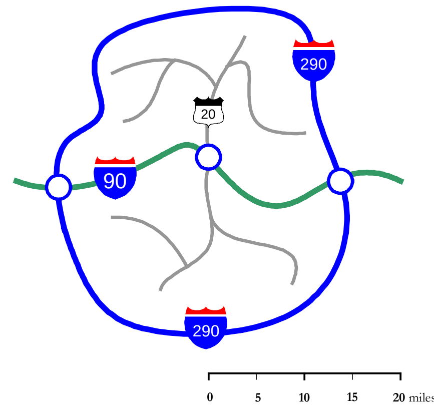
Rail Dominates around Access Points
– the area of the blue region almost doubles, depending on the location of the new access point.

Air Domination is Decreased
– airlines continue to dominate in areas not covered by rail terminals, but hopefully these are areas of low demand.

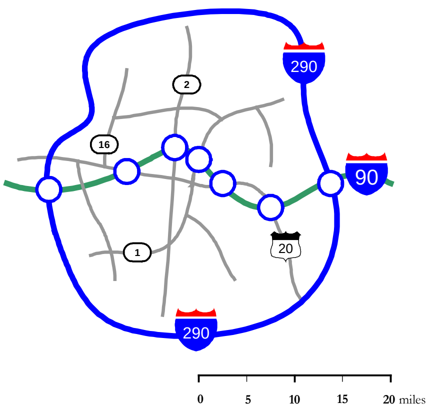


WHY WAS THE INTERSTATE HIGHWAY SUCH A BIG HIT?

For a moment, we would like you to image a possible world in which urban interstate highways were built with just three interchanges in the major cities, and one interchange for the smaller towns. This in fact represents a major saving on construction costs, since finding the land within urban areas to build large and complex interchanges can be a major part of the expense of building urban expressways. However, would the interstate system have been so successful for intercity passenger traffic if it had been built that way?



It's hard to imagine an effective interstate system where exits are constructed every 40 or so miles in the rural areas, and cars would proceed on arterial streets to the downtown before joining an expressway. The current high-speed rail apparently operates on this business model.



The current interstate system have effectively become a predominantly commuter facility. True "interstate" usage on the interstate highways remains very low – as evidenced by the continuing attempts to widen interstates close to urban areas, but not the line-haul portions over the Prairies. Access is the key to the urban expressway's success – both for attracting commuter traffic and encouraging auto use for intercity trips, partly through the convenient provision of the local-portion.

The Interstate is a *Commuter Highway*…

Equity Arguments for Scarce Urban Infrastructure, when framed in the context of serving a greater number of people with transit than intercity and commuter rail, is valid. However, when pitted against the funds continuing to be expended in upgrading urban and suburban expressways and airport access infrastructure to benefit a small proportion of travellers, incremental investment in intercity rail transportation looks socially just and wise. Most captive transit riders from the city do not drive on interstate expressways, either.

Other Methods of Addressing Inequities

- Differential Intercity Rail Pricing
  - Ticket restriction based (market segmentation based on likely travel purpose, and thus ability to pay)
  - Time-period based (allowing off-peak fares close to marginal cost)
  - Accommodation based (utilizes commuter vehicles in between peaks)
- Explicit Rail Discounts for Low-Income Users
- Congestion Pricing on Urban Highways

Providing the service at the lowest common denominator is not a way to ensure equity – it encourages the rich to drive.

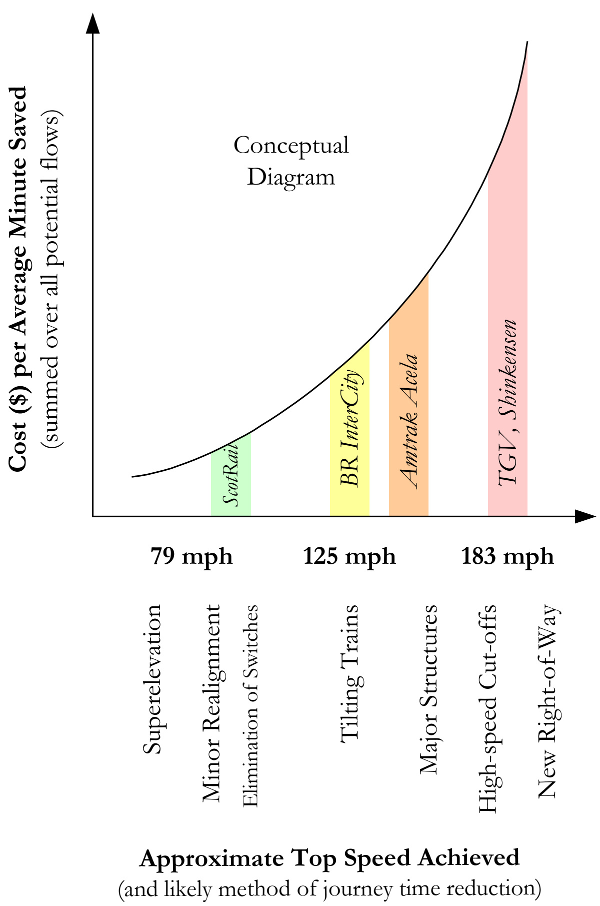
How many people here are really engaging in Interstate Commerce? Even if you removed the commuters, would many people be driving to New Hampshire instead of taking the train if the only exits were downtown and at Route 128?

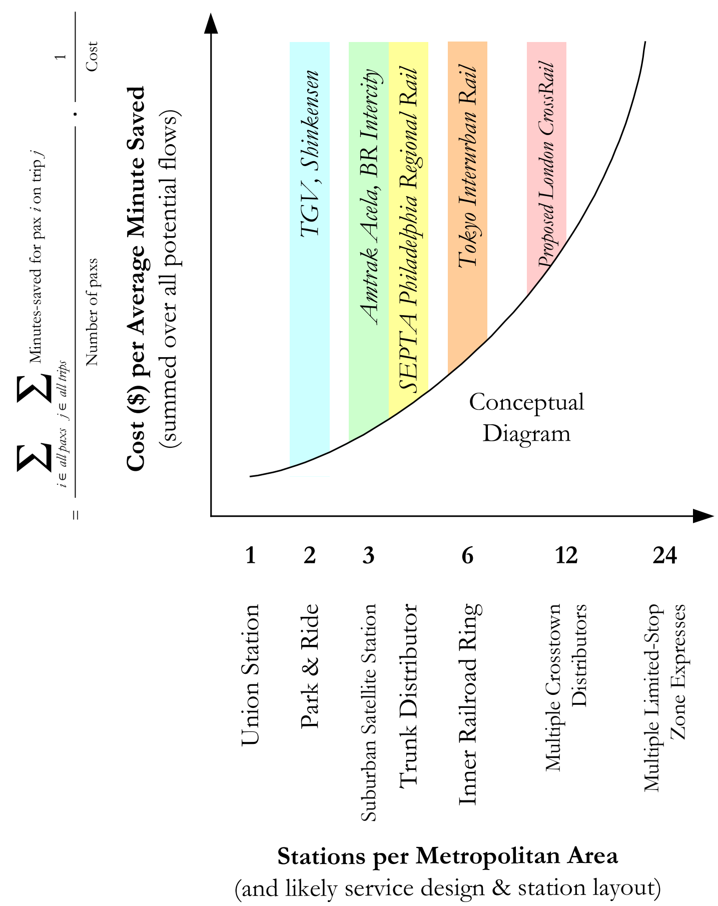
Photo: Dan "SPUI" Moraseski, MIT

RAIL UPGRADE COMPARATIVE EVALUATION

Rail Upgrade Strategies. Invariably, when evaluating rail upgrades, the cheaper (or more cost-effective) options are usually exercised first, followed by more expensive ones, up to the point when the combined values of public benefits and rail operator revenues exceed the fully allocated costs of the upgrade. Thus, there is a point of diminishing return. In many cases, you can achieve the majority of the benefits (say 80%) by investing a little (e.g. 20%), but to achieve the maximum benefit you must invest heavily.

If you accept this hypothesis, then it is possible to conceptualize a graph correlating the cost-effectiveness of upgrades (measured in perhaps cost per average minute saved) against the maximum speed achieved or the method with which journey time reduction is achieved in the quest for speed. Obviously, some methods of increasing speed, such as constructing a new right-of-way, are more expensive than others, such as increasing superelevation by tamping. Increasing accessibility is a totally different way to reduce the trip time, and therefore comes with its own cost-benefit tradeoff. The first station opened apart from the union station would be most effective, and the incremental benefit from each additional station decreases as the number of station increases.





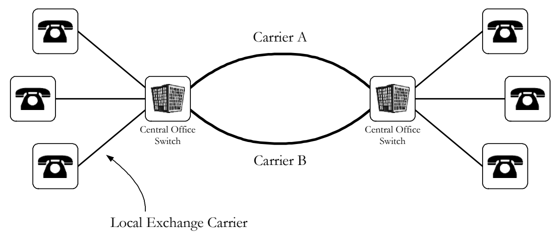
Interestingly, it is the commuter and low-speed interurban carriers that have generally understood the importance of access, while flagship trains like TGV and Shinkensen tended to terminate at a union station. In evaluating further upgrades, additional stations ought to be considered as an alternative to achieving higher maximum speeds – if the maximum speed is already more than about 110mph, often the more effective investment would be in accessibility and not in further raising the speeds.

WHY DO INTERCITY CARRIERS LOSE MONEY?

The moon glows through a cloud bank, San Diego, California.

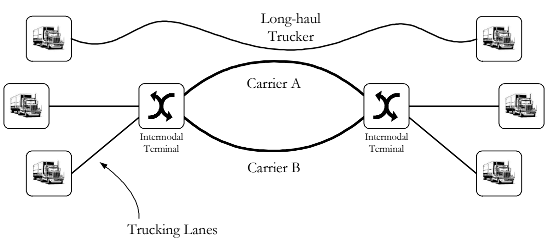
Photo: Joe Klein (http://skychasers.net/joeklein.htm)

Where is the Value in this Network? Consider the telecoms network shown. The Local Exchange Carriers (LECs) have direct access to customers, and are a monopoly element of the business. The economies of density in local connections result in a natural monopoly, making competition amongst rival LEC's extremely difficult. The customer is captive to the incumbent LEC.



The Inter-Exchange Carriers (Carriers A and B) on the other hand, are afforded no such protection. Since the number of exchanges are limited, there is no natural monopoly. Depending on the regulation, it is also possible for the LEC to influence competition between Carrier A and B substantially, by choosing to route its traffic differentially.

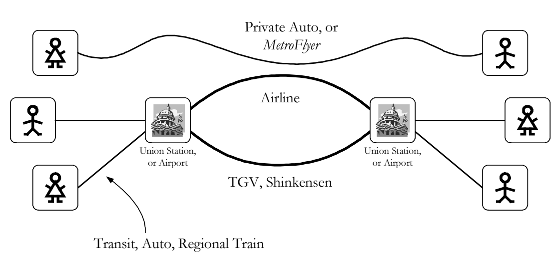
Thus, the value of the network is in the LECs – even if there were specific regulation allowing end-customers to choose between different long-distance carriers, competition is likely to reduce long-distance rates to close to marginal costs. On the other hand, the LECs have substantial pricing power. If LECs were permitted to enter the long-haul business, it would have a substantial competitive advantage.



In the freight industry, the local access carriers (trucking firms) are indeed permitted to enter the long-haul business. Truckers have substantial advantage over the railroads, due in part to their control over the customer interface – and the natural monopoly of urban highways. In effect, the truckers have only passed to the railroads the traffic which is uneconomic to truck – such as container flows over 1,200 miles.

Discarding the Value. Not surprisingly, in the passenger rail industry, even the premier trains of Europe and Japan are not profit-making propositions when fully-allocated infrastructure costs are taken into account. By going head-to-head with the airlines and not focusing on access issues, the high-speed rail has effectively turned over control of the customer interface to transit or highway authorities! High-speed rail technology will simply not win against the airlines on speed alone. In effect, the traditional high-speed rail has discarded the value in the business by competing where it simply cannot win – on the line-haul portion of the trip.

Capturing the Customer. The *MetroFlyer* concept exploits the inherent advantages of rail transportation and captures the customer interface at the local level (and with it much of the value in the business). Rail is most effective in congested urban areas, while airline and auto are least effective. In much of Europe and heavily populated parts of the United States, the population centers are often close enough to allow rail's inherent disadvantage in line-haul to be overcome by much, much shorter access time.



Some Hypothetical Case Studies

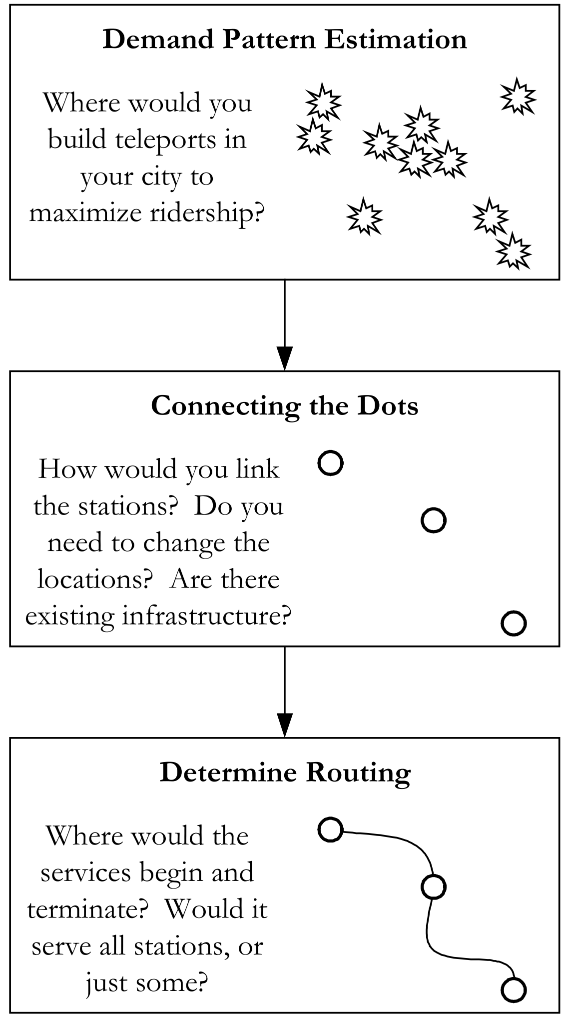
Reality is the Dreams of our Forefathers.

(Norfolk Southern freights passing at Toledo, Ohio, on the former New York Central mainline.)

METHODOLOGY FOR CASE STUDIES

In determining the access requirement for a given city, there are three major considerations:

- Demand Pattern
- Existing Infrastructure and Geography
- Routing



These can be described as something similar to a three-step process.

Demand Pattern. First, the demand pattern is established, using a combination of local knowledge, census data and perhaps limited passenger surveys. The census data at either the census tract, traffic analysis zone or even block level can be very useful, since it carries a wide variety of information. Median household income is a fairly strong predictor of intercity travel demand, since intercity travel is mostly a discretionary activity. Very-high income neighbourhoods should be avoided, as with very-low income neighbourhoods. High-speed rail's target customers lie within the middle income bracket. This enables us to determine the approximate location of the stops. This type of micro-analysis is vital in building an effective local distribution system.

The notion of "teleport" is a useful one to consider at this stage. For the average rail journey of two-hours in duration, if it is possible to save an hour in access time for our target customers, in terms of utility, high speed rail effectively becomes a teleport, since the access time has twice the disutility of in-vehicle time. Thinking about "teleports" also allows the planner to focus merely on the access issues, and not worry about how to route the train – at least, not at this stage. A usual question to ask is: "If you had to plant five intercity teleports in this city to maximize ridership, where would you put them?"

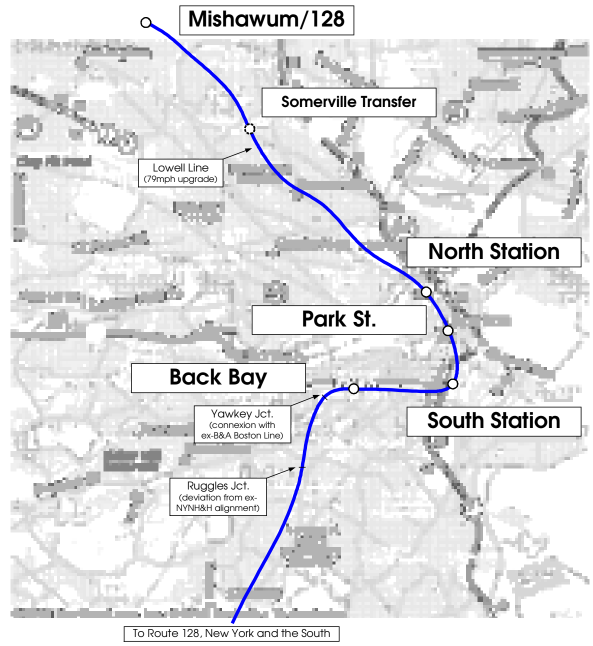
Connecting the Dots. Having determine the location of the "teleports", the planner then attempts to connect them in a logical fashion, keeping in mind the need to maximize the utilization of existing infrastructure and corridors, and the local geographical constraints. At this stage, the locations of the teleports may need to be moved. The extent to which they can be moved will depend on whether it is designed as a walk-up or a drive-through access point. Walk-ups tend to be very sensitive to the exact location to within ¼ mile – thus deviations should be kept within that number.

Determine Routing. Finally, the planner determines the routing by making a service plan – given the routes that will operate through or terminate in the city in question, what would the train service look like? The important issue here is that most trains should be able to depart from most stations. At this stage, the infrastructure may be revised to form a ring-layout, a trunk distributor, or other possible layouts. With the layout, journey time and competitive mode-split analysis can then be carried out. The whole process is not too dissimilar for the planning process used to design urban bus routes. Although the focus is different, the basic ideas are the same. It is likely that similar planning tools as buses could be applied to find the optimal route.

NORTH AMERICAN EXAMPLES

How can the Urban Distributor Concept be Appied? To demonstrate that the journey time savings are real, we evaluated the concept of the intercity urban distributor in Boston, Massachusetts. The journey times shown are based on a variation of the *Boston MetroFlyer* scheme. While the precise alignment must be selected through a rigourous and specific project evaluation process, the sample journey time savings projected here will be fairly robust regardless of the actual alignment eventually selected.

Boston. This is a hypothetical scheme, and is referred to here only to illustrate the order of magnitude of the actual journey time savings possible if a similar scheme was implemented. While this may not be possible in Boston, due to the expense of construction downtown, there may be other cities where such rights-of-way already exist and can simply be interconnected to give rise to journey time savings.



Columbus. For instance, in Columbus, Ohio, existing freight railroads already criss-cross the city. The former Big Four alignment passes within one mile of Ohio State University and I-270/I-71 at Worthington, an ideal site for a Park & Ride. If the Big Four corridor was ever considered for a high-speed passenger rail upgrade, it is important that multiple stops are made in Columbus to ensure the maximum catchment of potential demand.

Before the Railroad Dig (Boston)

Total Journey Time, Boston Residence to New York Penn Sta. (after Acela speed-ups through CT)									
	Road		Air		Bus		Train		Air-Rail Di
	hrs	mins	hrs	mins	hrs	mins	hrs	mins	mins
Mishawum/128	4 hr	35 mins	3 hr	20 mins	6 hr	15 mins	4 hr	28 mins	68 mins
Framingham, MA	4 hr	13 mins	2 hr	50 mins	5 hr	40 mins	3 hr	43 mins	53 mins
North Station	4 hr	39 mins	2 hr	50 mins	5 hr	20 mins	3 hr	38 mins	48 mins
Park Street	4 hr	39 mins	2 hr	50 mins	5 hr	10 mins	3 hr	23 mins	33 mins
South Station	4 hr	39 mins	2 hr	50 mins	5 hr	00 mins	3 hr	08 mins	18 mins
Convention Center	4 hr	39 mins	2 hr	35 mins	5 hr	25 mins	3 hr	15 mins	40 mins
Route 128, MA	4 hr	22 mins	3 hr	05 mins	6 hr	00 mins	2 hr	56 mins	-09 mins
Providence, RI	3 hr	44 mins	2 hr	50 mins	6 hr	20 mins	2 hr	50 mins	00 mins
New York, NY									
[5] Negative is rail faster									

After the Railroad Dig (Boston)

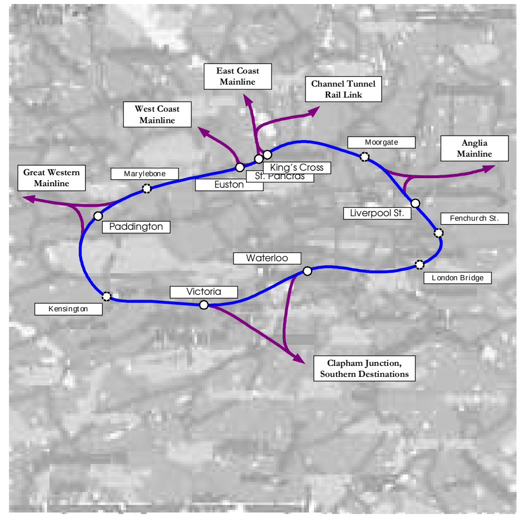
Total Journey Time, Boston Residence to New York Penn Sta. (after Acela speed-ups through CT)									
	Road		Air		Bus		Train		Air-Rail Di
	hrs	mins	hrs	mins	hrs	mins	hrs	mins	mins
Mishawum/128	4 hr	35 mins	3 hr	20 mins	6 hr	15 mins	3 hr	45 mins	25 mins
Framingham, MA	4 hr	13 mins	2 hr	50 mins	5 hr	40 mins	4 hr	13 mins	83 mins
North Station	4 hr	39 mins	2 hr	50 mins	5 hr	20 mins	3 hr	18 mins	28 mins
Park Street	4 hr	39 mins	2 hr	50 mins	5 hr	10 mins	3 hr	13 mins	23 mins
South Station	4 hr	39 mins	2 hr	50 mins	5 hr	00 mins	3 hr	08 mins	18 mins
Convention Center	4 hr	39 mins	2 hr	35 mins	5 hr	25 mins	3 hr	00 mins	25 mins
Route 128, MA	4 hr	22 mins	3 hr	05 mins	6 hr	00 mins	2 hr	56 mins	-09 mins
Providence, RI	3 hr	44 mins	2 hr	50 mins	6 hr	20 mins	2 hr	50 mins	00 mins
New York, NY									
[5] Negative is rail faster									

Orlando. In Florida, where there had been much discussion about a high-speed rail system, rail would likely be much more successful in Orlando if it connected the downtown, the airport, and DisneyWorld® at Kissimmee to Tampa, Miami and beyond. Although new construction would likely be required, an arc connecting the three intercity demand generators would be much cheaper and nicer than a system to funnel people to a downtown collection point. Critically, both the airport and DisneyWorld® is en-route to Tampa and Miami; additional stations will eliminate "backtracking" for rail riders.

OPERATIONS ANALYSIS: LONDON, ENGLAND.

We developed a detailed operational planning model for a hypothetical downtown distributor ring in London for intercity trains to understand the operational feasibility of the idea in more detail.

The hypothetical distributor (for intercity trains) is based loosely on London Underground's Circle Line. The main result of the study was that it was necessary to restrict the number of stops to achieve journey time savings. However, if six key stations (out of 11) around London were designated as "union terminals" where departures were possible in every direction, the average cross-town travel times could be reduced by 11 minutes. This is in addition to enabling a one-transfer ride across London (instead of the present-day two-to-three transfers) and one-seat ride into downtown. In general, transfer times using a "union terminal" is reduced by 20 minutes, while the transfer times from the other terminals remain unchanged. The twenty-minute saving is extremely significant, against Railtrack's 2000 Network Management Statement which calls for a "2020 Vision" of 2~5 mins in-vehicle time reduction on most commuter routes, and ~10 mins on intercity routes.



Cut *Cross-London* journey by **20 minutes**

	Miles	Station Dwell at Arriving Station (min) [1]	Average Running Speed (mph) [4]	Running Time for skip-stops (min)	Station Dwell for Thru Trains (min)	Stage Time Contrib. (min)	Anti-clockwise Timing (min)	Clockwise Timing (min)	Anti-clockwise Time passing KingsX	Station Dwell at Exiting Station (min) [1]
KingsX								16.9		
Euston	0.4	7	12.0	2.0	1	3.0	3.0	13.9	13.9	10
Marylebone	1.2									
Paddington	0.7	7	33.9	1.2	1	2.2	5.2	11.7	11.7	10
South Kensington	1.3									
Victoria	1.2	5	44.0	1.6	1	2.6	7.9	9.0	9.0	5
Waterloo	1.4	7	26.0	3.2	1	4.2	12.1	4.8	4.8	10
London Bridge	1.4									
Fenchurch St	0.7									
Liverpool St	0.5	7	45.8	0.7	1	1.7	13.8	3.1	3.1	10
Islington	0.9									
KingsX	1.5	7	42.3	2.1	1	3.1	16.9		0.0	10
Total	11.2						12.9		120	

	Cross-London Journey Time [6]	W	1	2	3	4	5	6	7	8	9	10	Station	Tube Stop
W	Walk [1]		12	12	12	15	17	15	18	15	9	10		
1	Anglia	12	25	25	25	28	59	30	37	33	48	40	Liverpool St	Liverpool St
2	ECML	12	30	30	30	30	55	32	39	35	52	56	KingsX	KGX/St Pancras
3	MML	12	40	40	40	40	65	42	49	45	62	66	St Pancras	KGX/St Pancras
4	WCML	15	28	25	25	25	50	24	31	27	58	56	Euston	Euston Square
5	M40	17	74	65	65	65	40	66	76	83	73	76	Marylebone	Baker St
6	Great Western	15	30	27	27	24	51	25	29	25	68	65	Paddington	Paddington
7	South Western/Portsmouth	18	37	34	34	31	61	29	25	26	48	60	Waterloo	Waterloo
8	Brighton	15	38	35	35	32	73	30	31	30	64	60	Victoria	Victoria
9	Kent Coast	9	56	55	55	66	66	76	56	67	33	60	London Bridge	London Bridge
10	Southend (LTS)	10	55	66	66	71	76	80	75	70	67	40	Fenchurch St	Tower Hill

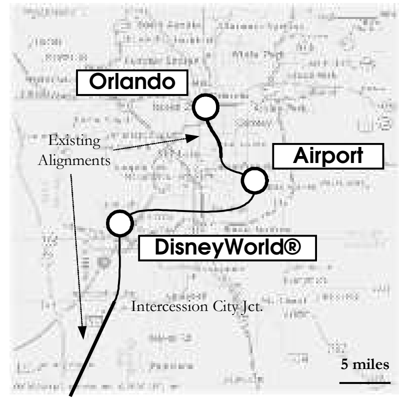
BEFORE					
… % of which		**pax/day**	**Transfer Ti**	**Value $/hr**	**Access Ti**
Cross London Transfer pax (including Commuter Rail	25%	231,393	58	$15	$3,355k
Downtown London Terminating pax	55%	509,064	29	$15	$3,691k
Non-CBD Terminating pax	20%	185,114	58	$15	$2,684k
AFTER					
… % of which		**pax/day**	**Transfer Ti**	**Value $/hr**	**Access Ti**
Cross London Transfer pax (including Commuter Rail	25%	231,393	47	$15	$2,719k
Downtown London Terminating pax	55%	509,064	23.5	$15	$2,991k
Non-CBD Terminating pax	20%	185,114	58	$15	$2,684k
Sum saved per day =					$1,336k

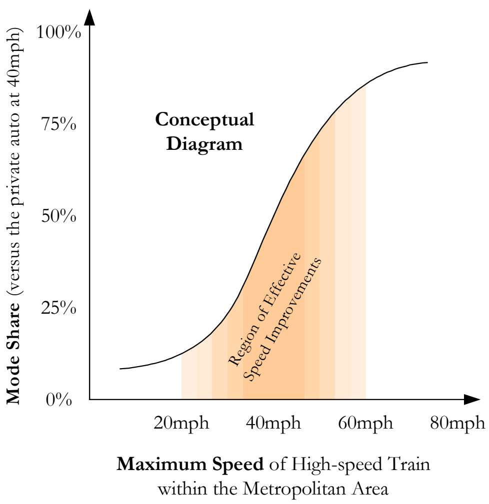
Using a relatively simple methodology and conservative assumptions, we estimated the daily *direct* benefits to commuters and intercity riders to be *at least* $1.34 million *per day* in time saved alone. Although the infrastructure necessary for this type of public works are necessarily expensive, the benefits are substantial and are distributed widely to a large proportion of riders (instead of route-specific high-speed upgrades which only benefit specific origin-destination pairs). By constructing the infrastructure at the focal point of the system, riders on many routes would benefit.

Of course, investment in intercity infrastructure downtown should not divert scarce funds from urban infrastructure. However, track-sharing is possible; re-use of existing urban infrastructure is possible; and removing outer suburban commuters from transit systems at peak hours may actually benefit local transit riders. The environmental concerns of such major works in established urban areas are considerable, but the benefits are also considerable. Downtown distribution is clearly a leveraged area in passenger rail.

CONSTRUCTION IMPACT CONSIDERATIONS: ORLANDO, FL.

Where is it useful? High-speed rail will necessarily involve substantial new construction. When considering constructing a new system, attention should be focused on where the demand generators are – simply linking downtown to downtown in a straight line is not necessarily effective, especially in cities where the downtown may not be the economic, tourism, or cultural focus. The example shown here, a conceptual diagram of how the distribution network around Orlando might look, serves to illustrate how this idea might have practical value. Visitors to DisneyWorld® from Tampa, is unlikely to choose the high-speed train if they have to travel to Orlando and "backtrack" some 12 miles out to the final destination. DisneyWorld® also serves as a Park & Ride for I-4 and the suburbs.





How do we build it? The effective re-use of existing infrastructure and rights-of-way is key to constructing a cost-efficient urban distribution network. By limiting the train speed in the urban area to just a little more than what can be expected from a subway car (say about 45~60 mph), many alignments previously considered too constrained now become viable. The subway-like speed is key: in congested urban areas, the subway remains the most effective way of getting around. Even with urban expressways present, that speed will remain competitive with the private auto as a feeder mode, while the highway network experiences increasing congestion in future. Increasing train speed beyond about 60mph in local portion of intercity trips is expensive, and probably will not lead to significant increase in ridership. In addition, speeds above 60mph make track-sharing with subway-like service extremely difficult.

Re-use of *Existing Infrastructure* is key…

The Florida Example. The existing Atlantic Coast Line alignment is used between downtown Orlando and Bee Line Expressway, where a 3-mile diversion alongside the highway right-of-way would be needed to reach the airport terminal. Exiting to the south, an existing industrial spur could be used to reconnect to the mainline. Another 8-mile diversion alongside the Florida Greenway would be necessary to reach DisneyWorld®. Exiting to the south, another 5-miles of new trackage would be necessary to connect to the mainline at Intercession City. Compared to simply constructing a high-speed cut-off through heavily urbanized areas to reach the downtown perhaps 15 minutes faster, the winding alignment is likely to be cheaper and offer better ridership potential.

Without detailed engineering studies, it is not known if the line will permit the desired speed of 60mph. Since it is mostly laid out alongside existing corridors, disruption will be limited to easing tight curves. Very little wholesale taking of properties would occur.

Driving to reach the beach once you get to Florida is almost unavoidable, but driving from a Park & Ride with car-hire facilities near a freeway is better than having to drive from a downtown rail terminal.

Photo: Daytona Beach, Florida (http://www.daytonavisit.com/)

WITHIN-CITY DEMAND ANALYSIS: LOS ANGELES, CA.

Decentralization of Economic Activities. Access is even more important in decentralized cities, although the focus would not be on walk-up demand but on situating Park & Rides such that the high speed rail can be reached from most parts of the city reasonably quickly, and the parking lots do not become so large as to make the auto-to-platform walk substantial.

In lesser dense and highly decentralized cities such as Los Angeles, constructing a new right of way to host high-speed rail and give increased access may be easier from an engineering standpoint. However, from a planning perspective, the more suburban living style may mean planning permissions are more difficult to obtain. Nonetheless, a state-level agency may have the authority to bypass local zoning ordinances.

Even though there is a recognizable downtown in Los Angeles, most of the economic activity occur in suburban business districts.

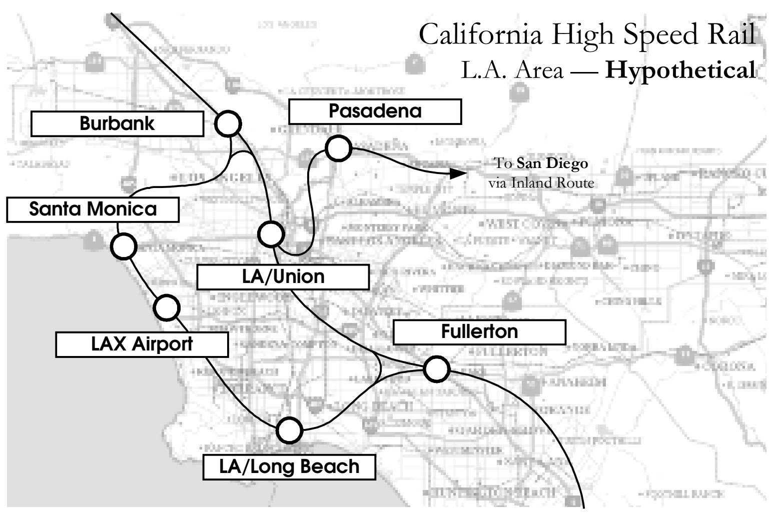
Photo: Matthew Weathers, http://www.matthewweathers.com/

The current plan in Los Angeles calls for study of a number of stations, but does not seem focused on the needs of the core city itself.

The two routes to San Diego follow traditional corridors but the airport spur seems operationally inconvenient and many areas of Los Angeles seems underserved. Potentially, transfers would be required at Union Station, which may also become an operational bottleneck. Los Angeles does not seem to be designed as a through-node, and the routing appears to be based on existing Metrolink services.

Direct service… enables work *without* interruptions

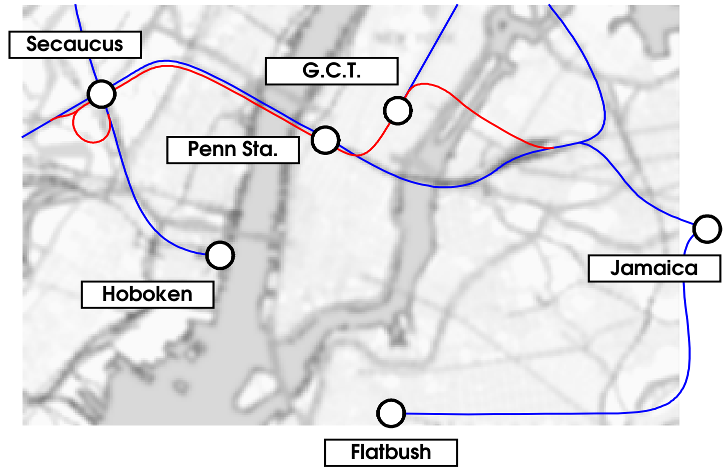
Applying the 'Ring' concept, we believe that Los Angeles's dispersed origin-destination pattern is better served by a high-speed rail network similar to the one shown to the right. By making LAX a through-station and part of the metropolitan ring for LA, we can avoid the awkward spur and serve the busy business districts of Santa Monica, Long Beach, and students at UCLA directly. Terminating trains will travel around the ring and reverse directions, while through-trains will travel either via LAX or LA/Union. Arriving trains on the Inland Route may continue to San Francisco or simply return to San Diego via LAX and the Shore Line.



Too many permutations of services would be confusing to passengers. However, with reasonable service design, many more points on the network would be directly connected without transfer at LA/Union. Not only does this save time for passengers, they may also have luggage and may be travelling with small children, or prefer to work without interruptions. Direct service looks a lot more attractive than a hub-and-spoke type design.

CURRENT ACTUAL PLANNING STUDY: NEW YORK, NY.

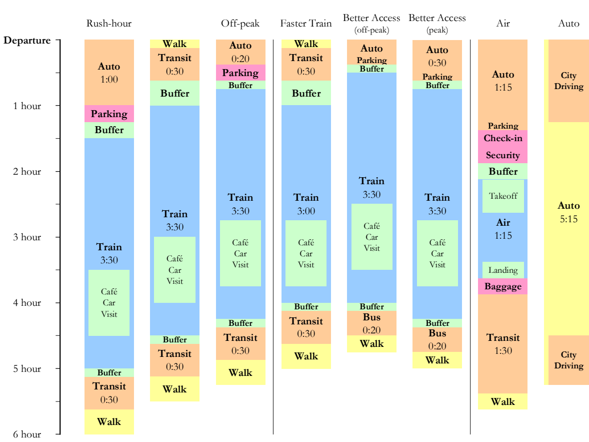
New York's Railroads was like London. Through historical accident, commuter railroads around New York have long terminated at a number of different stations. In the past, each terminal was dedicated to a fixed set of routes, as in London. More recent improvements has allowed some terminals to be reached from more routes, through transfer stations such as Secuacus, Jamaica, Newark, Flatbush and Hoboken. The presence of many terminals recognizes the fact that New York has many activity centers (Midtown, Downtown, Jersey City, Brooklyn Heights) and that a single union terminal would be inappropriate.



Relationship between Local Transit and Intercity Rail. The multiple terminals serve to decentralize the distribution of commuters, reducing the need for very large terminal facilities. Nonetheless, Penn Station continues to experience capacity shortages. The current MTA planning studies "East Side Access" and "Access to the Region's Core" acknowledge the need for regional trains to service more than one location in the downtown by proposing a link-up between Penn Station and Grand Central. Ideally, Downtown, and other activity centers of significance would be directly served by intercity rail, although at present the benefits seem limited, given the high density of local transit.

At off-peak times, when the commuter-oriented downtown distribution infrastructure is not being intensively utilized, it is likely that the mode-share of high-speed intercity trains would benefit from calling at more than one station within the metropolis. Amtrak trains from Boston can call at Baychester/95 Park & Ride, 125th Street, Grand Central, Penn Station, Secaucus/NJ Turnpike Park & Ride, and Newark to maximize accessibility to high-speed rail service.

How does Access Impact Total Trip Time? Taking a trip between Harvard Sq., Cambridge, Mass. and the Upper West Side in Manhattan, New York as an example, improving access reduces the trip time by more than 30 minutes, in addition to allowing a longer in-vehicle time.



Comparing the auto as a feeder mode against transit is appropriate as a faster train that terminates in the downtown will not allow the auto to be used as a feeder mode. Parking & congestion are major issues at downtown terminals.

The high density and quality of local transit options in Manhattan means that incremental benefit of enhancing access for intercity rail is limited. However, access is still an important issue, and needs to be addressed for the intercity rail to compete effectively against those who choose to drive to a Park & Ride on Metro-North or fly into JFK Airport and take Transit.

Both Photos: Father Mark Meyer, Maryknoll Catholic Mission. (http://www.marksmission.org/)

MISCELLANEOUS CASE STUDIES

Cleveland. Expert panel analysis suggests the main downtown activity center lies between Public Square (near Cleveland Union Terminal) and I-90, an area of approximately 1.5 miles in length. The current Waterfront station is relatively distant from the main activity centers. MetroFlyer-type approach would restore direct rail service to Cleveland Union Terminal, and open a new station near Cleveland State University to serve both walk-up demand and to provide a downtown Park & Ride. New infrastructure would be required in the form of a new rail line beneath or above I-90.

Pittsburgh. The main constraining factor in Pittsburgh is likely to be the challenging terrain. The downtown is divided into two main activity centers: The Golden Triangle, and Oakland. Using mostly existing rights-of-way, it was found to be possible to serve the downtown, Oakland at Forbes Ave., and a number of Park & Ride options outside the city. The MetroFlyer approach would consider the location of existing mainlines with respect to modern demographics, and re-route trains accordingly (after infrastructure upgrades). For instance, trains departing to the East could exit via the former Pennsylvania, if it happens to serve the best suburban locations, but interchange to the former B&O via the Youngwood/Scottsdale alignment (if the B&O were chosen as the main East-West passenger trunk route).

High Speed Routing. If the U.S. is committed to a high-speed passenger rail system, it is conceivable that the New York Central and Pennsylvania mainlines could be re-constructed as four-track freight arteries, taking the pressure off the B&O, which could then be re-constructed for high-speed passenger use. The current approach of designating existing historical trunk corridors as "high speed corridors" may (1) overlook real opportunities for consolidation and maximizing service-effectiveness by using a combination of old mainlines, branch lines, spare highway rights-of-way width (reserved for widening), and abandoned alignments; (2) require more mitigation for freight customers than otherwise necessary. Fundamentally, there are not many reasons to build more than one dedicated passenger mainline between the Northeast and Chicago (and similarly, not many reasons for more than one dedicated freight mainline).

San Francisco. Although San Francisco is not a city with multiple "walkable" downtown business districts, the current California high-speed rail plan acknowledges that access is an important issue in the greater metropolitan area. Especially in dispersed cities on the West Coast, economic activities occur in many locations other than the downtown. The plan provides for branch to Oakland and stops at Redwood City and San Jose – important suburban city terminals upon which the success of the high speed rail depends.

In San Francisco, the ring concept is inappropriate as the San Francisco Bay Crossing is more than four miles wide and it would be very expensive to connect San Francisco to Oakland. Especially for residents living far from the airport, having a local station within a 15-minute drive is a major advantage for rail service. The stations need to be designed with the local environment in mind – while we can expect some walk-up ridership in downtown San Francisco, the other stations are likely to be more of a Park & Ride nature.

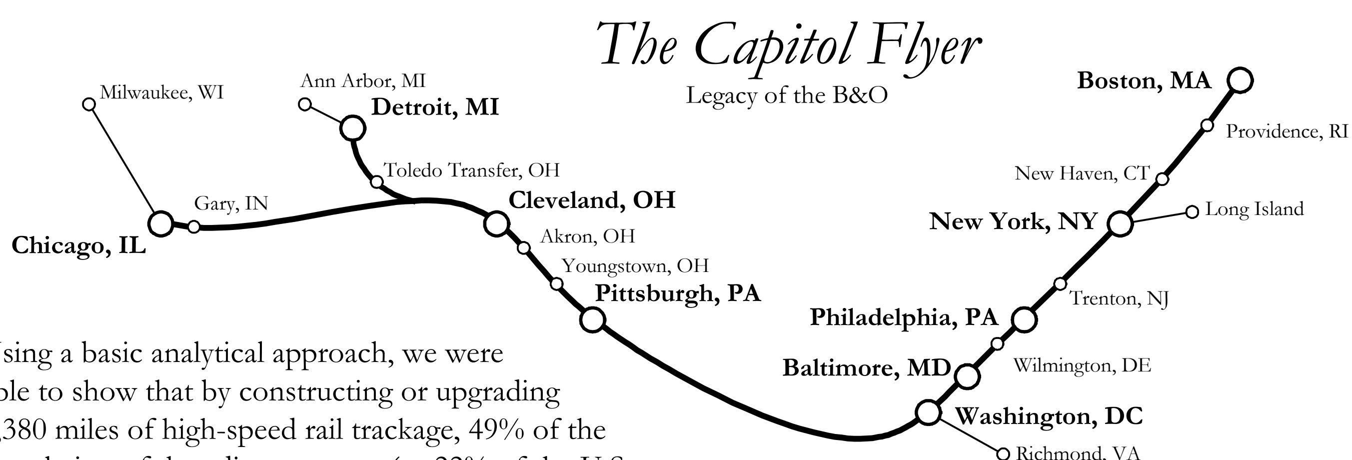
In practice, exiting the Bay Area due South is likely to be the only high-speed alignment in the future, due to the lack of large populations due North and the physical difficulty of constructing a direct line to Sacramento. The Bay Area, being a stub-end type location, the ring concept is not as important as it is in a node where the rail services depart in many different directions.

WHY IS OVERNIGHT RAIL SERVICES IMPORTANT?

In the same way that urban rail corridors could also be used for subway service if the vehicles were made compatible, a series of interconnected high-speed rail and regional rail corridors could be used for overnight services. Given the dominance of infrastructure costs over vehicle costs, if a service could reach operating self-sufficiency at all, it should be operated – the increased utilization of interurban infrastructure (typically not capacity-constrained at night) will increase the benefits leveraged from the investment beyond that available from economic development fostered by high-speed rail corridors.

Overnight Service: journey time *Magically* disappears!

Why is Access Important in Overnight Rail? Overnight Rail's main competitive advantage lies in the fact that, operated over reliable infrastructure, it is able to depart from the originating stations close to the time when the travellers are ready for bed, and arrive at the destination shortly after they have finished breakfast. To the traveller, this feels like being teleported: journey time has magically disappeared. Even if they departed the previous day or early in the morning, they would still have had to sleep at home or in a hotel room. However, that important advantage is eclipsed if the traveller needs to spend more than about an hour at either end getting to and from the rail terminal; over the distances that overnight high-speed rail are typically competitive (600~1,200 miles), a morning flight can just as easily result in an arrival at the same time at the final destination, while allowing the traveller the same amount of sleep, if more than an hour is required in access time. Transfers to and from late-night corridor rail services is not acceptable, since sleep would then be interrupted. Thus, the overnight train must fulfil the functions of both the regional collector and the overnight line-haul. In heavily urbanized areas such as the Northeast, this means station stops are required about every 30 minutes of runtime – even if it is not strictly optimal, as it is necessary to maximize catchment and retain competitive advantage.



Using a basic analytical approach, we were able to show that by constructing or upgrading 1,380 miles of high-speed rail trackage, 49% of the population of the adjacent states (or 22% of the U.S. population) would be within an hour's drive (or transit ride) of a high-speed rail station, where there would be local corridor departures and long-distance overnight departures. Demand analysis demonstrated that all stations would receive at least one train daily, and some will receive two trains, in addition to the corridor services already planned or in operation on these corridors. There are substantial benefits to operating overnight services over interconnected high-speed corridors, and more research, perhaps with GIS, is needed to explore the possibilities.

OVERNIGHT CASE STUDY: THE CAPITOL FLYER

Assuming a service speed of 125mph, we found that overnight services between the Northeast and the Industrial Heartlands are indeed feasible operationally, and could generate considerable demand. Coupled with the corridor services in the Northeast, the Midwest, and perhaps throughout Western Pennsylvania and Eastern Ohio, a credible National Interurban Passenger Rail Network could be built. At a time when air infrastructure is perceived to be subject to disruptions, if the right incentives are offered, broad support from the states may be possible – given the large number of people it would serve.

Who would support this? The urban population would be a core supporter, especially if the investment results in new urban infrastructure for transit, with differential pricing applied such that the urban poor is not disadvantaged. The suburban population perceives a large advantage in no longer having to drive to the airport, and having their own local access point (Park & Ride) to the national network, reducing trip times and providing additional intercity transport options at times of heavy interstate congestion. The rural population, which makes up about half of the U.S. population, have the strongest reason to object, although if the construction leads to economic boost in the short term, and the environmental effects are mitigated in a sensitive fashion, there may be some support from states that are predominantly rural.

Capitol Flyer Service Points

City	Counties or Towns Served	Population [1]	Served by train #	State	State Catchment	State Population	% Pop Served (Direct)
MBTA Area							
Haverhill, MA	Middlesex	1,426,606	3049	MA			
	Essex	704,407	3049	MA			
Boston, MA	Suffolk	641,695	3049	MA			
Route 128, MA	Norfolk	643,580	3049	MA	3,416,288	6,175,169	55%
Providence, RI	Providence	574,108	3049	RI	574,108	990,819	58%
Metro-North Area							
New Haven, CT	New Haven	793,208	3049	CT			
Stamford, CT	Fairfield	841,334	3049	CT	1,634,542	3,282,031	50%
New Rochelle, NY	Westchester	905,572	3049	NY			
Long Island Railroad Area							
Patchogue, NY	Suffolk	1,383,847	3045, 3041	NY			
Hicksville, NY	Nassau	1,305,057	3045, 3041	NY			
Jamaica, NY	Queens	2,000,642	3045, 3041	NY			
New York City Subway Area							
New York, NY	New York	1,551,844	3045, 3041	NY			
	Bronx	1,194,099	3045, 3041	NY			
	Kings	2,268,297	3045, 3041	NY			
	Rockland	284,022	3045, 3041	NY			
	Richmond	413,280	3045, 3041	NY	11,306,660	18,196,601	62%
NJTransit Area							
Newark, NJ	Hudson	552,819	3045, 3041	NJ			
	Bergen	857,052	3045, 3041	NJ			
	Essex	747,355	3045, 3041	NJ			
Metropark, NJ	Union	498,759	3045, 3041	NJ			
	Middlesex	717,949	3045, 3041	NJ			
SEPTA Area							
Trenton, NJ	Mercer	333,861	3045, 3041	NJ	3,707,795	8,143,412	46%
	Bucks (PA)	594,047	3045, 3041	PA			
Philadelphia, PA	Philadelphia	1,417,601	3043	PA			
	Montgomery	724,087	3043	PA			
Wilmington, DE	Delaware (PA)	541,502	3043	PA	5,608,573	11,994,016	47%
	New Castle	487,182	3043	DE	487,182	753,538	65%
MARC Area							
Baltimore, MD	Baltimore County	723,914	3043	MD-VA-DC		5,171,634	
	Baltimore City	632,681	3043	MD-VA-DC		6,872,912	
New Carrollton, MD	Washington PMSA [2]			MD-VA-DC		519,000	
VRE Area							
Richmond, VA	Richmond MSA	961,416	3047	MD-VA-DC			
Fredricksburg, VA	Washington PMSA		3047	MD-VA-DC			
Lorton, VA	Washington PMSA		3047	MD-VA-DC			
Washington, DC	Washington PMSA	4,739,999	3047	MD-VA-DC			
Rockville, MD	Washington PMSA		3047	MD-VA-DC	7,058,010	12,563,546	56%
Total population served East of Sleeping Sidings		31,461,822					

Population catchment estimate for the Northeast Zone, The Capitol Flyer.
(**Source:** *How to Run Overnight Services Profitably – a Case Study in Eastern U.S.*, Alex Lu, 2002.)

	2151	2153	2155	2157	2159	2167	2171	3047	3443	2173	2175
	Acela Express	Acela Express	Acela Express	Acela Express Midwest Direct	Acela Express	Acela Express	Acela Express	The Capitol Flyer	Detroit Congressional	Acela Express	Acela Express
	Coach	Coach	Coach	Coach **	Coach	Coach	Coach	Full	Half	Coach	Coach
Boston, MA	05.25	06.25	07.25	08.25	09.25	13.25	15.25			16.25	17.25
Providence, RI	06.05	07.05	08.05	09.05	10.05	14.05	16.05			17.05	18.05
New York, NY	08.41	09.41	10.41	11.41	12.41	16.41	18.41			19.41	20.41
Newark, NJ	08.76	09.76	10.76	11.76	12.76	16.76	18.76			19.76	20.76
Philadelphia, PA	09.83	10.83	11.83	12.83	13.83	17.83	19.83			20.83	21.83
Baltimore, MD	10.99	11.99	12.99	13.99	14.99	18.99	20.99			21.99	22.99
Washington, DC	11.79	12.79	13.79	14.79	15.79	19.79	21.79	22.00	22.50	22.79	23.79
Pittsburgh, PA				18.48				—	—		
Cleveland, OH				20.12				—	07.33		
Detroit, MI									08.84		
Chicago, IL				22.91				08.37			
Milwaukee, WI				00.25				09.70			

	3043	3143	3449	3041	3045	2391	3067	3245	3049	2371	3149
	Broadway Flyer	Detroit Pennsylvanian	Detroit Flyer	The Early New Yorker	21st Century Limited	Acela Midwest	Midwestern Night Owl		New England Flyer	Acela Midwest	
	Full	Half	Half	Full	Full	Coach	Coach *	Half	Full	Coach	Half
Boston, MA							18.25		21.00		22.00
Providence, RI							19.05		21.80		22.80
New York, NY			22.50	23.00	22.00		21.41	23.00	00.16		01.16
Newark, NJ			22.85	23.35	22.35		21.76	23.35	—		—
Philadelphia, PA	22.00	22.25	23.91	24.41	23.41		22.83	00.41	—		—
Baltimore, MD	23.16	23.41	—	—	—		23.99	—	—		—
Washington, DC	23.96	00.21	—	—	—		00.79	—	—		—
Pittsburgh, PA	—	—	—	—	—		04.48	07.53	—		—
Cleveland, OH	—	07.33	—	—	—		06.12	09.18	—		—
Detroit, MI		08.84	09.29							06.42	09.29
Chicago, IL	08.57			07.80	08.80	08.50	08.91		08.36	09.00	
Milwaukee, WI	09.90			09.13	10.13	09.84	10.25		09.70	10.33	

	3445	2351	2353	2373	2355	2375	2357	2377	2359		
	Cleveland Express	Acela Midwest	Acela Midwest	Acela Midwest	Acela Midwest	Acela Midwest	Acela Midwest	Acela Midwest	Acela Midwest		
	Half	Coach	Coach	Coach	Coach	Coach	Coach	Coach	Coach		
Boston, MA	22.50										
Providence, RI	23.30										
New York, NY	01.66										
Newark, NJ	—										
Philadelphia, PA	—										
Baltimore, MD	—										
Washington, DC	—										
Pittsburgh, PA	07.53		06.56		10.56		16.56		18.56		
Cleveland, OH	09.18	06.41	08.21		12.21		18.21		20.21		
Detroit, MI				10.42		16.42		19.42			
Chicago, IL		09.20	11.00	13.00	15.00	19.00	21.00	22.00	23.00		
Milwaukee, WI		10.53	12.33	14.33	16.33	20.33	22.33	23.33			

Public Timetable, based on Preliminary 125mph Operating Plan, The Capitol Flyer. (**Source:** *How to Run Overnight Services Profitably – a Case Study in Eastern U.S.*, Alex Lu, 2002.)

The broad accessibility of the Interstate Highways helped to secure bipartisan support for its funding. If high speed rail were to become more accessible, both to the rural and the urban population, it may receive similar support.

Operating Plan, The Capitol Flyer. Based on preliminary operations analysis, an electrified double track main line would be sufficient for all services shown in the example public timetable. Using methodology similar to that demonstrated in the earlier Boston MetroFlyer case study, high density signalling in urban areas will further enhance the usefulness the infrastructure by allowing regional rail and urban transit services to be offered. The overnight service will leave from strategic stations at between 9pm and 11pm, arriving at the destinations at between 7am and 9am – in plenty of time for the start of the next business day. Some trains are required to pause at a "Sleeping Siding" near Cumberland, Maryland, to ensure that the trains do not arrive too early. Essentially, this operating plan is based on a linear hub-and-spoke network.

BALANCE SHEET: HIGH SPEED RAIL V.S. METROFLYER

	High Speed Rail	*MetroFlyer*
Typical Route Length	200 miles	220 miles
Typical Scheme	upgrade 100mph to 125mph (rural areas)	10 miles of 60mph new right of way (urban areas)
Typical Costs	$ 1.0 billion	$ 2.0 billion
Ratio of Investment	1	2
Typical Annual Ridership (enhanced facility)		
Intercity	1 million paxs	200,000 paxs
Regional	zero	1,250,000 paxs
Urban	zero	5,000,000 paxs
Typical Time Savings		
Intercity	24 minutes	15 minutes
Regional	zero	12 minutes
Urban	zero	20 minutes (over bus)
Elimination of Transfers	zero	saves additional 10 mins
Pax-hr Savings /year	400,000 hours	**3,041,667 hours**
Values of Time Saved /hr		
Intercity	$25	$35 (saves access time)
Regional	not applicable	$25
Urban	not applicable	$10
Typical Benefits /year (calculated)		
Intercity	$10 million	$2.92 million
Regional	zero	$11.5 million
Urban	zero	$25 million
Total	$10 million	**$39.4 million**
Benefits recoverable through farebox (75% Intercity, 50% Regional)	$7.5 million	$7.92 million
Net Present Benefit (50 yrs, discount rate = 7%)	$138 million	$544 million
Benefit per unit of investment	1.4	**2.7**

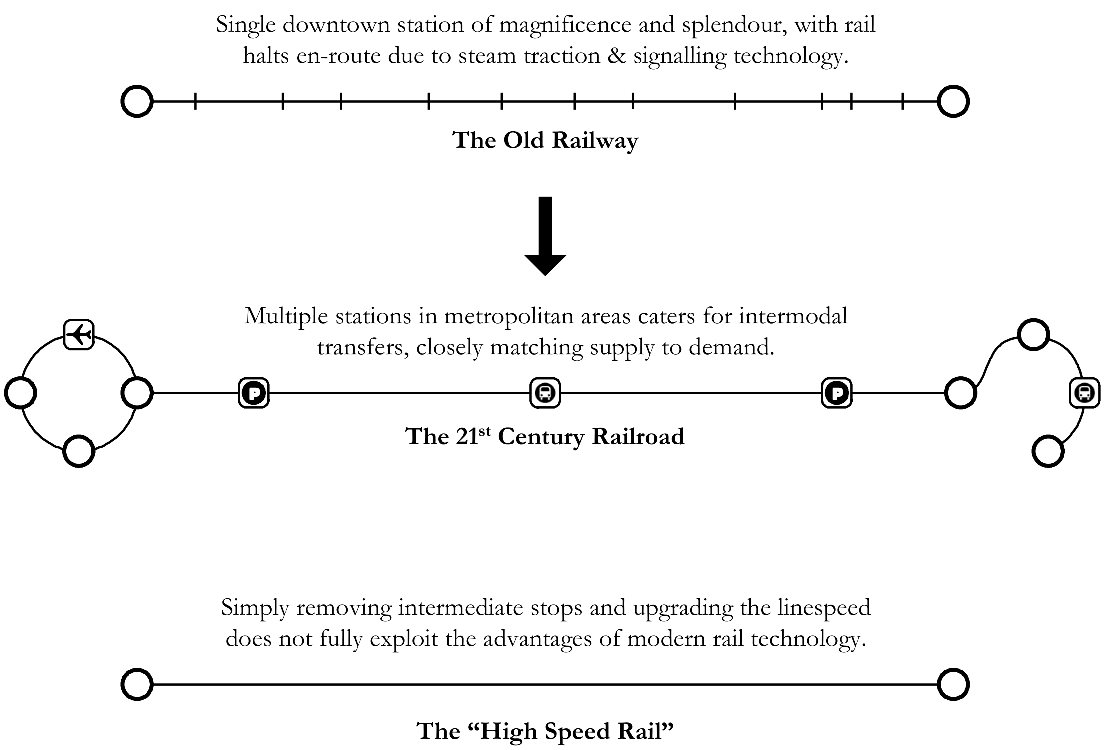
Dollar for $, *MetroFlyer* is about twice as effective as a comparable High Speed Rail scheme.

FROM THE LIMITED EXPRESS TO THE METROFLYER

In the past thirty or so years, high-speed rail has pursued a limited-stop express business model. There are good logic behind this:

- Customers prefer not to stop en-route.
- Short point-to-point times are required to compete with the airlines.
- High speed rail is perceived as a niche product serving the downtown-to-downtown business travel market.

Such a business model has not generally proven to be profitable without government subsidies. Some of this must change in future, to ensure a more sustainable basis for intercity passenger rail. Rail technology, by nature, enjoys greater economies of density, scope, and scale (in seats per vehicle, number of stops en-route) than air technology. Thus, it is in the rail advocate's interest to serve the mass-market, recovering capital costs through Ramsey-pricing.



Better downtown distribution is one way to expand rail's market reach and market share, while realizing potentially cost-saving economies. Having multiple rail terminals in the walkable neighbourhoods of large cities is not only a good competitive response to cities with multiple airports, it is also a good way to serve the large suburban population currently in a better position to access the out-of-town airfields.

The main emphasis should be matching the supply of rail terminals to the originating travel demands within the immediate locale, enabled by technology changes over the last century. Ideally, the "nearest rail terminal" should always be more accessible in any part of the city except for the communities immediately adjacent to the airport. The rail depot could then once again return as the focus of the community in an urban landscape, in a way that airports simply cannot – in addition to providing good transportation services.

MetroFlyer equipment is comfortable, not value-engineered, just like your lounge at home – not a subway car, not a high-speed train, not an aeroplane.

(Amtrak #449 at Albany, New York, waiting for a connexion with #49 en route to Chicago.)

G. TECHNOLOGY VIGNETTES FOR RAILROADS

Lexcie Lu, MIT Center for Transportation Studies

Based on the research group's practical railroad operations experience, a number of ideas for potential applications of technology had been developed for future railroad research programmes. The approach taken in this section is generally thought of as "market-pull", where the current operators and managers are attempting to persuade the technologists to come up with an invention to solve their problems. The technological ideas and application we discovered through brainstorming and interviewing operating personnel range from near-term, immediately applicable technologies that enhance day-to-day operations to long-term concepts that may change the system as fundamentally as the steam to diesel and D.C. to A.C. transition. The following table is a summary of the technology ideas:

- Optical Coupler for Budd Cars
- Long Pantographs Stable at High Speeds
- Electroluminescent wire/surface
- Combined Intermodal Dispatching Systems
- Biological Breeding of Coach Designs
- Half Person Crew: Remote Operations
- Sensor Chair: For a More Comfortable Ride
- Application of Neural Technologies to Traction Control
- No More Gauge Corner Cracking – Track that Changes Colour
- Magnetically-guided High Speed Rail Systems

A brief review of the ideas are presented in this working paper, from the most immediately applicable to the most conceptual.

5.1 Optical Coupler for Budd Cars

Couplers are a maintenance headache, well known throughout the railroad and transit industries. The current technology is inadequate. AAR-derivative couplers require a manual connection of 27-pin MU jumper, brake pipe, and HEP line between two carriages by the conductor. Not only is this a potential hazard, it is also a time consuming process, with a known history of high failure rates. Various solutions have been developed to address this problem. On British Rail metals, as many as three different types of "intelligent" couplers are in use. With the advent of optical technology, it is conceivable that the electrical connexion between adjacent carriages may one day be replaced with a laser-based information transmittal link. The laser link would function in all weather (given a line-of-sight between the transmitter and the receiver), and would require minimal maintenance since there will be no moving parts and everything would be solid-state. If an information link cannot be made, the operator simply needs to clean the glass.

5.2 Long Pantographs Stable at High Speeds

Long pantograph have not generally been developed. This has meant that there are height restrictions for freight vehicles in electrified territory. The longest pantograph available are those on the Eurostar which has British dimensions but has to traverse under the wires in Europe which has a more generous loading gauge. The loading gauge in the Chunnel is also high but it will not support double stack operations. By developing pantographs and catenary supports which will support double-stack operations "under the wires", greater economies of density can be reaped from an expensive piece of infrastructure by allowing double-stack and high-speed passenger trains to share the same track.

5.3 Electroluminescent wire/surface

Railroads used luminescent things for many reasons: signals, emergency lighting, permanent speed restriction warning signs, posession limits, etc. Over the past few years, traditional lamps with coloured lenses had been replaced with LED clusters. Electroluminescent Wire is a new technology which combines some of the properties of the existing lighting technologies. The basic design for the electroluminescent wire makes use of a transparent material (some kind of polymer) which is excited by the passage of A.C. current, and emits light of a specific color. It should be theoretically possible to build the device into a flat panel. This can clearly be used as a subsitute for a railroad signal whilst occupying less space than both the conventional bulb. It would also be possible to build active panels for speed restriction warning signs.

5.4 Combined Intermodal Dispatching Systems

The current state-of-practice in the trucking industry calls for dispatching decision-support models which use a combined demand model and optimization model to dispatch trucks for optimal utilization and also to assist in pricing. The concept has not been extended intermodally. Conceivably, if the railroad intermodal network is run in a scheduled departure fashion, the 'slots' available onboard an intermodal train could affect optimal utilization of truck trailers and tractors. Under a total logistics company framework, a model could be developed to assist the railroad carrier in winning a greater proportion of intermodal business if through its scheduled network, trucking companies are able to decrease their operating costs through more efficient use of drivers and tractors.

5.5 Biological Breeding of Coach Designs

There are many different coaching stock designs throughout the world, each with its own strengths and weaknesses. Each had been designed to different engineering standards. The efforts to standardize had been slow and the lessons learned by a particular group of design engineers are not necessarily applied to the designed produced for a different railroad by a different group of engineers. Genetic algorithms are already able to "cross-breed" different diesel engine designs to produce a more efficient diesel with characteristics such as lesser emissions and design features such as shape of cylinders etc "inherited" from its "parents". Through an iterative process of introducing random perturbations and then selecting the most successful engines, development is cut down drastically. This process may be applied to the coaching stock design process.

5.6 Half Person Crew: Remote Operations

In general, in low density freight operations on single-track railroad, the train spends much of its time sitting in sidings waiting for passing maneuvers. This is not an effective use of traincrew time. With better and cheaper video transmission technologies, it is conceivable that a train could be operated with a remote crew, especially in rural areas this could lead to considerable savings. The view of the right-of-way and the instrument panel readings could all be transmitted back to an office using a wireless link. While the train is waiting for the signal, the train could be immobilized and the engineer could take over the control of a different train, effectively allowing less-than-one-man crews on average on a given set of trains. There are also economies associated with eliminating field operations – traincrew logistics would be simplified, with a central sign-on and sign-off location. Working environment for the traincrew could also be improved.

5.7 Sensor Chair: For a More Comfortable Ride

Train seats are uncomfortable. Current seats aren't specifically designed for comfort. Aside from ergonomic designs adapted from office furniture, sensors also could be fitted to seats, along with active support fibres woven into the seat that will change stiffness and other physical properties with an electrical signal. The chair thus "adapts" to each rider depends on her posture and gives a more comfortable ride.

5.8 Application of Neural Technologies to Traction Control

This is a century-old problem which forms the core of the train engineer's skill: the ability to start a train against a steep grade in the rain. This is the reason why engineers have to 'learn a traction', and a very important part of 'learning a route'. More commonly this is done in a brotherly fashion; experience is passed on from generation to generation, whether correct or not. Not running the train at the maximum coefficient of friction permitted by the rail conditions will lead to unnecessary loss of time and deviation from schedule; attempting to run the train at above the maximum coefficient of friction will result in signal overruns and mechanical damage when the wheel spins.

EMD has developed very sophisticated wheelspin control systems, giving the engineer much control even in the worst of rail conditions. Nonetheless in bad rail conditions it is still possible to spin the wheel. Defensive driving isn't really a satisfactory solution. The performance of the rail system could be enhanced if the engineer didn't have to worry about braking when the machine could operate at its maximum performance. Neural networks are already used in many areas to create illusion of artificial intelligence. Basically, neural networks are used to detect subtle correspondences between a set of inputs and a set of outputs which are perhaps to complex to be derived analytically. Neural networks also appears to give machines a way of 'learning' a skill.

5.9 No More Gauge Corner Cracking – Track that Changes Colour

Tracks are a high maintenance item, because when they break the consequences are disasterous. The inspection costs are too high. Current focus in technology is in developing technologies which will detect a rail break more efficiently and earlier, so that preventative maintenance can be carried out. However the current technology still depend on an active polling process – "the search for broken rail", instead of a passive listening process, whereby the rail tells you if it is about to break. Development of either self-strengthening or "smart" materials may lead to a breakthrough in safety in this area. For example, a new type of track material or additive which turns hot pink when subjected to stress beyond design levels or when cracks are expected to appear could dramatically cut down the cost of inspections whilst improving safety. Although ultrasonic testing technologies are already available, this remains nevertheless a passive mode of track defect monitoring.

5.10 Magnetically-guided High Speed Rail Systems

High Speed Rail requires sweeping curves to minimize lateral acceleration while traversing a curve. However, sweeping curves are amongst the most expensive components of high speed rail systems. A breakthrough in level of passenger comfort whilst traversing restrictive curves was pioneered by Amtrak in the 1960s with the lightweight aerotrain. However, vehicle stability and rail wear issues had not been adquately addressed. Magnetic levitation (Maglev) technology for ground passenger transportation applications is already mature, although cost has precluded its deployment or planning except in Germany and China. The proposed solution combines Maglev technology with conventional rail.. The magnetically-guided conventional train will only use superconducting magnet for one purpose: forming a guideway. On straight or slightly curved sections of right-of-way, conventional wheel flange guidence will be used. On severely curved right of way and a small transistion section on either end, electromagnets will be installed on one or both sides of the track.

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with a scene from the B&O Mainline at Fostoria, Ohio]

Performance-Based Technology Scanning for Intercity Passenger Rail Systems:
The Incremental Maglev and Railroad Maglevication as an Option for Ultra High Speed Rail

Lexcie Lu, Carl D. Martland, Joseph M. Sussman

Rail Industry Technology Scanning Group • MIT Center for Transportation Studies
77 Massachusetts Avenue • Room 1-153 • Cambridge • Massachusetts 02139-4301
Phone: (617) 253-5326 • Facsimile: (617) 258-5942
lexcie@mit.edu (Corresponding Author) • martlan@mit.edu

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Abstract

New technologies offer ways for railroads to reduce costs, increase market share, and achieve higher profitability. Determining the best opportunities requires understanding of the marketplace and translation of technological improvements into competitive advantage for the rail industry. This three-year research effort uses the Performance-Based Technology Scanning (PBTS) methodology for identifying such "leveraged" areas. Applying PBTS to intercity passenger rail revealed that line-haul speeds and access times are both very important. High line-haul speeds differentiate the service from the private auto, while better access time competes with air service.

The current high-speed rail research programmes in the United States have focused on two distinct approaches: (a) upgrading existing rights-of-way through conventional technologies such as tilting vehicles, track realignment and positive train control to enable service speeds of up to 150mph; (b) constructing new rights-of-way with advanced propulsion technologies such as magnetic levitation to enable service speeds of up to 300mph. The former approach sometimes fail to make appreciable difference in journey time or market share, and introduces conflicts with freight trains, while the latter isn't currently considered economical for corridors longer than about 30 miles, due to the high cost of new infrastructure.

We therefore recommend a hybrid approach for further engineering research & development. Rail vehicles with magnetic guidance equipment could travel as conventional trains over "wide open spaces" on low-cost existing rights-of-way at up to 110mph, then switch to magnetic guidance to climb very steep grades or achieve higher speeds around sharp curves. Climbing steep grades allows more direct new routes through mountains, avoiding potentially costly tunnels. Maintaining stability with magnetic guidance allows usage of existing, curvaceous infrastructure at higher speeds to reach downtown areas. Hybrid maglev vehicles and railroad maglevification is backwards compatible, thus allows sharing of the high, fixed infrastructure costs with commuter and freight trains already running over the national rail network.

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Introduction

New technologies offer ways for railroads to reduce costs, increase market share, better service offerings, and achieve higher profitability. Determining the best opportunities requires understanding of the marketplace and translation of technological improvements into competitive advantage for the rail industry. This three-year research effort uses the Performance-Based Technology Scanning (PBTS) methodology for identifying such "leveraged" areas. Applying PBTS to intercity passenger rail revealed that line-haul speeds and access times are both very important. High line-haul speeds differentiate the service from the private auto, while better access time competes with air service.

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In this paper, we introduce the concept of maglevication of existing railroad infrastructure. When Pennsylvania Railroad electrified the Philadelphia-Paoli mainline in 1914, they designed the catenary such that ordinary steam freight trains could run 'under the wires' to reach Lancaster and points beyond. Maglev could be seen as the next step forward – and maglev infrastructure should be designed such that ordinary diesel freight trains could run 'over the magnet'. More importantly, since maglev infrastructure is expensive, express passenger trains should be able to switch between maglev and conventional modes, to navigate different types of terrain at different speeds. We call this process of retro-fitting magnetic infrastructure to existing railroads the process of railroad maglevication.

Lifting the steel wheels from the track may not actually be necessary to achieve the range of journey time savings customers desire. With advanced truck designs, rolling contact resistance could be substantially decreased compared to the typical levels when maglev trains were first proposed. Maglevication would utilize the existing steel wheel-rail interface to provide support for the weight of the rolling stock, while utilizing magnetic forces to assist horizontal and lateral movements.

Performance Based Technology Scanning

PBTS is a methodology whereby the process of determining the technology strategy for railroad carriers and industry is broken down into five distinctive steps, ranging from the general broad-brush explorations to the very specific strategic direction. The highest level is a generalized search for new and emerging technologies, often conducted by science and engineering graduates using industry sources and the science press (e.g. *New Scientist*, *Scientific American*). The objective is to identify novel and exciting technologies that may have an impact on the transportation industry. Technologies can affect transportation in quite subtle ways: travel patterns, nature of goods being transported, the technologies available to transport them, and the relative economics of different modes, could all change with new technological development.

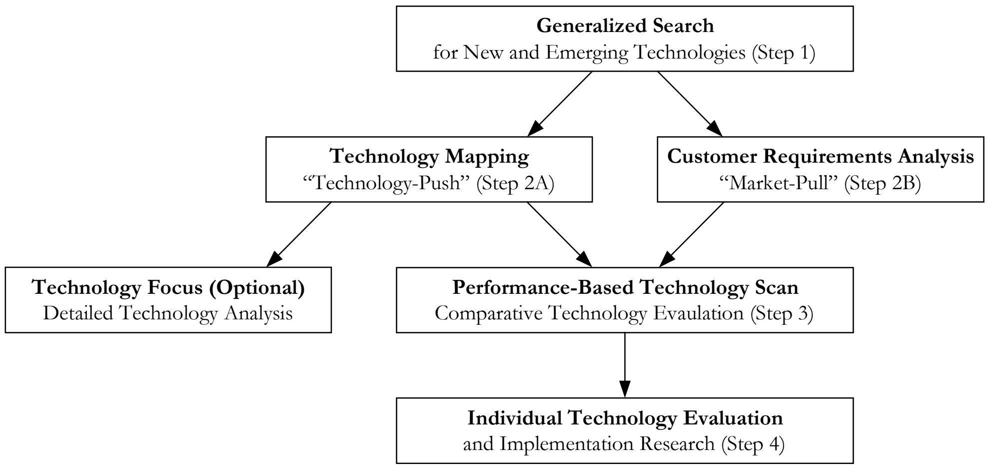


Figure 1: The Five-Step Process of Technology Scanning

Two approaches of classifying the impact of technologies could be distinguished: (a) Technology Mapping, and (b) Customer Requirements Analysis. The former is a "technology push" approach where vendors of technologies identified in Step 1 attempts to identify the areas where the emerging technologies could be applied to transportation. The latter is a "market-pull" approach where transportation companies actively seek technological solutions to existing operational problems. The potential technological applications are then evaluated using a comparative technology evaluation framework to ascertain whether the proposal will generate the best net social benefit (versus not deploying the technology, or deploying an alternate technology), in Step 3. The final step is to develop and implement the most promising (or leveraged) ideas. Substantial development costs could be incurred at this stage, and the comparative technology evaluation serves as a screening process to differentiate between lemons and silver bullets.

Detailed discussion of the PBTS process developed as part of this project is detailed in a prior publication (Lu, Martland, et al., WP-2002-3). In the present paper, a promising idea for high-speed ground transportation, as identified in the Step 3 of the PBTS process is described.

The State of Practice in High Speed Ground Transportation

There are a number of technologies currently competing for the 100~600 mile transportation market in the developed world. Amongst them: (1) private auto, (2) intercity buses, (3) conventional train, (4) high-speed train, (5) magnetically levitated train, (6) conventional aircraft, (7) tiltrotor and other light aircrafts. There are also a number of permutations of each type of technology, e.g. high-speed trains could be electrically propelled, gas-turbine driven, or carry diesel prime movers; conventional aircrafts could be large aircrafts or regional jets. The argument between whether airbourne or land-based transportation modes should be preferred could rage on due to unaccounted externalities. Assuming that a ground transportation option is desirable, a range of current options is reviewed here, to better understand their cost structure and service characteristics.

The Private Auto

In North America at least, the private auto is by far the dominating form of intercity transportation, at least in terms of trip volumes. For person-trips between 100~499 miles, the private auto captured 93.7% of the market, while commercial airlines captured 2.3%, intercity bus 0.4%, and intercity rail 0.7% [1]. This automobile dominance is not limited to the rural areas. In the Northeast Corridor, where intercity rail service is well developed, the private auto nevertheless achieved a 72% market share between New York and Washington (Consolidated Metropolitan Statistical Areas), while airlines carried 22%, and rail 6% of all person-trips [2].

What explains this automobile superiority? There are a variety of reasons: (1) collective transportation requires either geographical or temporal consolidation, sometimes both, thus a high demand-density is needed; (2) other benefits are associated with having "your car" -- including easier freight carriage, the convenience factor, choice of schedules, etc.; (3) usage of the private auto is subsidized to different extents by the government than other modes of transportation; (4) the incremental cost per person is approximately zero, for the same origins and destinations.

For shorter trips in the 100~600 mile market, the access time is an important part of the total journey time, where the route structure could mean convoluted routings that make collective transportation unattractive. 55% of all passengers in New England drive more than 16 miles to an airport [3]; nationwide median distance for airport access is 21 miles [4]. These statistics suggest that with today's North American metropolises, which are sprawled over large areas, the private auto has an important advantage in its totally-connected route network that collective modes will find difficult to surpass. Lu & Martland (2002) discusses the accessibility question in greater detail in a previous publication.

Intercity Buses

Common carrier intercity buses has all the disadvantages of collective transportation, but none of the speed or comfort advantages associated with the other modes. The statistics demonstrates this: despite a much wider route network than intercity rail, common carrier buses achieves only half the market share. Intercity buses tend to carry captive riders without access to an automobile, or choice riders with very low value-of-time whose major criteria is price. However, in some areas, the demand density is so low that the only intercity mass-transportation option is coach. While remaining an important element of rural public transportation in states such as Vermont, Maine, New Jersey, Ohio, Utah, New Mexico and Texas, the common carrier intercity bus is unlikely to be a serious contender for choice travellers in high-volume corridors.

Conventional Train

The conventional train is sometimes seen as a large bus. In the intercity sector at least, there aren't many corridors in the world that would justify conventional train service on the basis of capacity alone. Bus service, on the other hand, could be much more flexible and offers much better access. The main advantages of the train is that it is able to offer hereto unparalled level of comfort and amenities, in addition to immunity from highway congestion and much higher speeds where infrastructure permits such operations. If the conventional train is unable to offer higher speeds than the intercity bus, it will be seen as simply a large bus and destined to fail even more miserably than the bus. On the other hand, if the train is able to distinguish itself from the automobile through a combination of higher speeds, better amenities, plus immunity to congestion experienced at airports and on urban expressways, it would be the dark horse of intercity transportation.

Much research has already been done in making the conventional train more competitive through incremental upgrades. The current FRA Next Generation High Speed Rail Technology Demonstration Program is focused on four distinct areas: (1) positive train control; (2) high-speed non-electric locomotive; (3) high-speed grade-crossing protection; (4) high-speed track and structures (FRA, 2002). This is consistent with the incremental high-speed rail approach discussed in Roth (1994), where existing rights-of-way are retrofitted with technology enhancements to enable higher-speed operation of passenger trains.

This approach has several distinct advantages, compared to the other high-speed rail solutions: (1) it takes advantage of inherent value in existing railroad networks; (2) because of its phased nature, positive cash flows occur earlier in the investment cycle, providing financing for later stages; (3) due to the total backwards-compatibility of the equipment, high-speed trains are able to penetrate areas with lighter demand density on conventional infrastructure, resulting in a much wider route network than otherwise possible; (4) the comfort level and space available associated with conventional equipment is preserved -- a very important market consideration in the North American market.

The disadvantages of this approach are inherent in the paradigm: (1) because of the need to share track space with other trains operating as slowly as 30mph, dispatching trains efficiently becomes a major issue for speeds above 70mph or so -- track capacity for mixed speed traffic is much lower than that for traffic at a given speed; (2) the level of investment to reach a given speed could be higher, because of the additional safety precautions needed on a mixed-traffic railroad; (3) at higher speeds, conventional wheel-flange guidence systems become disproportionately expensive to maintain safely; (4) to cater for different types of traffic, the engineering parameters for track geometry are constrained by the least common denominators, making high performance for a particular traffic type difficult if not impossible to achieve.

High-Speed Trains

Pioneered by the Japanese Tokyo-Osaka Shinkansen in 1964, exclusive-guideway high-speed trains have always been seen as the silver bullet to the passenger rail problem by advocacy groups. What is often not appreciated is that the Tokyo-Osaka Shinkansen was justified not on the basis of increased performance, but as an alternative to four-tracking the Old Main Line (Yamanouchi, 2000). Even in traditionally exclusive-guideway systems, penetration into conventional trackage by high-speed rolling stock is usually considered an advantage, as doing so greatly enhances the accessibility of high speed services. During the first phase of the Paris-Lyons TGV, services extended beyond Lyon to provincial cities running on conventional infrastructure. In Britain, Intercity 125 sets operated on a scheduled basis to the north of Scotland, often operating over trackage that enabled a maximum speed of only 45mph. Such "penetration" by Shinkansen trains was impossible in Japan due to the existing narrow-gauge infrastructure.

The fundamental problem with high-speed trains remain the high cost of infrastructure. On high-speed track structure, gradient is practically limited to about 3%, and there are strict standards on curvature, length of transisiton, cant and cant deficiency, as well as tolerances in track gauge, track level, and axle-loads. For a mixed-traffic railroad, these constrants are even more severe: gradient is limited to about 2%, cant about six inches, and curvature limited by the highest speed passenger train that is designed to operate over it. These engineering constraints are not a major problem on the prairies, where the costs of laying straight track may simply be associated with buying out specific farms. In mountainous territory, however, these engineering constraints may increase (in a non-linear fashion) both mileage and the amount of rock blasting required.

On the Usui Pass between Tokyo and Nagano, relaxing the maximum permissible grade from 2.5% to 6.7% would half the construction expenses from ¥7.1 billion to ¥3.6 billion, while decreasing distance from 16 miles to 7 miles and drastically reducing the curvature required (Yamanouchi, 2000). Similar experience was found while constructing transcontinentals in North America. Many cut-offs were later built to reduce operating costs and transit times on originally curvaceous and heavily graded mainlines. In most cases, the revised alignment was more expensive and only made possible through reinvesting revenues generated by earlier traffic.

Magnetically-Levitated Trains

Magnetically-levitated trains is the ultimate in exclusive-guideway technology. Instead of using steel-wheels on steel-rails to provide support and guidance, maglev use magnetic forces to accomplish the same. Vehicle bodies are slightly elevated above the track structure with magnetic repulsion to eliminate any contact resistence, while the train is both pulled and propelled forward with magnetic attraction and repulsion, generated by fixed superconducting magnets buried into the track structure.

Maglev was designed to be a high-cost, high-performance system worthy of the space age. However, the high costs of creating a brand-new right-of-way in an urban area (where the demand density is sufficiently high to justify high speed rail), and the inherent high costs of superconducting magnets has limited its potential. Commercial implementations of maglev have been limited to very-short distance, transit-like applications, usually proposed as a non-stop, ultra-high speed link from an airport to the downtown area -- playing a similar role to that proposed for the tiltrotor aircraft 20 years ago. The only commercial implementation to date has been one 17-mile link between downtown Shanghai and its airport in China (Blow et al, 2003).

Maglev has the high per-mile costs of fixed-guideway technology, while being unable to share that cost with any other type of traffic due to its exclusive-guideway nature and lack of backwards compatibility. Applications of maglev, at least in its purest form, is likely to be limited to very-short distance markets where use of aircrafts is infeasible, and where the journey time differece between ten and 30 minutes is able to justify billions of dollars in right-of-way costs.

However, because of the enhanced technical characteristics of maglev, several possibilities have been raised that were not previously available to high-speed fixed-guideway transits. Because maglev technologies does not rely on adhesion, maglev trains are able to negotiate at very high speeds curves and grades (up to 10%) that are comparable with interstate highway engineering standards. This raises the possibility of putting maglev-type infrastructure along highway alignments, reducing costs and potentially allowing more direct alignments. The Baltimore-Washington maglev (BWMaglev.com, 2002) proposal is substantially based on placing an elevated maglev alignment over the existing I-95 Corridor. Nonetheless, the need for a brand new guideway could make any maglev scheme very capital intensive; about 53% of the projected costs of the BWMaglev are in the construction of the right-of-way, despite the existence of the interstate highway.

Strategy to Combat Automobile Dominance – Technology Needs

For collective intercity ground transportation to be successful, it must emulate the automobile as far as possible in terms of accessibility, retain the speed advantage of steel-wheel guidence, space and carrying capacity advantage of a railcar, while minimizing the cost of capital construction. In traditional service planning and design, the trade-off between speed and accessibility has often been represented as a hierachy (see Van Nes, 2001). Higher-speed, limited-stop modes offers lesser accessibility, but make up for it through shorter journey times. Van Nes suggests that when changing hierachical levels, the higher-speed mode ought to travel at about three times the speed of the lower-speed mode. As seen in Figure 2, there may be a niche market between the automobile (extremely high accessibility at about 50mph), and the commercial airline (very low accessibility at around 550mph). In theory, the high-speed rail could succeed by offering better accessibility than the commercial airline at an average speed of 110mph, provided that the infrastructure costs remain under control.

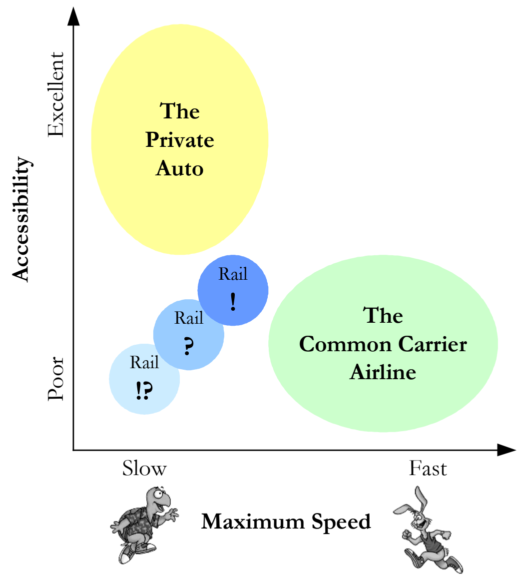


Figure 2: Intercity Rail's Possible Strategic Positions
on the Accessibility/Speed Plane

In certain circumstances, where a travel corridor covers regions of high demand density (requiring three or more levels) and low demand density (requiring only two levels), it is conceivable that high-speed rail could transcend between levels without change of vehicle, simply by changing the station spacing between stops -- in the same way that an automobile would interchange between an interstate highway and a rural route without having to stop or transfer passengers. The critical business needs for intercity ground transportation therefore are:

- Reasonable infrastructure costs, especially over urban and mountainous terrain
- Comfort factor similar to a conventional train
- Fast acceleration to permit stop spacing of about two miles in urban areas
- Average speeds of about 110mph for most station pairs
- Both a line-haul and a distribution mode – transcend network layers without transfers

The technology needed resembles essentially an FRA-compliant subway car with a generous loading gauge that is capable of travelling at very high speeds (150~200mph) in the rural areas to achieve an average speed of 110mph while making multiple stops within an urban area. Although this appears to be a technology that is already available, part of the problem is the persistent high costs of making steel guideways support heavy vehicles travelling at speeds above about 100mph, and the engineering constraints in terms of curvature and vertical alignment that can dictate viable high-speed rail alignments, as already discussed.

Rapid Transit Technology Case Study – Relationship to High Speed Rail

In infrastructure-intensive systems, sunk investment plays a major role in determining what technologies are viable, given what has happened before. In the rapid transit industry, this has resulted in subways being maintained where its large carrying capacity is no longer needed. Successful technologies have mostly been designed to be backwards-compatible. In North America, the railroad network is extensive and represents considerable sunk investment. It is imperative for the success of high speed rail to leverage the value of existing infrastructure and rights-of-way, while maintaining freight access.

The Importance of Inherent Value in Existing Infrastructure

The effect of sunk investment on the economics of infrastructure-intensive systems is reviewed here. Historically, as technology progressed, newer technologies have not always replaced older systems. There are many examples: (1) Light rail is considered more cost-effective than heavy rail, although many cities continue to operate heavy rail systems constructed at the turn of the century; (2) The double-stack innovation in North American railfreight have generally not spread to Europe, due to the high costs of raising bridges and enlarging tunnels.

The common reason for these seemingly backwards decisions are the same. The value inherent in existing infrastructure is so large that the new technology has no choice but to interface with the older technology. Economically efficient decision-making would allow the older technology to live out its 'life-cycle' while introducing new technology alongside it to provide enhancement and capacity relief at the most constrained points. In most cases, the new technology does not offer a sufficient performance boost to justify immediate replacement of the previous-generation technology at its current replacement value. Premature abandonment of assets has a very real economic cost associated with it. Only in rare cases where there is a performance step-change, would it be worthwhile. One such example is the wholesale replacement of diesel locomotives with D.C. traction motors in coal service during the late 1980s. Even in that case, the value of the scrapped D.C. locomotives are far from zero -- most were traded into the manufacturer to be reconstructed into A.C. units, or sold to shortlines to replace locomotives built in the 1950s.

There are examples outside transportation also: (1) Until recently, personal computers have been shipped with 4.77MHz ISA expansion slots which were developed by IBM in 1981, even though many different types of expansion buses have been developed since then. (2) Microsoft Windows continue to start a computer in 16-bit mode and with a memory limit of 640 Kbytes before loading a protected mode kernel to enable linear addressing, available in Intel hardware since 1984. In these examples, the replacement value is in terms of hardware peripherals built with the older interface, and software drivers already written assuming a 16-bit architecture.

Systems Engineering in Rapid Transit Applications

Systems Engineering is the discipline that studies the attributes of different technologies, and designing a system that may involve one or more technologies, to accomplish a desired goal in the most cost-effective manner. An example of a systems engineering question would be the choice of mass-transit technology with which to construct a transit line – and whether to build the line at all. Different parts of the same transit corridor might have different demand characteristics, thus the 'optimal' technology for different parts of the corridor might not be the same. A radial route around a city may traverse both an affluent low-density neighbourhood and a poor high-density neighbourhood with large demands and large number of captive riders. From a capacity standpoint, heavy rail subway might be most suitable for the high-density neighbourhood, while a light-rail might be able to offer higher frequencies in a low-density neighbourhood to attract choice riders.

Here a logical solution might be to develop a hybrid scheme where some light-rail vehicles are able to inter-operate with the subway in the core section of the corridor, while providing a higher frequency to the lightly-travelled portions. With train-separation provided by coded-track circuits, special light-rail vehicles fitted with third-rail shoes and able to dock at high-platform stations, it is not necessary to split the radial corridor into two distinct lines to utilize the most appropriate technology for each section. The downside is that this flexibility could be more expensive than a totally segregated solution.

This is certainly not a new concept: the Everett-Dudley Main Line elevated (now the Orange Line) in Boston inter-operated with the Boston Streetcar Company between Boylston and Haymarket prior to the construction of the tunnel beneath Washington St., today's Orange Line central subway (see Moore, 1999). The Riverside branch of the Green Line was a former New York, New Haven & Hartford commuter rail line, and is today operated with electric streetcars but retains commuter-rail type station spacing, demand characteristics, and some element of rail-rapid type signalling. Hybrid-type schemes can work well because the incremental costs of creating a hybrid is usually small compared to the costs of new rights-of-way or applying the inappropriate technology for the sake of standardization. In the case of the Riverside branch, the bankrupt Penn-Central was able to realize the sale value of the four-track right-of-way between Brookline Jct. and CP-Cove (part of which became the Massachusetts Turnpike) by allowing the MTA to replace its commuter rail service with a streetcar service, thereby sharing the costs of downtown access infrastructure with the other Green Line branches.

Applying the Rapid Transit Experience to High Speed Rail

In transit, subway, streetcars and buses have been seen as distinctive modes with different characteristics. The example above suggests that in some circumstances, the modes could be made to inter-operate to allow different parts of the same corridor to be tailored to its demand characteristics, without necessitating a change of vehicle between different sections. In the same way, highway designs are tailored depending on the purpose of the link and geographical characteristics; the same automobile may travel over access roads, arterials, highways and interstate turnpikes all in a single trip.

Traditionally, conventional train, high-speed rail and maglevs have been seen as different modes. As already discussed, conventional rail and high-speed rail could coexist given suitable engineering parameters and sophisticated train-separation technologies that ensure safety. In a sense, tilting train is simply a technological reponse to the need to better adapt the high-speed rail vehicle to conventional rail infrastructure where the demand density is insufficient to justify all-out investment in a brand new alignment or realignment schemes to retro-fit conventional lines with sweeping curves.

Perhaps maglev should not be seen as a separate mode at all. The performance increase have been clearly shown not to justify the costs, at least for intercity corridors of more than about 30 miles in length. However, if maglev is seen as an add-on infrastructure component that could be applied to the most constrained locations on a conventional rail network, the economics become much more feasible. In the same way that railroad electrification is often done for high-density suburban commuter corridors where the high acceleration and higher reliability is vital to service delivery, railroad maglevication could be done for sections of track that meet one of the following conditions: (1) sufficiently high demand density justifies the high speeds on performance grounds alone; (2) the terrain is sufficiently difficult such that relaxing the gradient constraint would result in construction and substantial journey-time savings; (3) the existing urban corridor would require more curvature than could practically be achieved by conventional high-speed rail trains running at reasonable speeds.

The Incremental Maglev and Maglevication Technology

The concept of incremental maglev is essentially very simple. Instead of building a dedicated guideway and dedicated vehicles, stations, facilities, and other such large capital items, magnetic guidence infrastructure is simply retro-fitted to parts of existing railroad network in a backwards-compatible fashion. This process will be termed 'railroad maglevication', in the same way that retro-fitting electric power distribution infrastructure (i.e. catenaries) to steam railroads is called 'railroad electrification'.

The Incremental Maglev Vehicle (and Truck Assembly)

The vehicle is essentially a tilting conventional train with reengineered truck assembly that is capable of running on existing railroads, but enters an enhanced 'magnetic' mode when it encounters maglevified infrastructure. Truck technologies are already mature, and there are a number of design possibilities for an ultra-high performance truck: (1) active steering radial trucks could reduce rolling contact resistance beyond what is available from passive radial trucks currently used on EMD diesel freight locomotives; (2) higher wheel conicity than typical on current rapid transit vehicles would enable trucks to steer much more efficiently, especially on very tight curves and when running at very high levels of cant deficiency (or inbalance).

For the magnetic guidence system, several possibilities exist: (1) guidence magnetic plates could be fitted at a suitable position beside the rail, exerting magnetic repulsion on the wheel, the truck frame, or the vehicle body (see Figure 3, Options 1, 2, 3) on the outside of the curve; (2) propulsion magnetic plates could be fitted in the four-foot, between the running rails, to guide the truck by magnetic attraction (see Option 4), similar to the linear induction systems currently used on the Vancouver Skytrain and proposed for the New York JFK Airtrain; (3) propulsion and guidence magnets could be fitted on both or either side of the running rails (see Option 5 & 6), guiding the train with a combination of attractive and repulsive forces; (4) guidence magnets could be made to act directly on the middle and upper parts of the coach body (Options 7 & 8), providing both tilting and guidence functions; (5) a flexible contact guidence system could be developed in place of magnetic guidence. Clearly, more research would be necessary to identify the system with the lowest costs or the highest likelyhood of success. Nonetheless, these proposals are much closer to existing knowledge and experience in truck design than pure maglev proposals, in addition to offering the advantage of backwards-compatibility.

With this design, it is possible to put all the intelligence on the vehicle. The track-bourne equipment could be permanent magnets or very strong electromagnets that are either on or off. Intelligence aboard the vehicle will adjust the polarity and strength of magnetic field generated by the vehicle-bourne magnet to give the necessary guidance forces for the speed at which the vehicle is travelling at that point. Conceivably, the vehicle could guide itself through a feedback system that measures the accelerating forces required and adjusts the on-board magnetic plates accordingly, given knowledge about the physical magnetic infrastructure available en-route. By putting the intelligence on the vehicle, the infrastructure costs per route mile could be kept to a minimum – an important factor in the success of intercity transportation systems with high route mileage and relatively small fleets.

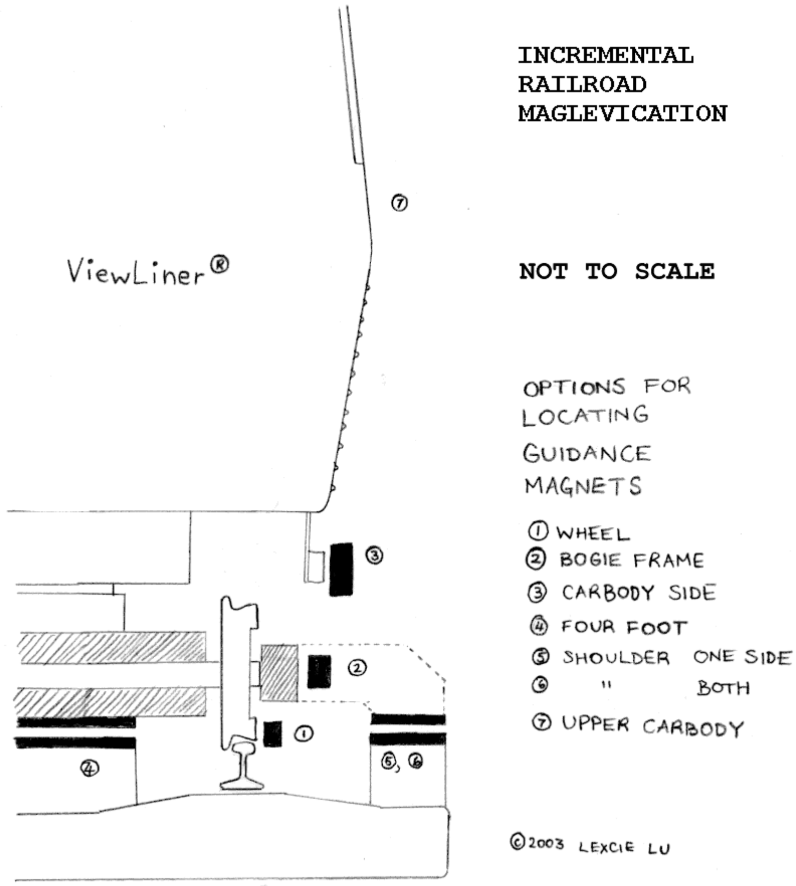
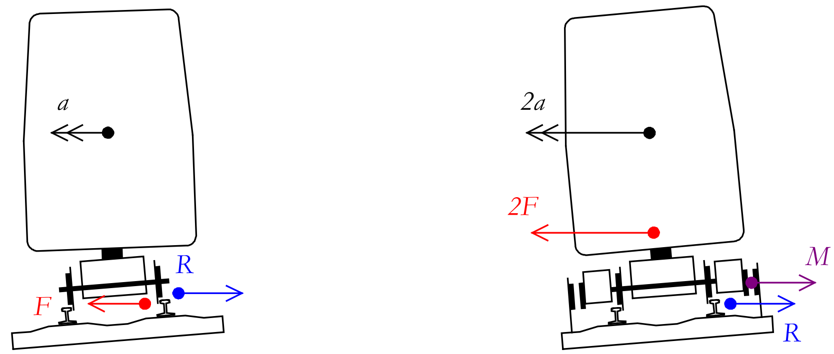


Figure 3: Options for Locating Guidance Magnets
On Dual-Mode Incremental Maglev Vehicle

Engineering Feasibility

How feasible is this from an engineering perspective? Obviously, detailed engineering and design work would be required to answer that question. In principle, the concept is not ridiculous. Conventional rail is unable to achieve grades of more than 3% due to adhesion limitations. If the bogie frame was magnetically assisted by being dragged up a grade, the reaction forces at the wheel-rail interface remains constant, but the work required against gravity is reduced, as part of the work is done by invisible magnetic forces that act on the bogie frame independently of friction. Conventional rail is unable to negotiate sharp curvatures at high speeds due to the limited ability of the wheel flange to provide reaction forces for lateral acceleration. At locations with high rail cant, this force is augmented by the component of gravitational force that is parallel to the plane formed by the two rails. If the bogie frame was magnetically assisted by being repelled against a magnet on the outside of the curve, the required lateral acceleration to be provided by gravity and the wheel flange is reduced (see Figure 4). The bolster assembly would require considerable re-engineering, as it could no longer be assumed that gravity would hold the carbody on top of the trucks. Obviously, the trainset would also need to be designed with a low centre of gravity, or other stabilization features, to minimize the overturning risks at high levels of imbalance.



Conventional Train
Speed Limited by
Superelevation, Reaction
Forces, Passenger Comfort

Hybrid Maglev Tilting Train
Speed Limited only by
Passenger Comfort.

Track is Freight Compatible!

Figure 4: Forces available to accelerate the train around the curve is the sum of magnetic and reaction forces in an maglevified vehicle. Active or passive tilt systems addresses passenger comfort issues.

Signalling systems would prevent non-authorized trains from entering the maglevified cut-offs that could create a dangerous condition if non-maglevified vehicles were to enter. Maglevified cut-offs actually serve a natural purpose in regulating traffic. In a highly congested, mixed-traffic intercity corridor, passing high-speed passenger trains and coal trains may be problematic. Where a maglevified cut-off of about 20 miles in length is constructed, the older railroad by-passed essentially becomes a low-grade freight route. Since the slower coal trains are likely to take a long time to cover the ascent to the summit, the high-speed passenger trains using the maglevified cut-off could overtake the coal trains while they are in the low-grade loop. In urban corridors, commuter trains can conceivably benefit from the maglevified infrastructure through greater acceleration and therefore shorter time between closely-spaced stops (see also Lu, 2001).

Operation of Freight Trains Over Maglevified Trackage

Of course, maglevified sections of trackage that depend on the linear induction motor to prevent stall on a steep gradient would be incompatible with freight applications, although any trains fitted with maglev trucks could in principle traverse the trackage (just as any train with pantographs may receive power from the catenaries while traversing electrified trackage). The design values used for the magnetic infrastructure could have interesting implications for the operation of freight trains. On gradient-limited portions of maglevified lines, only a portion of cars are required to have magnetic trucks – provided the 200,000 lbs knuckle load limit is not exceeded at any point along the consist, and that the weight of the consist could be supported by those trucks within the consist that are magnetic. It is possible that a maglevified locomotive would be able to tow ordinary freight cars over the maglevified route, although this is unlikely to be economic except for highly time-critical freight. On curvature-limited portion of maglevified lines, any train may traverse maglevified trackage, but only trains that are completely maglevified on every truck would be able to traverse it at the higher speed permitted for maglevified traction on that section of the railroad, since high levels of cant deficiency without magnetic assistance could result in derailment risks.

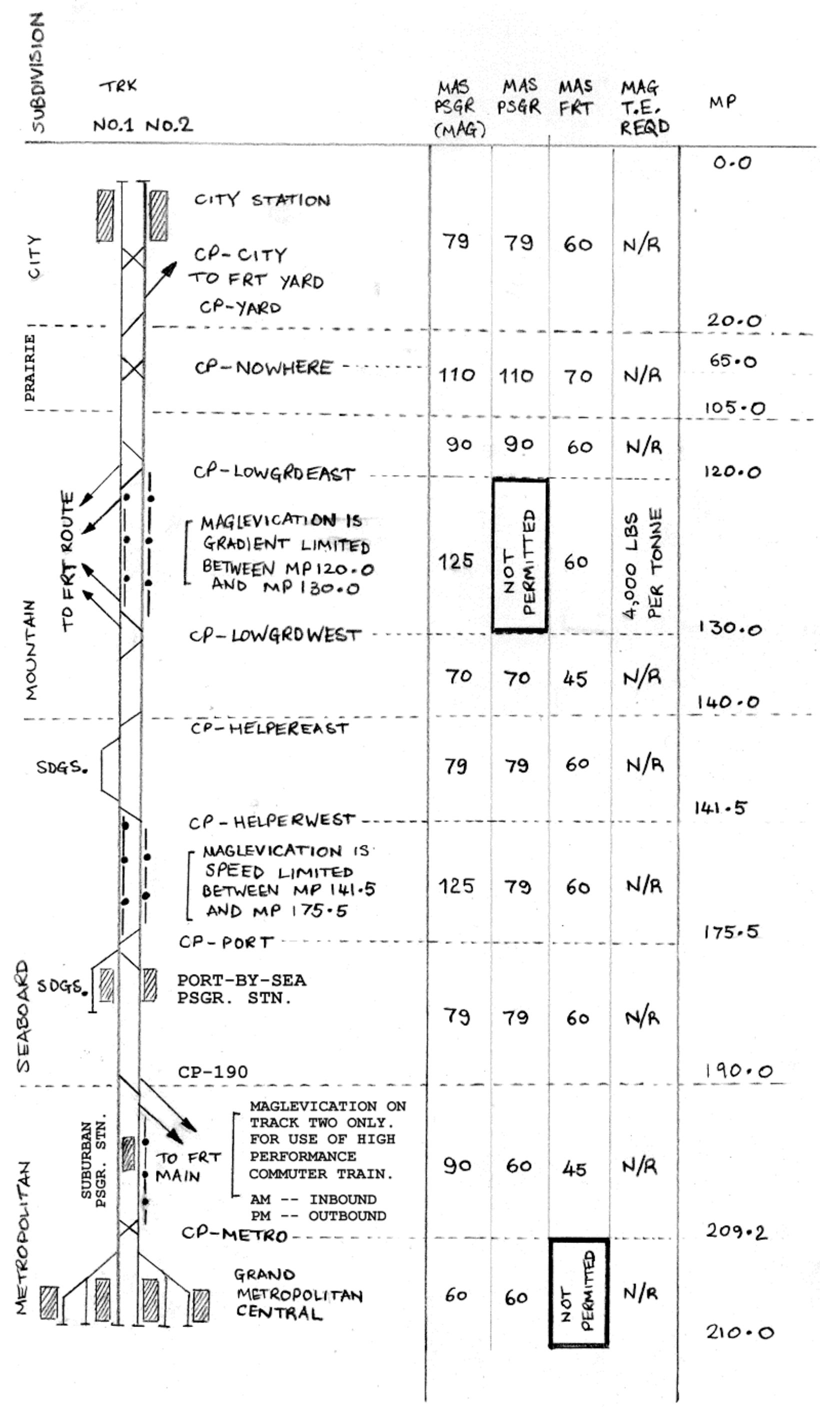


Figure 5: Sample System Timetable for a Maglevified Line

The operations of freight trains have always been a highly skilled discipline. Geographic familiarity in terms of gradients, maximum authorized speeds, and other infrastructure constraints have been required for freight train crews since the early days of railroading. The addition of knowledge of maglevified infrastructure, and the necessary calculations of magnetic versus adhesive tractive effort available from given types of traction (and consumed by given types of freight cars) would complicate matters, but with increasing portability of computer systems it is possible for these complex calculations to be performed on-the-fly with onboard intelligence as part of the train control and regulation system. How the system timetable might look, to convey all necessary information about the maglevified infrastrcuture, is shown in Figure 5.

The Technology: Would it Stick?

Whenever novel ways to approach engineering is proposed, there is inevitably a forest of criticism suggesting why it wouldn't work, citing previous experiences that have failed to accomplish their goals. One example frequently mentioned is the proposal to attach retractable rail trucks to buses so that buses could also operate on rail rights-of-way. The fundamental reason why railbuses failed to take off have very little to do with engineering: track maintenance crews on railroads routinely use hi-rail vehicles, which are designed for both highway and railroad use. The reason the railbus did not succeed is because allowing buses to run on rails offered very little benefits. Buses operating on interstate highways can achieve almost as high speeds as buses operating on railroads, thus railbuses offered little differentiation from highway-only buses. In the case of the hybrid maglev-HSR vehicle, maglevs clearly offers a significant speed advantage, plus considerable infrastructure cost savings at certain locations compared to a rail only vehicle. These costs and benefits are analyzed in greater detail in the next section.

Cost-Effectiveness of Railroad Maglevication

To assess the cost-effectiveness of the incremental maglev proposal, a typical intercity corridor is considered in terms of journey time performance, construction investment costs, and cost-per-minute-saved as a cost-effectiveness measure. The typical corridor is 210 miles in length, consisting of five stops each in two large metropolitan area at either end, and two intermediate nodes at mileposts 70 and 150. The metropolitan-area stops are spaced at two-mile intervals. The typical corridor is further divided into five subdivisions: City, Prairie, Mountain, Seaboard, and Metropolitan. The Metropolitan Subdivision hosts extensive commuter rail services that share a corridor with the intercity service. The Seaboard Subdivision features three major bridges and many curves, limiting speed of conventional operations to 79mph. Mountain Subdivision features one major mountain pass and two tunnels, the resulting curvature and gradient limits speed of conventional operations to 60mph. Prairie Subdivision features featureless plains and farmland which allows bee-line construction of conventional lines that allows unimpeded 110mph operations. The City Subdivision features similar urban constraints, limiting speed to 60mph, but without commuter rail service. The detailed assumptions for the typical corridor is given in Table 1.

Subdivision	Begins	Ends	Speed (Conventional)
City	MP 0.0	MP 20.0	60 mph
Prairie	MP 20.0	MP 105.0	110 mph
Mountain	MP 105.0	MP 140.0	60 mph
Seaboard	MP 140.0	MP 190.0	79 mph
Metropolitan	MP 190.0	MP 210.0	70 mph

Table 1: Assumptions of Geography for a Typical Intercity Corridor

The base case is a conventional express service that currently connects the two cities at slightly below the posted speeds (due to station stops and other speed restrictions such as that associated with bridges and switchwork). The trip currently takes just over three hours, resulting in an average station-to-station speed of 70mph -- only slightly better than the private auto, and the majority of people drive between the cities.

The journey time resulting from each type of upgrades was compared to the base case to ascertain the time-savings, while a typical cost-per-mile for the type of infrastructure and the type of terrain was used to calculate the likely costs. The cost-effectiveness measure was then calculated. Although this is a surprisingly simple methodology, it is extremely powerful, and can differentiate between the sour lemons, the silver bullets, and the marginal cases that warrant detailed modelling and assessment work.

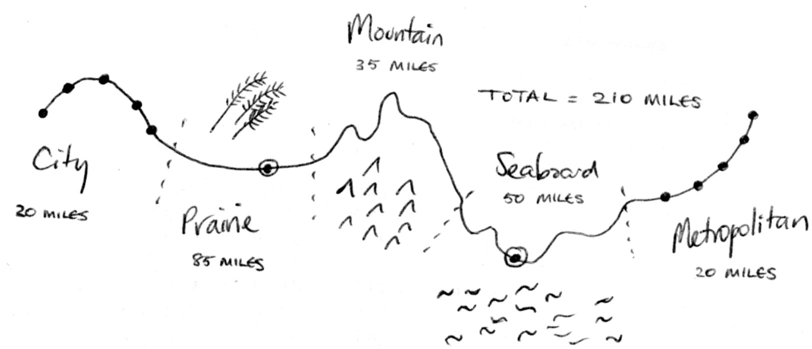


Figure 6: Graphic Representation of a Typical Corridor

This type of cost-effectiveness analysis, where technological alternatives are compared in terms of their benefits, costs, and likely impact in terms of performance (often modelled using a customer utility measure), is Step 3 of the Performance-Based Technology Scanning framework (see Figure 1). Railroad maglevication was one of the more promising ideas identified using this method. Other technological ideas analysed are detailed in a separate working paper (Lu & Martland, WP-2002-03).

Traction Performance Modelling

In the City and Metropolitan Subdivisions, a key issue is whether maglevification will truly enhance the performance of the metropolitan distributor, where station spacings of around two miles is required to maintain access competitiveness with the private auto and thus continued running a very high speeds are impossible. Using a traction performance model that calculated sectional running times based on installed power, rolling contact resistance, consist weight, and calibrated using British Rail traction performance data, it was determined that on flat terrain, the best-performing conventional traction will reach a top speed of about 70mph between two stations spaced two-miles apart, taking approximately 150 seconds. On the other hand, a consist with performance characteristics more consistent with maglev-type traction will reach a top speed of 115mph, and travel the same distance in about 100 seconds. The likely time saving for our assumption of five stations per metropolitan area is therefore about four minutes.

This result has more implications for commuter rail than intercity rail. Many commuter rail lines feature ten or more stops. Daily round-trip time saving for travel from the outer suburbs could be as much as 18 minutes per day with maglevification. This time saving is very significant for a daily commuter, and for the commuter operator.

This result is sensitive to station spacing. Instead of assuming five uniformly-spaced stations, if stations for the City Subdivision were located at MP 0.0, MP 8.0, MP 10.0, MP 12.0, MP 20.0 to describe the typical configuration of Park & Ride stations in the exurbs with three downtown distribution stations, the time-saving of maglevication could be about six minutes. However, because of the relatively short distances involved between stations, maglevication could not realize its full potential, as no extended runnnig at very high speeds take place.

Mountain Railroading

In the Mountain Subdivision, the key issue is whether maglevication would deliver the required cut-off offering time savings and higher speeds. In typical mountain terrain, if gradient constraints were relaxed, analysis of topological maps of Maryland revealed that a mileage savings of 20%~40% may be possible (the Usui Pass at 56%, was an extreme case). For the purpose of the case study, it was assumed that the construction of a 10-mile maglevified cut-off would reduce the total mileage of Mountain Subdivision from 35 miles to 30 miles. Maximum permissible speed on the cut-off would be 125mph. Using the traction performance calculator, assuming an entry speed of 70mph, the maximum speed achieved on the maglevified cut-off would be 125mph, achieved two-miles into the cut-off. Due to the gradient considerations, 125mph may not be actually achievable within that distance, although with a 10-mile cut-off and presumably a considerable downhill section, at least 5-mile of the cut-off could be assumed to be crusing at 125mph.

Based on these assumptions, journey time over the ten-mile cut off would be about 350 seconds, compared to the base case of 900 seconds (15-miles @ 60mph). The total journey time saving achieved is therefore 9 minutes. If speeds were unconstrained for the cut-off, the train will reach a top speed of about 180mph, travesing the cut-off in 250 seconds, achieving a total journey time saving of 11 minutes.

Coastal Railroading

In the Seaboard Subdivision, since gradient is not a constraining factor, it is conceivable that maglevication is only necessary where there are severe reverse curves. In addition, some economies are possible since maglevication is only necessary for those sections of track where realignment would be required to handle conventional traffic at high speeds. It is incorrect to consider only those section of trackage affected by maglevication, since removal of severe permanent speed restrictions due to curvature could enable higher actual trains speeds to be achieved in neighbouring sections where the train is unable to make use of available line speeds due to acceleration characteristics. In this study, it was assumed that 40% of non-contiguous trackage in the Seaboard Subdivision required maglevication to handle trains travelling at 110mph, while the other sections will handle 110mph using conventional techniques and with very little track realignment work. Thus the result of upgrading 20 miles of track is to enable trains to travel over the Seaboard division at an unimpeded 110mph, except the permanent speed restrictions associated with the structures.

Based on these assumptions, journey time over the Seaboard Subdivision would be about 1,800 seconds, compared to the base case of 2,600 seconds. The total journey time saving achieved is therefore 13 minutes or so. If the structural constraints could be removed, the journey time savings would be 16 minutes. If the entire Seaboard division could handle trains operating at 125mph, the journey time saving would be 19 minutes.

It is likely this technique could also be applied to the portion of Mountain Subdivision not affected by the cut-off, generating further time savings. Using this method, if Mountain Subdivision required maglevication for 60% of all track miles to achieve 110mph operating speeds in the section of track not by-passed with the cut-off, an additional eight minutes of the time savings would be possible.

Benefit Analysis

Using the most aggressive version of the schemes discussed in the previous section, the total journey time saving over the 210-mile trip would be 50 minutes. Using the least aggressive version, the total time saving would be about 30 minutes. Utilizing a similar methodology, journey time saving estimates was made with reasonable assumptions, for a variety of investment and upgrade options. The results are presented in Table 2. It was assumed that maglevication would not achieve savings in the Prairie Subdivision beyond conventional methods.

	Minute Saving by Investment Alternative					
Division	*Hybrid Best Case*	*Hybrid Conservative*	*Conventional*	*HSR New Line*	*Maglev New Line*	*Maglev Port to Port*
Seaboard	19	11	5	9.5		
Mountain (cut-off)	11	9	—	—		
Mountain (realignment)	8.5	0	5	10		
Prairie	—	—	—	14.6		
City	6	4	—	—		—
Metropolitan	6	4	—	—		—
Total	50.5	28	10	34.1	96	43.5

Table 2: Results of Benefit Analyses for Different Route Improvements Technologies

Purely from the perspective of journey time savings, obviously the highest-technology option (new maglev line) achieves the highest speed and the most time savings. Given the relatively high speeds in the existing conventional railroad corridor, it is not clear that a new, dedicated high-speed rail line could achieve much time savings, even though the new alignment in the Prairie Subdivision was designed for 150mph operations. The time savings available with the maglevication option depends to a large extent on the aggressiveness of combining maglevication with conventional realignment methods, but it is clear from the above analysis that the time savings are in the order of a new dedicated high-speed rail line – not as good as a new maglev line, but better than simple realignment and re-engineering. The port-to-port maglev does not save nearly as much time as the downtown-to-downtown maglev once access time and transfer time has been taken into account.

The hypothetical corridor under current discussion is typical of North American rail corridors: capacity issues can be addressed without new infrastructure, thus the Tokaido Shinkansen type of benefit is unlikely to be seen – all benefits accured are in terms of reduction in trip times. In the next section, cost-effectiveness of the upgrade is considered in terms of investment cost per time saved.

Cost-Effectiveness Analysis

To assess the costs of construction, some typical cost figures from publicly available industry sources were used. The cost of maglevication was assumed to be similar to the cost for track and structures in recent cost estimates for maglev proposals. The 40-mile BWMaglev project is costed at $3.7 billion -- $93 million per mile, 53% ($49 million) of which is in the guideway structure. A significant proportion of that cost is in the elevated structure, which maglevication of existing trackage would not require, thus $30m per mile seems a reasonable figure. Using the assumptions described in the above discussion, a cost model to estimate the cost of different investment alternatives was created. In essence, the cost model separates the cost of realigning, maglevifing existing infrastructure, and constructing new rights of way. A representative run of the model is shown in Table 3.

Rail Route Improvement Cost Model						
Lexcie Lu, MIT Center for Transportation Studies, 26/05/03						
Costs	**Scenario 1A:** Incremental Maglevication (Aggressive)					
Subdivisions	*City*	*Prairie*	*Mountain*	*Cut-off*	*Seaboard*	*Metropolitar*
% new right of way				100%		
% maglevication required	50%		60%	100%	40%	50%
% realignment/track required	10%	20%	15%		10%	10%
Total Mileage	20	85	20	10	50	20
of which new				10		
maglevified	10		12	10	20	10
reconstructed	2	17	3		5	2
existing	8	68	5	0	25	8
Cost per mile ($ million/mile)						
new right of way	75	2	20	25	20	100
maglevication	30	30	30	30	30	30
conventional enhancements	8	8	8	8	8	8
Total Cost ($ million)	316	136	384	550	640	316
Allowance for Structures					300	
Cost of Speed Enhancements	**$2,642**	**million**		**$12.89**	**million per mile**	

Table 3: Representative Run of Rail Route Improvement Cost Model

Using this (admittedly primitive) model, the costs and cost-effectiveness for different investment alternatives were evaluated. The average cost-per-mile clearly reflects the relative costs of the different technologies, with conventional route improvements being the cheapest option and the city-to-city maglev being most expensive, due primarily to the costs of constructing new rights-of-ways (or constructing elevated viaducts or tunnels over existing highway corridors) to provide downtown and suburban access. However, the cost-per-mile does not trade off investment against performance. The cost-per-minute-saved is a better cost-effectiveness measure and a better proxy for the likely cost-benefit ratio of the technology. The results in Table 4 show that conventional route improvements and maglevication are roughly equally as effective in terms of cost-per-minute, although obviously much greater savings are available with maglevication than with conventional methods alone. Although savings associated with dedicated maglev is substantial, the costs are a lot higher. It is only half as cost-effective as the incremental schemes where the capacity of existing rights-of-way is not constrained.

Cost-Effectiveness Analysis for Maglevication					
Lexcie Lu, MIT Center for Transportation Studies, 26/05/03					
	Distance	*Costs*	*Cost/mile*	*Time Saved*	*Cost/min*
Investment Alternative	(miles)	($ million)	($m/mile)	(minutes)	($m/min)
Aggressive Maglevication	205	2,642	12.9	50.5	52
Conservative Maglevication	205	1,688	8.2	28	60
Conventional Route Improvements	210	656	3.1	10	66
Conventional HSR New Link	216	3,898	18.0	34.1	114
Maglev New Link, City-Metropolis	203	11,770	58.0	96	123
Maglev New Link, Magport-Magport	163	7,070	43.4	43.5	163

Table 4: Cost-Effectiveness of Maglevication Versus Other Methods of Route Improvements

There are two most notable features of this table: (1) different methods of route improvements may yield an alignment of different length, due to the engineering and cost contraints of the chosen technology; (2) the new maglev travelling between remote Park & Ride lots on the outskirts of the metropolitan area is the least cost effective of all options, since maglev offers little advantage in the wide open spaces of Prairie Subdivision, and the transfer time required from a local mode to the high-speed mode could negate much of the time savings. In high-speed rail, access to the urban neighbourhoods, suburban business districts, and the downtown, can be a constraining factor.

Other Implication of Maglevication Versus New Alignment Construction

From a project evaluation perspective, the beauty of maglevication lies precisely in the fact that it is incremental in nature. At discount rates of 7% to 8% typically used for public sector projects where tax increases may be necessary for its financing, the need to achieve significant benefits within the first few years of the project is important. Large projects are extremely difficult to justify, because of the huge debt burden incurred initially. The new alignment options, whatever the technology, is the typical 'big project' where large costs are incurred up front and the revenue stream builds up slowly over the life of the project. The route improvement and maglevication approaches are incremental, where smaller projects could be carried out in a number of phases, reducing the debt burden. Although the dual-mode maglev/conventional vehicles could be as much as three times the cost of a straight high-speed electric set, the immediate pay-off would be the tilting capability which enables marginally faster journey times, and very high speeds that becomes available as each piece of maglevified infrastructure come on-line. In any case, vehicles are a small proportion of the total cost of an intercity high-speed rail scheme. If those vehicles could be constructed on a rolling basis and phased into the existing fleet, the debt burden of the project could be kept manageable, in line with a pay-as-you-go incremental high speed rail plan.

Discussion

The main uncertainties facing the incremental maglev proposal are twofold: (1) whether adaptation of magnetically-levitated technology to a purpose for which it was not originally designed would work; (2) given that the technology works, whether maglevication of existing railroad trackage could be achieved at a cost of $30 million per mile. $30 million per mile may seem like a lot of money, but in addition to the fixed magnets that are required, the associated civil and realignment works, sophisticated signaling systems would also be necessary to regulate coal traffic at running at 30mph, perhaps regular passenger trains at 79mph, as well as maglevified vehicles capable of running at 125mph and above. In this case, sensitivity analyses reveals that the costs of maglevication must exceed $70 million per mile for the new conventional high speed rail alignment alternative to rank with maglevication in terms of cost effectiveness. At $70 million per mile, it is likely that an incremental approach to constructing a new conventional alignment (by progressively building cut-offs of constrained sections) may be a cheaper alternative than maglevication.

Quite clearly, the performance of incremental maglev will depend to a large extent on the terrain. For an intercity corridor comprising entirely of geographical features similar to the Prairie Subdivision, it is likely that neither tilting trains nor maglevication will achieve much. However, in that type of corridor, common in the Midwestern plains, conventional methods of route improvement, such as the positive train control schemes currently being tested in Michigan, is perfectly adequate – at least for speeds of up to 150mph. Unless ultra high speed is desired, maglev or maglevication may have little role to play. In intercity corridors that lie either along a coastline, or cuts through mountains, curvature is almost unavoidable, and the benefits of maglevication are most significant. There is a limit (either in engineering or financial terms) to what could be accomplished through construction of sweeping curves and applying ever greater degrees of rail cant, especially in territories with significant reverse curvature. Maglevication could be the logical extension to the tilting train, conquering curves at ever higher speeds.

In worldwide terms, human population have traditionally congregated along the coastline, because of the important role of steamship in transportation from the 16th to the 18th centuries. Passenger railroads over wide open spaces have tended to be fairly rare except in North America. In Japan, Korea, Taiwan, the Southeastern coast of China, Britain, Sweden, Norway, the Rhine Valley, the Alps, and other similar locations, there are great demands for efficient transportation in congested urban, coastal and mountain corridors. Although maglevication would not be economically justifiable everywhere, especially where the passenger value-of-time is low, for the most common geographical features and demand characteristics, it is likely that maglevication would be a better alternative than either a new maglev alignment, or a new conventional high-speed rail alignment. The only exception to this are in locations where existing rail lines are already heavily congested.

Conclusions

In this paper, we have used some reasonable assumptions based on planning principles and engineering experience to demonstrate that if magnetically-levitated technology could be applied to conventional railroad equipment at a reasonable cost, the incremental maglev proposal offers better cost-effectiveness than either the exclusive high-speed rail or the exclusive maglev right-of-way options. The incremental maglev would take advantage of magnetic forces generated by large magnets to hold the train in place (and enable higher speeds without derailment) while a conventional train travels around a series of sharp reverse curves, and to assist conventional trains to climb sharp grades which wheel-rail adhesion alone cannot accomplish.

The basic premises underlying these planning assumptions are that: (1) accessibility to high speed rail within a large metropolitan area is important; (2) door-to-door journey time is more important than point-to-point travel speed. The basic engineering assumptions are that: (1) high-speed rail corridors travel over different types of terrain and incurs different type of engineering costs; (2) the cost of providing the right-of-way, including land and/or air rights acquisition, is independent of the cost of providing the guideway technology (i.e. railroad, or maglev). These are not unreasonable assumptions, although in some cases the choice of guideway technology would constrain the available choices of rights-of-way.

Analysis of a hypothetical corridor with typical geographical features of a high-speed rail corridor in the United States demonstrates that under those circumstances, incremental maglev is at least twice as cost-effective in terms of investment costs per journey time saved than either the dedicated high-speed rail and the dedicated maglev options. The cost-effectiveness of incremental maglev was found to vary fairly strongly with the terrain. The conventional high-speed rail (or other methods of route improvement involving limited realignments and deviations of existing rail routes) was most effective over wide-open spaces, while the incremental maglev is most effective over mountainous territory and near bodies of water, where reverse curvature are commonplace. As most heavily populated rail corridors are near bodies of water, incremental maglev represents a very attractive technology which offers better performance than conventional methods without resorting to the high costs of brand new alignments. In a situation where the existing rail corridors are not already congested with low-speed traffic, maglevication represents a technology option worthy of further study and engineering research.

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Appendix: Demand Sensitive Cost-Effectiveness Analysis for Railroad Maglevication

As a teaser for possible future economic analysis work, a demand-sensitive cost-effectiveness analysis was carried out for railroad maglevication as applied to the intercity passenger market. Railroad maglevication at $30 million per route mile was found to be far more cost-effective in terms of cost-per-passenger-mile and cost-per-passenger-trip than the new alignment alternatives, but slightly less cost-effective than the conventional route improvement alternative. This is not surprising, as diminishing returns are likely in the quest for ever higher speeds.

The results from this model should be treated with caution. Firstly, the $30 million figure has not been verified with engineering research, and will substantially affect the cost-effectiveness vis-à-vis the conventional realignment method. Secondly, the assumptions made in the demand model were extremely, exceedingly, almost pompously simplistic. Better demand models that are sensitive to fares, competition by the other modes, and other such factors, will deliver different conclusions for different circumstances. In this appendix, an exposition of this simple demand-sensitive model is provided, in the hope of stimulating further research interest in the topic.

Market Share Model

The market share model is essentially a simple Gaussian distribution with mean and standard deviation that varied with the distance between markets. It was not based on any survey data, and was calibrated according to author's experience. In essence, at low mileages, automobile competition is likely to be dominant, and thus increasing train speed would do very little to woo passengers who are probably looking for lower access time. Thus, an asymptotic value for the cumulative Gaussian distribution is set according to the distance between markets. In this sort of market, people who take trains are likely to be choosing trains for reasons other than speed, thus the distribution is likely to be quite flat, with a large standard deviation with respect to speed.

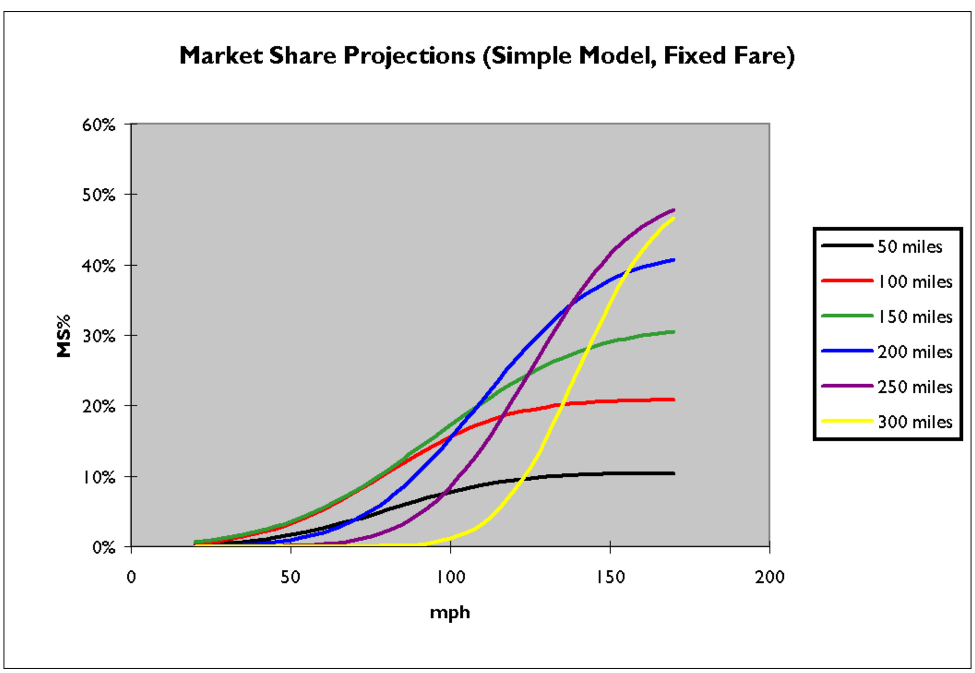

Figure 7: Market Share Projections w.r.t. Corridor Length and Speed, Simple Model

At higher mileages, airline competition is dominant, thus increasing train speeds would help, but nothing would happen unless train speed exceeded a certain threshold value – presumably where the door-to-door time by train is become competitive with door-to-door time by air. However, the distribution is likely to be much narrower, with all passengers switching to train if the effective train speed exceeded the effective airline speed by a long way (e.g. Paris-Lyon, Tokyo-Osaka, London-Birmingham). Thus, the demand model was calibrated to reflect this set of assumptions, using four variables: mean, sigma, base_asym, and asym_div. The resulting demand curves are reproduced in Figure 7, and appears vaguely consistent with expert opinion.

Ridership Model

The Ridership Model is also very simple. It is essentially a two-variable gravity model (population and distance), calibrated using a few single data points from the American Travel Survey. The traffic carried by the train is then the total demand (from the gravity model) multiplied by the mode share (from the market share model) at the average speed generated by a specific investment alternative. Thus, in the 210-mile base case, the market share would be the market share captured by the train at 70mph in a corridor about 200 miles in length (i.e. 4%). A representative run of the ridership model is shown in Table 5.

Ridership Analysis for Maglevication

Lexcie Lu, MIT Center for Transportation & Logistics, 31/05/03

Discount Rate %	7%		(from Summary Sheet)			
210 miles (Base Scenario)	*Cost/mile*	*Distance*	*Time Saved*	*Base Time*	*Average Spe*	*MS %*
Investment Alternative	($m/mile)	(miles)	(minutes)	(minutes)	(mph)	(Look Up)
Base Case	0	210	0	180	70	4%
Aggressive Maglevication	12.9	210	50.5	180	97	13%
Conservative Maglevication	8.2	210	28	180	83	7%
Conventional Route Improvements	3.1	210	10	180	74	4%
Conventional HSR New Link	18	210	34.1	180	86	8%
Maglev New Link, City-Metropolis	58	210	96	180	150	38%
Maglev New Link, Magport-Magport	43.4	210	43.5	180	92	11%

210 miles (Base Scenario)	*Demand*	*Annuity*	*Traffic*	*Cost/pax*	*Cost/paxmil*	*Cost/newrid*
Investment Alternative	(kpaxs/yr)	($m)	(paxs/yr)	($/pax)	($/pmile)	($/pax)
Base Case	3,462	0	131,558			
Aggressive Maglevication	3,462	189.63	445,018	$426	$2.03	$8,642
Conservative Maglevication	3,462	120.54	228,836	$527	$2.51	$17,702
Conventional Route Improvements	3,462	45.57	131,558	$346	$1.65	—
Conventional HSR New Link	3,462	264.6	291,827	$907	$4.32	$23,585
Maglev New Link, City-Metropolis	3,462	852.6	1,310,787	$650	$3.10	$10,329
Maglev New Link, Magport-Magport	3,462	637.98	364,181	$1,752	$8.34	$39,179

Table 5: Sample Ridership Analysis for Different Investment Alternatives

To calculate the cost per passenger, an annuity method was used at a discount rate of 7%. It was assumed that the cost per passenger is at least the annual payment on the cost of the incremental upgrade, amortized over a long time (~30 years), divided by the annual ridership. This yields a lower-bound on what the ticket prices would have to be to make a profit.

In this particular case, although the Maglev New Link option clearly achieves the highest market share and highest market share gain, it does so at twice the invesment cost per passenger trip of the conventional route improvement option, and 1.5 times the cost/trip of the aggressive maglevication option. Although the conventional route improvement achieves the lowest investment cost per passenger mile, the model doesn't even register any ridership increase (thus the cost per new rider could not be calculated).

The Verdict

In terms of cost-per-passenger mile, maglevication is generally twice as expensive as conventional route improvements. However, maglevication is still half the cost (per passenger mile travelled) of a new high speed rail alignment, and quarter the cost of a new maglev alignment, and eighth of the cost of a maglev alignment that only went from magports to magports. These results are shown in Table 6.

Demand-Sensitive Cost Effectiveness

Lexcie Lu, MIT Center for Transportation & Logistics, 31/05/03

City Size	2,000,000	• Ridership from gravity model, single parameter (city size
Discount Rate	7%	• Rail is price taker, therefore Profit = Cost - Airline Price

Cost per Passenger Mile	Corridor Configuration					
Investment Alternative	50 miles	100 miles	50+50 mile:	150 miles	210 miles	250 miles
Base Case						
Aggressive Maglevication	$0.91	$0.91	$0.36	$1.25	$2.03	$5.15
Conservative Maglevication	$0.80	$0.80	$0.32	$1.15	$2.51	$9.59
Conventional Route Improvements	$0.41	$0.41	$0.16	$0.60	$1.65	$8.67
Conventional HSR New Link	$1.54	$1.54	$0.62	$2.21	$4.32	$14.27
Maglev New Link, City-Metropolis	$2.86	$2.86	$1.14	$3.03	$3.10	$3.77
Maglev New Link, Magport-Magport	$3.34	$3.34	$1.34	$4.71	$8.34	$24.05

Table 6: Cost per Passenger Mile for Different Geographic Assumptions and Technological Investment Alternatives

If the assumption is that there is severe airline price competition and that the railroad is a price-taker in the express passenger market, then it is possible to calculate the carrier profit potential given geographic assumptions and technology assumptions. In the analysis shown in Table 7, the air-fare between two points was assumed to be $150 flat, regardless of mileage. With these assumptions, except in the case where there are three cities of 2 million population each, spaced 50 miles apart on a straight line (the 50+50 miles alternative), the new conventional and maglev links would require substantial decrease in the cost of technology to cover the costs of investment. In the 50-mile corridor, 100-mile corridor, and 50+50 configuration, maglevication and conventional route improvement could at least cover the costs of investment (although it is not clear whether they will cover the cost of operations).

Carrier Profit per Trip	Corridor Configuration					
Investment Alternative	50 miles	100 miles	50+50 mile:	150 miles	210 miles	250 miles
Aggressive Maglevication	$105	$59	$114	-$38	-$276	-$1,138
Conservative Maglevication	$110	$70	$118	-$23	-$377	-$2,247
Conventional Route Improvements	$130	$109	$134	$61	-$196	-$2,018
Conventional HSR New Link	$73	-$4	$88	-$182	-$757	-$3,417
Maglev New Link, City-Metropolis	$7	-$136	$36	-$305	-$500	-$793
Maglev New Link, Magport-Magport	-$17	-$184	$16	-$557	-$1,602	-$5,864

Table 7: Carrier Profit Potential Assuming a Ticket Price of $150

These results are not set in stone. There are a lot of quick-and-dirty assumptions in these models, some unsubstantiated. The readers should develop their own models and reach their own conclusions. **ENDS**

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