Case Study
Applying Performance-Based Technology Scanning to Intercity Passenger Transportation

This case study applies performance-based technology scanning to intercity passenger services, drawing upon research conducted for the UIC (Union Internationale de Chemins de Fer).[1] As the research was conducted for a railway organization, the focus was on how to enhance the competitiveness of rail transportation, and that is the perspective that is taken throughout this section. The research ultimately related to the types of projects that would be desirable for attracting more intercity travelers to the railways of the world. Increasing the maximum train speed is often seen as the best way to improve the competitiveness of passenger rail service, but considering technological options using the PBTS framework suggested many other opportunities for improving rail competitiveness. Construction of high-speed rail corridors will be helpful in some locations, but other types of projects may prove to be just as useful and more cost-effective.

Competition for Intercity Passenger Services

The role of rail in intercity transportation varies widely around the world. In China, India, and Russia, where incomes are low and the rail network is extensive, rail has the largest market share for intercity travel. In much of Latin America, bus is the preferred mode even for distances greater than 600 miles. In the most developed countries, railways must compete with air for longer distance travel and autos for shorter distance travel. Still, when railways are able to offer service on the order of 100 mph along 200-300 mile corridors, they can capture more than half the non-auto market. Examples include Paris-London, Stockholm-Gothenburg, and Rome-Bologna. Where railways offer service in excess of 120 mph, they can dominate such markets, e.g. Paris-Brussels, Paris-Lyons, and Tokyo-Osaka. In the US, passenger rail services are highly competitive only for the Northeast Corridor, and rail market share is very low elsewhere.

Competition for intercity passenger services is based upon cost, time, and quality of the available services, which can be modeled using the economic concept of utility. Travelers' utility can be increased by reducing costs, increasing speed, or improving the quality of their experience. Travelers will choose the mode that allows them to reach their destination with the greatest utility. Technological changes can improve utility for potential customers and therefore increase market share, as demonstrated in this section.

Air, bus and auto are the primary modes competing with rail for intercity passengers. For air, the key factors are the time required at the terminal and the number of stops, as well as the actual flight time. For rail competitive trips (less than 1,000 miles), flight time is at most several hours, often less than half the total trip time. Fares, access time, terminal processing and time and hassle associated with connections are key elements affecting travelers' utility.

Bus is much simpler than air or rail, as the terminal time and amenities are both minimal. The average trip time is dependent upon highway conditions and the number of stops. Travel by bus allows opportunities for work, and seats in the best buses are at least as comfortable as coach class on most planes. Design of bus networks is extremely flexible and readily integrated with air or rail networks.

Auto travel is the most flexible, the most comfortable, and often appears the cheapest. Most people ignore depreciation and treat insurance and taxes as fixed or sunk costs, worrying only about out-of-pocket costs (fuel and tolls for personal automobiles, plus daily fees and mileage fees for rental cars). Auto competition varies greatly across the world, in terms of availability, service, and cost. Where roads are poorly developed or extremely congested, auto is too slow for anything but short trips. Where auto ownership is high and highways well-developed, auto is a convenient, cheap

[1] Martland, C.D., Alex Lu, Dalong Shi, Nand Sharma, Vimal Kumar, and Joseph Sussman. *Performance-Based Technology Scanning for Rail Passenger Systems*. UIC/MIT-WP-2002-02. MIT, Cambridge, MA (July 2002).

option for traveling quite long distances. In Europe and Japan, out-of-pocket costs are high because of tolls and fuel taxes. In China, railways are losing mode share to autos and especially buses as the highway network is expanded.

The Utility of Time

Economists use the concept of utility as a means of understanding how people make economic decisions. People are assumed to make choices that maximize their utility, perhaps unconsciously, thus providing a basis for understanding and modeling the way people make choices. In principle, utility can encompass cost, travel time, comfort, and other factors such as safety and security. Surveys and statistical methodologies can be used to develop models of utility based upon user choices or their stated preferences. Assuming that such models exist, we can compare the utility associated with using rail, air or other modes. If utility is identical for two modes, then we would expect travelers to be indifferent to which mode they use. If utility varies with distance, there may be a breakeven distance at which mode shares will be equal. Models that estimate the percentage of travelers that will choose a particular mode are called travel demand models. These models are used extensively in evaluating transportation projects, as the predicted benefits of any transportation project will depend heavily upon the demand for the new facility or service.

Some general insights concerning utility have been gained from research on travel demand:

- Trip times and reliability are important factors in addition to out-of-pocket cost.
- Value of time is related to, but less than, the hourly wage and may depend upon mode or trip purpose.
- Time spent in different activities is valued differently; time spent moving in a vehicle is generally less onerous than time spent waiting in the terminal.
- Ease of access and ease of using the mode are important.
- Time of day, trip purpose, and service frequency affect choice of departure and arrival times.

These results document great variations in value of the time for different groups of people in various activities. A study of intermodal facilities for intercity rail, bus, and transit facilities, suggested using 1/3 of the prevailing wage for the travel time from home to work, 1/6 of the prevailing wage for non-work travel, and 200% of the prevailing wage for work-related travel.[2]

Studies of demand typically use rather general independent variables, often just separating trip time into in-vehicle and out-of-vehicle time. A study of high speed rail conducted for the U.S. Federal Railroad Administration, for example, used trip time, fares, and frequency of service in developing demand models for various market segments.[3] That study addressed the potential markets for high speed rail as an alternative to air and auto travel; it defined service to be total trip time, without attempting to distinguish among the utility associated with different trip segments. However, since passengers make much finer distinctions concerning utility than this, it is necessary to make some assumption about passenger utility as part of PBTS.

The researchers in the UIC study assumed that time and comfort utilities can be expressed in monetary terms and compared directly to fares and other out-of-pocket costs. They then made assumptions concerning utilities for different segments of a trip in order to illustrate the relative importance of these segments and the opportunities for technological improvements. After all, it is clear to anyone who has ever traveled that the time spent in some portions of the trip is very onerous, while the time spent in other portions of the trip may be neutral or pleasant. Saving a few minutes in travel time by introducing faster trains may not be nearly as beneficial as using better information technology to save the same few minutes in terminal processing or providing in-vehicle communications and entertainment to make travel time more productive or more enjoyable.

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[2] Horowitz, Alan and Nick Thompson, *Evaluation of Intermodal Passenger Transfer Facilities.* Final Report to the U.S. Federal Highway Administration, DOT-T-95-02. U.S. DOT Technology Sharing Program, Washington, D.C. (September 1994).

[3] Federal Railroad Administration,"High-Speed Ground Transportation for America", US Department of Transportation, Washington, DC, September 1997, pp. 5-10

A Preliminary Model of Passenger Utility

To begin, consider how a business traveler with an average billable rate of $100/hour and a salary of $40 per hour might view the various segment of an air trip:

- Drive to airport, including buffer time required because of access unreliability: unproductive time valued at 50% of the average salary or $20/hour
- Process time: standing in lines, checking-in, going through security, and boarding are not only unproductive, but uncomfortable and stressful, so this time is valued at $50/hour
- Extra time at the airport: conceivably useful for shopping, eating, or reading, but likely broken into segments too small to be productive; valued as somewhat better than driving at $10/hour
- Time on the plane resting, eating (peanuts), waiting: similar to the time in the car, probably negative, but at something less than average salary, so this is valued at $20/hour
- Time on the plane having fun: time spent watching a movie, eating (a real meal), or reading a book may be indistinguishable from time spent at home, so some of the time could be considered neutral, i.e. $0/hour
- Time on the plane working: this could be billable time with a positive value of $100/hour

This individual would presumably associate similar utilities with the corresponding segments of a trip by rail, bus or automobile, although the duration of similar segments could be quite different for each mode. If we break the competing travel options into logical trip segments and use consistent values of time for each activity, then we can estimate the utility associated with the various options available for any trip.

Let's begin with a 250-mile trip, a distance long enough for rail to be competitive with auto and short enough to be competitive with air. Tables 1 to 3 give representative inputs for evaluating trip utility. These tables were copied directly from a PBTS model that was created in a spreadsheet. Table 1 shows sample inputs for calculating out-of-pocket costs. To facilitate sensitivity analysis, some of the expense items have fixed and variable components. Air is the most expensive ($289 one-way), automobile is the least expensive ($123)[4], and rail is in the middle ($162). The table also shows the time required to make a reservation, which is not an out-of-pocket expense, but which will affect utility.

Table 2 shows the factors used to estimate total travel time, including access, terminals, and buffers sufficient to cover likely delays. Non-stop air is the fastest, requiring 5.25 hours; rail and auto are nearly an hour longer. Table 3 shows hypothetical values of time that might be reasonable for a business traveler in the United States for the various activities specified in Table 1; the final row shows the value per hour for the extra time gained by using the fastest mode. Most likely, the extra time is a net benefit to travelers at something close to their average value of time. However, it could be more or less. For a business traveler, the extra time might be spent with the client, leading to a higher probability of having a successful meeting. Table 3 therefore shows that the extra time is worth $150/hour, 50% higher than the value of work time for our hypothetical business traveler. Other travelers might have completely different perspectives on the value of this extra time. For a student traveling home for the holidays, extra time on the train might be valuable time to finish an assignment – or it might mean missing the start of a great party. A vacation traveler might lose 2% of the daylight hours available on the beach during the vacation – or gain time to finish up work before relaxing on the beach.

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[4] Some business travelers are reimbursed for their use of their own automobiles on company business. The travel allowance is likely to be based upon the fully-allocated costs of owning and operating a car, which is on the order of $0.50 per mile. For a 500-mile round trip, a business traveler might therefore be reimbursed $250, which would be $100 more than the variable costs of gas, tolls, and wear-and-tear on the vehicle, estimated in Table 1 as $0.30/mile or $150 for a 500-mile trip. When passenger service was cancelled between Pittsburgh and Harrisburg in 2009, this factor was cited as a major reason for the lower than expected ridership: the rail service was competing with the private service operated by the potential passengers themselves and subsidized by their employers in the form of mileage reimbursement for use of their cars!

Table 1 Calculating Out-of-Pocket Cost for Each Travel Option

	Air Non Stop	Air Via Hub	Train	Auto	Rental Car
Circuity	1	1.2	1.1	1.1	1.15
Distance 1 way	250	300	275	275	287.5
Days at destination	2	2	2	2	2
Reservations (hours)	0.25	0.25	0.25	0	0.1
Cost (1-way)					
Access to station	$4	$4	$4		$4
Fare – fixed	$100	$50	$25		
Fare/mile	$0.50	$0.40	$0.30		
Expenses/trip					$40
Expenses/mile				$0.30	$0.05
Expenses/day					$40
Access to destination	$20	$20	$10	$0	$0
Parking per day	$20	$20	$20	$20	$20
Total Out-of-Pocket Cost	$289	$234	$162	$123	$178

Table 2 Calculating Total Trip Time, by Mode

	Air Non Stop	Air Via Hub	Train	Auto	Rental Car
Time for trip					
Access to station	0.75	0.75	0.5		0.5
Buffer for access unreliability	0.25	0.25	0.2		
Process time	0.1	0.15	0		0.25
Queue time	0.25	0.35			
Available time in station	0.5	1.5	0.25		
Boarding time	0.2	0.4	0.2		0.2
Travel time - fixed	0.75	1.5	0.2		
Travel time - per 100 miles	0.2	0.2	1.25	2	2
Total travel time in vehicle	1.25	2.1	3.64	5.5	5.75
Travel time - work %	75%	75%	75%	0%	0%
Travel time - entertainment %	0%	0%	0%	10%	10%
Travel time - rest & other %	25%	25%	25%	90%	90%
Travel time - work	0.94	1.58	2.73	0	0
Travel time - entertainment	0	0	0	0.55	0.58
Travel time - rest & other	0.31	0.53	0.91	4.95	5.18
Exit time from vehicle	0.2	0.4	0.2	0	0.25
Exit time from station	0.25	0.25	0.1		
Access to destination	1	1	0.5	0.25	0.25
Buffer for access unreliability	0.5	0.5	0.5	0.25	0.25
Total time	5.25	7.65	6.09	6	7.45

Table 3 Hypothetical Value of Time, by Mode and Type of Activity

	Air Non Stop	Air Via Hub	Train	Auto	Rental Car
Reservations	50	50	50	50	50
Time for trip					
Access to station	20	20	20	20	20
Buffer for access unreliability	20	20	20	20	20
Process time	50	50	50	20	50
Queue time	50	50	50	20	50
Available time in station	10	10	10	10	10
Boarding time	50	50	50	50	50
Travel time - work	-100	-100	-100	-100	-100
Travel time - entertainment	0	0	0	0	0
Travel time - rest & other	20	20	20	40	50
Exit time from vehicle	50	50	50	0	0
Exit time from station	50	50	50	50	50
Access to destination	50	50	50	50	50
Buffer for access unreliability	10	10	10	10	10
Extra travel time	150	150	150	150	150

With these detailed inputs concerning travel time and the value of time, it is possible to estimate our traveler's utility for each mode (Table 4). Time is shown as a "disutility" so that it has the same sign as cost – the mode with the lowest disutility is therefore the preferred mode. The quality of time spent traveling is clearly important; ranking the available options in terms of their disutility gives much different results than ranking by either out-of-pocket costs or time. In particular, rail looks much better, because there is extra time for work and less for processing and access. Although rail takes an hour longer, its disutility is less than the disutility of flying. For someone who can work on the train, driving is not a good option. Renting a car, which looks good in terms of direct cost, is by far the worst choice; it takes time to rent the car and it is usually impossible to work in the car, so the disutility of the time is quite high relative to train or plane.

This particular example emphasizes the importance of "work time" to the decision and shows that the cumulative benefits of lower terminal time, easier processing, and greater accessibility help rail relative to air travel (but hurt rail relative to driving your own car). It also suggests a framework for comparing technologies or projects. Any intercity market will have groups of travelers with diverse needs and values. Some people may be able to think effectively when driving, so they may look forward to having several quiet hours in a car. Vacation travelers are concerned with baggage handling facilities – but day trippers are not. Self-employed businessmen undoubtedly view time and costs of travel far more carefully than corporate travelers, whose personal finances are unaffected by their travel choices. The value of terminal services depends upon the expectations of the customer. Hungry students devour fast food, as long as it is cheap and plentiful; wealthy couples en route to a resort prefer to pass an extra hour enjoying a fine meal; a "road warrior" might grab pizza and a beer and check e-mail. The next section considers how passengers in four market segments might respond to various changes in mode or trip characteristics.

Table 4 Hypothetical Disutility of Travel, by Mode

	Air Non Stop	Air Via Hub	Train	Auto	Rental Car
Direct Costs	$289	$234	$162	$123	$178
Reservations	$13	$13	$13	$0	$5
Travel time					
Access to station	$15	$15	$10	$0	$10
Buffer for access unreliability	$5	$5	$4	$0	$0
Process time	$5	$8	$0	$0	$13
Queue time	$13	$18	$0	$0	$0
Available time in station	$5	$15	$3	$0	$0
Boarding time	$10	$20	$10	$0	$10
Travel time – work	-$94	-$158	-$273	$0	$0
Travel time - entertainment	$0	$0	$0	$0	$0
Travel time - rest & other	$6	$11	$18	$198	$259
Exit time from vehicle	$10	$20	$10	$0	$0
Exit time from station	$13	$13	$5	$0	$0
Access to destination	$50	$50	$25	$13	$13
Buffer for access unreliability	$5	$5	$5	$3	$3
Extra travel time	$0	$360	$126	$113	$330
Total travel time disutility	$43	$381	-$58	$326	$636
Total disutility	$344	$627	$117	$448	$820

Estimating Mode Shares

Given the utilities (or disutilities) for each available mode, it is possible to estimate mode shares using what is called a logit model. The mode share for mode j is calculated as follows:

(Eq. 1) $$\text{Mode Share} = (e^{-\text{disutility mode j/scale factor}}) \; / \; (\Sigma\, e^{-\text{disutility mode k/scale factor}})$$

This type of model is commonly used in travel demand studies. If the disutility of two modes is within 5 or 10%, they each have a sizeable market share; if the disutility of one mode is much greater, then it has a very minor share of the market. The scale factor was assumed to be 25% of the average disutility of the mode with the lowest disutility for each market segment. This factor determines how strongly mode shares vary with the relative costs.

The base case for the sensitivity analysis added three market segments to the example from the prior section: general business, vacation, and student. The latter three market segments have values of time that are 50%, 25%, and 10% of the values for the executive considered above. Each market segment was assumed to have an equal number of travelers.

Six cases were investigated in addition to the base case (Table 5). The first two considered airline strategies:

Case 1 – Discount Air Fares: a new carrier enters the market, halving air fares, but doubling processing times. Rail retains more than half the market, because the trip is too short for air speed to make much difference. Since business travelers expect to be productive, the rail option still looks good.

Case 2 – Business Shuttles: major airlines introduce a service aimed at business travelers. Fares match the discount airlines, but processing, queuing and wait times are halved. This service captures more than 90% of the business market. Vacationers also appreciate the time savings; more than half switch to air. Students, still searching for the best deal, divide fairly evenly among the two air modes, rail, and auto. Overall rail market share plummets to 10%.

Table 5 Sensitivity Analysis for Mode Share

	Air Non Stop	Air Via Hub	Train	Auto	Rental Car
Base Case	2%	1%	67%	29%	1%
Discount Air Fares	18%	3%	56%	22%	1%
Business Shuttle	72%	9%	10%	9%	1%
Lower Rail Fares	58%	14%	24%	4%	0%
High Speed Rail	40%	12%	43%	4%	0%
Easy Access	17%	8%	71%	3%	0%
Two Travelers	2%	0%	54%	40%	4%
Easy Rail & Business Shuttle					
125 miles	7%	4%	69%	20%	1%
250 miles	17%	8%	71%	3%	0%
375 miles	35%	12%	51%	1%	0%
500 miles	56%	16%	27%	0%	0%
625 miles	68%	19%	13%	0%	0%

The next three cases address possible rail responses to the business shuttle. Each helps retain market share, with the greatest benefits for this particular example coming from improving access:

Case 3 – Lower Rail Fares: railways respond to the shuttle by cutting fares by 20%. Executives don't even notice the change; the other groups increase their rail mode share to a quarter or a third. Overall, the rail share recovers to 24% of the market.

Case 4 – High Speed Rail: average rail operating speed is 150 mph rather than 80mph. This is more successful than simply lowering fares, and rail is projected to gain 43% of the market. However, a major project would be needed to achieve such high speeds and it is unclear if prices could remain unchanged.

Case 5 – Easy Access: the average speed is again 80mph, but times are halved for rail processing, access, and reservations, while better on-board seating and services increases the value of time by 20% for business travelers. The value of terminal and on-board entertainment time is increased for everyone with more entertainment, retail and culinary opportunities in the stations and better food and services on the train. Executives are assumed to increase their working time from 70 to 80% of the trip time. The results are very strong for the railways, which become dominant in the first three markets and capture a third of the students.

Sometimes a group is traveling:

Case 6 – Two Travelers: travelers share the cost of auto trips or cab rides. The dominant result is to make driving a very good option, with almost all air traffic and more than 20% of the rail traffic diverting to auto. Rental cars also improve, increasing their share from 1 to 4% and becoming a good option for vacationers and students. Clearly, if a family is going on vacation with children, the automobile will look better for even longer distances. Likewise, if three or four people are traveling together on business, then renting a car may look better, particularly if they can conduct some business while driving.

Distance is obviously another key factor for sensitivity analysis, as rail works best for distances that are rather long for highway travel, yet rather short for airlines. "Easy Access vs. the Air Shuttle" was used as the base case. For the 125-mile trip, rail captured 69% and autos took 20% of the market. For the 250-mile trip, the highway modes essentially drop out and direct air flights capture 17% of the market. As distances increase to 625 miles, the rail share drops steadily, while the air share grows. Air travel via a hub is increasingly attractive for the longer distances, as the cost savings become large enough to justify the additional time.

Implications for Carriers and Terminal Operators

The implications of utility analysis are generally well understood. There is value in reducing travel time, in minimizing process time, and in increasing passenger comfort. There is value in providing a variety of ways for travelers to spend their time and their money. Carriers attempt to capture this value by offering premium services at higher prices. First class and business class travelers enjoy quicker check-in, comfortable and productive waiting areas, larger seats and better food – and they are willing to pay a premium of $100-$200 per flight hour for these privileges. This premium is high compared to the coach fare, but not unrealistic when compared to executive salaries or consulting rates. Carriers also advertise their on-board services, including telephones, movies, games, magazines, and shopping opportunities.

Terminal operators may have been slower to understand the importance of time and utility, but they have certainly responded well over the past 10-20 years. New airports feature greatly enlarged shopping opportunities, food courts, fine restaurants, lounges, TVs, internet access, ATMs and other amenities that make waiting time more valuable to the traveler (and more profitable to the terminal owner). Government agencies and airlines are also concerned about airport access, recognizing the importance of time and comfort to the user as well as the costs of the infrastructure. Similar trends have affected some major train stations, which now offer varied retail and dining opportunities

Implications for Project Selection and Project Evaluation

This example shows how markedly different technologies and types of projects can be compared in terms of their potential effects on passengers' utility. The most striking comparisons are among the three generic responses to the business shuttle for the 250-mile trip (Cases 3-5). Lower fares could be interpreted as investments in any of the many technologies that might reduce cost while leaving service and access unchanged. High speed rail is of course a dominant theme in the evolution of rail technology, in rail R&D, and in proposals for rail investment. Easy access relates to entirely different types of projects, including not only improvements in terminal processing, but also improvements in terminal access. For this example, access is somewhat more important than train speed, and much more important than cost reduction. In general, saving time in access and processing or allowing more productive use of time may be more effective – for the customer – than saving time by running faster.

The rail industry and public agencies are well aware of the potential for high-speed rail systems to attract traffic from congested airports and highways, and extensive R&D and investment programs are in place to advance such systems. In the U.S., the "next Generation High-Speed Rail Technology Demonstration Program" was funded at more than $25 million annually in fiscal 2001 and 2002, exceeding the rest of the FRA's budget both passenger and freight R&D[5]. However, as demonstrated in this case study, higher speed is not the only way to reduce travel time or to enhance travelers' utility, and quite different kinds of technologies and projects may be equally effective in enhancing rail competitiveness.

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5 Federal Railroad Administration, "Five Year Strategic Plan for Railroad Research, Development, and Demonstration", Chapter 8, U.S. Department of Transportation, Washington D.C., 2002

This PBTS analysis shows that train speed is only one factor, and perhaps a relatively minor factor influencing travelers' decisions. Total door-to-door trip time, the quality of time spent in each portion of the trip, and the opportunity to use the time for enjoyable or profitable activities are all very important factors. Comfortable trains operating over a dense network at reasonably frequent intervals can compete effectively with both air and auto for trips of 100 to 500 miles.

Figure 1 Dublin Train Station

Resource: Project Evaluation: Essays and Case Studies
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