# The Vital Role of Metropolitan Access in Commuter, Regional, Intercity and Overnight Rail Passenger Transportation -- and Its Relationship to Technology 

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by Lexcie Lu
B.A., Natural Sciences (2000), University of Cambridge, England
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Submitted to the Department of Civil
Engineering in Partial Fulfillment of
the Requirements for the Degree of
Master of Science in Transportation at
the Massachusetts Institute of Technology

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Certified by
Carl D. Martland Senior Research Associate
Thesis Supervisor

## BARKER

# The Vital Role of Metropolitan Access in Commuter, Regional, Intercity and Overnight Rail Passenger Transportation -- and Its Relationship to Technology and Transit 

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## Abstract

The main thesis of this work is that planners and transportation professionals must think broadly in designing systems. Specifically, when designing an intercity transportation system, the objective is getting the customers from their actual origins to their ultimate destinations. With today's large and sprawling metropolitan areas, interconnections between urban and intercity transportation systems are a must - the customer's actual origin and ultimate destination are usually nowhere near an airport or a rail terminal. Whether this 'access leg' is provided by intermodal transfers or direct service is a matter of local circumstances, but it must be considered in the intercity transportation system planning process.

Future rail technology should not be designed to emulate either aircrafts or taxicabs. An aircraft is very good at traveling long distances quickly, but is unable to make intermediate stops, and thus a poor alternative for servicing dispersed demands. An automobile can make many intermediate stops efficiently, but cannot travel very fast. The ubiquitous automobile also suffers from ubiquitous urban congestion. Thus, it cannot service either extremely high demand densities or long corridors. Rail technology offers an intermediate option. In urban areas, rail offers efficient service to massive demands through high carrying capacity and dedicated rights-of-way. In rural areas it offers higher speeds by virtue of steel-wheels-on-steel-rails guidance. The combination of these two qualities makes intercity rail a winner in connecting one sprawling metropolitan area with another nearby - especially when coupled with such incremental enhancements as 'maglevication' of existing railroads. 'Shiny-gofaster' or personal rapid transit approaches ignore these advantages of rail transportation at their peril.

Intercity rail must exploit both advantages to compete effectively. The traditional, limited-stop highspeed rail approach ignores rail's ability to service many dispersed points of origin (streetcar suburbs), while the 'airport access' approach ignores the possibility of a direct service from a neighborhood 'subway station' to another one in a different metropolitan area. The key to success is not the one-seatride, but in eliminating the transfer, terminal and 'backtracking' time associated with many air-rail or airbus solutions. These advantages are best demonstrated with a passenger utility model that is sensitive to the different values-of-time a customer perceives during difference phases of a door-to-door trip.

In the United States, higher speed rail is necessary in many cities for rail to stay competitive, but highest speeds are neither cost-effective nor necessary. Each scheme for increasing line-haul speed should be judged, using the total logistics-utility framework, against alternatives to improve access and options to make time disappear. Demands for speed, accessibility, amenities, and other upgrades that improve the customer utility must be balanced against each other. The results from the customer utility studies should be used to inform intercity transportation system design, to create a system that works in harmony to move people.

| Thesis Supervisor: | Carl D. Martland |
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## Biographical Note



Grandson of a Formosan trucker, Lexcie Lu was born in the English textile city of Leeds -- a city served by both the London \& North Eastern Railway and the London, Midland and Scottish. It is thus unsurprising that he developed a lifelong love for the railroads. As a foetus, he began his intercity commute between Bradford and Leeds on a British Rail Heritage diesel multipleunit, since mom and dad hadn't found an apartment together yet.

True to the railroad tradition, he is a modern boomer who attended National Hsinchu Science \& Technology Park Elementary School (1985-89), The Edinburgh Academy (199295), Felsted School (1995-97) before Trinity Hall, University of Cambridge (1997-2000) where he majored in Natural Sciences with specialization in Physics and Psychology. Before attending Massachusetts Institute of Technology, he was employed by two former British Rail companies: Railtrack (1998-99) and ScotRail (2000-01) in Glasgow, Scotland. Before he even finished his thesis, he decided that two years without setting foot on railroad property was too much, so he went to work for Massachusetts Bay Transportation Authority in Boston, even if it was only for 37 days.

Asked by his British friends why he moved, he jokes about moving from the Land of Pomp and Circumstance to the Land of Freedom and Truth. In reality, the first time he visited the United States, he was so impressed by the big trains and friendly people on Amtrak (Lake Shore Limited, 1998) that he decided he couldn't ride a British Rail Sleeper again and still think it's a real train. So he moved to be with the real trains.
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## Chapter 1

## Introduction

This thesis is a very general and very broad attempt at reframing the high-speed rail debate in the United States. This thesis represents a realization that intercity rail is a set of cross-cutting issues. Technological evaluation inevitably involves assumptions about network design and service planning, which in turn has implications on travel demand and institutional relationships between carriers operating different modes. In the longer term, infrastructure investment decisions and project evaluation would be influenced by all of the above. Focusing in any one area while assuming that all other areas would remain unchanged or continue the present trend, would inevitably result in a wrong answer. Worse still, the accumulation of small incremental changes (wrong answers) could result in the system evolving in a way that results in a state of affairs many would agree is undesirable.

The present research in many aspects of high-speed rail and other transportation options are too narrow in focus, and there is a strategic void in the role of rail in the future. At a policy level, there are many issues requiring discussion. Recently, issues such as the role of Amtrak, incremental high speed rail, intermodal connections, and transportation security have taken the center-stage in discussions of the future intercity ground transportation system. These are important issues, but these do not address the systems question - how would the U.S. deliver a transportation system that provides a reasonable service to a large number of people, at an affordable cost? The transportation system as a whole -highways, railroads, airlines, urban transit, and other movement technologies -- should be thought of as different ways of getting people from one location to another. The transportation system user should be at the very center of this discussion: how would people want to travel from here to there? What is needed is not a supply-oriented approach that discusses modes, investment, institutions and service delivery, but a user-oriented approach that discusses market segments, their different needs, and the most economically efficient way to consolidate these needs so that services could be provided in bulk at lower costs. Warning: this approach would almost certainly cause disruptions in existing institutions, funding mechanisms, and modal coalitions.

At the heart of this thesis, there are a number of core ideas. When considering intercity passenger transportation, it is necessary to evaluate the utility of the entire trip experience from door to door -similar to a total logistics cost model in freight transportation. When constructing a model of
generalized costs, it is important to appreciate that different activities that occur during the trip have different values of time, depending both on the market segment and the quality of the experience. When evaluating high-speed rail projects or advanced guideway technologies, it is necessary to use this door-to-door utility model, applied from the customer's standpoint for a representative sample of origins and destinations, to ensure its success.

The United States is a country with a vastly distributed economy. Within the cities, suburbanization is rife -- people commute for up to 100 miles daily, and even within city neighborhoods the densities are low compared to many other countries. Between the cities, interstate commerce dominates most production operations as cities assume equally important roles in the region and the nation's economy. This type of economic geography calls for a totally-connected transportation network that takes people from one point directly to another, due to the general lack of 'supernodes' or natural hub locations. The result of applying this model suggests that provision of fast access from all locations is a necessary prerequisite to high-speed rail's success. Similarly, with important clusters of metropolitan areas being separated by large distances of rural plains, overnight rail could become competitive if service design were driven by a home-based generalized cost model, and amenities were made available but charged at marginal costs. In essence, overnight trains are able to 'pick up' within multiple cities in a region, travel overnight over areas of low demand density, and deliver people to multiple cities within the next industrial region.

Accumulation of small changes may result in important consequences. A historical example would be William Mulholland's great aquaducts, which brought more and more water into Southcrn California, but resulted in significant environmental damage elsewhere. The more sustainable solution would have been to include water demand management. Another example would be the phenomenon of urban sprawl -- which is wonderful in moderation, but dreadful when taken to extremes. The quest for ever higher speeds in rail transportation, is likely to be a similar wild goose chase, if maximum or average line-haul speed remain the only criteria for evaluation of high-speed rail schemes.

### 1.1 Thesis Outline

The total logistics cost model is necessary to understand the customer's journey experience. A total logistics perspective calculates utility as a function of traveler, trip, and transport characteristics, taking into account such things as the value of time for particular travelers and activities. The passengers are your customers from the moment they leave their home or work, and they remain your customers until
they either arrive at the vacation resort, the home of the friend or family they are visiting, or back at their own home. Supporting the business traveler with hotels and local transportation at the destination city and providing them with information they need to navigate an unfamiliar city are all legitimate business objectives. Intercity transportation is a happy business; it's about taking care of people -- until they are safely in the hands of another trusted party, or no longer requires looking after. Thus, getting people from a transportation node to another node by the fastest possible means isn't necessarily in the best interest of an intercity carrier. This concept is reviewed in Chapter 2.

The value of time concerns the customer's experience during a particular point in the journey. Clearly, customers feel different about different experiences, and some may be willing to pay a premium to travel in a more pleasant environment. More importantly, amenities that the customers are willing to purchase may actually alter the perceived value-of-time. Although the morning commuter pays marginal costs to purchase a cup of coffee, the morning commute would be unbearable without it. If carriers were able to price onboard and en-route amenities at marginal costs, it can induce customers to behave in a way that lowers the perceived disutility of time spent en-route, indirectly influencing mode share. This idea is presented in Chapter 3.

Recent academic literature and state-of-practice on high-speed rail planning have mostly neglected the multi-faceted service dimension of the intercity transportation business. Technologies that are hailed as the next-generation high speed rail have mostly focused on increasing speed and reducing line haul time, sometimes at the expense of access and amenities. This approach is inappropriate, except in cases where the existing speeds are dismally slow (e.g. in a few very old parts of coastal and suburban corridors in the United States). Reducing line-haul time by skipping stops will increase total logistics costs for some passengers and may increase average logistics costs for all passengers if access time is properly accounted for. Increasing speed by reducing vehicle weight, reducing consist length, and introducing other such technical 'improvements' may actually increase the generalized logistics costs and diminish the value of the journey experience for the customer.

Some of the current high-speed rail schemes under consideration by state and Federal authorities could actually be a 'double whammy' when examined in light of this framework: sacrificing amenities for maximum speed not only increase the average passenger logistics cost for the market, but also fail to provide sufficient incremental benefits of journey time saving to offset the capital costs required for a new right-of-way or technology. With minimal amenities, the automobile with its low incremental cost per passenger, low out-of-pocket costs, easy access to amenities offered en-route by independent
vendors, begins to look like an extremely attractive proposition. The 'shiny-go-faster' approaches that focus on maximum speed are at best not cost effective when examined in light of rational project evaluation and in some circumstances are a retrograde step for the average customer. Current plans and state of practice are analyzed in Chapter 4.

An important result when applying this framework to a region with sprawling metropolitan areas such as those in the United States is that the access time is actually a significant portion of the intercity travel time for the majority of customers. Thus, further reducing line-haul time may not achieve the desired goal. The most highly leveraged technologies in intercity rail travel may not be technologies that enable higher speeds on the mainlines, but those that allow many more stops with less time penalty per stop. Air technology is extremely apt at minimizing point-to-point travel time, but suffers from very poor access and inability to make multiple stops efficiently. Highway technology is limited to traveling at much lower speeds and suffers from the effect of urban congestion, but it is ubiquitous. Rail technology may find a niche by offering an intermediate level service that connects neighborhoods and suburbs in one metropolitan area directly to neighborhoods and suburbs in another metropolitan area. This idea is expostulated in Chapter 5.


Photo: Lexcie Lu ed Mike Brotzman

Plate 1.1: Today's Sprawling Metropolitan Areas Require More Than One Intercity Transportation Access Point

The biggest payoff in the creation of this type of infrastructure is likely to be the enhanced commuter and regional rail access it will achieve, but intercity rail must take regional access seriously to withstand attack from both sides by air and auto. Contrary to what some public transit activists may believe, inability to offer one-seat rides is actually seriously hampering the competitiveness of regional and intercity rail in large metropolitan areas.

High speed rail advocates in the United States like to position overnight rail as the enemy. Those who are focused on increasing efficiency in a particular corridor portray overnight rail as outdated, outmoded, and an obstacle to efficient daytime train operations. Those who are focused on maximizing profitability realize that overnight rail has never been particularly profitable even in its heyday and prefer to focus management attention on shorter corridors that are both easier to manage and more profitable. These views are reasonable, but inconsistent with sound economic analysis. Although the demand for long-distance rail service is small, it is not zero, and long-distance trains are also able to carry local passengers unlike long-haul flights. Overnight rail fulfils an important niche in rail operations, and expands the portfolio of the rail carrier's offerings. Although it would never be the most profitable service, in partnership with airlines it could provide the day-return business traveler with a much upgraded service, while providing a late train for intermediate origins and destinations, and serves many other disparate purposes including express freight. The overnighter is a 'catch all' train. If its costs could be kept under control, continued operations of overnight trains will maintain network benefits for rail carriers and attract people living in rural areas to use rail network when they visit the metropolitan areas. A detailed evaluation of overnight services in the United States appears in Chapter 6.

### 1.2 Important Note

High speed rail investment proposals and evaluation criteria in the United States require a thorough rethink from the perspectives of potential customers. The current plans have mostly resulted from discussions between the operators, the informed current customers, and the politicians. Occasionally, non-customers enter into the discussion if the promoters threaten to take their house. Missing from the list of stakeholders are the millions in the United States who have never ridden a train and may not realize that trains still carried passengers. That's a big market to leave behind.

Using a theoretical model that evaluates passenger utilities for the entire door-to-door trip, this thesis demonstrates that the potential customers do not take the train for a good reason: the train does not meet their needs and is not competitive with the private automobile. Many live in a rural areas, but
others live in suburbs around large metropolitan areas with rail service. Many of these are potential rail customers. For example, in the states traversed by the 'Capitol Flyer' - a hypothetical overnight service corridor running from Boston via Washington to Cleveland, Chicago and Milwaukee, approximately $40 \%$ of total population would live within a county with (or within 50 miles of) rail service. However, even within the Northeast Corridor in such origin-destination pairs as Washington-New York, both rail and air achieves a poor market share against the private auto. Longer door-to-door times compared to driving likely a handicap for collective intercity transportation in these areas.

Investing in access, amenities, and other improvements that increase the customer's total utility over the entire trip, from their departures from home until their arrivals back home, is likely to be as important and much more cost-effective - than simply investing in speed. It is the customers - passengers patrons - guests that we take care of, that ultimately make or break the railroad. We feed the customers, we keep them warm in the winter and cool in the summer, we give them material to read or provide other forms of entertainment, we give them directions and help with baggage. We price these services at marginal costs and we might then have some pricing power in terms of the fares. For instance, a New Jersey Transit study demonstrated that regular passengers in a commuter market would be willing to pay an additional $\$ 0.15$ per trip for the convenience of having a luggage rack on board the vehicle. These amenities are much cheaper to provide than line-haul journey time reductions, but may have much more dramatic effect on revenue potential.

Intercity passenger transportation is a set of cross-cutting issues. Planners, carriers, and technology developers should be aware of these issues. Evaluation of intercity passenger rail proposals should take the wider, all-encompassing approach that may better represent the needs of potential customers who are not currently choosing rail.

## Chapter 2

## Transportation Demand and Utility Analysis Fundamentals

This chapter reviews the current state-of-practice in transportation demand modelling for both freight and passenger flows, and ridership forecasting. Implicitly, some generalized cost models (utility models, logistics cost models) are also reviewed as "feeder" to demand models. Predictive approaches that allow demand prediction sensitive to changes in transportation characteristics are favoured over explanatory approaches that simply correlate demand with non-transportation factors such as land-use and regional culture. The review of modelling methodologies is broad and all-emcompassing, but the comments on the current approaches will focus on adapting the methodologies for the purposes of high-speed intercity rail (HSR) planning and evaluation.

The chapter both demonstrate the wide variety of excellent approaches that have been developed in many different fields and highlights how application of the existing methodologies could be improved when specifically applied to medium-speed passenger transportation (i.e. $90 \mathrm{mph} \sim 150 \mathrm{mph}$ ). In general, the existing approaches encounter the following difficulties when applied to HSR: (1) inappropriate geographic aggregation, resulting in insufficient attention to access time; (2) insufficient detail with respect to utilities derived by passengers during various parts of the trip, resulting in a bias towards short and uncomfortable journeys; (3) failure to account for induced demand, resulting in a focus of investment in areas that are traditionally successful at the expense of rapidly developing areas.

The review of the many different demand modelling approaches may seem totally arbitrary and unrelated at first, however, each approach features strengths that could augment the development of an evaluation framework for HSR. Traditionally, urban transportation planning techniques have been applied to intercity transportation planning. However, adaptation of such models to HSR without due attention to the special conditions of the intercity travel market could result in misleading conclusions. Specifically, in the area of service planning, demand modelling issues must be well-understood to develop the optimal service plan.

### 2.1 Total Logistics Cost Models

Economists have studied the movement of goods for almost as long as goods have been moving. Not always in a formal way, but it is clear from the actions of the robber baron railroad tycoons in the late 19th century that they were aware of the changing value of goods due to spatial movement, and the inter-dependence between the cost-basis of the production facility and the economic well-being of the serving carrier (Schafer \& Solomon, 1999). As evidenced by the rate-making structure that existed following the establishment of the Interstate Commerce Commission in 1887 for the regulation of railroads and other common carriers, it is clear that the notion of logistics costs were well understood by those in the industry. Higher-value items were subject to higher carrier tariffs, partially due to the firm's increased willingness-to-pay for the then-fastest mode of transportation, but also to account for the logistics costs that were avoided over slower modes such as canals and initially, the much higher costs of air transportation. This set-up for distributing the high capital costs of the railroad over many industries for essentially a shared facility functioned adequately for many years.

The basic ideas behind relating freight transportation demand to transportation costs, economic geography, and land-use patterns are very simple: the price charged by the retailer at the consumer's premises for given goods is made up of two components, the cost of production and the cost of transportation. This is called the spatial price equilibrium of commodities. Theoretical treatments of this concept at first considered the cost of production as fixed for each commodity, and the cost of transportation as linear with distance (Isard, 1956). More elaborate version of this model appeared subsequently, which suggested that transportation and production costs can be further fragmented into different components (Kresge \& Roberts, 1970).

Production costs contain a component of land-rent, which changes as the location of production facilities are changed but does not change with the quantity produced; it contains a component of capital costs for production facilities, which does not vary with location in the long term (but will in the short term, when some costs are considered sunk); it also contains other terms which may or may not vary spatially and may or may not change with the quantity produced, such as the cost of labor and other inputs. Transportation costs can also be fragmented in the same way: there are fixed costs and variable costs, which may be affected by variables such as the transportation technology, transportation demand in a given corridor, and other variables. Other costs are also incurred in transit, such as warehousing costs, insurance costs against loss or damage to consignments, and time-value of money of capital tied up in goods-in-transit (called inventory costs). The basic thesis, thus, is that freight moves in such a way
as to minimize total logistics costs. The total logistics costs is simply defined as the sum of all the aforementioned costs, summarized in the following equation (Roberts, 1971, 75).

## Total Logistics Cost $=$ Production cost + Ordering cost + Line-haul cost + Warehousing cost + Local delivery cost + Inventory cost + Risk + Stockout cost

Line-haul and local delivery costs are simply transportation costs associated with different modes (e.g. Line-haul cost might come from a rail freight bill, whilst Local delivery cost might be the cost of drivers and delivery vans); the warehousing cost is associated with the warehouse capacity requirements, and can possible be demand responsive (i.e. when goods compete for warehouse space, it is more expensive); the inventory cost is like the time-value of money (or value-of-time in passenger transportation), it is the cost associated with holding onto inventory and essentially paying interest on the value of the goods; the risk term is a way of quantifying the insurance cost against shipping and warehousing damage, which may be related to the mode or transport, the length of time that the inventory is held, and other factors such as the location of the warehouse. In an optimization model, the decision variables might be: the line-haul mode or carrier, the local delivery mode or carrier, the warehouse location and capacity, the minimum delivery quantity, and the inventory cost under different economic scenarios.

Given the abstract framework, Roberts formulated a utility model which predicts consumer choice based on extensive information about the available options (Roberts, 1975). In essence, the consumer utility is assumed to be equal to the total logistics costs, and relevant variables are changed until equilibrium is reached. If the objective is to evaluate choice of manufacturing sites, the quantity produced at each site is changed; if the objective is to evaluate whether to invest in a new technology for a specific corridor, the transportation cost or delay is changed. Sometimes, a joint-evaluation is required, since choices of production sites may depend on investment in new transportation facilities.

In a series of follow-up work, the total logistics cost idea (i.e. the utility model describing consumer preferences) was integrated with a number of different approaches to predicting transportation demand. A disaggregate choice model, combined with a logistics cost model, was used to develop a policysensitive working model for forecasting freight demand (Chiang, Roberts \& Ben-Akiva, 1981). Empirical estimation of model parameters was carried out by building a database of intercity shipment flows, level-of-service attributes, commodity attributes, receiver attributes, and market attributes. The model allowed the practitioners to test the sensitivity of transportation demand with respect to a vast array of parameters and derive useful insight about the transportation system, however, the report
acknowledges that there are innumerable ways in which the statistics can be improved though the better use of data. Carrier system concepts, combined with a total logistics cost model, gave rise to a decision support model that enabled carriers to leverage more value from high speed service, and shippers to make more optimal decisions amongst bids from different carriers and modes (Sheffi, 1988). Here, an optimization model is used to find the lowest cost for getting a piece of freight from the factory to the shopfloor.

Interestingly, the freight literanture is much closer to total logistics analysis than the passenger literature, possibly due to the traditionally vertically-integrated institutional arrangements in the freight industry (i.e. the same freight consolidator would take your freight at the origin and ensure it gets to the destination with one price). Models in the urban and air passenger transportation have traditionally had utility functions which related to the passenger's total logistics costs in much less detail than the freight models outlined above. Application of the total logistics concept to passenger flows will produce some results which have been documented only in a handful of cases, and somewhat contrary to conventional models (although entirely consistent with industry experience). Some models in the urban and air transportation sectors will be reviewed later in the chapter.

### 2.2 Classic Passenger Transportation Demand Models

In Manheim's classic Transportation Systems Analysis text (1979), a top-down approach is taken to understand transportation demand. Manheim describes transportation demand as consequences of long-run choices such as locational choices, activity patterns, and lifestyle aspirations. Having acknowledged that it may not be entirely possible to separate the long-run decisions from the short-run choices, he presents a utility model to predict the short-run portion of consumer behaviour. The basic assumption behind the model is that the long-run choices remains fixed. Given that, how would an individual decide which mode to take for a given trip on a given day?

Manheim suggests calculating passenger utility for a given mode (or combination of modes) by assuming that the utility is a function of a number of modal characteristics such as in-vehicle time, access time, out-of-pocket costs, service frequency, and others. Given the utility of a particular mode or combination of modes (an intermodal path), the utilities are then fed into a discrete choice model which computes the probability that one individual would choose a specific one of the given options for a given trip. Thus, the discrete choice model acts like a decision rule: given the relative characteristics of the modes or paths, how likely am I to choose mode $n$ over all others? Many different formulations of
the discrete choice model are possible. The logit model assumes that the probabilities are distributed with respect to utility according to the logistic function. The probit model assumes that the utilities for each path is randomly distributed about the mean value calculated, and asks what the probability of the utility of mode $n$ (drawn from the normal distribution) is the highest of all modes. The assumption is then made that the total demand multiplied by the probability of a random individual choosing mode $n$ would predict the total ridership expected on that mode (or that path).

There are three classic criticisms of this model. First, it assumes that transportation demand is fixed, and changes in mode characteristics for any of the modes would not affect the total transportation demand. This is reasonable for marginal changes. Second, it assumes that transportation demand and transportation mode characteristics do not affect long-run choices such as locational choices and activity patterns, which is reasonable for a short-run forecast. (For long-run modelling, activity shifts reflected in a series of feedback loops was a classic but rarely implemented extension.) Third, a fundamental issue with this model is, like many models, the model is only as good as the analyst. In essence, this model takes a bottom-up approach, adding variables that the analyst believe that will be relevant one at a time. While the advantage of this model is that each and every step can be empirically shown to be relevant and robust, the disadvantage is that the lack of empirical data can cause important key variables to be discarded or not taken into account. For example, in Small and Winston (1999), they explicitly recognize that other independent variables, such as whether the vehicle in question is electrically powered, and the amount of luggage space available, can have a measurable effect on the mode choice. In the Manheim model, the effect of these variables would have been captured in the "idiosyncratic preferences constant", thus the model would not have been sensitive to changes in the service level in these variables. While this classic framework is fully extensible to cover any variables that a present-day analyst believe is important and influence travel choices, the classic framework does not provide a way to systematically disaggregate travel choices into its constituent drivers.

### 2.3 The Planner's Four-Step Model

The Planner's Four-Step Model was developed in the 1950s as a methodology for urban highway planning in the cities of Chicago and Houston (Mitchell and Rapkin, 1954). The basic idea is to forecast the highway capacity required given geospatial data on expected land-use pattern, such as population density per square mile, and other demographics data, such as the number of jobs, households, auto ownership, and other exogenous variables. Although referred to as a Four-Step Model, it is more of a framework consisting of a series of steps which different models could be used in succession to translate
the base dataset into a set of transportation flows and thus capacity requirements. The Four Steps are: (1) Generation, (2) Distribution, (3) Mode Split, (4) Route Assignment. (Mcnally, 2000)

Generation refers to the translation of demographic and land-use data into number of transportation generated per unit area. Generally, the trip production is considered to be a function of population and perhaps other variables such as car ownership rates and average household income. This is thought of as the transportation base demand. Conversely, the trip attractions could be calculated based on a function of number of jobs in a given unit area and the type of economic activity that takes place there. Distribution refers to connecting the origins to the destinations. In general, a friction factor is used to determine how far people will travel in order to conduct their desired activity (e.g. employment, school, shopping), and the origins are linked to the destinations. The gravity model is a method often used, which basically assumes that the attraction between an origin and a destination will decrease with the square of the separation distance, similar to the formula for calculating gravitational attraction. Given the demands between a number of origins and destinations pairs, these flows are then distributed over a number of modes and a number of routes. Usually a method similar to that described in Section 3.2 is used for assigning the flows to different modes and routes.

The classic criticism of this type of model fall into a number of categories: (1) the Planner's Four Step Model is designed to calculate traffic volumes given land use, and does not explicitly account for the interaction between transportation infrastructure provision and land-use patterns; (2) the model does not take into account of induced demand, the phenomenon that if the generalized costs of transportation is lowered, more transportation demand would be generated as a result; (3) the mode and route choice portion of the model is based on a discrete choice framework, as a result the model is very mode-based, requiring definition of distinct modes. While hybrid vehicles are still a rarity, it is not clear that the model accurately captures the effect of subtle changes in levels-of-service. In a wide transit network, it may be possible to travel between two given points via a variety of routes and mode combinations. Access can be achieved by walking or with the private auto; some nodes offer rail, bus rapid, express bus, and local bus services, while other nodes offer local bus service only. It is not clear how such subtle effects could be captured in this model, even with a nested-logit implementation of the combined Mode-Split/Assignment stage. While in urban transportation applications, since public transit captures such a small market share of all urban trips, these transit-auto interactions may not be important. However, in mid-distance intercity travel (about $200 \sim 600$ miles), where truly contestable markets exist and all line-haul modes (air, rail, and highway) capture a respectable share of the market, such micro-interactions could become the driving factor behind the mode choice.

### 2.4 Discrete Choice Methodologies

Ben-Akiva and Lerman (1985) offers a very theoretical treatment of discrete choice modelling methodologies in their book, discussing the advancement of the field into multidimensional choice, nested logit models. These are extensions of the basic discrete choice framework that were discussed in Manheim's treatise. The focus of the book, however, appears to be computationally estimating such models. Adaptation of the mathematical techniques into a form that will support transportation analysis is left up to the reader. Ben-Akiva and Lerman discuss some of the issues that arise when their approach is adapted for urban transportation planning, but this was not the main focus of the book. There was no explicit mention of application of this methodology for intercity transportation demand forecasting in the book. While it is evident that the approach could be adapted, clearly further work is required in that area.

Where the authors have provided examples of how to apply their model to an actual situation, great care has clearly been taken to ensure that the model is indeed sensitive to what the they were testing. For instance, in their study on urban transportation forecasting, Ben-Akiva and Lerman recognized that disaggregation of originating demands and flows down to a traffic analysis zone level is important. The question a policymaker or a manager is likely to ask may involve decisions to close a street, construct a bridge, or reroute a bus. Much of the impact of these decisions may be felt within a town or a neighbourhood, thus a town-by-town analysis may not capture all the expected congestion effects, or localized ridership changes. They did not provide a specific framework or checklist to ensure the modelling results are valid for the intended purposes. It was generally felt this was the task of the modeller, and not the developer of the modelling methodology.

As alluded to earlier, there is a fundamental problem with this statistical approach, especially when applied by analysts thinking too narrowly. When attempting to calibrate the model, the analysts collect the dependent variable (i.e. mode choice) and collect data on a number of independent variables that the analyst believe will influence the dependent variable. However, if a key independent variable was not believed to be important (or indeed, happen to have very similar values in all the data points that the analyst happen to collect), a model of high statistical significance could be obtained without considering the effect of the key variable. In that sense the model can only be as good as the data that is collected, and the modelling process does not challenge the analyst to seek further explanations of travel behaviour beyond what is exhibited in the dataset.

An analogy in the field of transit performance measures are the approaches presented by Lee (1989) and Fielding (1987), as summarized in Wilson (2001). Fielding suggested a bottom-up statistical approach where a number of performance measures are collected and measures that do not yield much information are progressively removed using correlation and factor analyses. The main problem with this approach is that measures that are not in the initial dataset would not be present in the final results. Lee suggested a top-down approach, disaggregating a cost-effectiveness measure into many constituent measures and searching for representative measures systematically down a tree. Perhaps a better approach to explaining travel behaviour is to start at the top and disaggregate the ultimate mode-choice decision into a series of factors, then collecting data on these individual factors to construct the ultimate model.

### 2.5 Demand Models Sensitive to Operating Plan

The sensitivity of travellers to the departure and arrival times has long been known. Especially in the intercity sector, there have been attempts to quantify the effects in a model. Slagmolen (1980) examined the concept of "adjustment time" in a study on intercity travel demand. Adjustment time is the extra time added to the trip because schedules do not conform exactly to the travellers' nceds. Rather than simply considering service frequency and/or expected wait time, with Slagmolen's model, it is possible to input the entire operating plan for a passenger railroad and forecast the effect of operating plan changes, such as insertion of additional stops into express trains, or scheduling a late-night departure to leave 30 minutes later to capture extra passengers. The model is then making an explicit tradc-off between the additional wait time for the passenger wishing to travel at, say half-past-twenty-three, versus those who would otherwise miss the train because they need to leave at midnight.

The classic criticisms of this type of model is that while it does attempt to capture an extra attribute not traditional considered, the model is very data-hungry and the preference parameters may not be fully transferable. It is conceivable that the value of adjustment time depends on the extent to which the trip is plannable. The plannability of the trip would in turn depend on factors such as the need for planning when travelling by a competitive mode, or historically the level of transportation services provided to the region. For instance, in a rural region where even a automobile trip requires substantial planning (e.g. fuel, maintenance, weather, and time-of-day concerns), the value of adjustment time for a highly reliable mode such as rail may be substantially lower than in an urban region with good infrastructure, where the automobile trip can be obtained on-demand. Conceivably the disutility of planning
requirements may also correlate with extraneous factors such as the gross regional product or the automobile ownership. Thus, due care is needed when applying this type of models to an environment for which it is not originally designed. In essence, the model is very sensitive to the operating plan, and has been an invaluable aid to carriers evaluating incremental operating plan changes, but it is not a type of model suitable for strategic planning.

Almost certainly independently, Boeing developed a "Decision Window Model" (1996) intended to forecast the effect of multiple-carrier airline operating plans on the consumer. The basic hypothesis is that there is a latent airline travel demand for a given airport-to-airport origin-destination pair, which is dependent on the time of day (i.e. more people like to travel at noon than at midnight). It is then up to the carriers to "cover" that demand by spreading flights out throughout the day that capture the maximum number of riders. Each passenger has a "decision window" which extend for $x$-number of hours around his or her intended departure time. If only one flight is available within this decision window, then he or she is captive to this flight. If more than one flight is available, then he or she could choose based on carrier, adjustment time or other criteria. If no flights are available within this decision window, then the traveller would elect to cancel the trip. Thus, two carriers scheduling their single daily flights both at 8am would capture only half the passengers that they would if the same two carriers scheduled their daily flights at 8 am and 8 pm respectively.

These effects are certainly replicated in the real world. Carriers have slowly been staggering their departure times to attain better coverage of the market. For instance, the two shuttle operators in the Northeast Corridor operate hourly shuttles, with one carrier departing on the hour, the other departing on the half-hour. The Decision Window Model (DWM) also correctly replicates the effect of "red-eye" flights, where a mini-peak in demand is observed for a flight lasting more than about four hours long, at around 9 pm each evening. For international flights, DWM correctly replicate the effect of time-zone changes on customer preference for flights. For instance, on transatlantic flights, most of the demand from London occurs in the morning and early afternoon, to reach New York in the afternoon or early evening (local time). In the reverse direction, most of the demand from New York occurs in the late evening, arriving in London early morning (local time). Of course, this also happens to allow a very simple aircraft-cycle every 24-hours, achieving high aircraft utilization (approximately 16 flying-hours per day).

### 2.6 Demand Models Recognizing Trip-Chaining

The issue of trip-chaining has already been considered by demand modellers, at least in the urban transportation sphere. Ben-Akiva and Bowman (1995) carried out research in the Boston area and constructed models that represented the entire day's activity, with data based on diary surveys. The model is thus capable of considering trips that are avoided due to either trip-chaining or substitute activities, such as eating at home instead of eating out. In a follow-up paper, Ben- $\Lambda$ kiva et al (1996) considered other elements of complexity such as activity time allocation, temporal variation of feasible activities over the day, and distribution of levels-of-service during the day (such as transit frequency, road congestion). Also, in an innovative step, "no-travel" options (tele-commuting, tele-shopping) were explicitly considered, along with information which can cause changes in departure time, mode, and route choice. This work tacitly acknowledge that the simplified approach of the 1970s and 1980s is insufficient to model the complex decisions facing the travellers with many more options. However, the work also acknowledges that even a typical person's daily activities cannot be modelled at a microscopic level of detail, due to the sheer number of permutations possible. In particular, Bowman estimated that there are $10^{16}$ different possible ways that a typical person with 10 daily activities may structure his/her day, therefore producing different permutations of transportation requirements.

### 2.7 Airport Ground Access

Coogan (2000) reviewed the current status of public transportation services to large airports round the world (Chs. 2 \& 4) and discussed a market research approach to planning public transportation service to airports (Ch.3). He postulates that airport ground access market can be divided into two segments: air travellers, and airport employees. Coogan then further classified passengers by geographic distribution and by trip purpose. The 1996 Logan Survey demonstrated that $36 \%$ of all traffic (or 13,644 passengers daily) to the airport originated from more than 16 miles away. The 1995 American Travel Survey suggests an even higher figure, $55 \%$, for New England airports. Coogan further proposes a methodology for developing a market research study, in which he suggested that market research for airport access should focus on data such as residence location, trip purpose, destination airport, access mode, origin of access leg, and other like variables. The uses for such a market research exercise includes: developing public transportation schedule, identifying suitable types of access services, and locating access boarding stops.

The Coogan report is titled "Improving Public Transportation Access to Large Airports". It is clear that, within the context of this work, the airport is seen as a trip attractor, a target, a destination in itself. The market research focuses on the destination "airport", and assumes that the objective of the exercise
is getting the traveller from wherever he is travelling from locally, to the airport, as quickly and comfortably as possible. No consideration is given to the possibility that the traveller may by-pass the airport altogether by choosing either highway- or rail-based intercity transportation. The report similarly assumes that there are no airside capacity problems, and as long as mass-transit can deliver people to the airport, endless streams of aircraft will come in and out seamlessly to gobble up the same passengers. Thus, the report isn't really what could be termed a regional intercity transportation strategy. At best, it is a strategy to improving airport access in the region. However, improving airport access may not be the most germane objective function if what we're trying to do is to improve intercity transportation between every point in a region to every point outside this region.

The airport focus aside, Coogan makes some good points about local distribution, and integration of the airport into the regional transportation system. Successful rail systems around the world are discussed in the report (Coogan, Ch.5), including a description of the Heathrow Rail Strategy which proposes local services from Heathrow stopping at key stations on the national rail network around London: Ealing Broadway, Wembley Central, Watford Junction, King's Cross, and following the Thameslink alignment to Gatwick Airport and Brighton. Coogan observed that the existing Heathrow Express service is a good substitute for a hackney carriage to a downtown location, but is not useful for other locations in the metropolitan area. London has a strong downtown, thus a downtown-centric approach to metropolitan distribution may make sense, but even with London Heathrow, a substantial number of patrons come from the greater metropolitan area, and expanding service beyond one single downtown node will most likely benefit more people than a single downtown dispersal point, as Coogan observes: "Examination of total trip times shows... only the stations immediately adjacent to Paddington show a time advantage for the Heathrow Express" (p.85).

Although the report states that the analysis is based on unweighted transfer times, the analysis demonstrates an important insight: the door-to-door time is more important than in-vehicle time for the express portion of the trip. "The data reveals... the comparative travel time on a door-to-door basis seems to influence choice." The report is clearly understanding of the customer's needs to reach a diverse range of destinations within the metropolis: "Travel-time characteristics to downtown may not be a surrogate for travel-time to actual destination." (p.87)

The report does not acknowledge that the same concept could be applied to not just the local-access portion of the intercity trip but the entire intercity itinerary. Having acknowledged that an airport-todowntown airport-express train is not the complete answer, it does not acknowledge that an airport-to-
airport, interairport express airbourne vehicle (i.e. an aeroplane) is also not the complete answer. At least for shorter trips, the airport access time and flight time could easily exceed the total journey time by high speed rail, if high speed rail became more easily accessible. Coogan came to exactly that conclusion on a different level -- the connexions to the regional transportation system and better accessibility of the London Underground is in fact a business advantage for the non-express transportation mode, and that convenience factors may drive mode choice more than the total trip times. Although the report is predominantly about airport access, many of Coogan's observations (Ch.5) are applicable to the intercity travel market in general. The Hong Kong Case Study (p.86) suggested that the directness of the service plays an important role in mode choice, implicitly suggesting the transfer penalty is substantial even with dedicated and well-timed connexions.

### 2.8 Air Travel Demand Forecasting

Much has been written on the subject of air travel demand forecasting, especially by Belobaba who leads the Passenger Origin Destination Simulator (PODS) research effort at MIT and Boeing (e.g. Belobaba (1989), Belobaba \& Weatherford (1996), Belobaba \& Hopperstad (1999), amongst others).

Traditionally, trending on a flight-leg basis had been used by airlines to understand travel demand, and to assign aircraft capacity. Before the deregulation of the American airline industry in 1978, the airlines only had to worry about individual flight legs, interline transfers were commonplace, and the focus is on capacity provision rather than management. Trend-based models, using seasonally-sensitive data, are often used to predict loads. Essentially, PODS expands the standard model to take into account of changes that have occurred since deregulation, and takes advantage of the increased computing power which had become available since then. Significantly, instead of dealing with a single flight-leg, the PODS model is able to forecast passenger demand on an origin-destination basis, with a variety of routings and connecting options. This allowed the airline industry to investigate network effects, and for the first time evaluate the system impact of route changes and hub connection dynamics quantitatively.

Another interesting feature of the PODS model is its ability to simulate the consumer's reaction to the revenue management system. The basic idea behind the revenue management system is that consumers will "bid" for airline seats with an internal willingness-to-pay. In a capacity constrained situation, the bid price would increase with time, as passenger who must travel would be afraid of not being able to secure a seat; where there is overcapacity, the bid price would decrease with time, as the airline would be keen to "sell-off" any unsold seats close to the time of departure. However, for any given flight, the load
situation may change from one of overcapacity to one of capacity constraint - depending in real time on the bookings received. The same airplane also services a number of market segments: commuters who must depart early in the morning and return in the evening, business travellers who must travel on specific days or at specific times, leisure travellers who may be able flexible on their travel dates. Thus, for each individual, there is a different willingness-to-pay, a different elasticity with respect to time-ofday and day-of-week, etc. The revenue management system is designed to extract the most consumer surplus from each individual consumers depending on their willingness-to-pay and flexibility to travel at off-peak times.

Belobaba's work has focused on both forecasting the loads and pricing the flights in such a way that the loads are even. In a way, the they are two different facets of the same problem - in operations planning, changes in aircraft rotations occur about once every two months, when the goal is to maximize the productivity of the assets by ensuring that demands can be met with the appropriate gauge of the aircraft (i.e. minimizing any passengers "spilled" due to inadequate capacity); in pricing, the goal is to maximize the revenue given the aircraft you have already assigned to the flight-leg (thus, in a capacity constrained situation, you would hope to capture the passengers with the highest willingness-to-pay). In a modern operations planning model, the two phases would be combined into the same optimization model to maximize profit: the challenge is to assign aircrafts such that the highest profit is realized systemwide. (As you change aircraft assignment, the costs also change as aircrafts of different gauge are flown different distances). Readers interested in this subject, and related subject areas may refer to Lohatepanont (2002) and TRB E-Circular No. EC-040 (2002). Relevant courses taught at MIT do not reference any textbooks (Belobaba, 2002), suggesting a gap in the current teaching literature.

### 2.9 Explicit Comparison of Amenities, Journey Time and Fares

Using adaptive conjoint analysis trade-off exercises, Spitz \& Adler (2003) asked a sample of commuter rail riders in New Jersey to explicitly compare costs of tickets to the level of amenity provided. The customer was asked questions like: "Which option would you prefer? 10-trip cartel for $\$ 52.50$ and vinyl seating, or 10 -trip cartel for $\$ 50.00$ and cloth seating?" Rather than a simple yes/no answer, Spitz \& Adler asked the customers to rate the importance of their preference. The Spitz study went into utility analyses in some level of detail: customers were asked to trade-off across different types of seating arrangements (e.g. stand in aisle v.s. sit in aisle or window of three-across with center seat unoccupied), and reported that the latter arrangement is worth $\$ 0.95$ more than the former for a Newark Penn-New York Penn trip. The importance scores also revealed something quite interesting: four more trains per
hour is worth almost as much as a $20 \%$ change in fare or better seats. (Better seats was quite well defined in this study - Spitz allowed consumers a selection of six types of seats from commuter rail seat vendors, and had samples for the participants to sit in prior to completing the questionnaire). More importantly, an 8 -minute reduction in travel time is only worth half as much as the better seats.

The result from the frequency v.s. journey time trade-off is broadly consistent with previous studies: 4 trains/hr frequency change on an existing service headway of every 30 mins is equivalent to lowering the combination of adjustment time and expected waiting time from about 15 mins to about 5 mins - in other words, 10 mins time saving; if we assume from previous literature that access time is worth about one and a half times as much as in-vehicle time, it would translate to 15 minutes of effective in-vehicle time saving. The Spitz result indicated that the frequency change was worth approximately twice the 8minutes reduction in travel time; we calculated that the change in frequency is equivalent to about 15 minutes in-vehicle time saving.

### 2.10 Performance Based Technology Scanning

In an earlier working paper (Martland et al.,WP 2002-02), Martland hypothesised that intercity demand modellers are not disaggregating variables that drive travel demand in sufficient detail to capture the nuances of the different technologies. If the objective is to evaluate different technologies to find the best technology for a given intercity corridor, it would be necessary to understand the consumer's response to the all aspects of the technology, not simply the new technology's impact on traditional factors like journey time, reliability, and access time.

This review has found that many aspects of intercity travel technology have already been studied in great detail in the current or even older literature. Some of these models only apply tangentially to technology - for instance, the Belobaba model that simulate the interaction between operating plans, demand, and revenue management algorithms, may appear to have nothing to do with technology. However, in the real world, the costs of a new technology may constrain the operating plans to such an extent that it would be necessary to understand the impact of such a new operating plan on demand and revenue before it is possible to choose between technologies. However, all the models reviewed - and probably many others that were not reviewed - are important in evaluation of technologies. The current approach, of using standard utility analysis to understand the customer's reaction to different aspects of transportation operations and technologies, is termed Performance-Based Technology Scanning (PBTS).

In this chapter, a distinct number of methodologies traditionally considered separate domains were reviewed: (1) total logistics cost framework, usually found in the freight demand modelling and shipping decision support literature; (2) classic demand models driven by values-of-time, usually comprising of invehicle and access time, plus other factors such as service frequency; (3) explicit willingness-to-pay surveys based on certain amenities or aspects of design for a particular journey. These approaches are all germaine to evaluating intercity transportation system technology and design, and should all be used together in a PBTS study.

The problem of adapting these models to evaluation of intercity transportation solutions has not yet been solved. In the absense of a guiding framework - a checklist of all likely design considerations that will affect customer utility when using the system, it is very tempting to simply adapt a model that has already been calibrated based on a narrow subset of variables that happen to be the most significant factors in a particular situation, and use the model to do strategic analysis. Doing so results in strategic plans that may maximize or minimize a single variable (such as speed) while ignoring other aspects of the design, simply because the design variable were not included in the original model.

By encouraging practitioners to consider total customer utility, it is hoped that in the system design stage, more detailed consideration to design variables would be possible than with a standard approach that simply seeks to minimize journey time between two fixed points with several different technologies. In the rest of this thesis, several cases utilizing the PBTS framework would be demonstrated, showing different circumstances where variables other than average speed could have a dramatic impact on passenger experience - thus revenue, ridership.

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## Chapter 3

## The Disutility of Time in Transportation

This chapter postulates a new framework for examining the disutility of time in transportation. Traditionally, transportation demand modellers have assumed that journey time is onerous and generates a disutility which is added to the generalized costs of making the trip. The value-of-time is often assumed to be a percentage of patrons' salary. Service amenity improvements such as food service, seating, and entertainment were seen as ways to lower the average values-of-time and thus increasing ridership. Relative effectiveness of improvements is often gauged through either stated preference surveys of existing passengers, or revealed preference data after service improvements were implemented.

There are a number of pitfalls to this approach: (1) the analysts using this approach have not attempted to understand theoretically the effects of new technologies and amenities on the value-of-time, instead are treating it as an empirical result making prediction and sensitivity analyses difficult; (2) the traditional disutility analyses assumes that the time invested in travelling has no other purpose than travelling when in reality, especially in intercity markets, many things with positive utility could be accomplished while travelling; (3) the conventional framework has meant that transportation systems have been designed with users of average values-of-time in mind, when market segmentation (as apposed to aggregation) may achieve higher utility and ultimately revenues; (4) inappropriate uses of values-of-time has often resulted in a transportation system design question being treated as an optimization problem to minimize travel time or generalized costs when the objective ought to be the maximization of passenger utility; there may be multiple combinations of travel time, level of amenities, and other transportation system attributes that gives rise to the same passenger utility when subjected to an out-of-pocket cost constraint.

In this chapter, we develop a framework to enable system designers to take a fresh look at the value-oftime. The essences of this framework are: (1) the value-of-time is not an average value but a continuously changing function throughout the trip, depending not only on the activities that the traveller is taking part in during that time but also potential activities that are available to the traveller;
emerging technologies can influence that function; (2) travel time can "disappear" if the traveller is engaged in activities that would have needed to take place anyway had the travel not occurred; such activities may include sleeping, eating, or simply relaxing; (3) when evaluating values-of-time, a probabilistic evaluation is needed - the probability of one market segment taking part in a certain activity is $p[a]$ and generates a value-of-time for that segment of $v(a)$, thus the design calls for features that will maximize the sum of all $\mathrm{p}[\mathrm{a}]$ times $\mathrm{v}[\mathrm{a}]$, not simply the features that maximize $\mathrm{v}[\mathrm{a}]$. (3) when making travel choices, individuals are making a constrained optimization decision - given the out-ofpocket cash resources available, how can an individual best leverage that resource to produce the maximum utility associated with a trip (or indeed no trip at all).

### 3.1 Hypothesis Regarding the Value of Time

Martland et al (2002) postulated that traditional utility models do not evaluate the value-of-time in sufficient detail to examine specifics of technology change or operating change. As demonstrated in the literature review (Chapter 2), carriers have been developing models that forecast the effect of operating plan changes for at least thirty years (Roberts, 1971; Martland, 1972). However, even the more recent models developed in the airline industry (Belobaba, 1996) only take into account of a small number of service attributes. These models are typically highly sensitive at a detailed level to price, cost, and technical attributes such as trip time, number of transfers, frequency and departure time of service. When applied to passenger transportation, these models are often unsuitable to strategic analysis because they are not sensitive to some service attributes that the customer may consider important, such as amenities and access time. Some of the more sophisticated models attempt to estimate the value-oftime based on some function of the prevailing wage, whether this time is spent in the terminal, on board, or accessing the terminal.

The main hypothesis in this paper is that to equate the value-of-time to a function of the prevailing wage rate is misleading, and the value-of-time will depend on how that time is spent, or how else that time could be spent. The amenities available, the physical surroundings, and activity that the consumers are engaged in, will all affect their perception of values of that time. The New Jersey Transit bilevel study examined the impacts of level of crowding, type of seat, and the seat material on commuters' value of in-vehicle time (Spitz \& Adler, 2003), supporting our hypothesis. Spitz \& Adler demonstrated that the value of in-vehicle time differed by as much as $\$ 2.20$, of which $\$ 1.30$ is attributable to a capacity upgrade resulting in less standees, $\$ 0.65$ is due to the type of seating and $\$ 0.15$ is due to the type of luggage rack. Such empirical work is valuable. The transportation community have been aware for a long time that by
adding concessions or providing climate controls at the terminals, travellers' average disutility-of-time at the terminal could be reduced. However, without more such empirical work, it is difficult to say how much, and it is difficult to ascertain whether climate control is more important than presence of concessions.

Furthermore, Martland et al (2002) suggested that the value-of-time depends on the motivation for spending time. In general, if the consumer chose to spend that time, the disutility of time tends to be very low; if the consumer feels trapped and feels that they must spend that time, the disutility of time tends to be higher. This paper builds on Martland's work by demonstrating the link between consumers' motivation for investment (in time), consumer's resulting quality of experience, and the disutility-of-time incurred while en-route between origin and destination.

Dealing with the average values-of-time over a large time period is counterintuitive. For instance, using a theatre example, if a two-hour movie cost $\$ 8$ in admission, it could be argued that the utility gained by the consumer per hour of movie is about $\$ 4$ per hour. However, consumers are generally unwilling to pay $\$ 6$ to watch the first 1.5 hours of the movie; on the other hand, latecomers will often pay $\$ 8$ for the last 1.5 hours of the movie. The entertainment example is appropriate since transportation industry is becoming more of a service industry as user-produced transportation (the automobile) is becoming more widespread. Thus, it is conceivable that the time spent on-board vehicles and in terminals could be further subdivided into different activities, each with different values of time. For instance, the disutility-of-time while standing in line at an airport waiting for check-in is most likely very different from the disutility-of-time after check in when the travellers may browse around in the airport mall.

### 3.2 How the Value-of-Time Relates to Concessions

Interestingly, although perhaps unsurprisingly, the literature in the economics of airport and transit center concession development has mainly focused on the success of the concession as a going concern rather than the value the retail development is adding to the traveller experience in the terminal. Most literature mention that the presence of concessions add to the traveller experience (Bay Area Economics, 1999); airports in Europe studied the possible effects of abolishment of intra-EU duty-free in 1999 on competitiveness of airports (Hopkins, 1998), competitiveness of international versus domestic vacation destinations, and its expected impact on stores that specialize in duty-free goods (Commission of The European Communities, 1998). There appears to be little quantitative work done specifically on the effect of the concessions on the traveller's experience, although its positive influence
is well documented. However, the reverse has been established, at least in one study: The House of Common contended that abolishing duty-free might encourage smuggling, and that the carriers profit from concessions onboard the vehicle or at the terminals (House of Commons, 1999).

This suggests some will travel more frequently or pay more because of the possibility of enjoying the duty-free concessions, and that the carrier is able to leverage additional profits from the consumer surplus resulting from decreased disutility-of-time while on-board due to the use of vehicle-bourne concessions. While the House of Commons report gives us an idea of the sign and the order of the benefit, it is not a quantitative assessment. Decreased travel demand in light of abolishment of duty-free would suggest the elasticity of travel demand with respect to the price of duty free goods is nonzero. If we hypothesize that the reason the elasticity is nonzero is because the purchasing of duty free goods are resulting in a consumer surplus, the nonzero elasticity suggests the surplus is affecting demand for travel and hence the utility of travel, it is reasonable to suggest that by removing the airport concessions, thereby removing the possibility of generating that surplus, travel demand would be aversely affected. The reverse may also be true: by adding concessions where they do not previously exist, travel demand may be stimulated.


Plate 3.1: Utility is Free

## The Channel Tunnel Example

Following the construction of the Channel Tunnel, the crossing of the English Channel with an automobile was cut from a four-hour ferry trip to a two-hour trip onboard a freight train. Originally, the ferry operators thought that their core business was being undercut and asked for government
compensation. When the government compensation did not materialize, they chose to refit some old cruise liners to offer luxury overnight service. Although the ridership declined compared to preChunnel levels, the carriers found a clear market niche and continued to operate profitably. Clearly, the onboard amenities were a sufficient attraction to compete at some level, compensating for the longer journey time.

## The Fishing Example

When a user is choosing to use a service, the user is making an investment in time to use the service. This is a well-known concept in transportation systems analysis called "generalized costs". However, when economists are evaluating other service industries, they do not generally include explicitly in their framework unless they are explicitly talking about time consumed by transportation as an overall vacation schedule. For instance, two studies in Central Idaho contained quantitative data on the number of vacation trips taken per year versus travel time (Normandeau Associates, 1999). Based on survey data, the study demonstrated that the demand for fishing is sensitive to both the trip cost, and the access time. Significantly, the study confirms what seems intuitively obvious:

> Each angler has a different travel cost (price) for a sportfishing trip from home to the river. Variation among anglers in travel cost from home to sportfishing site (i.e., price variation) [... is significant.] Nonmonetary factors, such as available free time and relative enjoyment for sporffishing, will also affect the number of river visits per year. The statistical demand curve should incorporate all the factors which affect the publics' willingness-to-pay for sportfishing at the river.

This suggests that the demand for fishing vacations depend not just on the price of the fishing permit and other costs, but also on the investment in time required to get to the site. The number of fishing trips per year drops significantly beyond about 7.5 hours or $\$ 100$. These results, backed by survey data and commonsense, suggests that the intercity demand modeller ought to consider a much broader range of variables than in-vehicle time in intercity transportation, especially when vacation travel is involved. The recognition that each angler has a different travel cost is key - in Chapter 5, the idea that each intercity traveller has different access costs to terminals serving different modes will be explored in much greater detail.

Economic research has recognized for a long time that the time taken to search for a service can be considered the cost of using a service (e.g., Stigler, 1961), and that good advertising and product accessibility can lowers that cost to the point that it's not worthwhile for the consumer to invest additional time in searching for a marginally cheaper or better alternative. The lowered communication
and search costs have also been implicated in the creation of cities (Mills, 1993). It is conceivable that a conceptual economic model could be formulated that breaks the generalized cost of using a service down to three components: (1) time taken to locate the service; (2) price charged by the service provider; (3) time taken to actually consume the service. The Stigler concept suggests substitutability between (1) and (2). The anecdotal evidence suggests that (2) and (3) are actually also substitutable, as evidenced by various initiatives that are offered by service industries that are queue-intensive: turnpike toll-collection, airport check-in, mail order companies and other retail outlets that charge extra for "express service". All these evidence suggests that the time taken to consume the service could be considered part of the generalized costs of using the service, and it is a necessary investment on the part of consumers choosing to use such service. In the restaurant industry, anecdotal literature suggests the time taken to prepare food at restaurants is a driver in restaurant demand (Foodservice.com, 2002), which would be consistent with the aforementioned economic model. In the next section, we will examine the restaurant model in more detail.

### 3.3 How the Value-of-Time Relates to Foodservice

It is possible to illustrate this using the example of timc spent eating in a restaurant. An investment in time is required to consume a meal in a restaurant, including the need to wait between ordering and serving. If prevailing wage rates were used to evaluate the value of time spent waiting and actually eating, it is not clear that restaurants are in general a very profitable proposition. The restaurant sells a product (a meal) at much more than the cost of the competition (cooking at home), with conceivably a much longer waiting time (access time to restaurant, queue at restaurant, plus time between ordering and serving). Yet restaurants are clearly a viable proposition, even in low-income economies. It is not clear that the amenities offered by the restaurant in fact creates sufficient consumer surplus to overcome the alleged disutility generated by the time-investment required. We postulate that the reason the time spent at a restaurant is grossly undervalued by the consumer because the consumer in fact is choosing to invest that time. Even with the same physical surroundings, if the consumers feel that they have no choice, restaurant economics would simply not work.

Basic economic theory suggests that there is a supply for food, and a demand for food. You will pay for food at a price if the food generates more utility than the price; the difference between the two is then the consumer surplus: the food is worth more to you than what the producer is charging, so you buy it.

### 3.3.1 The Culinary Utility Model

What does the food do to the value-of-time? Let's examine this in terms of the value-of-time framework. The consumer derives a positive utility from eating food; the consumer then has to spend time eating the food he just bought - an investment in time; the consumer then isn't hungry anymore hopefully the increased value-of-time while not feeling hungry, discounted back to the point of ingestion, compensates for the investment in time in eating, and investment in out-of-pocket dollars expended to buy food. The "consumer surplus" associated with the food is simply the value of not being hungry discounted back to time of ingestion minus the time spent eating food. If the consumer surplus is negative, then obviously the consumer isn't hungry enough; he will wait another few hours, until hunger-prevention becomes more critical; until the increase in future value-of-time by hunger prevention exceeds the present time-investment required to complete the ingestion process. In equation form:

## Consumer Surplus from Food $=-$ (Price of Food + Value of Time Spent Eating) + (Utility of Eating + Discounted Hunger-Prevention Value of Time)

Let's call this the Culinary Utility Model. This helps us explain why you hear people say, "I'm too busy to eat now, I'll eat later". The value-of-time before the deadline is reached dominates the disutility of enduring hunger. When faced with expensive food of poor value, sometimes people don't feel hungry; faced with all-you-can-eat buffets, people eat more than they normally do. Really, people in general are quite efficient project evaluation machines. Most people just don't realize it.

### 3.3.2 The Classical Justification for Making a Trip

Putting this in a transportation context: how do you change the value-of-time of someone either (1) sitting in a terminal waiting for a connexion, or (2) sitting aboard a vehicle waiting to get to the destination? Take the latter case, the justification for sitting in a vehicle is usually because whatever event that is anticipated at the destination (a business meeting, or a vacation) has a high value. People usually trade-off the generalized costs involved in getting there and back against the wonderful utility they will derive by being there. We can null-out the value-of-time "wasted" in getting there if we can somehow give the consumer another justification for investing his or her time. The consumer then wrongly attribute the time spent "in-vehicle" as the time spend doing something else, and the value-of-
time in-vehicle decreases to an insignificant value. Although people might be efficient projectevaluation machines, most people are really quite bad at joint-value attribution.

This is an important concept, and has widespread implication in the world of transportation demand modelling and investment evaluation. Let us illustrate with an example, seen from the traveller's frame of reference:


Plate 3.2: Are we there yet?

Exhibit 3.2 illustrates the way in which a traveller may evaluate a trip. The traveller has to make all the investment up-front: out-of-pocket costs of carrier fees, and the investment in time in travelling. We hypothesize that the value-of-time is different for different parts of the trip - in this case, we simplify the trip to a single-segment door-to-door trip in which the traveller takes part in no activities except sit in a seat, we might expect the disutility per unit-time to increase nonlinearly with the time already elapsed. Even with simple trips, the disutility of time is not necessarily a linear function of time. In making a go/no-go decision about the trip, the traveller evaluates the expected benefits of the destination (in terms of utility generated), and compares that to the investment costs required to get there. If the cost/benefit ratio is less than one, the decision is a go. In some cases, as discussed previously, the traveller may have other constraints such as the capital available to invest. Some travellers will use a decision rule; others will use different implicit methodologies of project evaluation (such as payback time analysis, etc.)

### 3.3.3 Changing the Travellers' Value of Time Through Food

Supposing the carrier now elects to make food service available either on-board or during a particular part of the trip, for example, in the terminal. Assuming that the food is made available at marginal cost, so the travellers purchase socially optimal amount of fude. Thus, anyone who can afford it buys some food, stores it until he or she is hungry, eats it such that hunger is prevented during the time on board. How does the cost-benefit diagram look now?


Plate 3.3: Are we there yet? (with food)

Exhibit 3.3 shows the evaluation diagram, from the travellers perspective. The out-of-pocket transportation costs and benefits of taking the trip remain the same, but now there's the incremental costs of buying food. Under what circumstances do people buy food? The Culinary Utility Model tells us that people will not buy food unless the price of food and value-of-time spent eating it is justified by the increase in future value-of-time by hunger prevention. The food costs are therefore attributed entirely to hunger-prevention; the value-of-time spent eating is also attributed to future hungerprevention.

All this occurs on board a carrier vehicle, during which time the traveller is also moving in space. But we just attributed the time-taken-to-eat to hunger-prevention: a self-sufficient profit center in its own right. So does this mean the same time expended eating on board, during which we are also moving in space, comes free? No longer are we investing time in order to move in space; we are investing time to prevent hunger. From the perspective of the investor who likes to move in space, the time expended eating on board is a sunk cost: "I gotta spend this time eating anyway - I am hungry!" So the cost-oftime involved in hunger-prevention and movement-in-space are joint costs which the traveller allocates exclusively to eating. The traveller is reaping economies of scope in joint time-utilization (normal
people call this "saving time" or "doing two things at once"). To achieve movement in space, without investing time, is called teleporting. If you believe this time-cost-attribution model, teleporting is really possible.

Exhibit 3.3 also shows another very subtle point. The time between when the traveller finishes eating, and when the traveller arrives, the traveller is sitting on board a vehicle, and investing time to achieve the movement in space. Let's ask this hypothetical traveller a simple question: "Would you rather travel hungry, or having had some food?" Question of motion-sickness aside, most would prefer to part-take in everyday activities, including travel, while their stomach are not making gurgling noises. In other words, the value-of-time in vehicle is lower if the traveller is not hungry; being hungry on board a vehicle adds to the disutility of simply sitting bored. Thus, by making food easily available, you are actually changing the value-of-time on-board a vehicle by encouraging travellers to feed their stomachs.

### 3.3.4 Issues in Railroad Café Economics

You might argue that the baseline case is a traveller travelling when he or she is not hungry; the fact that he or she hadn't eaten adds to the disutility, and making food available brings it back to the baseline level. Is this correct? Two issues with this argument: (1) Business travellers are too busy to eat before departure; students are too disorganized to eat before departure, so people end up hungry. (2) A carrier with relatively long in-vehicle times and no possibility of en-route stops, such as the high-speed train, would compete with modes such as air which offers short journey times, and modes offering unlimited unplanned stops such as the private auto. People will get hungry. Thus, making food available either at terminals or on board is key to a rail carrier, but not to others, since the other carriers offer other means to combat hunger while in-transit.

Why should food be priced at marginal cost? Pricing at marginal costs mean that everyone who is hungry enough to justify food production will get food. It ensures that the evaluation process for deciding whether to buy food or not is based on entirely the same Culinary Utility Model whether you're in a grocery store, at a terminal, or onboard a vehicle. On board a vehicle or in a terminal, there is always the temptation to price up since the customers are perceived as captives. Yes, they are captives, but if you price at more than the marginal costs, that means some passengers who want food will not get food, because they can wait until later - or perhaps take another mode of transportation the next time just so they won't have to go hungry. If the passenger elects to wait, you the carrier have just made his in-vehicle experience miserable. If the passenger elects to travel by another mode to avoid the hunger
or the overpriced food, well, you've just lost a ticket revenue. Either way, you can't win, because the customer utility is tied to his or her stomach and to your bottom line.

Why not subsidize food? Not only does it lead to wastage, some passengers who do not need to eat will end up with food just because it's cheap. To the carrier, or the provider of the food, this represents a deadweight loss. Of course, any such loss-making operation eventually comes back to haunt the carrier through increased ticket prices to cover increased costs. This will tend to divert customers to other modes which do not have such overhead. After all, if you're in a private auto, you have near perfect competition in the market for food provision, and price is going to be pretty close to marginal costs. The railroad café is not a monopoly; it competes with all other food providers available to all other transportation modes, and it has an important effect on the railroad's ticket revenue through the value of time.

This is not necessarily an argument for the Café Car. A Café Car might be an effective way to sell food, or it might not. The whole point is that the access to food for those who are prepared to pay the marginal costs must be available. The provision of a microwave oven, a hot water source, and a vending machine in a vestibule area may be all that is needed. The facilities that are made available converts onerous on-board time into neutral time spent cooking as if in one's own kitchen. In the context of the maintenance and capital costs of railcars, these facilities are loose change. By providing a Café Car, the carrier is providing a value-added service, an opportunity to dine on board or purchase food services in a café setting. Like the roadside café or diner, this feature should be self-sustaining. Perhaps legislative changes would be required owing to liability concerns before this type of scheme will become practical.

I've caught myself refusing to eat at airports because of the inflated prices of airport concessions and thus making my own journey very uncomfortable. Moms will pack food for college students going off to college; moms will tell you always to travel with food. No one calls a convenience store or a gas station a luxury. A restaurant might be a luxury, but it's providing a service at a price the consumer is willing to pay, and it's making it (i.e. the cost of production is below the price charged). You'd be pretty dismayed if you drove into a small town and didn't find any restaurants or any stores, no Dunkin' Donuts and no McDonald's. That sort of place is called a ghost-town, and people tend to minimize the amount of time they spend there. On the other hand, it's hard not to stop while driving through a quaint village peppered with touristy places. The presence of businesses, even those that charge a little more than marginal costs, clearly enhance the value of time in the close proximity. People like to trade. People go to great lengths to trade - they even created the silk road.

### 3.3.5 Food Can Make Onerous Journey Time Disappear

Let us complete our discussion on food service with some old railroaders' wisdom. Railroaders (and truckers, too) are kind of a special breed. They always know where to go eat. They always have food, even if it is just a can of spaghetti that explodes in the engine room of a Missouri Pacific locomotive (Santucci, 2001) - because you don't want to be "stuck hungry on a train". Employees are on the system day-in and day-out; employees know that they do not like to be stuck without food. Customers don't necessarily know this, or have the organizational skills, time, or local geographic knowledge to buy food. Let's feed them.

## "Journey Time Just Magically Disappears"

I originally coined this phrase with respect to overnight services, meaning that the time spent sleeping is nearly equivalent to the time spent sleeping at home. Thus, if one is able to sleep while achieving movement in space, in effect, the movement in space becomes a byproduct of whatever other activity the traveller chooses to engage in. The onerous "journey time" has then disappeared from the traveller's mental model of the trip, because the traveller attributes that time to something elsc. We have already seen the application of this principle to the time spent eating on board. It also applies to a variety of other activities that could be performed on-board, such as work, entertainment, rest, and socializing.

### 3.4 The Dollar Value of a Day Methodology

The Dollar Value of a Day Methodology is gaining increasing recognition amongst the academic community. Britain, for example, has conducted surveys in recent years that attempted to calculate the economic impact of household or voluntary work (BBC News, 2002). According to analysis performed on data generated in The UK 2000 Time Use Survey, the average hourly rate for housework is $£ 4.72$ (about US\$ 7). In Switzerland, a recent paper describes an analysis of the 1997 Swiss Labour Force Survey, where the allocation and value-of-time assigned to housework and childcare was analyzed. The value-of-time quoted was calculated with two market replacement cost methods and three opportunity cost methods (Sousa-Poza, 2001). In Spain, where the food market is being influenced by rapid cultural and economic changes, a study determined that high-income families are more likely to consume food away from home and spend more than others on food away from home (Justo \& Jensen, 1998). This
tacitly suggests that in effect, different families have different evaluations of the value-of-time required in preparing food.

The British analysis is driven by The UK 2000 Time Use Survey, which is a field-survey involving individual questionnaires and telephone follow-ups. Selected household heads or their partners completed a household questionnaire. All individuals aged eight or over were asked to complete individual questionnaires, two one-day diaries and a one week work and education time sheet (National Statistics Online, 2002). The data provided no information about how these individuals valued the time, but the aggregate results enabled useful insights into how individuals allocate their limited time. For instance, the average Brit spends about 80 minutes each weekday eating, a further 50 minutes each weekday on "food management", but only about 80 minutes per weekday travelling. Significantly, the average Brit spends up to 140 minutes each weekday watching television or video. Interestingly, in an independent study (Schafer, 1999) using American subjects, Schafer concluded that the average person spends about 90 minutes per day travelling, and a faster mode simply induced people to travel further each day (for work or other purposes). The 2000 U.S. Census, which gave an average commute time of 94 minutes, is consistent with Schafer's findings. Given the totally different demographics, and perception of longer commutes in the United States, it is surprising that the time spent travelling is very similar. The data are not directly comparable, since the 80 minutes cited in the British survey included the non-work population who may spend time travelling to a shopping mall, while the Census data deals in work-travel only, but the consistency of the data is striking.

In the U.S., a comparable data source was the Dollar Value of a Day publication available from Expectancy Data (Ward, 2002). Ward and Associates used a similar time-diary data provided by the National Human Activity Pattern Survey (Environmental Protection Agency) and a Department of Labor Survey of wages by occupation by geographical area.

The common element of the Dollar-Value of a Day methodologies reviewed is that they only attempt to evaluate those parts of the day which are actively engaged in producing monetarily valuable work for others. For instance, in the housework category, the recipient of the benefits is everyone in the household, while a specific task might be carried out by a specific member of the household. In that way, they produce external benefits which can be evaluated using the replacement cost method. If the household member was not available to do the specific task, what would be the market rate for hiring a replacement for that length of time? In some other surveys, the opportunity cost method asks the question, if the household members were not engaged in performing that task, what value could they
generate (for others) if they performed other tasks? Neither method was able to evaluate the question: what is the value of time for the time that individuals invest for the benefit of themselves?

## When Producer and Consumer of Services is the Same Individual

The value of time where the individual is both the producer and consumer of services is a particularly interesting question economically because it is both difficult to estimate by conventional methods and related to many transportation problems. It is difficult to measure since it's not possible to hire an individual to produce the same services - if you hire somebody to eat for you, you don't exactly gain any weight; if you hire somebody to travel for you, you don't get to go on the trip. While it is possible to ask a subordinate to make the trip for you in a business situation, most business travel involves at least some kind of incentive for the individual (whether that be because the individual values the opportunity to attend the conference for personal career development, or the individual just likes to travel), and pleasure travel requires the presence of the individual. The conventional argument that the consumers' willingness-to-pay in out-of-pocket price for the trip represents the utility they derive from that trip is misleading for two reasons: (1) the price is determined by competition in the market, consumer surplus is generated over and above the investment, thus the price is in fact a lower-bound on what the individual is willing to pay for that trip; (2) the individual is investing time to make the trip, and it is not clear how that time should be valued. Conventional methods assume that the individual would otherwise be at work, but this may not necessarily be true. Other leisure options are available, but most individuals choose a mixture of leisure options over the course of one year. While welfare-maximizing economics will suggest that the individual will persistently choose the leisure option that generates the best "return" on the time invested - other than adamant philatists, electronics enthusiasts, and train spotters, it is rare that individuals will devote all their free time to the same leisure activity. There are also other activities which are necessary to sustain life, such as eating. The value-of-time spent eating (or utility derived from investment in out-of-pocket cost and time seeking and eating food) is likely to be somewhat dependent on the level of hunger. The value-of-time in those cases could be difficult to evaluate.

How does this relate to transportation? The case of the automobile operator on a business trip, with a bagel in hand and talking on a personal cellphone while listening to the news on the radio demonstrates that a person can easily be fulfilling lifetime necessities while accomplishing both personal enjoyment and a business goal. Such individuals are not only consumers and producers of transportation services
at the same time, but also utilize the same time to take part in activities that generate surplus both personally and perhaps for others.

## Marketing-Informed Design of Transportation Systems

In transportation systems design, the system should be designed to facilitate activities for a range of different user groups, and not simply the "average" user. The type of activities that are likely to be of value to travellers could be found through analysis of time-use survey data. The most leveraged activities - in the sense that the type of activities that travellers would most likely to want to take part in during a long journey, are presumably the ones where individuals spend most of their time doing during a day, such as sleeping, watching television, or eating. The Metro newspaper became an astounding success around the world in transit-friendly cities because the Metro's owner realized that he could produce a newspaper that are suitable for reading in between transit stops. At the margin, the Metro probably produces a small benefit for the carrier, as a subway ride without reading material incurs more disutility than one with.

Transportation users are individuals, and it is these differences in individual characteristics that we must exploit to consider design issues. The ideal transportation system may not be the same for every individual, but it is the designer's goal to ensure that it is close to ideal for a sufficient number of people that the investment is justified. Systems that are tailored to the average values tend to end up being unsatisfactory for every individual. It is possible to argue that those who eat or socialize while they travel are the minority or the exception, and for most people the time they spend travelling are wasted and thus must be compensated for by an explicit remuneration at rates similar to their wage. But there are many different alternatives in transportation systems, and the goal of creating alternatives is so that certain alternatives can attract certain types of consumers. By tailoring the system to cater towards certain type of consumers, not only do we do "better than average" in terms of value-of-time, the consumer's behaviour can also be influenced - hence altering the average value of time for a particular mode, market segment, or any other population.

### 3.5 How the Value-of-Time Relates to Time-Use Surveys

The Time-Use Survey data can be further analyzed to gain insights into consumer behaviour, and how travellers might like to spend their time on board a transportation vehicle for prolonged periods. Intercity transportation, typically associated with door-to-door travel times of at least three hours, will
necessarily create a distuption in the day's activities. Research into how transportation companies could leverage the time that consumers spend in their custody, both to generate additional revenue from offering additional services, and to generate better market share by allowing the consumer to utilize the journey time (especially on the slower modes) more effectively.

## Interpreting Aggregate Time-Use Survey Data

The UK 2000 Time Use Survey suggests that, amongst the adult population, the average male spends 520 minutes per day working at a paid job outside the home ( 8.7 hours), and a similar amount of time sleeping. However, the average female only spend 350 minutes per day working ( 5.8 hours), but 520 minutes sleeping. This does not necessarily mean that females who do work spend less time per day working than their male counterparts. It probably reflects the fact that the percentage of adult females who choose to work is smaller than the percentage of adult males who choose to work. Thus, it is quite difficult to predict individual behaviour (on which individual travel decisions would be made) based on the average time-use data. Nonetheless, this does not mean the aggregate data is unusable; it can in fact be quite useful, if one is careful to notice such aggregation effects. When combined with the shape of the distribution, time-use data can be very helpful indeed.

## Understanding How Travel Time Could be Used More Effectively

The average individual spends 80 minutes per day travelling. It is possible to hypothesize that this represents the time taken to commute daily from work, and on non-work days this represent the time taken to travel between leisure activities and maintenance activities (such as shopping). It should be highlighted at this point that much research has been done already in building activity-based models of travel demand (See Chapter 2 for a review). The current approach is much more proactive - given the typical activities that take place during the day, and given that the individual has decided to travel, how can we enabled the "dead" time invested in travel to be used more productively?

The key to integrating the travel experience with an individual's daily routine, and thus making the time "disappear", is to identify the activity which takes up a large portion of the day for many individuals, and enable those to take place while travelling. Some activities would not be practical on board transportation vehicles, but could be practical in the terminals. Other activities are possible on board at least some vehicles. The average individual spends 520 minutes per day sleeping; 220 minutes watching tele; 160 minutes eating; and 50 minutes a day socializing. These are activities which are perfectly
practical on board vehicles. By presenting a range of options to occupy the consumer's time that would otherwise be idle and invested solely for the purpose of travelling, the carrier is able to leverage the value of much of that time. Different people will value that time differently, but provided that the carrier is able to provide the option on a break-even basis, it really does not matter what the value of that time is; the value of that time is known to be positive.

### 3.6 Consumers' Attitudes Towards Travel Time

Previous research in social psychology has demonstrated this phenomenon in quite a different setting. Miller and Form (1951) described an experiment at the Hawthorne Works of the Western Electric Company in Chicago between 1924 and 1927. In this experiment, team of six girls were chosen to determine the production rate of telephone relays against such variables as rest-breaks, availability of free hot-meals at lunchtime, and physical conditions such as lighting. The increased amenities apparently caused an increase in output. However, at the end of the experiment, the team was returned to the same physical conditions, the output increased even more. The explanation offered by Brown (1985) in his review is that by asking for the cooperation from the girls, the experimenter has made them feel important and thus the girls' attitude to the work changed, and they worked harder than ever before, irrespective of the physical conditions. The fact that the experimenter listened to the workforce and pampered them was producing increase in output far greater than the loss resulting from rest-breaks and shorter work hours. Mayo (1933), author of several textbooks on the subject, researched the behaviour of Philadelphia mill workers, reached broadly the same conclusions.

Applying the concept to transportation would suggest that the consumer's attitude towards the time he or she is spending on onboard the vehicle is important. If the transportation company makes amenities or other entertainment options available that signals to the consumer that the company cares, the disutility of time could be reduced or may even become non-existent. This research would suggest that the economics of provision of amenities should not be analysed on a case-by-case basis; it is the existence of options that allow the consumers to spend the time as they please which generates the surplus, and not the existence of any particular amenity.

This would also be consistent with the hereto unexplained dominance of the automobile in mediumdistance transportation. Despite the long journey time, the automobile achieves 8.3 m trips per year, much more than the 0.2 m trips by train (American Travel Survey, 1995) and roughly 0.5 m trips by air. Some (Morrison \& Winston, 1985) have attempted to explain this in terms of unrealistically low
disutility-of-time of over-the-road intercity travellers. Significantly, in the Morrison \& Winston study, the data was collected from vacation travellers. These travellers are clearly choosing to spend the time in the vehicle, where the drive itself is part of the vacation experience. The travellers are also able to choose to spend the time as they wish -- vacation highway routes are typically peppered with entertainment options ranging from restaurants, hotels, scenic spots to casinos en-route.

Exactly how much of these options can be replicated by intercity rail carriers economically remains to be seen, since it is both a function of carrier technology and the actual cost of the entertainment business. However, it is conceivable that with creative design of terminals and vehicles, sufficient competitive choices of activities could be offered by long-distance carriers to change the attitude towards the investment in travel time of most travellers. Another observation to follow logically is the importance of educating the consumers on ways of enjoying the journey. The auto industry spends a great deal of its budget on reinforcing the auto dominant image, and stressing the freedom element associated with the automobile. The consumers also respond by spending a great deal of resources on luxuries onboard the vehicle.

### 3.7 Conclusions

The most important conclusion that follows from this research is perhaps that evaluation for high-speed rail or other intercity transportation technologies should not focus too narrowly on the technical attributes such as journey time, frequency, and capacity. Equally important are the human attributes of how the time on-board could be spent and the ability of the technology to adapt to changing human demands.

In this chapter, we demonstrated that concessions and other activity options en-route influence transportation demand sufficiently significantly that a carrier should take notice. We proposed a model for understanding how people evaluate decisions regarding how to invest their time. Using this model, we were able to explain why dining concessions, shopping opportunities, and other amenities can make journey time 'disappear' - essentially by incurring transportation time as a joint cost with another activity. To determine what kind of amenities are most leveraged, and most likely to be applicable to many market segments, we briefly reviewed results of time-use surveys. Thus, a proactive approach to transportation systems design is introduced - given the typical activities that take place during the day, and given that the individual has decided to travel, how can we enabled the "dead" time invested in travel to be used more productively?

In examining the nuances of technological enhancements of the travelling experience, it is necessary to examine the nuances of the travel experience. If new technologies can enable mobile communication from within the train, we can quantitatively determine what percentage of travellers would derive a higher value of time as a result, and compare that to conventional technologies that may reduce travel time, or service enhancements that would provide food or other amenities. By evaluating the cost and benefits of each of the options, using the value-of-time framework, we are able to rationally prioritize all possible service enhancements or technological innovations. It is likely that a combined package featuring some journey-time reductions, some service enhancements and some hi-tech gizmo would be optimal.

In large metropolitan areas, where further capacity expansion of the highway network is nearly impossible, rail's ability to haul large amount of weight cheaply and its relatively small terminal footprint may become a strong advantage in offering the diversity of entertainment options en-route that the consumers are likely to expect. The ability to haul weight increases the options of entertainment onboard, while those elements that are not available on-board could conceivably be offered at the terminal. The small terminal would enable such options to be offered close to population centers, decreasing the reliance of such businesses exclusively on travellers -- as is the case at an airport mall. In addition, the small terminal footprint may allow multiple terminals to be constructed in an urban area, allowing substitution of onerous access time for more pleasant in-vehicle time - an idea explored further in Chapter 5.

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## Chapter 4

## High Speed Rail Technology and Route Planning Fundamentals

This chapter reviews the current state-of-practice in high speed rail technology and route planning in the United States. In particular, attention is devoted to the following three areas: (1) How the high-speed rail routes in terminal areas are determined, using currently proposed schemes in North America and existing arrangements in Japan and Europe as case studies; (2) What is the role of magnetically levitated ground transportation (Maglev) in intercity passenger and freight transportation, and how it might fit into the current strategic planning for high speed ground transportation (HSGT), using the deployment of the Tokaido Shinkensen in Japan in the 1960s, and the construction of Shinkensen-type high-speed rail in the Formosa in the 2000s, as case studies in quantum improvement of radical technologies.

With respect to route planning, we emphasize the importance of access time and control of access mechanisms to the competitiveness of high speed rail. With the Performance-Based Technology Scanning (PBTS) framework introduced in Chapter 2, we demonstrate that very high speeds of $150 \mathrm{mph} \sim 300 \mathrm{mph}$ available with expensive exclusive right-of-way technologies can achieve very high market shares at very high costs, but are not necessary and not cost effective ways of accomplishing mass intercity transportation. We postulate that Maglev technologies are most effective when deployed in an incremental fashion, and current high-speed rail strategic planning is too fragmented. Airport access, urban transit, regional rail systems, conventional high speed rail and Maglev-type technologies are really all different facets of intercity mass transportation. These different modes should be evaluated and designed together such that system optimal is achieved. In some cases, this may involve jointoperation and sharing of large capital facilities, such as track and stations.

### 4.1 General Review of Current High Speed Rail Planning Studies

In this section, we will review very briefly the current high-speed rail strategic plan in North America, and compare it to the high-speed rail vision of Japan in the 1960s, France in the 1970s, Britain in the 1980s, and Germany in the 1990s. Review of specific high-speed rail schemes such as the California,

Midwest, Florida, North Carolina, Baltimore \& Washington Maglev, Pittsburgh Maglev schemes, will be deferred to a later chapter.

### 4.1.1 Federal Railroad Administration Next Generation High Speed Rail Technology Demonstration Program

The Federal Railroad Administration (FRA)'s Next Generation High Speed Rail Technology Demonstration Program (NGHSR) today appears to be focused on the development of enabling technologies. The Five-Year Strategic Plan for Railroad Research, Development and Demonstrations (2002) devotes Chapter Five to the programme, which is divided into four sections: Positive Train Control, High-Speed Non-Electric Locomotive, High-Speed Grade-Crossing Protection, High Speed Track and Structures. This is not surprising, since the FRA's statutory mandate is to ensure safe operation of railroads, but not necessarily to promote the railroad industry.

The Positive Train Control programme is mainly intended to deliver a more cost-effective cab signal technology than the current state-of-practice on the Northeast Corridor, which is a system based on coded track circuits first developed by the Pennsylvania Railroad. Demonstrations are being conducted using digital radio communication technologies in the Michigan Corridor for operating speeds of up to 110 mph . The High-Speed Non-Electric Locomotive Technology programme is mainly an attempt to develop high-speed locomotives using alternative technologies, including gas-turbine and flywheel, to give rise to a lower-weight locomotive with better acceleration. No attempts are currently being made to build advanced diesel locomotives (such as the British Intercity 125) to achieve the same functional performance. The High-Speed Grade-Crossing Protection programme is mainly concerned with physically preventing impatient motorist from jumping the crossbucks as an alternative to full-grade separation. The main technologies being considered are four-quadrant gates, and full-width drag-nets. The High-Speed Track and Structures programme aims to use innovative methods to reduce the cost of high-speed, freight-compatible track structures, both in terms of construction and maintenance. Attempts are also being made to address ride-quality concerns.

### 4.1.2 Intermodal Surface Transportation Efficiency Act Section 1010 Designated Corridors

The Five-Year Strategic Plan builds upon prior work which had already been carried out on high-speed corridor planning as part of the Intermodal Surface Transportation Efficiency Act (ISTEA). Section 1010 of the act identified five corridors, which were supplemented by three additional corridors in Section 1103(c) of the Transportation Equity Act for the 21st Century (TEA-21). These are: the Pacific

Northwest Corridor, linking Eugene, Oregon and Vancouver, British Columbia through Seattle Washington; California, linking Los Angeles, San Diego, Sacramento and the Bay Area; the Chicago Hub linking St. Louis, Missouri, Minneapolis, Minnesota, Milwaukee, Wisconsin and Detroit, Michigan; the southeast, extending the northeast corridor through Charlotte, North Carolina, Spartanburg and Greenville, South Carolina, to Atlanta and Macon, Georgia and linking Raleigh, North Carolina to Columbia, South Carolina, Savannah, Georgia and Jacksonville, Florida; and Florida linking Miami to Tampa via Orlando. The new 1103(c) corridors are: the Gulf Coast corridor linking Houston, New Orleans and Mobile plus New Orleans to Meridian and Birmingham; the Empire Corridor linking New York to Buffalo via Albany; and the Keystone corridor linking Harrisburg and Philadelphia, Pennsylvania.

Sporadic references to the ISTEA corridors can be found in a variety of documents that discuss highspeed rail planning, especially in literature distributed by high-speed rail advocacy groups. As evident from this quote, achieving the Federal designation status is a symbol of having "arrived" in the North American high-speed rail scene:

> Pennsylvania gained a designated HSGT corridor with the enactment of the Transportation Equity Act for the 21st Century (TEA-21). The newly-designated Keystone corridor, which runs between Philadelphia and Harrisburg, is owned by Amtrak, is fully clectrified, and contains very few grade crossings. With official designation, dedicated Federal authorization for a Philadelphia-Pittsburgh HSGT study, and the current cfforts by the State, there are now expanded opportunitics to improve the speed and service of cast-west passenger rail in Pennsylvania, to complement the superb north-south Northeast Corridor service already in place and constantly being improved.

-- Pennsyluania's Role in High Speed Rail, Federal Railroad Administration

The designated corridors seem to reflect the results of political discussion as apposed to demand-based transportation planning. In the original process for selecting Amtrak routes, the Secretary of Transportation simply designated endpoints of transcontinentals, which left many important intermediate cities without direct service. The corridors designation followed a similar process which was based on historical rail traffic levels, instead of a detailed analysis of current highway travel patterns.

None of the four studies reviewed (Southeast Corridor study, Midwest Corridor study, Boston to Montreal study, Florida study) demonstrated a demand-driven way to determine routing, or showed multiple routing options. Studies that are at an advanced stage and involve selecting a route amongst different options tend to take the form of selecting a route given that a fixed list of station locations. No attempts were demonstrated to study demand variation within metropolitan areas, or refining designated routes and corridors on the basis of expected travel patterns. The current DOT high speed
rail strategy seems mainly driven by a political process at a strategic level, and not a city-to-city search for the route with the highest benefits.

There also appear to be a general lack of planning resources at the local level. In FRA's NGHSR enacted budget (2002), corridor planning represents $21 \%$ ( $\$ 5.9$ million) of the total budget; in the 2003 budget request, corridor planning receives a mere $7 \%$ ( $\$ 1.7$ million). Track structures -- a major part of costs of high-speed rail systems, received an average of $5 \%$ of total budget over the two years (2002-03).

The maps that are produced by the planning process shows a number of nodes, but no intermediate points, and treat metropolitan areas as single nodes. For instance, Chicago is one node, Boston is one node, New York is one node. There is also little coordination between the different corridors: The Empire Corridor to Buffalo and the Keystone Corridor to Pittsburgh are both designated corridors; both of the ex-New York Central alignments (via Detroit and via Toledo) are designated corridors. Apparently it was deemed unwise to connect Cleveland to Pittsburgh or to serve Detroit via Toledo (or Toledo via Detroit!). Some other designations that appear suboptimal include the designated New Orleans-Houston v.s. the undesignated Texas Triangle, Houston-Dallas Ft. Worth and Houston-San Antonio. The track mileage required to serve New Orleans-Houston is approximately the same as that from Dallas Ft. Worth-San Antonio via Houston.

### 4.2 Detailed Analysis of An Example High Speed Rail Plan

The Boston-to-Montreal High Speed Rail study is in a very preliminary stage. We chose the Boston-and-Montreal study as an example due to the availability of data, and the cross-border international significance of the line. Other high speed rail studies in the United States may be subject to some of the same issues. This analysis is intended to serve as an example of some of the wider issues that should be considered when considering implementation of high speed rail corridors.

The Boston to Montreal Corridor (B\&M HSR) is 325 miles long ( 309 miles by highway, MapQuest.com). Without considering whether such speeds are in fact attainable, the journey time at an average speed of 90 mph is thus 3 hours and 36 minutes, compared to driving times of around four and a half hours. The principle cities visited by the B\&M HSR are: Boston (Mass.), Nashua, Manchester, Concord (N. Hamps.), White River Jct., Montpelier, Burlington (Vt.), and Montreal (Que.). There is, in fact, a current Amtrak service that covers parts of the B\&M HSR route from White River Jct. to St. Albans that attained an annual ridership of 76,784 passengers (NARP, 2001), or 210 passengers daily.

The study website compared the B\&M HSR to the Northeast Corridor between Boston and Philadelphia. Let's see if there is anything wrong with that picture. Firstly, a demand model of the Amtrak Northeast Corridor, using very simple gravity models and Census data on metropolitan area population, is constructed. The spreadsheet analysis is shown in Plate 4.1:

| Gravity Model Constant |  |  | $2.50 \mathrm{E}+07$ |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Train Average Speed |  |  | 90 |  |  |  |  |  |  |  |  |
| Seats per Train |  |  | 200 |  |  |  |  |  |  |  |  |
|  |  |  |  |  | Annual Ridership |  |  |  |  |  |  |
|  |  | Distance | Journey TiI | Population | BOS | PVD | NHV | STM | NYP | EWR | Sum |
| Boston Me | BOS | (miles) | (hours) | 3297201 |  |  |  |  |  |  |  |
| Providence | PVD | 50 | 0.56 | 1125639 | 267225 |  |  |  |  |  | 267,225 |
| New Haver | NHV | 102 | 1.13 | 522279 | 40785.6 | 20749.33 |  |  |  |  | 61,535 |
| Stamford | STM | 41 | 0.46 | 332835 | 20470.08 | 9431.8 | 15263.36 |  |  |  | 45,165 |
| New York | NYP | 40 | 0.44 | 8712600 | 443853.6 | 192929.4 | 202240.4 | 260987.2 |  |  | 1,100,011 |
| Newark Mt | EWR | 10 | 0.11 | 1954671 | 95480.64 | 41041.01 | 40386.6 | 46841.97 | PATH |  | 223,750 |
| Philadelph | PHL | 89 | 0.99 | 4949867 | 176971.5 | 71128.89 | 51704.23 | 42668.78 | 1568226 | 391362.9 | 2,302,062 |
| Total |  |  |  | 20895092 |  |  |  |  |  |  | 3,999,748 |
|  |  |  |  |  |  |  |  | Riders per | day (both | directions) | 10958.21 |
|  |  |  |  |  |  |  |  | Trains per | day (in each | direction) | 27.39554 |

Plate 4.1: Simple Model calibrated with Boston-Philadelphia Amtrak Ridership Data

We calibrate the model to give us roughly the correct number of annual riders and trains per day, using important variables such as average train speed, seats per train, and a constant. This model gives us a reasonable number of four million annual riders between Boston, New York and Philadelphia. The actual current Northeast Corridor ridership is about 6.2 million for all services between Boston, New York, Philadelphia and Washington (NARP, 2001), excluding the Clockers. We don't expect this model to be sensitive to important attributes like service quality, on time performance, and locations of stations. However, we're only using this model to investigate how much demand we think there is in the corridor. It is simply intended as a screening tool to investigate the viability of corridor concepts. As a sanity check, this model was validated against the current Amtrak Vermonter ridership-performance statistics:


Plate 4.2: Simple Model validated against New York-Burlington Amtrak Ridership Data

With an average speed of 40 mph , having excluded the riders between New York and New Haven (which are attributed to the Northeast Direct service group), the model gives a number close to the actual performance: ridership audit gives the actual number as 76,784 (NARP, 2001), v.s. projected number of about 83,000 . These analyses, surprisingly simple, but give us reasonably accurate results. Considering that the model was not calibrated in any scientifically defensible way, but was based on engineering estimates of constants coupled with simple linear functions, the model appears to be robust even when applied to a corridor of a very different characteristic. So, applying the model to the BostonMontreal corridor:


Plate 4.3: Simple Model applied to Boston-Montreal Market

The model tells us that annual ridership of about 109,000 on the corridor can be expected, or about 300 passengers per day in both directions. Since one train will carry 200 passengers, 0.75 trains per day, or one train every 32 hours could carry this load.

Is this analysis credible? The Boston \& Montreal is a Federally-designated high speed corridor, and the present analysis is claiming that it will only carry some 150 passengers a day in each direction - fewer than current average ridership between New York and Chicago on Amtrak's Lake Shore Limited (based on a 18 -hour one-way, non-high-speed service). Surely a Federally-designated corridor should perform better?

In many markets, the current traffic carried by existing air service is often a good indicator of how successful high-speed rail service could be. Air service could be fast and frequent, but is marred by long access times in a mid-distance market. Rail service usually attract between about $20 \%$ and $500 \%$ of riders compared to air service - for instance, between Boston and New York, high-speed rail carries some twice as many riders as the two air shuttles combined, while between Chicago and Milwaukee, air carries about three times as many local passengers daily as air service. The present model predicts that in the Boston-Montreal local market, about 37,000 passengers annually would be carried by the proposed high speed rail, or about 100 passengers per day. Examining the current airline operating plan in that same corridor, Air Canada and Delta Airlines currently operate eight regional jet flights daily, each carrying 40 passengers between Boston and Montreal. Assuming a load-factor of $70 \%$, and a typical ratio of originating v.s. connecting passengers for hub airlines of $50 \%$, these flights carry a total of 112 Boston-Montreal passengers per day. The Boston \& Montreal will carry about as many passengers per day as air service, according to the present model. Even if the model is based on very simple linear functions, it predicted a number which is consistent with high-speed rail experience everywhere. Any rational analyst would have serious reservations believing that the Boston \& Montreal would generate anything remotely approaching Northeast Corridor volumes (some 1,000~1,500 passengers daily between Boston and New York alone). By the same token, any serious analyst would have problems believing that Boston \& Montreal deserves similar levels of Federal funding as the Northeast Corridor, even after the economic redevelopment potential is accounted for.

The current model does not take into account of induced demand, the economic development effects that will come about as a result of the high speed rail, or even intermodal trip opportunities that will be created by people driving from elsewhere in New Hampshire and Vermont to the high speed rail line and taking the train into Boston. Even if we assumed that these effects combined will give us four times the demand than the model projected, the load would still only justify three trains daily - probably a morning train, an afternoon train, and an overnighter extending through to Washington or elsewhere in Canada. It is unlikely that the infrastructure costs incurred in upgrading the rail line could be justified by a grand total of six passenger trains in either direction daily.

Boston-Montreal is a low-density corridor, unlike the Northeast Corridor, which is a high-density corridor. The cities between New York and Washington may have owed their development to the Pennsylvania Railroad and the Corridor, but that was a long time ago. Building a high-speed rail through Vermont and New Hampshire will not achieve the same effect, because there is now a formidable competitor providing transportation services in the region: the Interstate 89. There are probably better places to spend high-speed rail money than in the Boston \& Montreal corridor. It's hardly even a corridor - nobody lives there.

There are subtle points that this model does not capture, but this model was not designed to be a comprehensive evaluation of the possibilities of the corridor. It was intended to demonstrate the type of problems associated with a strategy that focuses on a political planning process. The BostonMontreal High Speed Rail Study Group, perhaps due to the Federal designation, docs not address some fairly basic issues in project evaluation. For instance, does it make sense to simply extend the Northeast Corridor through Boston and terminating at Manchester, New Hampshire? If the Northeast Corridor were to be extended, is Manchester, New Hampshire the best destination? What about Portland, Maine? If the Northeast Corridor were to be extended, how should it traverse downtown Boston? It can go via the Grand Junction Railroad, by-passing the downtown, or the North-South Rail Link could be built, connecting the two mainline stations in Boston. Should the North-South Rail Link go through the airport? North-South Rail Link is an expensive scheme - does it make more sense to expend those funds in Connecticut and accelerate the upgrade of former New Haven trackage? These are important system design questions, which are omitted when certain corridors are given the designated status, and institutions are created to represent the interests of specific corridors.

To answer these questions, a high-speed rail vision, or strategy, is required. The vision would define the critical issues in high speed rail planning, and would lay out what the high-speed rail service seeks to provide. High-speed rail service is not good at providing service to spread out areas of small demand density; it is better at connecting points of concentrated demand density. The strategy would recognize this and provide ways to make grand schemes like the Boston \& Montreal more cost-effective. High speed rail is much more than drawing straight lines between cities - it's about getting people from where they are to where they want to go. High-speed rail planners should recognize that they are not constrained by existing corridors and that they need to examine options beyond taking an already defined corridor and determining the level of investment required to generate the ridership target they have in mind.

What I have provided in this section is only a screening analyses using very general data and without consideration of important micro-effects. In the rest of the chapter, we will explore some of the questions raised in the previous paragraph. But first, we review the high-speed rail strategy and policy (whether inadvertent or deliberate) of other regions of the world.

### 3.3 How They Really Built the Shinkensen

A common myth amongst passenger rail activists is that Shinkansen is the model high speed intercity railroad, and that if you get the speed high enough, everybody would ride the rails, the system would be successful like the Shinkansen, and the rail line would make both a profit and economic sense. This is clearly not true, not even in the case of the Shinkansen. The original Tokaido Shinkansen, now operated by Central Japan Railway Company (JR Central), was essentially a capacity relief scheme. The later Shinkansen extensions reflect political will to connect the country with Shinkansen, and resulted in poor investment decisions that eventually bankrupted the Japan National Railway.

During the building of original Tokaido Shinkansen, a very unlikely set of circumstances occurred: (a) The Tokaido Main Line, busiest line in Japan, was facing capacity problems; journey times were slow but yet the trains were filled to the brim, to the extent that four-tracking the Tokaido Line was being seriously studied as an option; (b) In postwar Japan, there was a great sense of optimism and will to realize economic growth; (c) The existing railroad infrastructure in Japan was dilapidated and run down, due both to the effect of the War and the narrow gauge lines were never designed to handle the traffic volumes, tonnages, and speeds that were being asked from it (Yamanouchi, 2000).

Thus, the Tokaido Shinkansen was justified on the following basis: given the choice between fourtracking the narrow-gauge Tokaido Main Line, versus the construction of a set of standard gauge lines alongside the Tokaido Main Line alignment specifically for express passenger service, the incremental benefit from halving the journey time (from six-hours to three-hours between Tokyo and Osaka) and the performance gain on the narrow gauge lines (avoidance in having to pass high-speed express and freight trains) was greater than the difference in costs between two extra narrow gauge tracks and the two standard gauge tracks (see Debassay, 2003 for a detailed discussion).

The important feature to note in this case is that not even a $50 \%$ reduction in end-to-end journey time was able to justify the cost of the brand-new alignment. In this case, the reduction in journey time was
only able to justify the difference in cost between narrow gauge and standard gauge infrastructure, laid down alongside the existing rights-of-way in most places by widening. Obviously, the original Tokaido Shinkansen is an astounding success - but only because the traffic was already mature and overflowing, and essentially no new rights-of-way were required. The original Tokaido Shinkansen was built in the part of Japan with the least difficult terrain, and did not enter urban areas through elaborate viaducts and tunnels; it entered urban areas by widening and realigning existing narrow-gauge infrastructure to utilize space more effectively in the existing rights-of-way.

There are many high-speed rail schemes currently in progress in Asia and Europe. Some will succeed, and some may not fare as well as the promoters hope. The on-going scheme in Taiwan bears all the hallmarks of the original Tokaido Shinkansen: the existing 70 mph narrow-gauge lines are capacity constrained, especially by local commuter trains; the highways are congested, and the distances are too short and the weather too unpredictable for domestic aviation to be a major player; the new infrastructure will be constructed through mostly coastal farmland, especially in the southern part of the island; the new infrastructure will half the journey time from five hours to about two and a half hours.

On the other hand, the Channel Tunnel Rail Link, currently being constructed in Southern England, seeks to upgrade a capacity-constrained 100 mph line to 183 mph standards by constructing a brand-new alignment through heavily populated London suburbs. The journey time savings associated with the new alignment is in the order of 60 minutes, cutting the London-Paris journey from three and a half hours to two and a half. Apparently a good case for investment, it differs from the original Tokaido Shinkansen in that people are not exactly flocking to travel from Paris to London, or vice versa. The suburban rail congestion could be relieved with advanced signalling technologies, without resorting to a brand new alignment. A study by Virgin Rail suggested that Regional Eurostars (from Glasgow, Manchester, Birmingham and other cities to Paris) would only be justiffed with a frequency of one train per day from Glasgow, and two trains per day from Manchester. The Channel Tunnel Rail Link is likely to see a maximum of ten trainloads (perhaps a maximum of about 8,000 passengers) in each direction per day, compared to the inaugural hourly service ( 18 trains per day) planned for the Taiwan high speed rail, and the seven-minute rush-hour headways that currently run on the Tokaido Shinkansen. The economics of the Channel Tunnel Rail Link pales in comparison.

### 3.4 Conclusions

In this chapter, we have illustrated a few fundamental principles of high-speed rail planning through case studies, logic, and literature review. First and foremost is the important realization that high-speed rail planning is a detailed exercise. Cities cannot simply be treated as nodes of different sizes, since at the distances where high-speed rail is most likely to be competitive (i.e. under 300 miles), the access time to and from the central station could be a significant part of the total journey time, and factors into competitiveness against the other modes very significantly. The current status quo of designating specific corridors to be studied as high-speed rail corridors could lead to undesirable results by allowing a fixed-route or fixed-endpoints focus to develop, when a rational analysis of which nodes to include, what route to take, and where to stop, is needed. Secondly, in terms of infrastructure investment, it is extremely difficult to justify new infrastructure based on journey time savings. Proposals for new infrastructure, new technologies, or new rights-of-way are much more likely to succeed where capacity is a constraint. Economic analysis showed that the age-old rule of investment decision: 'buy the best you can afford, then use it until it claps out' seems to apply to high speed rail also. The unfortunate result for high-speed rail advocates is that quantum speed improvements are unlikely to occur unless a situation exists where the existing infrastructure is already handling as many trains as it possibly can. In the case where existing infrastructure is unable to attract sufficient riders to justify its operational costs, investment in new infrastructure is likely to fail also.

A full analysis of the implication of this result on magnetic levitation technology appears in the Lu , Martland and Sussman paper (2003) - see Appendix H.

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## Chapter 5

## Case Studies in Downtown Access Design

This chapter is both a review of existing schemes for intercity rail's access to the downtown core, and an application of the Performance-Based Technology Scanning framework (See $\$ 2.10$ ) to designing an adequate distribution system for a large metropolitan area with a population of more than one million. The central idea is that when evaluating high speed rail strategies, it is easy to get carried away with maximizing speed when the most leveraged infrastructure investment could be in the downtown, especially when high speed rail schemes are considered jointly with commuter rail and rapid transit improvements.

There are a number of urban distribution system designs for intercity transportation: (1) travellers could transfer to the local public transit system; (2) travellers could transfer to local public or private transport at a central collection point; (3) travellers could transfer to local private transport at a number of collection points. In this chapter, we use the Performance-Based Technology Scanning framework to demonstrate that alternative (3) would make intercity rail most competitive with alternative modes of highway and airline. Given the same technical capabilities and amenities, alternative (3) would result in the longest "breakeven" distance; given an origin-destination market, alternative (3) would allow lower costs by requiring lower speeds for a given target mode share. In transit-oriented cities, (1) can appear to be the most cost-effective solution, but the de-facto need for most target customers to make two or three transfers makes it unattractive.

In the final part of the chapter, we review a number of actual examples where this concept has been applied to a number of cities. While no attempt was made to survey the examples in a level of detail required for engineering, attention was devoted to existing infrastructure and demand patterns to enable evaluation of benefits and whether this approach makes sense for the cities concerned.

### 5.1 Review of Intercity Rail Distribution Systems

As part of research carried out on the behalf of the Union Internationale des Chemins d'Fer (UIC), the author reviewed urban rail networks in many of the world's metropolitan areas. The coverage was not intended to be exhaustive but aimed to cover a representative subset of downtown distribution designs. The detailed case studies were previously published in a working paper submitted to the sponsors (Martland et al., WP-2002-02). The following is a representative summary of the relevant sections.

### 5.1.1 Tokyo, Japan

The non-Shinkensen rail in downtown Tokyo are integrated into the extensive city subway network, and there is track sharing and vehicle interchange between the Tokyo Municipal Subway and some of the regional rail operators. The vehicles are interoperable on both types of the infrastructure. Like other subways and regional rail networks in very large metropolitan areas, Japan has a nearly totally-connected downtown rail system. The incoming regional/intercity train will often visit a number of stations before finally terminating at Tokyo Central. Some trains run through the city. Real estate experience over the most recent decade suggests that other business districts have developed around rail stations that are not in the downtown, and a substantial number of regional rail riders travel directly to their target business district without transferring at the central station. Connecting eight of the most important business districts within the Greater Tokyo region is a circular rail line called the Yamasaki line. Shinkensen Expresses continue to call only at the central station.

### 5.1.2 London, England

Downtown distribution in London is something of a historical accident. In the era of private railways, each long-haul railway constructed its own magnificent London terminal and transferring between lines often required crosstown connections on the Underground network. In the downtown, tracks were not generally shared between full-gauged mainline trains, small-gauged surface line trains, and tiny-gauged deep level tube trains. Reaching the final destination after reaching the London terminal of the line in question was often difficult, involving multiple transfers or a congested hackney carriage ride.
Beginning in the late 1980s, British Rail recognized the need of crosstown travellers and instituted the Thameslink scheme which called for construction of a new elevated railway across London to provide a North-South connexion. Additional stations were also provided. Today, two other schemes, named Thameslink 2000 and Crossrail, are in progress to open more direct cross-town links for mainline trains.

### 5.1.3 Harbin, Heilongjiang, Cbina

The downtown distribution facilities in Harbin have historically been based on the London model, where tracks from the South and from the North each terminated at separate stub-end termini. There are four rail stations within the urban area, linked by a circular railroad, but two (Binjiang and Xiangfang) are mainly loose-car freight stations, while the two passenger stations deal with diesel (Northbound) and electric (Southbound) trains respectively. The 2002 operating plan and track speeds do not allow the circular railroad to act as a collector for long-distance trains in a competitive manner; passenger trains traverse round the ring mainly due to operational reasons. However, in Harbin, this is less of a problem than one might imagine, due to the tendency towards highly compact planned cities in former communist China. There are a number of business districts in Harbin, but the main station is the only station close to the largest and busiest part of the downtown; the freight stations lie in industrial areas and other stations lay beyond the main conurbations. Thus, the fact that Harbin is still a singlenode city isn't a major problem, since the population is also highly concentrated, unlike in the developed world.

### 5.1.4 Pbiladelphia, Pennsylvania

Philadelphia's regional rail system has three main stations in the downtown: 30 th Street, Suburban, and Market East. Prior to 1984, the Reading Railroad and the Pennsylvania Railroad independently operated Broad St. and Suburban regional rail stations which were not interconnected, while $30^{\text {th }}$ Street was exclusively reserved for long distance trains. The downtown tunnel, constructed for $\$ 300$ million, permitted abandonment of Broad St. and allowed access to all regional rail lines from all three stations, including a brand-new interchange with the transit system at Market East. An indoor mall connected $8^{\text {th }}$ \& Market transit stop with Market East regional rail station. Access time to regional rail service from the downtown was greatly reduced with the tunnel. Regrettably, due to existing infrastructure and other constraints, intercity trains continue to call only at $30^{\text {th }}$ Street, including commuter trains from New Jersey. Although reaching downtown is an easy transfer, access from other significant demand generators in the city neighbourhoods is problematic.

### 5.1.5 Boston, Massacbusetts

Boston's intercity rail system has evolved much over its 150 years' history. As the cultural center of New England, initially the London model was adopted. Major restructuring during the 1890s by the Boston \& Albany and the New York, New Haven and Hartford saw the consolidation of many smaller stations into two stations, Back Bay and South Station, which both served all of the south side lines. Unfortunately, the Boston and Maine kept its own North Station for the north side lines. In the Amtrak era, a suburban park-and-ride station known as Route 128 was added. Later, two stops within the city, Forest Hills and Ruggles, were added to the regional rail network to serve major demand generators besides the downtown and provide transit connexions. In general, accessibility of regional rail service is much better in Boston than in many other American cities. Currently, there are proposals to link the North and South stations by a downtown tunnel to create a Philadelphia-like layout, and new regional rail stations that provide transfer opportunities away from the downtown are in the process of being created as part of the Urban Ring project.

### 5.2 Some Basic Concepts

### 5.2.1 Why is Urban Transportation Relevant to Intercity Rail Providers?

After the public takeover of urban mass-transit systems occurred on a wholesale scale during the 1950s, there was a growing body of opinion amongst intercity carriers that local distribution was the responsibility of the local government, and while intercity carriers' responsibility terminated at the local access point for that particular mode of transportation, whether than be an out-of-town airport, a downtown railhead, or a remote freeway interchange. Although the intercity carrier will work in conjunction with the local government to provide interchange facilities, the public intercity carrier saw little reason to enter a market in which a public monopoly was unable to operate profitably. However, there are often tremendous economies of density in urban transportation, to the extent that certain busy urban corridors may be profitable to operate independently of the local transit authority - a phenomenon evidenced by the increasing independent private investment in downtown-to-airport type shuttle buses. In this section, we argue that the intercity carriers are not only able to profit from this type of urban distribution market, but will also enhance their mode-share in the intercity market by providing better access to its services. These access issues are particularly important in congested cities where demands for intercity services are high and alternatives to the rail mode are also easily accessible.

In other words, access to the rail mode only needs to be as good as access to the competing modes such as limited-access highways or airways.

### 5.2.2 Local Feeder Routes in a Metropolitan Urban Setting

In cities with a large population, many modes compete with intercity rail for travel over distances of between 100 and 1,200 miles. Typically, at the "origin" end, a mode-choice tree in a major metropolis such as New York City might look something like this:


Plate 5.1: Local Feeder Routes in a Metropolitan Setting

More importantly, each of the paths in the mode-choice tree has a utility and idiosyncratic preference associated with them. Thus, when the traveller is making the decision with respect to the line-haul mode, the utility associated with the "local" and "crosstown" access modes will affect their decision. While intercity service providers seldom control local access, they should be aware of its importance.

In order to encourage patrons to choose their mode on the line-haul portion, a carrier must consider not just the line-haul leg, but also the access legs, so that overall utility for the journey experience for the line haul plus some combination of the "access" modes comes out to be the highest. In major metropolises, airports are frequently easily accessible using the local transportation infrastructure, as are intercity bus terminals. For that reason, the rail operator needs to choose a routing and stopping pattern carefully to enable the best downtown access by patrons who may "prefer to access the line-haul mode by private auto" or "are only able to access the line-haul mode by subway".

### 5.2.3 Local Feeder Routes in a Rural Setting

Interestingly, this can be contrasted with a small town or rural area, where the accessibility to much of the infrastructure that city-dwellers take for granted are simply not present. In these areas (such as North Carolina in the United States), the mode-choice tree will look more like this:


Plate 5.2: Local Feeder Routes in a Rural Setting

The key observation here is that in working to improve access to intercity rail travel, the access only needs to be as good enough to make the overall trip experience better than that offered by the competing modes. In general, there is much more competition in the large cities both between access modes and line-haul modes, thus it is a much more difficult market to break into. In rural areas, the only access mode is the private auto; thus intercity rail can attain a larger potential customer base simply by ensuring that its stations are strategically spaced such that a drive from most points in the rural state is less than the drive to the nearest major airport in the area, and by ensuring that the disutility of transfer is more than compensated by the utility in travelling by train (versus driving directly to the destination).

In many ways the rural market is a much simpler market than the urban market. In a developed economy such as the United States, where it can be safely assumed that the majority of the rural population have access to a car, access barriers such as "an hours' drive to the nearest rail station" isn't really an issue. Rural population and suburban population in general accept that a longer drive and increased disutility of access to "urban" facilities is part of the cost of living in exclusive suburbs or rural locations. A possible reason behind the failure of railroads in developed countries to attract a significant
rural ridership may lie with their inability to distinguish its product from driving directly to the destination.

### 5.2.4 The Coupling Between Local and Long-Haul Transportation Systems

The success of intercity transportation carriers are inseparably linked to the effectiveness of the local distribution system from the long-haul nodes. Consider Slide 15 in Appendix B. The airline community discusses airport access in many publications (for a review, see Chapter 2), and the importance of such local runs are extensively documented in literature dealing with intermodal freight. It appears that the success of intercity rail may depend on the availability and quality of the local transit system and highway access network. As noted in Appendix B, in a number of case studies and example itineraries that were examined, provided that an intercity rail line of a medium-speed standard (about $90 \sim 110 \mathrm{mph}$ ) exists, the most leveraged investment may be to improve revenue through reducing access time by offering better access within the metropolitan areas.

### 5.2.5 The Folly of the Union Station

Many transit (and intercity passenger transportation) professionals have come to believe in recent years that a consolidating approach to intercity services is a good thing - many cite the Union Station's downtown location (a intercity rail "hub") as a great attraction for travelling by train rather than by private auto or aeroplane. In fact, the Union Station's downtown location is an impediment, not an attraction, to suburban dwellers who wish to depart from their home and those who work in suburban business districts. In contrast, the out-of-town airport offers much better access if the origin is within the suburbs. 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 which are within easy walking distance of the downtown Union Station. Some graphical illustrations of the demand studies are shown in Slide 12 of Appendix B.

Although a beltway "Park and Ride" similar to Route 128 station in Massachusetts and New Carrollton station in Maryland solves the problem for suburban dwellers who live on or near the beltway, it does not make the intercity train any more attractive than the plane which is also similarly situated at a beltway location. In addition, the "Park and Ride" does not make it any easier for those who work in suburban business districts or city neighbourhoods that are not within easy reach of the downtown. Especially in a major metropolis, getting downtown by either transit or private auto can be a major
hassle, comparable to getting to the airport. In addition, other issues exist in congested downtown that make the out-of-town airport even more competitive; for example, the lack of direct access via highperformance urban expressways to the downtown rail terminal, and the lack of affordable parking at the rail terminal, all impair the ability of the downtown terminal to serve the suburbs and some city neighbourhoods effectively.

The simple analogy with the interstate network will demonstrate why more than one downtown station is required. An intercity railroad terminating only at the Union Station and beltway Park \& Rides is akin to an urban interstate expressway which has only three exits - one at the eastern intersection with the beltway, one at the downtown, and another at the western intersection with the beltway (see top of Slide 5.3), requiring the traveller to proceed through the city on slow arterial streets (akin to feeder transit systems or feeder buses to the Union Station and beltway Park \& Rides). Obviously, the nature of the railroad technology requires the minimization of stops for through passengers to minimize the dwell times. However, where a train is terminating in an end-of-the-line type city (such as Boston, Mass), or a service is obviously designed for short-haul passengers (such as the Amtrak Clocker and Keystone services), increasing the accessibility of such services through a downtown distributor can make the service much more attractive than a point-to-point, airplane-like service (see middle of Slide 13 in Appendix B). It is also important to note that premium express services, such as the Acela Express, should probably not spend time picking up passengers around the loop in Baltimore, Md. or Philadelphia, Penn.; but it should be sent around (hypothetical) distributor loops in major destinations such as Boston, Mass.; New York, N.Y.; and Washington, D.C.

The goal of such downtown distributor 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. Thus, the scale is 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 much less attractive; had we retained the downtown Union Station, the congestion in the downtown area would probably make airport and Union Station access time similar in a taxicab from most suburban locations and city neighbourhoods.

### 5.2.6 Advantages of the Downtown Loop

The downtown loop also allows the large mega-city to be converted from a stub-end stop to a throughstop which has certain operational advantages. Decreased platform occupancy times allows more effective platform capacity utilization in an area where additional platforms may be an expensive
proposition, in addition to allowing large preparation yards to be moved out-of-town where land (and possibly labor too) is cheaper. Conceivably the through services, shown in deep blue, will simply travel once around the loop, adding about 20 minutes to the through journey time (which is a lot better than the one-hour usually allowed for cross-London transfers), whilst terminating services will go around the loop before reversing at a siding or simply continue via a wye back towards the origin having completed loading and unloading at a number of intermediate stops. In the latter case, all train preparation will occur at the other end of the line, or in a yard situated in a rural area between two mega-cities. This is, in a way, the merry-go-round concept in coal transportation as applied to passenger service.


Decentralized
Terminals Design
(Service Pattern)

Plate 5.3: Decentralized Terminals Service Design

Aside from the operational and access benefits, the downtown ring has an additional benefit over other possible layouts to enhance access. Instead of building a number of lines that independently cross the city center, a ring can effectively channel traffic from any direction through the city without incurring the expense of connecting all lines to every other line. To be precise, if there are more than two connectors through the city (i.e. more than a single North-South link and a single East-West link), the ring can provide an alternative with less mileage and nearly the same through journey time and access time for those who live in the metropolitan area.

### 5.3 Results from The City of London Study

To illustrate the concept of better rail access for intercity carriers operating to major metropolises, a scheme was designed around the City of London to evaluate the potential benefits and feasibility of
applying such an idea in an actual situation. The access scheme designed involved constructing a circular heavy-rail alignment which would connect most of the intercity terminals in downtown London. In this study, the following questions were addressed:

- What are the estimated 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. Of course, there are many constraints on London's radiating intercity lines which will prevent interlining between them, at least in the short term. However, as a long term proposition, the idea has some potential.

A draft diagram showing the proposed route of the scheme, which in fact closely mirrors London Underground's Circle Line, is shown on Slide 18 of Appendix B. The existing Circle Line alignment is unsuitable for use by intercity trains due to its restrictive loading gauge and other elements of infrastructure geography. The costs are thus based on a new-build scenario.

Many assumptions are necessary to complete the preliminary study:

- Thameslink and other cross-town schemes (e.g. LUL Met Line) do not exist.
- Transfer passengers must disembark at downtown London terminals, transfer via the Tube, wait for the train at the originating terminal for an "average" length of time.
- Average wait time is half the expected headway.
- Expected headway is the number of trains per hour divided by number of branches served by the downtown terminal. (e.g. London King's Cross serves the Cambridge Flyer (half-hourly), Peterborough Local (half-hourly), Leeds Intercity East Coast Train (one per hour) and Newcastle Intercity East Coast Train (one per hour), thus the average headway is six trains an hour divided by four destinations $=$ every 40 mins ).
- Walking times between Tube stations and Train Platform are Railtrack's official figures, to include waiting time on LUL during daylight operating hours.
- Walking between mainline stations is permitted, and walking times are used where possible.
- Transfer times include the walking time, Tube time, and expected waiting time for the mainline train.

The most important assumption is that crosstown schemes do not exist, since the crosstown links are in fact a part of an expensive solution that a ring-railroad would be attempting to avoid. Given that all lines are interconnected through the city, it makes the case for a ring railroad weaker. In many cities (such as Chicago, London and Boston), the lines from north side and south side are not in fact fully
connected. In this study the base case of having none of the lines connected (except by transfer to a local transit system) is evaluated against building a downtown distributor to connect more stations.

### 5.3.1 Methods and Results from Running Time Analysis

To calculate a set of transfer times across London, it is necessary to calculate the amount of time it will take for a terminating intercity train (or indeed run-through intercity train) to travel around the inner ring railroad. In addition, running time analysis allows us to determine whether the amount of vehicle time spent in sending the train around the ring results in a saving over the turn-around time at a stubend terminal. If the time spent around ring were significantly longer than the turn-time at terminals, it would be hard for intercity operators to justify tying up their productive asset for what is effectively a service enhancement that may or may not generate significant additional revenues. Also, if the time spent trundling around the ring is slower than what can be offered by local transportation options, the exercise becomes pointless since the added convenience of a one-seat ride will be unlikely to offset the additional time-cost of travel for many travellers. Thus, for the idea of a ring to be viable, we must fulfill the following market (competitive) and cost (operational) constraints:

- Journey Time faster than local transportation options (which may involve waiting and transfers, but will almost certainly take a more direct route)
- Running Time around the ring faster than turn-around time achievable at stub-end terminals
- Sufficient capacity on the ring to accommodate trains from most important destinations

To calculate the running times, distance around the ring was measured and an average speed achieved between any two station-stops was calculated based on a formula which took into account of the distance between stations. The formula was roughly calibrated to those sectional running times that are achieved by the London Underground's Circle Line, taking into account the added station stops served by the LUL trains but also the better acceleration and low-speed characteristics. Station dwell time at each terminal were assumed to be one minute - the stations would have to be designed as throughstations with either a center platform or two platforms with center express tracks and outer local tracks/sidings to minimize station dwell times (See Exhibit 5.4 below).


Plate 5.4: Station track layouts suitable for downtown ring railroads

The main result in this case study was that it was impossible to stop at all of the BR London terminals yet maintain a sensible running time around the ring. However, if limited-stop service was introduced, overall journey time savings are possible and the majority of passengers would still be able to make a same-platform or cross-platform transfer to a service departing in a different direction, and most parts of Central London remains directly accessible from the stations at which the intercity trains stop. In particular, the running-time for an intercity train around the loop was calculated at 51 minutes for the all-stop scenario, and 30 minutes for the limited-stop scenario (including schedule padding and time taken for crew changes). The current London intercity operators schedule between 40 and 50 minutes for servicing at their London terminals, although it can be accomplished in 15 minutes if an incoming train were to arrive late. The limited-stop schedule would suggest that no extra vehicle costs will be incurred by any operator if they were to send the trains around the ring; on the other hand, if the incoming arrival is more than about 20 minutes late, a decision could be made to terminate and turn the train at the operator's own London terminal in a stub-end platform.

Using the existing Train Service Database information maintained by Railtrack, and running times around a hypothetical ring, the train services' arrival times at King's Cross station was calculated and schedules created using King's Cross as a timing point. The result of this analysis demonstrates that at off-peak times, theoretically, most of the long-distance arrivals at the London terminals could be handled with a single-track ring-railroad, although obviously with a single-track loop the traffic would only be able to travel in one direction. If three-minute headways were to be maintained at King's Cross, minor adjustments of up to 6 minutes is required on some line-haul schedules, but the majority of the trains would receive a train-path on the ring. Although the practical capacity is likely to be much lower, the idea of sending most long-distance arrivals around a ring appears plausible in London provided that a double-track ring is equipped with signalling for about 20 trains per hour, roughly the limit of current technology.

### 5.3.2 Metbods and Results from Transfer Time Model

The transfer time model is fairly straightforward. Basically, the three components of a cross-London transfer time were added together, using Railtrack recommended values. Some of the values were then changed to reflect the presence of a 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 expected transfer times from all nodes to all other nodes (including cross-platform transfers at the same node) was then calculated in a matrix. The expected transfer times were then averaged across all possible combination of nodes and this is known as the average cross-town transfer time. Although this methodology is not totally watertight (for instance, it fails to account for the fact that some transfers are heavier than others in terms of passengers, thus should be weighted more), it gives a good indication of how long one may expect to spend on an average cross-town transfer in London. Due to the difficulty of obtaining detailed transfer details, no modelling was attempted in this area. The resulting access times between every station pair are presented in Table 5.1, and summarized below:

## BEFORE

- Average cross-town transfer time between major downtown terminals $=\mathbf{5 8}$ minutes.
- Best average access time* from any one major downtown terminal $=\mathbf{5 2}$ minutes (from King's Cross and St Pancras to all other stations).


## AFTER

- Average cross-town transfer time between major downtown terminals $=47$ minutes.
- Best average access time* from any one major downtown terminal $=40$ minutes (from King's Cross and St Pancras to all other stations).

[^0]|  | 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 |  |  |
|  | 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 | KGXISt Pancras |
| 3 | MML | 12 | 40 | 40 | 40 | 40 | 65 | 42 | 49 | 45 | 62 | 66 | St Pancras | KGXSt Pancras |
|  | 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 Wester/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 |
|  | Southend (LTS) | 10 | 55 | 66 | 66 | 71 | 76 | 80 | 75 | 70 | 67 | 40 | Fenchurch St | Tower Hill |

Table 5.1: Cross-London Journey Times between all Mainlines, with hypothetical Ring Railroad

Because some of the minor mainline terminals are not included in the London Inner Ring Railroad scheme, the passengers arriving at those stations will continue to have to rely on the Tube for crossLondon transfers. Most stations excluded were stations designed to serve only commuters. Because of this, the actual benefit realized for long-distance intercity travellers would in fact be higher than the result of 47 minutes would suggest. Although it is disputed as to whether long-range commuters or long-distance intercity passengers are the more leveraged area of the market, since this study mainly concerns intercity passengers, the assumption is made here that long-distance passengers generate more revenue per train for the railroad industry. It would not be difficult to simply substitute the set of intercity trains which we choose to send the ring with a set of long-range commuter trains, should the latter turn out to be the case.

For a conservative estimate, we shall consider the transit time from a location inside Central London to be half of the transit time between stations. We know that the access time to a Central London business/residential location is between half and one times the transfer time between London Terminals.

### 5.3.3 Simple Benefit Analysis

The simple benefit analysis evaluates the benefits to riders, taking only into account of the time saved for those who are already travelling by the rail mode. The actual benefits are likely to be higher as people switch to rail for its increased convenience.

Typical daily weekday flow at King's Cross = about 77,000 pax/day (Calculated using a simple model based on average load factors on the intercity expresses and their seating capacity). Since King's Cross is an average station (e.g., Paddington, Euston and Victoria are all busier than King's Cross, while St

Pancras, Fenchurch St, and Marylebone are quieter), if we assume the typical weekday flow is an average, the typical weekday flow through London is thus approximately 930,000 pax/day.

Commuters are likely to be in high-paying jobs, thus average value of time is assumed to be $£ 10$ per hour ( $\$ 15$ per hour). Calculating the average value of time spent in access after an outer-suburban commuter rail or intercity rail ride, using the following passenger mix:

- 25\% Cross-London Transfer pax (including Commuter Rail Transfers)
- $55 \%$ Downtown London Terminating pax
- $20 \%$ Non-CBD Terminating pax (requiring a Tube ride)

Sum saved per weekday (in terms of access time) $=\$ 1.34$ million per weekday (or $\$ 350 \mathrm{~m}$ per year). This is sufficient to support a project costing about $\$ 3.5$ billion over 15 years. Some of the detailed analyses supporting these claims are shown in Slide 18 in Appendix B.

We are not trying to build a business case for the Inner London Ring Railroad. There are many external benefits which are not explicitly accounted for in this model, e.g. greater mode-share due to better accessibility, and possibility of deferring capacity enhancements on the London Underground. A closer examination of the costs and the local conditions would be needed before any firm conclusions could be drawn for London. The ring railroad is likely to more generally remain a viable option as a way to reduce access time and through journey time for any city with more than about two million population.

### 5.4 Application of Performance-Based Technology Scanning

How could the Performance-Based Technology Scanning (PBTS) framework be applied to designing a distribution for the core downtown? The two critical ideas in the PBTS framework are: (1) Different types of technological improvements or infrastructure investments may result in very different changes in journey experience; these changes could be evaluated with suitable assumptions regarding values-oftime; (2) Investment should be targeted in areas where the maximum return could be obtained for a given investment. Because of the complex nature of transportation systems, it is likely that the most effective investment would comprise of a package of moderate improvements rather than maximization of a single variable such as speed or accessibility.

Some emerging technologies will affect the cost-base of providing the service directly, while others will affect the revenue potential directly. Some technologies will enable service designs that were previously uneconomic to be operated -- this is a very subtle effect, which could be termed the second order impact of technologies. In this section, we design a downtown distribution system to increase revenue, which may or may not be profitable. Then we ask the question: are emerging technologies able to reduce the costs to the extent that this design becomes economic? Various answers are possible. Perhaps no new technologies are necessary, or perhaps the technological advancements required are beyond even the most optimistic current projections.

In the remainder of this chapter, a conceptual model is presented to support what was demonstrated through examples and case studies in the earlier work.

### 5.4.1 Assumptions of The Model

In developing the model, a number of simplifying assumptions were made. The simplifying assumptions were necessary for two reasons: (1) to keep the model tractable and implementable without specialized programming tools; (2) to retain some generality in the model, such that the results will be applicable to a wide range of metropolitan with roughly similar structures. With the necessary resources, it is possible to extend the model to cover a wider range of modes, better spatial resolution, and more detailed consideration of any or all aspects of the many variables.

There are three modes available for intercity travel: Rail, Air, and Auto. Other possible modes for an extended version of the model are: Rental Car, Intercity Bus, Air via Hub, and Auto via State Highways. There are two modes available for access to terminals: Auto and Transit. Other possible modes might be: Walk, Bicycle, Taxi, Express Bus.

### 5.4.2 Structure of The Model

The metropolitan area is divided into a number of quadrants of equal sizes ( 25 , in the case of the experimental model), and the central business district is located in the middle quadrant. The terminal locations for each of the modes are then identified. In the case of air, the airport may be within a quadrant far from central city; in the case of rail, the union station may be in the quadrant containing the central business district. In an intercity rail system with a downtown distributor (MetroFlyer style, see Appendix B), three stations may be located in different quadrants of the metropolitan area. For each
intercity mode, the locations of terminals are entered into a two-dimensional array ( $5 * 5$, in the present set up), and the terminals are given an unique identifying number. Quadrants without terminals are assigned a value of NULL. For the auto mode, each quadrant is a terminal.

| Terminal Locations (Rail) |  |  |  |  | Terminal Locations (Air) |  |  |  |  |  | Terminal Locations (Auto) |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  | I | 2 | 3 | 4 | 5 |
| 1 |  |  |  |  |  |  |  |  |  |  | 6 | 7 | 8 | 9 | 10 |
|  | 2 |  |  |  |  |  |  |  |  |  | 11 | 12 | 13 | 14 | 15 |
|  |  | 3 |  |  |  |  |  |  |  |  | 16 | 17 | 18 | 19 | 20 |
|  |  |  |  |  |  |  |  |  |  |  | 21 | 22 | 23 | 24 | 25 |

Plate 5.5: Model Spreadsheet, Part 1

Using a simple algorithm, the nearest node to every quadrant in the metropolitan area was then determined, storing the results in a separate array. Using a shortest path algorithm based on distance, the shortest paths between each quadrant and the nearest node is calculated. The result is stored in a linked-list using an array of pointers. This array of pointers would later be used to calculate the access time.

## Congestion Factors

In most metropolitan areas, significant auto congestion occurs in the downtown at most times during the period when intercity travel is most likely to take place. Even if actual congestion does not occur (i.e. when vehicle density exceeds critical density), it is likely that in the downtown area, private autos will achieve a lower average speed than in the suburban areas, due to a mixture of factors such as higher density of traffic lights, lower lane widths, speed limits, and higher probability of pedestrian interference. To accurately assess the access time, these factors need to be taken into account. If the degree of congestion (between zero and one) was assumed to be inversely proportional to the distance from the city centre, the following array of congestion factors are obtained:

| Congestion Factors ( $0=$ freeflow) |  |  |  |  |
| ---: | ---: | ---: | ---: | ---: |
| 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| 0.25 | 0.5 | 0.5 | 0.5 | 0.25 |
| 0.25 | 0.5 | 1 | 0.5 | 0.25 |
| 0.25 | 0.5 | 0.5 | 0.5 | 0.25 |
| 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |

Plate 5.6: Model Spreadsheet, Part 2

If the freeflow speed of private autos on arterials were assumed to be 40 mph , and the quadrants were assumed to be four miles in length (giving a total metropolitan area of about 20 miles in diameter), the access times from each quadrant to the nearest node using the shortest path is calculated for each mode. Perhaps of crucial importance at this point is the need to stress the obvious fact that the access times are not directly comparable for the different modes from the same origin, since the location of the terminals may be different. The result from this part of the model is a set of arrays, one for each mode, containing the access times from each quadrant to the nearest terminal, using the private auto as an access mode.

For transits, the freeflow speed is similarly assumed to be 25 mph (clearly achievable with high-quality heavy-rail transit or high-quality bus service on uncongested highways). For simplicity, a generic transit network of two core rail trunk lines radiating from the city centre in an X-shape was assumed, with bus feeders serving all other quadrants. The number of transfers required to reach the central rail station and the airport was then manually calculated, based on the assumed transit network. The results are stored in an array. Again for simplicity, it was assumed that in a multi-station configuration, all travellers using transit will depart using the central rail station and the main airport. This assumption is reasonable since the majority of American cities have hub-and-spoke type transit systems which will usually result in minimum access time if travellers departed via a city centre location. Using the freeflow speeds, distances, number of transfers required, and an assumed delay per transfer ( 12 minutes), the access time to the intercity terminal was calculated for each mode from each quadrant. Some example results are shown:

| Transfers Required (Transit to Air) |  |  |  |  | Access Time (Transit to Air, hrs) |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 2 | 2 | 1 | 0 | 1 | 1.04 | 0.88 | 0.52 | 0.16 |
| 2 | 1 | 1 | 0 | 1 | 1.2 | 0.84 | 0.68 | 0.32 | 0.52 |
| 2 | 1 | 0 | 1 | 2 | 1.2 | 0.84 | 0.48 | 0.68 | 0.88 |
| 2 | 0 | 1 | 1 | 2 | 1.2 | 0.64 | 0.84 | 0.84 | 1.04 |
| 0 | 2 | 2 | 2 | 1 | 0.8 | 1.2 | 1.2 | 1.2 |  |

Plate 5.7: Model Spreadsheet, Part 3

Note that transit access time along the Northeast-Southwest diagonal is particularly good, consistent with the assumption of the X -shaped trunk rail network, and an airport located at the extreme Northeast corner of the metropolitan area. Although these results are clearly for an arbitrary city, because the model captures in an impressionist fashion all the common features of a metropolitan area that are likely to drive mode choice, the results that are obtained may be generally applicable.

## Assessing Transit Access Time

Using the access time matrix, it is possible to calculate the transit mode share for each cell. It is clear that the transit mode share would be different for each cell, and for each line haul mode. Since cell $(1,1)$ lies on the subway line that serves the downtown union station, transit mode share for rail passengers from that cell would be particularly good; however, to reach the airport from the same cell, the passengers must transfer at a centre-city transfer point, resulting in lower transit mode share relative to the private auto.

The data in the analysis captures the key features of some typical transit network designs: the airport is served by one diagonal subway line, while the railroad union station (and satellite stations, if any), are served by a different diagonal subway line, and in most part of the city the population must reach both the airport and the union station by making one or more transfers, either subway-to-subway, or bus-tosubway. The features described applies in Boston, New York, Philadelphia, and Washington (although modal transfer specifics might be different, e.g. Philadelphia airport is reached only by regional rail service). These assumptions are not intended to be accurate depictions of any city in particular or of any transit system designs. Of course, with a specific city in mind, much more detailed models could be developed; however, it is hard to imagine a transit system where significantly more people (cells) would have a one-seat ride to the union station. Sensitivity analyses could show to what extent the transit mode-share changes with number of transfers. In calibrating this model, the average transit mode share across the metropolitan area for trips to the airport was assumed to be around $15 \%$-- not unrealistic for transit-oriented cities with heavy-duty transit infrastructure and good intermodal connexions (Horowitz, 2003).

## Line-haul Mode Share

Having obtained the access modal split matrix, it is then possible to calculate the line-haul mode split between the three modes under discussion. However, this has to be done for each cell, since each cell has a different access time, thus a different total trip-time, thus a different mode share. The critical concept here is that the accessibility of the line-haul terminal (be that the airport, or the rail station), affects the total intermodal journey time and thus the line-haul mode share. This reflects the argument that high-speed rail advocates have often used to promote high-speed rail -- that it brings you right to the heart of the downtown. By calculating the mode share for each cell, and integrating the demand
density across the metropolitan area, it is possible to quantify the extent to which this downtown advantage plays a role in attracting traffic, and how much traffic is actually coming from the suburbs.

The most recent numbers in intercity travel surveys show a vast majority of the traffic (more than $90 \%$ in most markets) is captured by the highway mode (American Travel Survey, 1995). Thus, potentially, enhancing the access for collective carriers could apply both to the airlines and intercity rail. Indeed, airport access has already been identified as an issue constraining the growth of domestic aviation, although it is not clear that the airport access research has focused on reducing the access time to airport as an airline growth strategy (see Chapter 3), instead it has focused on moving as many people to the airport by mass-transit as possible. The argument that aviation technology is inherently constrained by the long access time, due to its massive land requirements, is not often heard, but is potentially important to the passenger rail industry.

| Rail Mode shares, by cell |  |  |  |  | Air Mode shares, by cell |  |  |  |  | Auto Mode shares, by cell |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.37 | 0.35 | 0.34 | 0.31 | 0.29 | 0.4 | 0.42 | 0.44 | 0.47 | 0.51 | 0.23 | 0.22 | 0.22 | 0.21 | 0.2 |
| 0.37 | 0.38 | 0.34 | 0.32 | 0.31 | 0.39 | 0.4 | 0.44 | 0.47 | 0.47 | 0.24 | 0.22 | 0.22 | 0.21 | 0.21 |
| 0.38 | 0.36 | 0.37 | 0.34 | 0.34 | 0.38 | 0.41 | 0.42 | 0.44 | 0.44 | 0.24 | 0.24 | 0.21 | 0.22 | 0.22 |
| 0.37 | 0.36 | 0.36 | 0.38 | 0.35 | 0.39 | 0.41 | 0.41 | 0.4 | 0.42 | 0.25 | 0.23 | 0.24 | 0.22 | 0.22 |
| 0.35 | 0.37 | 0.38 | 0.37 | 0.37 | 0.4 | 0.39 | 0.38 | 0.39 | 0.4 | 0.25 | 0.25 | 0.24 | 0.24 | 0.23 |

Plate 5.8: Model Spreadsheet, Part 4

While calibrating this model, it was discovered that there is an unexplained tendency for the current population to congregate towards the private auto. A likely explanation for this is that auto dominates for more than one person trips, and the majority of intercity travellers travel in parties of two or more. Although a collective transportation market share of up to $25 \%$ is possible in cities with good transit infrastructure such as New York City, the majority of intercity trips are still made by the private auto. The auto mode shares predicted by this model seem unrealistically low. There are a number of reasons for this. The model in question only considered utility of time, and did not consider two important mode-choice drivers: the actual costs of making the trip, and the perceived out-of-pocket costs of making the trip.

The distinction between actual costs and perceived costs are important: most consumers, when choosing the private auto, consider only out-of-pocket gasoline and toll costs; the ownership costs, maintenance costs, insurance costs, infrastructure costs and other costs not directly associated with the trip are attributed as 'cost of living' and thus sunk costs. When choosing a collective mode, these 'hidden' costs are charged up front by the carrier. Thus, the auto trip appear so generally attractive that in many cases
consumers do not even consider other modes as a viable option. The other issue is that the consumers are making a constrained optimization decision given that the sunk costs associated with the auto (often in the form of a car loan and pre-paid insurance) is a commitment they cannot retract from. This explains the popularity of the auto in intercity markets even though rationally it seems to be a terrible choice for one individual.

### 5.4.3 Results and Sensitivity Analyses

The model initially predicted a $35 \%$ mode share based on the input assumptions that were made, with three stations distributed in a linear fashion within the metropolitan area. By removing two of the stations and leaving the downtown union station, the model suggested that the rail market share will fall to $33 \%$. Significantly, with the single station, it was necessary to upgrade the average line-haul speed from 90 mph to 100 mph to bring the market share back to $35 \%$, recovering the market share 'lost' when the number of stations were reduced.

The result may seem somewhat obvious, and could have been found simply by trading off average access time and line-haul time. However, many in the transportation professional community still focus on speed more than access or total travel time.

There are a number of problems with this model that preclude useful sensitivity analyses. When testing sensitivity to distance, the model gave the result expected: that better access for shorter corridors created more impact than better access for longer corridors, since the high line-haul speeds of the air service became relatively more important as the length of the corridor increased.

### 5.4.4 Discussion

The small changes observed in this model could easily be dismissed as noise. However, these are important noise. This model suggests that simply by opening two new access nodes, along the alignment of an existing right-of-way, could have as much impact as upgrading the entire 250 -mile line to achieve an increase in average speed of 10 mph . The $2 \%$ (or less) market share changes are not significant, against the backdrop of $80 \%$ or more of intercity trips completed by private auto.

The important question here is, where else in the transportation network, could you add two nodes, to achieve such dramatic impact? This is an operating environment in which hundreds of million of
taxpayer dollars could be justified to re-open a commuter rail line which will carry a measly 12,000 trips per day - something like a $0.24 \%$ market share increase in daily commuting trips.

As will be examined in the next section, these extra nodes (and perhaps new urban rights-of-way) could bring important benefits for the city, if the right-of-way could be shared between urban and intercity transportation.

### 5.5 Analysis of Alternate Technologies

The application of Performance-Based Technology Scanning (PBTS) in this case, would pit a number of alternatives against one another. The utility resulting from shorter access time and minimization of transfers would be traded off against incremental speed improvements, amenities enhancements, and deployment of new e-commerce technologies. The methodology used is one of systems analysis: instead of focusing too closely on a specific geographic situation, with its specific nuances, the situation is simplified to give a general idea as to which areas are the most promising. Having identified the likely mix of technologies required, detailed engineering analyses for a specific corridor could then be carried out to robustly demonstrate a business case for a specific enhancement package.

## Base Assumptions

The base case is a 200 -mile corridor connecting major population centers, with three intermediate stops and competitive highway and air access between the metropolises. The current air service provides an in-vehicle time of 75 minutes, plus access time from out-of-town locations and extra terminal time for security clearance. The current highway access is provided by high-capacity urban expressways through the middle of all population centers en route, and the current rail access is provided by a traditional-style rail service that provides a service at an average speed of 75 mph , stopping at all downtown areas. Not surprisingly, the rail carrier is finding it difficult to attract any customers. The government has mandated $\$ 2$ billion to be spent on rail infrastructure in this corridor, to bring it up to standard. The question is, how should we spend the funds?

## The High Speed Rail Proposal

The high speed rail advocates have tabled a proposal which would spend the $\$ 2$ billion exclusively on right-of-way enhancements to bring the maximum track speed up to 150 mph , a modern standard.

Engineering analyses has shown that in this particular corridor, an average speed of 110 mph is sustainable if all intermediate stops were removed, and $\$ 2$ billion were spent on right-of-way improvements in the most cost-effective manner, including the use of tilting vehicles.

## The e-train Proposal

The electronic commerce advocates and the business community have advocated a proposal which would install high-speed wireless internet service points along the right of way which would turn the train into a mobile office. Computer power-supply points would be provided in the train, and the trains would be refitted to provide space for working, including a limited number of public terminals which could be used by patrons without laptop computers. The wireless service points will also ensure highquality, low-price cell phone calls, for those equipped with the suitable cell phone plans. Together, this package of improvements will cost $\$ 2$ billion in new vehicles, telecommunications infrastructure, and other equipment. The wireless service will also create positive externalities (worth $\$ 30 \mathrm{~m}$ annually) by providing cheaper wireless communication for the residents adjacent to the rights-of-way.

## The Hotel Train Proposal

The vacation travellers have suggested that the $\$ 2$ billion could go towards subsidizing luxury cruise trains between the two metropolises to bring luxury rail fares in line with current airline levels. $\$ 500$ million of the funds would be spent on station improvements at either end, to institute such features as walkways to the downtown tourist centers and resorts, as well as setting up concessions in and around the stations to create a transit-center mall; another $\$ 500$ million could be spent on new luxury railcars; while the $\$ 1$ billion remaining would be invested, and its proceeds used as a fare-stabilization fund that will keep the fares at affordable levels.

## The Downtown Proposal

The neighbourhood groups from one city has presented a plan for expending the $\$ 2$ billion on a new rail alignment downtown which would move the rail alignment into a more affluent part of the city. $\$ 1$ billion of the funds would be expended in creating two new Park \& Ride stops and other urban neighbourhood stops that did not previously exist, while the remaining $\$ 1$ billion would be expended in constructing a tunnel to by-pass a congested freight rail yard in the city, resulting in a 5-minute journey
time saving. The new by-pass will also serve as a subway alignment that creates positive externalities (worth $\$ 60 \mathrm{~m}$ annually) by providing transit in an area that did not previously have heavy-rail transit.

## Benefit Analyses

Given the fixed-cost nature of this analysis, it is possible to simply consider the benefits in each of the proposals, and presumably the scheme with the most benefits is the best scheme. This does not necessarily mean that scheme should be chosen - whether the scheme is viable would depend on such matters as the opportunity cost of funds, which are outside the scope of this analysis. The application of the PBTS framework is intended to demonstrate that such completely different benefits and proposals could be evaluated with a utility analyses framework.

|  | Base | HSR | e-train | Hotel | Downtow |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Distance | 200 | 200 | 200 | 200 | 200 |
| Speed | 75 | 110 | 75 | 75 | 75 |
| Rail Time (rt)/hrs | 2.7 | 1.8 | 2.7 | 2.7 | 2.7 |
| Access Time (at)/hrs | 1 | 1 | 1 | , | 0.5 |
| Disutility of rt/\$-hr | 20 | 20 | 15 | 12.5 | 20 |
| Disutility of at/\$-hr | 30 | 30 | 30 | 30 | 30 |
| rt saved/person | 0 | 0.85 | 0 | 0 | 0 |
| at saved/person | 0 | 0 | 0 | 0 | 0.5 |
| Annual Ridership/m | 4.0 | 6.0 | 4.5 | 4.5 | 4.5 |
| Sum(rt saved) | 0 | 5.1 | 0 | 0 | 0 |
| Sum(at saved) | 0 | 0 | 0 | 0 | 2.3 |
| Sum(utility gen.)/m | 0 | 102 | 60 | 90 | 68 |
| Externalities/m | 0 | 0 | 30 | 0 | 60 |
| Annual Benefits/m | 0 | 102 | 90 | 90 | 128 |

Plate 5.9: Model 2 Spreadsheet 1

Using this very simple framework, coupled with an equally simple set of assumptions, the downtown access package was found to be the most beneficial. Interestingly, the high speed rail option was found to benefit the riders the most, while the downtown access and e-train proposals have significantly positive externalities.

## Other Possible Analytic Improvements

The analysis performed here is simply an example, and contains many assumptions which may or may not be justified. It is very simplistic, but it serves to illustrate the gamut of issues that a project evaluator or public funding body must consider when contemplating investment. A private company would
obviously only be interested in benefits they are able to capture; in the case of high speed rail, if rail is a price-taker in the market, perhaps none of the journey time advantages would actually be captured in the revenue stream. On the other hand, in the e-train exampline, it may be possible to capture these nontransportation benefits by offering the wireless telecommunication services to the abutters, at a fee.

To form a defensible analysis of technologies, each of the values of benefits must be substantiated either through a revenue model, or other methods of evaluating consumer surplus. As detailed in another paper, Lu \& Martland (2003) investigated the cost-effectiveness of a number of high-speed rail technology options: (a) dedicated right-of-way high speed rail; (b) magnetically levitated ground transportation; (c) a number of incremental retro-fit methods, including an adaptation of maglev technologies to conventional rail lines. The study found that, on the basis of infrastructure investment cost per minute saved over typical terrain in the United States, conventional route improvements (such as minor realignments of existing rail rights of way) were about equally cost effective as the incremental maglev method, where guidance magnets are retro-fitted to existing infrastructure to enable curving at higher speeds. The benefit of incremental maglev over conventional route improvement is that it is able to achieve much more journey time reduction than small-scale realignment. Both of the approaches frequently advocated by high-speed rail lobby groups, new conventional HSR link, and new maglev link, was less than half as cost effective, even though a new maglev link could potentially achieve many more minute savings. There is thus a diminishing return effect with respect to time saved. Those who are interested are encouraged to read that paper.

Geographically-based analyses, which can be carried out by dividing metropolitan areas up into cells and calculating journey time from each cell to the nearest access point, will give us a much better idea as to how much access time can be feasibly saved. Multimodal mode-spilt analysis will tell us how much the access is likely to affect existing highway and airline pattons. The positive externalities could be subject to a much more rigourous analyses than is presented here. The utility of time and of time-saved could be disaggregated into different market segments and other such detail. For instance, in Slide 5.4, we demonstrated that an average time saving of 20 minutes per passenger trip was possible if London rail terminals were directly connected with each other.

Computer simulations could be used to calculate the loci of influence of introducing a new rail terminal, as detailed in Slide 12 in Appendix B. The mode-shares were predicted using a simple nested logit model, involving two choice phases: the mode-choice for the access mode, that subsequently affects the mode-choice of the line-haul mode by altering the total trip time that includes the access time. By virtue
of the short total trip time, airlines can dominate an entire metropolitan area from one single airport, unless rail access in a locality is extremely good. This suggests that introducing extra stations in the metropolitan area will have a very positive benefit for the rail carrier.

The Track Capacity Studies, shown in Slides 9 and 25 in Appendix B, used an operations-planning simulation model implemented in Excel to calculate the likely positive externalities by introducing an intercity rail tunnel through the downtown and some city neighbourhoods. The operations planning simulation showed that track sharing is indeed feasible given operating discipline, while the ridership model showed that, especially on low-volume intercity corridors, the most significant benefit of an intercity tunnel is through carrying the city population while the tunnel isn't being used by an intercity train. The high-speed rail option in the present analyses assumed fairly high ridership volumes of 4 million annually; if that number were lower, the external benefit of the downtown upgrade begins to look much more significant against the rider benefits of having a faster train.

### 5.6 Conclusions

In this chapter, we have demonstrated an important methodology with which high-speed rail schemes should be evaluated. Firstly, the issue of access to high speed rail services has to be taken seriously, if high-speed rail advocates wishes to be considered as a viable voice in promoting mass intercity transportation. Secondly, to demonstrate that a high speed is really necessary, the speed enhancement must be explicitly traded off against other possible enhancements in a utility framework.

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## Chapter 6

## High Speed Rail Route Planning for Overnight Services

This chapter reviews a Swedish study on overnight train service (Troche, 1999), and our own study of overnight train service, carried out independently in 2002. Our study is roughly based on the Performance-Based Technology Scanning framework, while the Swedish study came from a carrier operations planning perspective. The central thesis is that, given the general principles of: (1) shared traffic rights-of-way, (2) market-oriented service planning, (3) no 'subsidized' competition, in certain markets overnight rail service can actually be a lucrative proposition. Corridor proponents often incorrectly see overnight service as 'the enemy'; whereas the two services actually complement each other, and both have their own strengths and problems.

The main problem with corridor service is the service frequency that is needed to compete with other transportation options such as the private auto, highway, air, or even buses, which carry much smaller number of passengers per vehicle-formation. In very high density corridors, high-speed, highfrequency, short-distance service has carved out a niche; however, to support that type of service, great demand density is required. In longer and lighter density corridors, rail service should exploit a different niche -- a service that operates a few times daily overnight, offering a comfortable journey and the opportunity to wake up at the destination with a full business day ahead. While overnight services have higher vehicle and infrastructure costs, they requires much lower frequency and are likely to carry far higher load factors due to temporal-consolidation. Operationally speaking, it is somewhat more cumbersome and must be managed in a different way - however, efficiently run, the economics should work in at least a number of corridors.

### 6.1 Review and Discussion of the Swedish Findings

Gerhard Troche has done the intercity rail community a service by issuing his working paper on overnight services. He addresses issues that are poorly understood by those who have little experience with night-train traffic -- which is a strange combination that falls somewhere between the expertise of the freight transportation, regional rail, and hotel management communities. The overnight service is like a freight train because it is a 24 -hour operation and typically uses loose cars; it is like a regional rail because it transports people and is important for it to arrive on time; it is like a hotel because amenities and service are a very important part of the package. Thus, the issues are: (1) railcar interior design; (2) trunk service design; (3) connection with day trains. These may sound like familiar issues, but they require a different kind of thinking than those in the parts of the transportation industry who are seeking to minimize journey times are used to. Unfortunately, with the demise of overnight ferry services in Europe, and the demise of the streamliners and much of the rail cruise industry in North America, much of this expertise has been lost.


Plate 6.1: Overnight Services do not have to rely on fully depreciated assets

## Economic Issues

Troche paints a very negative but realistic picture of night-train economics. Intercity buses, airlines, and the private auto have all become much more formidable competitor since even the 1980s. An issue unique to Europe is the added complication of the need for cross-border cooperation. Due to the generally increasing speeds of rail services, overnight trains are travelling over increasingly long distances and thus have a higher probability of crossing national boundaries. Troche asserts that even though the day-train market had been growing and night-train market shrinking, this is because there had been major investment in day-trains but no comprehensive effort to coordinate night-train traffic. Despite the increasing prominence of the day train, the night-train is not 'just a niche market' -- it is an important area of the passenger rail core business, especially if the full network benefits of multi-national highspeed networks are to be realized.

Troche asserts the night train suffers from high costs and poor utilization. A simple analysis of available-seat/bed-miles (ASM) per vehicle shows the regional day train to be four times as productive as the night train, and the high-speed train to be six times as productive. In addition, there are additional crew costs associated with the night train. These are accurate characterizations, except that in regions of low day-train demand, analysis of revenue-passenger-miles (RPM) will tell a different story. Using Boeing's Decision Window Model, the following temporal-demand prediction for an eight-hour trip is obtained:

Allocated Time of Day Demand (8.000 Hour Delta-T)


Plate 6.2 Allocated Time of Day Demand (8.000 Hour Delta-T)
This demand curve suggests that for an eight-hour trip, the majority of the people would prefer to depart some time between 7 am and 1 pm , arriving between 3 pm and 9 pm , although there is a sizable minority who would choose to catch the 'red-eye' and arrive the next morning. A few caveats are important here: (1) this demand curve assumes airline passengers, who had no other ways of getting
there; (2) this demand curve assumes the effect of journey time is unimportant: the time-of-day demand being driven entirely from the path with the shortest journey time, thus demand allocation sensitive to both journey time and departure time is not possible to capture with this model.

Using Boeing's model, six paths were created: one was the overnight train, leaving at 10 pm and arriving at 6 am with AEM-type equipment. The remainder are bihourly express trains (that also take eight hours), using Acela-type equipment. This timetable is typical of Northeast Corridor services between Boston, Massachusetts and Washington, D.C. The model shows that that the night-train captures $16.4 \%$ of the traffic with $16.7 \%$ of the resources (one out of six trainsets). Interestingly, the Morning Congressional leaving at 6am to arrive at 2 pm actually only captures $8.7 \%$ of the traffic!


Plate 6.3 Decision Window Path Preference Model (Time Model)

This is obviously an overly simplistic assessment of the situation. However, it is clear from this example that corridor daytime trains can be resource heavy because of the requirement for frequent service. If service went from bihourly to hourly, the night-train turns out to be the most effective at capturing passengers ( $14.2 \%$ ), using $10 \%$ of the resources (one trainset out of ten) -- more than the maximum of $13.4 \%$ captured by the 9 am departure and $13.2 \%$ captured by the 10 am departure.

The other issue not considered here is the effect of airline competition. As previously mentioned, the demand curve is for all passengers. In corridors where airlines are operating, the temporal-demands are actually split by the carriers based on both journey time and time of arrival and departure. The demand curve are likely to be driven at least partially by the equivalent 2 -hour journey available via air. The
shape of the curve is likely to depend on complex factors such as purpose of the trip, and itinerary planning. Day-trippers who can do so are likely to fly both ways; day-trippers or vacation-makers preferring no loss of sleep are likely to travel one-way by overnight train and fly the other way. The temporal-demand is at least partially driven by the choice of mode. Given an institutional framework that allows free-choice between overnight train and flights, with no financial penalties and any combination of air and overnight train, many more people may choose to take the one-way overnight train.

The problem for overnight trains with the current set up is that travellers often are constrained to choosing either a round-trip airfare or a round-trip train fare. The key innovation here is for the computer reservation systems (CRS) algorithms to smarten-up when planning itineraries: when pricing a round-trip between night-train served cities, rail-air combination ought to show up alongside day-trip flight combinations. Willingness-to-pay pricing could then be applied at this point, extracting the same consumer surplus, whatever combination of modes the passenger happen to choose.

None of this work is intended to discredit the current Amtrak timetable. The reason for the 6 am Acela Express departure from Boston is related to day-tripping New York passengers, not those wishing to arrive in Washington between 1 pm and 2 pm . In any case, the Boston to New York passengers give rise to a much higher yield than the longer-distance passengers. The additional complication with highspeed trains is that, unlike airlines, trains stop en-route thus a train-path is not necessarily the same as a passenger-path.

The day-train appears much more lucrative and productive as the schedule is designed for the day train vehicle to criss-cross between regions of very high demand density, compared to the market that nighttrains operate in. If the day-train vehicles were used to offer locals along the route of the night-train, it is likely that the night-train is likely to achieve much higher productivity and load factor. The core issue here is that the 600 -mile market has always been a much less lucrative market for rail -- and the key is to time night-trains such that arrivals can also serve peak daytime demand as the trains travel into town early in the morning. The creative tweaking approach is needed in such markets; abandoning such a market may be a management response to focusing on the most leveraged market segment.

There is a research need for an integrated intercity demand model which is sensitive to modepreferences as well as schedule-preferences. It is conceivable that with shared right-of-way with other corridor trains and freight trains, the overall system costs could be reduced by carrying some of the
current airline passengers who are flying in the morning peak in overnight trains instead, at the same time improving the passenger utility by allowing passengers to avoid waking up early for a flight. Part of the problem is that airlines and railroads have never cooperated to this extent, and airlines often don't understand that the highest fixed costs are incurred during the peak hour. The integrated system may well become impossible to manage due to its complex nature involving many modes, but the idea represent an as-yet untrialled transportation system configuration.

## Further Investigation of Time-of-Day Demand Curves

Using Boeing's Decision Window Model, an attempt was made to assess the amount of traffic that could be captured with an overnight train that is equivalent to a two-hour flight either in the morning or in the late evening. Using airline demand data for two-hour air journeys, it was found that $79 \%$ of demand occurs between arrival times of 11 am and 10 pm , a time-period when overnight trains are not competitive. The demand curve showed three peaks: a morning peak, presumably from business travellers travelling to a mid-morning meeting; a midday peak, presumably predominantly from vacation travellers, and an evening peak, presumably from business travellers heading homewards after work or meeting.


Plate 6.4 Allocated Time of Day Demand (2.000 Hour Delta-T)

It is not clear to what extent this demand curve, which is based entirely on airline passenger surveys, would be affected by the availability of overnight services. Using a simple model developed in Excel, a hybrid demand curve was created from the temporal-demand prediction for an eight-hour trip, and that from a two-hour trip, based on considerations of overnight services competitiveness for demands that occur within a specific departure time window. Based on this line of reasoning, the overnight services competitiveness depends on one key variable: to what extent overnight services are able to capture the airline demands that occur during the periods when airline services and overnight services are reasonably
substitutable? Consequently, this key variable also affects to what extent the demand curve would be affected by the overnight services: if overnight services can capture most of the traffic, then the demand curve would have a much more substantial late-evening peak centered around 10pm; if overnight services captures very little traffic, the demand curve would be very similar to the one shown above for a two-hour trip. Hereafter, this variable would be referred to as the overnight services base potential (ONSBP). Using ONSBP of $50 \%$, the following time-of-day demand curve was obtained:


Plate 6.5 Combined TOD Demand, OSNBP $=50 \%$

From this graph, it is fairly clear that overnight services would not have a major impact on the time-ofday demand curve -- since ONSBP of $50 \%$ is perhaps unrealistically high, at least for a market that isn't particularly mature. Based on the British Rail experience, where in corridors such as Glasgow-London, overnight services captured something like a 6\% market share of daytime trains (where daytime trains achieved a roughly $50 \%$ market share of total traffic), ONSBP really should be something more like $3 \%$ ! However, these numbers can be misleading, since overnight services in the Glasgow-London corridor is not well-developed and certainly British Rail's continual active effort to kill it between 1980 and 1994 has contributed to the low market share. As Troche notes in his report, overnight services have never particularly suffered from the lack of demand -- it's the high operating costs that is the problem! As previously discussed, the apparently high operating costs may have resulted from corridors that are not long enough to justify overnight services.

Thus, in a corridor where overnight services can potentially be justified (a market like New York to Chicago), we can perhaps expect overnight services to capture about $20 \%$ of market share available during the target periods. Sensitivity analyses gave the following results:

|  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Lexcie Lu, MIT CTS, 19 April, 2003 |  |  |  |  |  |  |
| Daily Passengers in Corridor |  |  | 4,000 |  |  |  |
| Train Capacity (8 cars) |  |  | 200 |  |  |  |
| ONSBP\% | 0\% | 3\% | 6\% | 10\% | 20\% | 50\% |
| Rail MS | 0.00\% | 0.71\% | 1.44\% | 2.4\% | 5.0\% | 13.8\% |
| Pax/day | 0 | 28.4 | 57.6 | 97.6 | 201.6 | 550.4 |
| Trainloads | 0 | 0.14 | 0.29 | 0.49 | 1.0 | 2.8 |

Plate 6.6 Sensitivity Analyses, OSNBP v.s. Rail Market Share

From this study, it is evident that the breakeven point for a large market requires an ONSBP of about $20 \%$-- not unachievable, but not easy. For instance, in Italy, where the overnight services network is very developed, $43 \%$ of all travel takes place during the night (Troche, 1999). The initial study (Lu \& Martland, 2001) overestimates the potential demand in overnight capacity, as it did not consider the effect of portions of trips that occur during the time window when overnight services are competitive. The current study suggests that daily passengers volumes of at least 4,000 and an OSNBP of $20 \%$ is required for operation.

However, this is not to suggest that overnight services are not an important product. With ONSBP of $20 \%$, the largest markets could support at least one train daily; smaller markets could be consolidated, since overnight train is able to "pick up" in many cities before embarking on the long overnight journey, a point discussed in more detail in the Swedish report.

Given the above quantitative analysis, it appears that the many advantages of overnight train are overshadowed by the fact that air travel is a lot faster, and could take place during the day without too much intrusion into the traveller's schedule in the $800 \sim 1,200$ mile market. Where overnight services are available, and effectively marketed in conjunction with air service, overnight services may offer an attractive alternative to travellers wishing to make their journey time "disappear" while they sleep. How the market will respond to this kind of trip-based multi-modal marketing is anybody's guess, as airlines around the world have never marketed overnight rail services as an alternative to early morning or late evening flights in an integrated sort of way.

### 6.2 Review and Discussion of the Initial Study

The initial study (Lu \& Martland, 2001) was primarily based on the author's experience while working with a train operating company responsible for operating the Anglo-Scottish Sleeper service in Britain.

Previously under British Rail, Britain boasted one of the most extensive overnight train services anywhere in the world, with services resembling a totally-connected network between most important origins and destinations. During the sectorization in the late 1980s, overnight services were singled out as a business sector that generated heavy losses. As train speeds increase on day time trains, journey time between most major population centers broke the four-hour psychological barrier, resulting in heavy cut-back of overnight services. As of 2000, only Anglo-Scottish overnight services remained, and overnight service to the north of Scotland was continually under threat.

The initial study examined ways in which the overnight service concept could be made profitable in North America, where urban centers are much further apart compared to those in Britain, and highspeed daytime train infrastructure much more lacking. As part of the study, many of the issues surrounding the overnight rail service design and infrastructure cost sharing with proposed high-speed daytime corridors were explored. In this section, the results of the initial study are compared and contrasted with those from the earlier Swedish study, which is predominantly aimed towards connection from Scandinavia to continental Europe. Potentially, the same findings could apply to connections from Britain to continental Europe, as the Scandinavian peninsula bores much resemblance to the British Isles in terms of their relative location from the major European population centers.

In the initial study, the Capitol Flyer scheme is suggested as a strategic solution to North America's high-speed rail problems. Local high-speed corridors could be planned in such a way as to accommodate long-distance overnight services, which provide an alternative to airlines both as redundancy and to provide travel options. In developing the initial study, focus of attention is devoted to capital costs as rebuilding the passenger rail infrastructure at vast capital expense would be necessary before either high-speed corridor or overnight rail would become competitive.


Plate 6.7 The Capitol Flyer - Legacy of the B\&O
(and successful overnight high speed rail proposal - by joining existing corridors)

## Market Segmentation

The Swedish makes a very important observation: that night-trains must be rolling hotels and youth hostels at the same time (Troche, 1999). In the airline industry, market-segmentation has been achieved through restrictions on ticket flexibility -- with the results that airlines were able to build a network that served both business and leisure passengers. The airline model works, as long as there are no low-price entrants. The low-price entrant builds a smaller network serving only the most profitable flows, resulting in the loss of cross-subsidy between routes and service levels. In the overnight rail market, market segmentation through ticket restrictions can be difficult to achieve since the traffic volumes are low, and the advantage of the overnight service (i.e. avoidance of an early morning or late evening flight) is insufficient to extract high willingness-to-pay from high-margin market segments.

The strategy suggested earlier of introducing multimodal, trip-based pricing may solve some of these problems. With control over both the rail and airline links, the carrier is able to price in a way which extracts most of the consumer surplus; in essence, the overnight rail will no longer compete directly with the early morning flight, but instead the price is simply based on competitiveness of other airlines, the overnight bus, and the private auto. Given the consumer's typical utility function, it is likely that overnight rail would be used to an extent much greater than the status quo if the competing airline trips were priced differently.

As it stands, it is not clear that either airline, rail, or highway costs reflect a fully-allocated costs of providing transportation; both air and highway modes have Federal capital subsidy, and increasingly rail carriers are accepting infrastructure subsidies from the Federal government. Permitting joint-pricing (or collusion) between air and rail carriers may actually induce more rational choices on the part of the consumer as to how they plan their trip. As demonstrated in the last section and concluded in the Swedish study, the lack of demand is not much of a problem in the overnight market; while the overnight rail costs are more than an early morning flight for the same travel distance, it also generates much more utility. If distorted market conditions in the short-run did not exist in the airline industry (i.e. infrastructure subsidies, sunk cost in expensive fleet), and costs were fully allocated, overnight rail could fit better with many consumers' travel schedules and plans.

In short, subsidy of air and highway travel has led to over-consumption of these modes that cannot be rectified in the short term due to the problems of long-lasting assets. As a result, from a strictly utility point of view, consumers are consuming less overnight rail travel (and more airline travel) than is optimal. Thus, market segmentation, airline-style, is not possible, as overnight rail has no pricing power.

## Service Planning Issues

The Swedish study distinguished between three types of night-train markets: (1) evening departure, morning arrival; (2) departure after work, morning arrival; (3) departure after work, late morning arrival. Each type of night train service also served markets of a particular distance (although the distance should be regarded as an upper bound, as it is always possible to operate the trains at a lower speed to enable a shorter distance to be covered by an overnight service. In terms of service planning, Troche observed that night trains are most competitive where a population center remains relatively isolated from a number of others (e.g., there is at least 625 miles between Stockholm and most large European cities). In those circumstances, the night-train could be an attractive alternative to airline service where direct service to most cities could only be sustained a few times daily.

Applying the concept to North America, it is conceivable that with trains operating at 90 mph , Washington is a city where this idea could perhaps be successfully applied. At 90 mph , a number of important population centers are reachable overnight: Boston, Pittsburgh, Cleveland, Buffalo, Cincinnati, Atlanta, and the Carolina coast. A similar concept could perhaps be applied to Chicago. However, part of the problem is that with smaller number of population centers and a more dispersed pattern of economic activities, flights with regional jets or simply the private auto may remain a cheaper
way to achieve roughly the same objectives. Because of the high capacity of an overnight train consist, it is likely to replace some four to eight daily flights, while many cities can only justify one to two flights daily to each destination.

In terms of operating principles, Troche discussed the concept of the CityNightLine philosophy. Night train would make a series of stops between 8 pm and midnight, and travel non-stop between midnight and about 6am, before dropping passengers off until perhaps as late as 10 am . The concept has been in practice on the Deutsche Bundersbahn network for a number of years. The concept was independently explored in the initial study (Martland \& Lu, 2002), using Scotrail's Sleeper services and a hypothetical American service as examples.

Troche explored in detail the concept of designing routes with many detours, making the important observation that while journey time is an important drive in day traffic, in night traffic the arrival and departure times are more critical. As a result, day trains often have a trunk section with many connecting branches, while overnight trains can take circuitous routes and 'drop-off long-distance passengers in a polycentric region like a local.

In the initial study, this concept was applied to North America geography, while attempting to minimize costs of right-of-way since high-quality, high-speed passenger railroad network is not readily available in North America. The initial study introduced a novel way of serving long corridors such as the Northeast Corridor with overnight services. Instead of having a single train which must pick-up from a range of cities along a corridor between 8pm and midnight, two trains could be used to cover a longer corridor. Thus the first section of the train would leave from the northern end of the corridor, while the second section would leave from the middle at the same time, thus shortening the pick-up window. Cars could then be exchanged as the southern portion stops and wait for the northern portion to arrive at a predetermined location. In the morning, the two trains could head off to different destinations (or different sections of the same long corridor) to perform drop-offs. (See discussion on Cumberland Sleeping Sidings, Lu \& Martland, 2002). This method of operations can be somewhat similar to today's package-express freight operations. The crucial feature of this operating plan is that the customers are not disturbed by the need to change trains in the middle of the night.

## Railcar Interior Design

This topic is discussed extensive in the Swedish report. Troche has collected a comprehensive set documentation of existing state-of-practice and new ideas in terms of how to lay out an overnight railcar. His recommendations centred on a design that would combine both daytime and overnight traffic in the same vehicle, so that effective use could be made of the vehicle during the day.

Given the comprehensive coverage in the Swedish report, this topic will not be covered in this thesis. It is conceivable that more effective use of space could be made than the current Viewliner and Superliner designs, but given the paucity of intercity passenger services currently in North America, it is unlikely that railcar interior design would be a driving factor in making North American overnight rail services more viable.

## Other Issues in Overnight Services

Attention was drawn to the fact that market expectations of transportation services in Europe may be markedly different from that in North America. In particular, some issues that have been raised with respect to adapting a proposed overnight service to the North American environment:

- Americans like their private space more than Europeans. One issue that has been raised in the Swedish report is the poor utilization of space in an overnight services car. If the seating density could be increased, the cost of overnight services would fall dramatically. The problem here is that to increase the seating density will necessarily require some sharing of space by fellow passengers, who may be total strangers. In Russia, overnight cars exist in which a single large compartment is shared by six travellers, none of who may have met previously. As an European, I do not find this strange, although apparently in the American culture such proposals are considered unsafe and unacceptable to most people. This may also explain in part the American's obsession with the private car, which offers a private space during travel not offered by mass transit. Certainly, security and privacy concerns are cited by non-transit users as reasons for not using transit.
- Americans like larger space than Europeans: Staying in a hotel may be preferable to staying on an overnight train simply because the hotel offers more space. In Europe, due to a number of practices that have been in place for a number of years, including traditionally higher costs of transportation and energy and more conservative zoning practices, the population are much more used to living within smaller spaces, which resembles a train more than it resembles a hotel room.
- Americans wake up earlier. In Europe, the business day starts at around 9am, although the practice varies from region to region and some regions of Spain has business schedules that calls for a midday break. In North America, because of the traditionally longer commute and earlier start of business day in some regions (8.30am in New England, 8am in Chicago), the attraction of the overnight train may be reduced because the barrier to waking up early for an insanely early flight is reduced. Although on a macro level, this should not make any difference, the author's experience suggests that business practices in Europe tended to rely much more on arriving at around 10am if intercity travel is involved, whereas in North America, because of the larger geographic area, peoplc are much more used to scheduling later meetings. Thus, comparatively, the attraction of overnight services are eroded.


### 6.3 Conclusions

In this chapter, a novel way to ascertain demand in the overnight rail market is demonstrated, with inconclusive results. Although it was not possible to show that a certain level of demand for overnight services exist, it was shown that the level of demand is not zero and that a significant consumers ought to prefer overnight services if cost is not an issue and that the service was marketed jointly with air services.

The overwhelming conclusion of this investigation that the problem facing overnight services is the current institutional structure which puts air carriers at odds with rail carriers, and commuter, corridor, and freight rail carriers at odds with long-distance rail carriers. Because commuter services affect a large number of people, while air services have up to recently been considered for-profit propositions, there has not been any real effort to integrate air and overnight rail services, while efforts to improve it has been sparse compared to the amount of attention and public funds devoted to commuter rail and other travel options, such as highways.

An important point to note is that expertise in overnight services management still exists at least in one segment of the professional community. Regions (such as Sweden and Scotland) that have traditionally been isolated from major population centres have developed considerable expertise in operating overnight services and making them work. While overnight service will probably never become the most leveraged portion of rail operations, if implemented wisely and coupled with existing high-speed
corridor infrastructure, it could be a much more formidable competitor than previous experience and studies have demonstrated.

Overnight rail is not an inherent loser. Overnight services possesses inherent advantages that cannot be matched by either daytime rail services, the private auto, or the airlines. It is up to managers of overnight services to exploit these advantages. Management of overnight passenger services is a separate discipline, distinct from management of daytime corridor rail services, freight services, or hotel business. Recognizing this unique position of overnight services management, railroads that have them should be establishing overnight services as a separate business sector and instituting a separate management team for such services that have special requirements and represent an unique facet of passenger rail operations.

Consumers may be willing to pay the increased costs associated with overnight services if true marginal pricing is instituted for all modes (or indeed, fully-allocated costing is instituted for all modes). There is currently no data to support or refute the claim of overnight services' poor economic performance, as the current poor economic performance of overnight service could be explained by other factors such as less-than full cost allocation on competing modes, or simply a lack of strategic management on the parts of some overnight services operators.

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## Chapter 7

## Summary and Conclusions

Metropolitan access in today's large and sprawling metropolitan areas plays a vital role in rail transportation - both in terms of its competitiveness against other modes, and in terms of costeffectiveness of investment alternatives in delivering customer satisfaction. This is generally true in all the market segments analyzed: commuter rail, regional rail, intercity rail, and overnight services.

The objective in intercity transportation is to deliver customers from their actual origin to their ultimate destination - and not from the nearest intercity transportation facility (such as an airport or a downtown union station) to the facility nearest to where they are going. Although a proportion of intercity trips are likely to originate from the downtown core, many more intercity trips today are likely to be originating from the suburbs or city neighborhoods and destined for the suburbs or city neighborhoods in a different metropolitan area. The designer of the intercity transportation system must consider both types of demands when designing a system.

This result has important implications in development of next generation high-speed rail technologies. The need to make multiple stops en-route mean that the ability of rail vehicles to accelerate from a standing stop would be an important technical attribute - an equally important one to the vehicle's ability to sustain long periods of high speed running. Many high-speed rail proposals (whether technological or project-oriented) have focused on constructing a beeline from one city center to another city center to provide the fastest point-to-point journey time. In fact, the vehicle's ability to negotiate 'classic' curvaceous infrastructure is likely to be as important if not more so than the need for sustained high speeds on unconstrained infrastructure. The reality of today's urban planning is that unconstrained infrastructure is almost impossible to retrofit, and even if it were possible, it would not serve the largest demand generators - ones that are dispersed throughout the gentrified inner-city neighborhoods. Such neighborhoods are reached through classic infrastructure that led to their development in the first place, and do not usually lie along a perfect straight line from the city center.

Just to reiterate this important concept, missed by many high-speed rail enthusiasts: the integral of demands throughout the city neighborhoods far exceeds the demand from the downtown core, even if
the downtown core remains the busiest node on the whole line. High-speed approaches that calls for a hub-and-spoke network based on a downtown hub through interconnection with the municipal transit system cannot be successful if the access time to the downtown hub is so abysmal as to rule out intercity rail as a viable option against driving directly to the destination.

The types of technology that are likely to be successful in future intercity rail markets are backwards compatible. Backwards compatibility allows the new technology to be deployed incrementally, avoiding high up-front capital costs and preserving network effects. It also allows sharing of high infrastructure costs with other modes such as commuter rail and urban transit. Retrofits of existing 'classic' corridors are likely to generate less objections and disruption to existing urban fabric. Technologies that build upon current steel-wheels-on-steel-rails guidance while enhancing its performance (particularly its performance on constrained 'classic' infrastructure) - such as flange lubrication to reduce L/V ratios, and magnetic guidance to allow higher superelevation (cant deficiencies) through twisting curves, will be far more important, cost-effective, and leveraged than proposals to construct brand-new rights of way. Magnetic levitation technology could be used in an incremental fashion by providing guidance alongside, and not instead of, steel-wheels-and-steel-rails. These hybrid concepts leverage the inherent value in the existing infrastructure, and is much more important than 'shiny-go-faster' approaches that focusing on relaxing the constraints through sledgehammer-like, environmentally insensitive engineering.

These findings have important implications for transit properties around the country. Transit property should realize that sharing infrastructure costs with intercity carriers could substantially reduce the cost of providing transit. Instead of seeing the intercity operator as the 'competition' and requiring them to interchange with the local carrier only at designated points, the transit property ought to see the development of a new intercity corridor as an opportunity to provide transit service to another section of the city. Intercity and transit providers should work together to allow new intercity infrastructure to create new transit corridors. New corridors should not be constructed alongside existing corridors, but instead should be constructed such that easy interchange is accomplished with radial lines running in all directions. Not only will that design provide maximum connectivity, it will also enable the intercity carrier to tap into important business centers all over the metropolitan area and not just the downtown. The new corridor could also serve as a crosstown transit corridor.

Not one solution would work for every city. Depending on the location and condition of the existing transit and intercity infrastructure, and the economic geography of the metropolitan area, different layouts of metropolitan access infrastructure (or if you prefer, terminal district infrastructure) would be
necessary. Above all, transit properties and intercity carriers need to demonstrate a willingness to work with one another in generating a good design from the customer's perspective - regardless of who will carry the passenger. There should never be a single 'interchange point' where one carrier's responsibility ends and another takes over. The issues such as: who will pay for the infrastructure, who will manage its construction, and who will own the tracks, are independent from how one might design a good transportation network. Once the network has been designed to give the best possible customer utility for the largest number of origin-destination pairs, those institutional issues would likely be resolved more easily. Links that carry predominantly intercity passengers would be paid for and operated by the intercity carrier; links that are common facilities would come under joint control, and perhaps even shared ownership - just as the union station brought together bitter rivals in $19^{\text {th }}$ century railroading, the union terminal district network should bring the transit property, the intercity carriers, and perhaps even the freight carriers together to design a layout that will work for everyone.

### 7.1 Analysis for Specific Market Segments

### 7.1.1 Commuter Rail

Commuter rail represents a market segment in which customers make trips daily - and decision about commuter rail ridership generally represent a long-term commitment. Demand pattern is generally concentrated in journey-to-work trips, comprising in the morning rush of pick-up in low-density suburbs and drop-off in a high-density downtown business district. However, in today's dispersed cities, the historical downtown is no longer the only location of concentrated business activity: firstly, downtown business districts have expanded into adjacent neighborhoods and can sometimes can be as large as three miles long; secondly, some inner city neighborhoods may have gentrified and represent significant business activity.

One design of commuter rail system would call for an easy transfer from a central dispersal point to the municipal subway, sometimes necessitating 'backtracking' to get to the traveler's eventual destination. Another approach allows all incoming commuter trains from any direction to call at multiple number of 'union terminals', enabling walk access to most centers of business activity, at the expense of perhaps not following the most direct route from the suburbs to the downtown. When transfer time, terminal time and buffer time are fully considered, most travelers would prefer the latter approach. In addition, by providing a one-seat ride, the value-of-time on-board the commuter train is increased - which can translate either into higher willingness to pay for the service, or higher social benefits.

There is much empricial results supporting this analysis in current heavy-rail transit experience: more recent systems such as Bay Area Rapid Transit (BART), the Massachusetts Bay Transportation Authority (MBTA) Red Line, Metropolitan Atlanta Rapid Transit Authority (MARTA) that have a commuter-rail like character have matched their station spacing to demand density, and designed their system such that many parts of the downtown core could be reached directly. These systems would probably not have been such a runaway success if a transfer to a bus or a streetcar had been required to reach the outer fringes of the downtown after an incoming ride from the suburbs.


Plate 7.1: Boston's Commuter Rail serves both the commuter rail and regional rail functions, but the two downtown terminals make cross-metro area journeys difficult.

Access time at the downtown end of the trip is particularly critical. Suburban commuting decisions are usually driven by long-term choice of residential location and not employment. Frequently, one household may have more than one commuter rail rider who is able to share an auto at the suburban end of the trip but not the downtown end of the trip. Requiring suburban commuters to make a second transfer onto the subway before walking to their final destination could make other arrangements such as carpool drop-off (either at place of work or at a Kiss-n'-Ride transit terminal) much more attractive, and would diminish both the social benefit and the political support for commuter rail. Commuter rail
ought to be seen as a limited-stop subway for auto-welding suburbanites who wish to reach a variety of locations in the city - just as an urbanite could travel from an urban neighbourhood to a variety of destinations served by a trunk line subway. The difference is that a suburbanite would drive to their transit access location while an urbanite would walk or take a bus. The 'commuter rail terminates at union station and serves the center of downtown travelers' paradigm is no longer tenable in all but the most compact and dense city centers today.

### 7.1.2 Regional Rail

The definition of regional rail is not always clear. For the purposes of this discussion, regional rail could be one of two types of services: (1) longer distance exurban commuting services which are unsuitable for daily use, but generally allows day-trips by business travelers - examples would include the Keystone and Empire corridors in the Northeast; (2) services that transcend the metropolitan area from one suburb to another, achieved by either a connection or a run-through train in the downtown - for this type of journey, the commuter rail schedule is often so constraining that daily commute is not a possibility except for the most determined employee. This definition allows regional rail to describe a different market from commuter rail, even if travelers from both markets may travel on the same physical trains. The needs of the two types of customers are very different, and serve to illustrate the importance of considering all customers in systems design.

Because of the lower demand density at both origin and destination for the crosstown regional rail rider, it is a practical impossibility to provide convenient access through the rail mode. However, it is likely that the leisure travelers in this market will be able to arrange a pick-up, as the motivation for travel is often to visit a friend in a different suburb. The need for regional rail customers is the ability to transfer easily once they reach the downtown.

Although the 'union station' design could potentially accomplish an easy transfer, several practical problems generally prevents that arrangement from being satisfactory. Firstly, the existing infrastructure in large cities is usually such that there are more than one union terminals, constructed in the late $1^{\text {th }}$ century by different railroads. For crosstown travel, frequently a short transfer in a taxicab or the urban transit system is required. This two-transfer solution is a poor alternative compared to driving, and is unlikely to create the type of competitive atmosphere where regional rail is considered an alternative other than for the autoless suburban poor. Secondly, there are usually good operational reasons for central stations to be decentralized in a large city - such issues as platform capacity, parking availability
and engine terminal location usually prevent a true 'union terminal' to develop for a large metropolis. Boston has two 'union' terminals for the North and South side commuter lines, while Chicago has four commuter rail terminals.

The solution for a true regional rail system is likely to involve decentralizing the union terminal - both such that the commuter rail market segment could reach a greater number of activity centers directly, and to allow regional rail riders to make an off-on same platform transfer. The design also happens to circumvent the platform capacity issue by requiring all terminating trains to run-through the downtown terminal district, making only 'intermediate' stops and looping back or departing on a different 'spoke' to lay-up in an outlying or suburban engine terminal.

The 'loopback' design is already widespread amongst today's high-density transit operations: Boston's Green Line has a loopback at Government Center and multiple access points along the Central Subway; Chicago's 'el' terminates and run around at the 'Loop'; Philadelphia's Regional Rail system embraces the run-through philosophy. Interurban rail systems that still operate on the push-pull philosophy out of a number of independent downtown terminals are relics of the $20^{\text {th }}$ century and will find themselves unable to service the increasingly decentralized suburb-to-suburb and suburb-to-city-neighborhood transportation demand effectively.

### 7.1.3 Intercity Rail

Intercity rail, the primary subject of this thesis, is essentially justified on an incremental basis. The capital cost required to create a system of access points in the busy downtown and adjacent city neighborhood activity centers that have gentrified could never be justified by the millions of passengers per year that travel in even the busiest intercity corridors in the United States. Cost of these terminal infrastructure run in the billions, thus have annuities in the region of hundreds of millions of dollars. The convenience of access is simply not worth the extra potentially $\$ 100$ each passenger would need to pay to have dedicated facilities constructed to enhance intercity access.

However, given how important distributed access is to the commuter rail system, the intercity rail operator simply need to reach agreement with the commuter rail authority to stop trains at key access locations in the city to benefit from the terminal district infrastructure. In drafting such an agreement, it is important to realize that commuter and intercity operators have different priorities and contribute towards the cost of such infrastructure in different ways. The commuter operator is likely to be most
concerned about the capacity at the rush-hour, while the intercity operator is probably far more concerned about getting departure slots that are on-the-hour or some other such easy-to-remember number. It is likely that an agreement that calls for shared ownership based on revenues, with provisions that enable the commuter rail operator to take charge of dispatching in the rush hour, while the intercity operator handles the off-peak, would be a sustainable situation in the long run. Any attempt for one party to insist on total control or absolute priority for all trains is likely to fail miserably.

One issue that is likely to occur in intercity rail is the need for exurban Park-n'-Ride lots. The current lots tend to be commuter rail oriented, and is structured to cater towards day-return demands with rates to match. Park-n'-Ride is key to intercity rail's outreach to suburban areas, and the status quo must change when intercity services are extended to more of these facilities.

Another side benefit for having run-through capability in the downtown is that it enables an intercity passenger departing due south to board the train in a northside suburb, ride through the city while the train picks up originating passengers, and depart due south without either having to transfer or drive through the congested city to reach a downtown terminal. The run-through capability is far less critical to the commuter rail market segment than to the regional and intercity rail market segments. However, it is likely that any design that enables access from most of the activity centers in the downtown and inner-city neighborhoods could easily accommodate run-through capability.

### 7.1.4 Overnight Rail

Once the commuter and intercity infrastructure is in place, accommodating the handful of overnight trains per day is simply a matter of service planning. The driver in service planning in overnight trains is that it must depart within a narrow time window, either between about 9 pm to 11 pm when passengers are likely to want to begin getting ready for bed, or between about 6 pm and 8 pm when passengers could board a dinner-and-overnight train. This is less of a problem than at the destination, where the overnight train will by definition arrive in the middle of the morning rush, and will compete for terminal district access slots with commuter rail arrivals.

One way to handle this potential conflict might be to schedule the overnight train much more robustly (say by using the $95^{\text {th }}$ percentile running time) than other trains, or to schedule their arrival towards the end of the morning rush when their impact would be minimal if they were delayed en-route. Needless to say, the passenger from another metropolitan area would need to be delivered to a variety of
destinations, and not just the central city - thus the metropolitan access idea is crucial to all market segments.

When dealing with long-distance trains, there is a temptation to cut down the number of stops especially stops within the same urban area, to minimize running times. This is likely to be a failing strategy. The key driver in the ridership of overnight trains is not the overnight running time, since most passengers would be sleeping and within reason, don't really care how long it takes. The more important factors are departure times, and how many passengers the train can pickup within the narrow time window in which overnight trains could begin. The train may have to stop at a number of suburban or downtown stops to pickup just a handful of passengers, but to require these passengers to travel to a central collection before proceeding is likely to add about an hour or so to their total journey time. Significantly, this hour is far more important than an extra hour overnight - since it is a precious evening hour that the passengers could spend enjoying the city. The likely impact of cutting those extra stops is that those handful of passengers would likely make other travel arrangements. This example demonstrates the importance of customer-centric utility analyses, based on different values-of-time for different parts of the trip and different time-of-day.

### 7.2 Summary of Important Results

This thesis is a very general and very broad attempt at reframing the high-speed rail debate in the United States. It demonstrates that models are just tools with which the transportation professionals study transportation systems. Just as "Do-Re-Mi and so on are only the tools we use to build music... you can sing a million different tunes by mixing them up", building a transportation system will involve an element of design, and models can serve to inform the impact of different designs on different market segments but should not be the driving force behind choosing certain designs.

Designs are done by artists who take many qualitative factors into account and bring about a vision, while modelling is done by engineers who quantitatively evaluate the impact of the design decisions on passenger utility, project cost, and other indicators that matter. Sometimes, it would be necessary to override the search for an optimum design if other factors such as equity and marketability results in the need to make the system suboptimal in order to serve a broader segment of the population, or achieve other design objectives. By the same token, the fact that a system does not turn a profit is not necessarily an excuse to seek the lowest cost design; in some circumstances a higher cost design will reduce losses by increasing revenues more than the costs.

### 7.2.1 Modelling Methodologies are Flawed

In Chapter 2, a variety of current approaches to modelling intercity transportation demands are reviewed. The review revealed that even though current methodologies do a good job of predicting incremental changes in passenger demands in response to operating plan changes, addition of new links, and other such minor adjustments, the models do a terrible job of explaining why such changes occur. Consequently, the current models are poor tools with which to inform designers of systems how the system could be altered to both make better use of existing infrastructure and to enhance the customers' intercity travel experience.

Trying to design an intercity transportation system with models of today is like trying to reproduce an elephant by measuring its skin perturbations with a sliderule. The sliderule is unsuitable for the job on two counts: (a) it examines the object with such a coarse resolution (i.e. a straight edge) that it misses subtleties of the elephant, such as the texture of its skin; (b) it examines the object on such a small scale that it fails to realize the right angle at the end of an elephant's belly is part of its leg and isn't because the elephant has been subject to folding action like a piece of paper. Current methodologies, in general, (a) examines the value-of-time too coarsely to appreciate that passengers prefer in-vehicle time spent reading the papers and drinking the coffee to in-vehicle time spent crowded out in a subway car; (b) fails to acknowledge that changes to other parts of the system (such as the addition of a highway link) could affect the part of system under study (such as air travel demand). Although the models are extremely sensitive to aircraft gauge, aircraft schedules, and perhaps even pricing strategies, they are no good for creating strategic visions and answering questions such as: should we widen the interstate highway or connect the high-speed rail to the airport and the suburbs? To answer these questions, a total logistics approach that calculates the total passenger utility by adding all constituent components, similar to the state of practice in freight carrier choice decision support, is required.

### 7.2.2 Making Journey Time Disappear

It is possible to make journey time "disappear" during long intercity trips. Through of a number of theoretical constructs and review of explicit references to differences in consumer values-of-time while engaged different activities, Chapter 3 demonstrates that it is possible, at least theoretically, to make onerous journey time "disappear" during long intercity trips. The journey time disappears in the sense it does not contribute to the disutility to making the trip. Under certain circumstances, such as when the
travellers are sleeping, eating, watching television, or taking part in other household activities that would normally be assigned a zero value-of-time at one's own home, the traveller is indifferent to a longer trip, as long as one would continue to choose to engage that activity and isn't constrained by the limited invehicle amenities available. In essence, when boredom sets in, that is when disutility shoots up through the roof. These differences in values-of-time explains the different values-of-time found in studies conducted on otherwise similar people.

Regular users of long distance services have already learned how to make journey time disappear: they chat, bring a deck of cards, or bring reading materials and refreshments. This result borders on stating the obvious, but it is under-appreciated by those who seek to reduce line-haul journey time at the expense of access time. The objective of the high-speed rail advocate should be both to reduce travel time and to make time disappear - and not simply to increase operating speeds.

### 7.2.3 State Rail Plans are Flawed

In Chapter 4, review of current high-speed rail planning exercise revealed that the planners are examining a gamut of variables that are too narrow. State Rail Plans, or even Federal high-speed rail designated corridors, sometimes define parameters that are too narrow for planners to design a good system. The very act of designating a corridor to be studied could encourage an engineering-approach where the planners come to believe the objective is to find the path of least cost to connect two illdefined arbitrary end points, such as Boston \& Montreal. Firstly, both Boston and Montreal are large metropolitan areas - where is the high-speed rail heading to and from? Secondly, is Boston \& Montreal the most logical corridor in the area - what about Boston \& Maine, or simply a connection to Manchester Airport? Thirdly, are there other enhancements in the area that would benefit the locality more than a high-speed rail - what about the North South Rail Link, or simply a number of intermodal passenger terminals coupled with medium-speed rail service? These are issues needing to be addressed in system design, and do not seem to have been addressed in the high-speed rail plans reviewed.

### 7.2.4 Metropolitan Access is Vital

In Chapter 5, this activity-dependent disutility framework (or total passenger logistics-utility) was extended to model a series of rail terminal locations, layouts, and service designs in large metropolitan areas. There are two main results. One main realization was that not only does the activity drive the value-of-time, the distribution of time available for activities are also important - simply by changing the
mix of times can reduce "logistics costs", or disutility, for many passengers. Another finding is that improved access can be an effective way of reducing total trip disutility - making the trip faster by cutting transfer time, and also more productive and more comfortable.

The first result largely reflects the idea that people do not like to be interrupted from their task, whether it is work- or leisure-related. Contrary to conventional wisdom in transit environments, a one-seat-ride could be an important factor in intercity mode choice. Each segment in an intermodal intercity itinerary or a longer commute tend to be of a length where productive work is possible, the passenger would have a stronger preference for uninterrupted time than a transit-rider.

Applying a version of the logistics-utility model, the City of London case study shows that investing in better access to the downtown core could save much more time for passengers than investing in increasing the speeds of commuter lines radiating from London. In the scenario studied, average journey time savings (for all origins on the former Network Southeast system) could be as much as ten minutes compared to a transfer to the London Underground Circle Line. The results are highly intuitive: journey time reductions on the line-haul segments tend to help the outer suburbs, where the demands are low, whilst enhancing access to the core help the inner suburbs, the outer suburbs, as well as crosstown passengers. Again, those who focus on one single origin-destination pair or one single corridor often ignore these important results. Intercity rail is a network, even if the corridor may seem as simple as a beeline between one city and the next - there is always a cluster of metropolitan neighborhoods that need to be connected with another cluster, and any evaluation must consider all origin-destination pairs.

Applying the total logistics-utility model to services between two smaller cities resulted in a design that calls for an intercity line that winds around the city to collect passengers from multiple neighborhoods in a linear fashion. This is the MetroFlyer concept, introduced in Chapter 5. In smaller cities, where there are insufficient demand density to justify a totally-connected network from every neighborhood to every other, it is possible to construct such a line to achieve better access before heading out towards another city or the suburbs. This type of infrastructure, which can sometimes be constructed out of abandoned and pre-existing rail lines, can benefit the city in a number of ways: (1) more city neighborhoods will receive regional and intercity rail access, (2) new corridors are created where a subway-like service may relieve capacity problems on the existing transit system, (3) intermodal and intramodal connections could be made at multiple nodes or multiple 'union stations', which will alleviate the congestion and parking problem typically associated with union stations.

The total logistics concept for passengers gives rise to an important methodology with which high-speed rail schemes should be evaluated. Firstly, the issue of access to high speed rail services has to be taken seriously, if high-speed rail advocates wishes to be considered as a viable voice in promoting mass intercity transportation. Secondly, to demonstrate that a high speed is really necessary, the speed enhancement must be explicitly traded off against other possible enhancements in a utility framework.

### 7.3 High Speed Rail Planning Synthesis

### 7.3.1 Regarding the Value of Time

The logical consequence of acknowledging the activity-dependent disutility of in-vehicle time is that the standard model of disutility equals the product of time and value-of-time will no longer apply. Instead, the disutility should be modelled as the integral of values-of-time over the entire trip, from the moment the travellers leave their point of origin until they reach their destination. Access time, terminal time, buffer time, in-vehicle time are all included, and the values-of-time in each category would still require careful evaluation - for instance, terminal time spent browsing through the concessions has a different value from terminal time spent standing in line waiting for a security check-in. These are factors that designers of intercity transportation systems must pay careful attention to. Once the infrastructure is built, the users may have already been trapped into a suboptimal path from the point of view of total trip utility.

Amenities may be expensive to provide from the carrier's perspective, but they are part of the carrier's competitive arsenal. Highway amenities are provided by independent businesses on a commercial basis, and airport amenities are provided by concessions. Rail carriers can do well by explicitly recognizing the link between amenities and value-of-time en-route. While it is not necessary to provide free amenities, they should be provided at a cost comparable to similar amenities at airports or highway rest-stops, to encourage the travellers to make their own journey time disappear.

### 7.3.2 Regarding High Speed Rail Planning in General

- Current models in intercity transportation often consider only one aspect of the broader intercity transportation problem. Airline demand models may deal with such issues as carrier choice and schedule choice, but do not address issues such as local access and terminal amenities -- nor were they designed to. Strategic planners in intercity transportation should not confuse the need for transportation systems design with short-term operations planning models that were essentially designed to evaluate incremental costs and benefits of improving the operating plan.
- Most of the important concepts in designing an intercity transportation system already exist in the literature. Total logistics costs as appled to freight transportation, mode-choice methodologies as applied to urban transportation, and even explicit considerations of customers' value of time, are all concepts that can assist the evaluation of different designs of intercity transportation systems. However, the existence of modelling methodologies does not alleviate the need for design. Design is a separate craft in which the professionals gather inputs from multiple stakeholder groups and combine them in such a way as to make a functional transportation system.
- By the same token, designing a transportation system is not a simple process, and may not relate to available transportation technologies as strongly as often suggested. The availability of a new technology will influence the design process, since new technologies may cater to certain users and stakeholders' interests better than older technologies. However, designing a good system is more than simply taking a new technology, building and calibrating a model to show an instance where the new technology would work better than the old. Only when much thought had been devoted to how best to utilize the new technology and how it affects role of the older technologies, should the whole system be evaluated using a model to show that the deployment will benefit many different stakeholders. In particular, it is important to avoid situations where new technologies may do well at the expense of an older part of the system -- good design would put existing infrastructure to good use while allowing the new technology to serve a useful purpose.
- In essence, a demand model that demonstrates that there is sufficient demand to justify financially the operations of a new corridor, a new technology, or some piece of new infrastructure, is not necessary and sufficient to justify its construction. A vision, a design proposal, coupled with a systems evaluation of what the new infrastructure will do to the users and the non-users, is much
more important than a narrowly focused study that simply claims 'new stuff is needed here, and it will make money'. This may seem obvious, but many state rail plans and other strategic plans for intercity rail or airports appear to overlook the need to examine the transportation problem on a systems level.
- Much expertise has been developed in urban transportation systems design. The Boston Metropolitan Transportation Plan (1972) captured the essence of the kind of design considerations that were needed. The plan integrated for the first time a proposal for new highways, new subways, and other transportation facilities in the area. When part of the plan was implemented, new housing was built along the new subway alignment to create a 'livable neighbourhood'. This type of attention to detail, and systems approach to planning, is needed in intercity transportation planning.
- The systems approach to transportation planning often calls for intermodal transportation connexions. Intermodal connexion is only one of many ways to achieve a systems vision. Integration of airports, commuter rail, and intercity rail can be important, but should not rule out the possibility of constructing infrastructure in such a way that a service can transcend many different modal roles. For instance, in the terminal areas, an intercity arrival could turn into a commuter train as it approaches an urban area; local trains should travel by different toutes from intercity trains where possible, to provide maximum connectivity; airlines should focus on what they do best -service isolated cities, and provide an ultra high-speed service for those who are willing to pay for it.

These conclusions are somewhat broad. An immediate possibility is to re-evaluate some of the proposals currently in progress in light of the metropolitan access findings, taking into account total trip time for all likely customers, and try to evaluate the value of time. It is likely that some changes will be needed to bring the proposals to a stage where it better benefits the regional transportation system as a whole, instead of being an isolated corridor.

### 7.4 Recommendations and Future Work

As indicated throughout this thesis, much remains to be done to develop a framework for planning intercity rail transportation systems. The current institutions involved in intercity transportation have tended to be modal-specific, sometimes resulting in mal-coordinated systems. In urban areas, because of the massive amount of public subsidy that has been poured into public transportation, methodologies
have been developed for coordinating the services provided by different modes, and catering for the different needs of the urban market though joint-planning and regulation. Although deregulation of intercity air carriers was hailed as a economic success, it has resulted in reinforcement of the modal mentality - only in the case of one carrier, has the issue of joint highway-air service been considered seriously. There is now a great need for each metropolitan area to examine their intercity service facilities: are the passengers getting from their origins to the destination city by the most efficient route through the urban area? The chances are that most passengers are taking a geographic detour because they have to travel to the airport, and may even be suffering time penalties in the case of shorterdistance origin-destination markets.

In terms of analyzing the economics of schemes such as MetroFlyer, and other urban distribution systems for intercity carriers, location specific studies are needed to examine the costs and benefits associated with alternatives for a specific location. The problem with some state passenger rail plans lies in not examining all possible alternatives, either because the MetroFlyer alternative is not initially obvious, or other factors are preventing it from being considered. If the systems analysis presented in this thesis is even halfway correct, in many metropolitan areas it will be demonstrated that improving access to intercity and commuter rail facilities will benefit more passengers (and save more passengerminutes) than simply improving speed for a specific origin and destination.


Plate 7.2: Considering the MetroFlyer alternative would not only help cities like New York, but also regional cities that could justify a trunk distributor through the metro area.

If there were a moral to this thesis, it would be to avoid the 'speed assumption' in future work in intercity transportation planning. To demonstrate that a high speed is really necessary, the speed enhancement must be explicitly traded off against other possible enhancements in a utility framework. Speed, like any other amenity, requires justification with sound project evaluation. Frequently, speed could be justified at the margin - like in the Tokaido Shinkansen; in many cases however, a lot could be accomplished with sound service planning and by exploiting synergies with parts of the public transportation system with much higher ridership, such as the commuter rail.

Currently in the United States, higher speed rail is necessary in many cities for rail to stay competitive, but highest speed rail is probably neither cost-effective nor necessary. Instead, each scheme for increasing line-haul speed should be judged, using the total logistics-utility framework, against a series of alternatives to improve access to locations of large demand density as well as options that help to make time disappear. In the same vein, more accessible rail offering shorter access time from all points in the city is more and more important in today's sprawling metropolitan areas. However, the most accessible rail (such a streetcar) that calls at every street corner, have little role in interurban transportation. Demands for speed, accessibility, amenities, and other upgrades that improve the customer utility must be balanced against each other. The results from the customer utility studies should be used to inform intercity transportation system design, to create a system that works in harmony to move people.

## Appendices

# Metropolitan Access, Intercity Rail and Technology 

## Metropolitan Access

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# The Vital Role of Metropolitan Access in Intercity Passenger Transportation 

From the Traditional Limited-Stop Express to the $21^{\text {st }}$ Century Ring Railroad

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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 $15 \sim 20$ minutes, which is roughly equivalent to increasing average line-haul speed from 120 to $168 \mathrm{~km} / \mathrm{h}(80 \mathrm{mph}$ to 105 mph$)$ over a $160-\mathrm{km}$ ( $100-\mathrm{mile}$ ) 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-toweight 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 $200 \mathrm{~km} / \mathrm{h}$ ( 90 mph and 125 mph ), it is clear that in the corridor market ( $320-960 \mathrm{~km}, 200-600$ 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 $20^{\text {th }}$ 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 Vebicle Time Versus Out-of-Vebicle 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-todestination 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 $(160 \sim 480 \mathrm{~km}$, or $100 \sim 300$ 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 $1 \frac{1}{2}$ 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 $11 / 2$ 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 atgument 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]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 invehicle 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 shorthaul 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 é Capacity Anabsis

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 ringrailroad 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 Necessayy?

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 ting.

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 Sbuttle 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 worldclass 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 trimodal 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 origindestination 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 enroute) 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 studics 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.

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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

Single downtown station of magnificence and splendour, with rail halts en-route due to steam traction \& signalling technology.


The Old Railway
$\downarrow$


Simply removing intermediate stops and upgrading the linespeed does not fully exploit the advantages of modern rail technology.
0

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


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 | Bufer | En-train | Total |
| Urban Dweller |  |  |  |  |  |  |  |  |  |  |  |  |
| (Downtown Office) | 0:10 | 0:05 | 2:00 | 2:15 | (use Union Station) |  |  |  | 0:10 | 0:05 | 2:05 | 2:20 |
| (City Residence, Central Neighbourbood) | 0:15 | 0:05 | 2:00 | 2:20 |  |  |  |  | 0:15 | 0:05 | 2:05 | 2:25 |
| (City Residence, Transit-Acressible |  |  |  |  |  |  |  |  |  |  |  |  |
| Neighbourhood, Right-side) | 0:25 | 0:20 | 2:00 | 2:45 |  |  |  |  | 0:15 | 0:15 | 1:55 | 2:25 |
| (City Residence, Transit-Accessible Neigbbourbood, 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 |
| (Vrong-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 <br> Access <br> Time | $\begin{aligned} & \text { Tube } \\ & \text { Time } \end{aligned}$ | $\begin{aligned} & \text { Exp. } \\ & \text { Wait } \\ & \text { Time } \\ & \hline \end{aligned}$ | $\begin{aligned} & \text { Line- } \\ & \text { haul } \\ & \text { Time } \\ & \hline \end{aligned}$ | Total Journey Time | Routing | $\begin{aligned} & \text { Access } \\ & \text { Time } \end{aligned}$ | $\begin{aligned} & \text { Exp. } \\ & \text { Wait } \\ & \text { Time } \end{aligned}$ | $\begin{aligned} & \text { Line- } \\ & \text { haul } \\ & \text { Time } \end{aligned}$ | Total <br> Journey <br> Time | Routing |
| Urban Dwellers |  |  |  |  |  |  |  |  |  |  |  |
| Big Ben/Westminster to |  |  |  |  |  | Circle Line/East |  |  |  |  | Victoria BR/Ring/ |
| The North East (Newvastle) | 0:10 | 0:38 | 0:15 | 2:35 | 3:38 | Coast Mainline | 0:20 | 0:15 | 2:50 | 3:25 | East Coast Mainline |
| Imperial College (Paddington) to Scotland (Edinburob) | 0:20 | 0:24 | 0:15 | 3:59 | 4:58 | Hammersmith \& | 0:20 | 0:15 | 4:11 | 4:46 | Paddington BR/Ring/ |
| Heathrow Aiport to |  |  |  |  |  | Piccadilly Line/ |  |  |  |  |  |
| The Anglia Region (Cambridge) | 0:15 | 0:59 | 0:15 | 0:45 | 2:14 | Cambridge Flyer | - | - | - | - | - |
| Heathrow Airport to |  |  |  |  |  | Heathrow Express/ |  |  |  |  | Paddington $\mathrm{BR} /$ Ring/ |
| The Anglia Region (Cambridge) | 0:32 | 0:34 | 0:15 | 0:45 | 2:06 | Cambridge Flyer | 0:32 | 0:15 | 0:57 | 1:44 | Cambridge Flyer |
| Harrow-on-the-Hill to <br> 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 |  |  |  |  |  | Thames Trains/ |  |  |  |  | Thames Trains/Ring/ |
| Scotland (Glasgow) | 1:24 | 0:34 | 0:15 | 5:15 | 7:28 | East Coast | 1:24 | 0:15 | 5:27 | 7:06 | East Coast |
| Henley-on-Thames to |  |  |  |  |  | Thames Trains/ |  |  |  |  | Thames Trains/Ring/ |
| Scotland (Glasgow) | 1:24 | 0:36 | 0:20 | 5:24 | 7:44 | Virgin West Coast | 1:24 | 0:20 | 5:33 | 7:17 | Virgin West Coast |
| Chelmsford to |  |  |  |  |  | Great Eastern/ |  |  |  |  | Great Eastern/Ring/ |
| The South West (Pymouth) | 0:47 | 0:43 | 0:20 | 3:54 | 5:44 | Great Western | 0:47 | 0:20 | 4:11 | 5:18 | Great Western |
| Portsmouth to The North West (Manchester) | 1:44 | 0:33 | 0:20 | $2 \cdot 46$ | $5 \cdot 23$ | South Central/ | 1:44 | $0 \cdot 20$ | 3:01 |  | South Central/Ring/ |
| The North West (Manchester) | 1.44 |  |  |  |  | Virgin West Coast |  |  |  | 5:05 | 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 $21^{\text {st }}$ Century MetroFlyer 

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

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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.
- 110 mph 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.


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## 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 ( $50 \sim 150$ 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.


## Zone Express

for mid-length trips ( $150 \sim 400$ 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 limitedstop 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 citycenter 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 

Rail is the fastest
Small metropolitan areas
Streetcar suburbs
Travel between city-centers dominates
Auto use not widespread Interstate Highways not yet built

## Acela Express Virgin 'Pendelino'

Rail is most comfortable Large metropolitan areas Automobile suburbs Travel between suburbs dominates Small carless population 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 upfront, 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 $150 \sim 400$ 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 <br> 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.


## 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 12 tph Subway, a 4 tph Commuter Rail, and a 3 tph Amtrak over the same doubletrack 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 (bttp:// www, nycsuhway,org/)

## Boston MetroFlyer - Operating Plan

|  | SUBW | R/R | AMTRA | AK | 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+DW | DWELL | xx/00 | xx/01 | xx/05 | xx/06 | xx/10 | $\mathrm{xx} / 11$ | xx/16 | xx/21 | xx/25 | xx/26 | xx/30 | xx/31 | xx/36 | xx/40 | xx/41 | $\mathrm{xx} / 46$ | x $/$ /51 | x $\mathrm{x} / 55$ | 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 $20^{\text {th }}$ 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 $1 \frac{1}{2}$ 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 $11 / 2$ 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.



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 oneseat 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.

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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.
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## New stations Significantly affects local mode share...

## After - Multiple Access Points

## Rail Dominates <br> 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 highspeed 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


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 110 mph , often the more effective investment would be in accessibility and not in further raising the speeds.

## WHY DO INTERCITY CARRIERS LOSE MONEY?

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.


Photo: Joe Klein (http:// skychasers, net/jock/ein, btm)


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 drivethrough access point. Walk-ups tend to be very sensitive to the exact location to within $1 / 4$ 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)


## After the Railroad Dig (Boston)



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 ${ }^{\circledR}$ 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 ${ }^{\circledR}$ 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 oneseat 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 $\sim 10$ mins on intercity routes.


## Cut Cross-London journey by 20 minutes



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; reuse 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 ${ }^{\circledR}$ 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 ${ }^{\circledR}$ 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 $45 \sim 60$ 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 60 mph in local portion of intercity trips is expensive, and probably will not lead to significant increase in ridership. In addition, speeds above 60 mph 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 ${ }^{\circledR}$. 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 60 mph . 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-bire facilities near a freeway is better than having to drive from a downtown rail terminal.
Photo: Daytona Beach, Florida (hltp:// www,datonavisit.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.


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.


Even though there is a recognizable downtown in Las Angeles, most of the economic activity occur in suburban business districts.
Photo: Matthew Weathers, http:// wywp,matthewneathers,com/ 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, $125^{\text {th }}$ 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 Manbattan 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. (btt: / / www, markesmission,ong)

## 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 walkup 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 $\mathrm{B} \& \mathrm{O}$ via the Youngwood/Scottsdale alignment (if the $\mathrm{B} \& \mathrm{O}$ 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 selfsufficiency 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 ( $600 \sim 1,200$ 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.
 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 125 mph , 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.


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.)


Public Timetable, based on Preliminary 125 mph 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 9 pm and 11 pm , arriving at the destinations at between 7 am and 9 am - 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 100 mph to 125 mph (rural areas) | 10 miles of 60 mph 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.


Simply removing intermediate stops and upgrading the linespeed does not fully exploit the advantages of modern rail technology.


The "High Speed Rail"

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 bigh-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 shate 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 selfstrengthening 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 magneticallyguided 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.
[This page was intentionally left 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 

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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 150 mph ; (b) constructing new rights-of-way with advanced propulsion technologies such as magnetic levitation to enable service speeds of up to 300 mph . 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 110 mph , 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 $100 \sim 600$ 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 $100 \sim 499$ 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 $100 \sim 600$ 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 totallyconnected 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-oftime 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-elcctric 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 30 mph , dispatching trains efficiently becomes a major issue for speeds above 70 mph 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 engincering 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 exclusiveguideway 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 45 mph . 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 50 mph ), and the commercial airline (very low accessibility at around 550 mph ). In theory, the high-speed rail could succeed by offering better accessibility than the commercial airline at an average speed of 110 mph , 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 110 mph 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 $(150 \sim 200 \mathrm{mph})$ in the rural areas to achieve an average speed of 110 mph 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 100 mph , 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 V alue 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 4.77 MHz 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 valuc 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 lowdensity 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 interoperate 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.


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 creatc 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 intcrcity corridor, passing highspeed 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 $\mathrm{Lu}, 2001$ ).

## 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 $200,000 \mathrm{lbs}$ 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 costeffectiveness 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 79 mph . Mountain Subdivision features one major mountain pass and two tunnels, the resulting curvature and gradient limits speed of conventional operations to 60 mph . Prairie Subdivision features featureless plains and farmland which allows bee-line construction of conventional lines that allows unimpeded 110 mph operations. The City Subdivision features similar urban constraints, limiting speed to 60 mph , but without commuter rail service. The detailed assumptions for the typical corridor is given in Table 1.

| Subdivision | Begins | Ends | Speed <br> (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 70 mph -- 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 timesavings, 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 70 mph 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 115 mph , 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 timesaving 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 $20 \% \sim 40 \%$ 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 125 mph . Using the traction performance calculator, assuming an entry speed of 70 mph , the maximum speed achieved on the maglevified cut-off would be 125 mph , achieved two-miles into the cut-off. Due to the gradient considerations, 125 mph 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 125 mph .

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 ( $15-\mathrm{miles} @ 60 \mathrm{mph}$ ). 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 180 mph , 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 noncontiguous trackage in the Seaboard Subdivision required maglevication to handle trains travelling at 110 mph , while the other sections will handle 110 mph 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 110 mph , 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 125 mph , 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 110 mph 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 |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Hybrid | Hybrid | Conventional | HSR | Maglev |  | Maglev |
| Division | Best Case | Conservative |  | New Line | New Line |  | 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 150 mph 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, costeffectiveness 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 $\$ 30 \mathrm{~m}$ 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



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 costeffectiveness 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 |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Investment Alternative | Distance (miles) | Costs (\$ million) | Cost/mile (\$m/mile) | Time Saved (minutes) | Cost/min (\$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, Magpor-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 30 mph , perhaps regular passenger trains at 79 mph , as well as maglevified vehicles capable of running at 125 mph 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 150 mph . 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 $16^{\text {th }}$ to the $18^{\text {th }}$ 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 costeffective 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 70 mph 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/newridr |
| 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 |
| Magler 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 ( $\sim 30$ 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 <br> - Rail is price taker, therefore Profit $=$ Cost - Airline Prici |  |  |  |  |
| Discount Rate | 7\% |  |  |  |  |  |  |
| Cost per Passenger Mile | Corridor Configuration |  |  |  |  |  |  |
| Investment Alternative | 50 miles | 100 miles | $50+50$ mile: 15 | 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 |  |
| Convertional 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, Magpor-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.
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[^0]:    * To all other stations, with equal weighting. The time can also be considered indicative of average transit access times from locations within the North Circular Road beltway - the walk time and wait time at the mainline station remains constant, while the Tube time and walk time from residential/business location to nearest transit stop is comparable to the walk time from stations and the Tube time.

[^1]:    ${ }^{1}$ Examples include Boston South Station and Boston Back Bay Station; Edinburgh Waverley Station and Haymarket Station (Scotland), Philadclphia $30^{\text {th }}$ Strcct, Suburban, and Market East stations.

