Sensitivity of Hudson-Bergen Light-Rail Transit System Model Forecasts

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Travel demand modeling and forecasting that were completed as part of the evaluation of a proposed light-rail transit (LRT) system in New Jersey's Hudson River waterfront area are described. The modeling required a unique approach because of several characteristics of the study area. The market for the proposed service includes those commuting into New York City from New Jersey as well as travelers within the waterfront area. This area has a complex mix of existing transit service, which the proposed LRT system would complement. The travel demand models were developed initially as part of a New Jersey Department of Transportation project. A residential choice model was added to the conventional four-step process, and a nested logit-based mode and path model was developed. The nested logit model estimates shares among existing and new modes, accounting for different levels of competition as observed among subsets of the modes. The model system was used to prepare a Draft Environmental Impact Statement for the proposed LRT system. In preparation of the Final Environmental Impact Statement, the model was refined, updated, and validated to 1990 conditions. The mode-choice model was adapted to better reflect elements of travel behavior that were observed in focus groups and a stated-preference survey. Data from a 1990 trans-Hudson survey were used to reestimate mode-choice coefficients using a specification suggested by the stated-preference surveys. Forecasting experiments are shown to illustrate the overall sensitivity of model forecasts to policy variables and future scenarios. Estimates of the ranges in forecasts that result from sampling error in the choice model estimation process are given.

In 1989 the New Jersey Department of Transportation (NJDOT) commissioned a project to create a new set of travel forecasting models that would replicate the travel patterns within the northern New Jersey area that extended across the Hudson River and capture the very important share of the travel market with destinations in New York City. The Federal Transit Administration (FTA) required this work be expanded in an Alternatives Analysis/Draft Environmental Impact Statement (AA/DEIS) for the Hudson River waterfront study for two reasons. First, the majority of trips headed to New York from west of the Hudson exit through Hudson and Bergen county portals. Second, rapid and current projected development along the Hudson River waterfront beginning in Bayonne, New Jersey (Hudson County), and ending in Edgewater, New Jersey (Bergen County), indicated the potential for a new transit investment to increase existing transit capacity and reduce congestion.

The enormous size and complexity of the New York City region required development of travel forecasting models that differ from conventional models. The length of commuter trips that employed individuals within the region are willing to make and the number of transportation modes that may be used defy comparison with other regions of the country. Even social patterns are quite different than those experienced elsewhere. For instance, households with relatively high incomes within New York City itself do not conform to the traditional relationships among income, automobile ownership, and transit usage. Consequently, it was necessary for the patronage forecasting model developed for the Hudson-Bergen Light Rail Transit System's (HBLRTS) AA/DEIS process to use innovative travel forecasting procedures. The initial model had to respond to the special needs of the Hudson River waterfront area, and more generally, the unique travel patterns of the New York City metropolitan area.

Initial Model Structure

To develop the initial HBLRTS model, the traditional four-step process of trip generation, distribution, mode choice, and trip assignment was employed, with two important modifications. First the distribution component for work trips was modified through the use of a residential location-choice model, which mirrors real-life choices by assuming that households select their place of work first and then choose a place to live on the basis of the location of the work site and a broad spectrum of social, economic, and travel time variables. Conversely, the conventional model approach distributes trips from home to work, implicitly assuming that people first chose where they will live and then chose where they will work.

By reversing the decision assumption, the residential location-choice model better predicts travel patterns for the Hudson River waterfront study through a feedback loop of transportation characteristics that were considered in the residential selection process. This model feature reflected the broad use of transit as a principal mode of travel for work trips for many people in the region. Mode shares for work trips during a 24-hr period into Manhattan are 43 percent automobile and 57 percent transit according to the 1990 All Modes Trans-Hudson Survey (*1*), and approximately 35 percent automobile to 65 percent transit for work trips into the waterfront according to the 1990 Waterfront Employee Survey (*2*). The share of transit is higher in both markets during peak periods.

The mode-choice model was extended to include both primary and access modes as "transit paths." Because of the highly competitive transit options available in the New York–New Jersey metropolitan area, it would be inaccurate to assume that all transit trips used the same "best" transit path between two pairs of zones. Consequently, the "mode and path" choice model was structured into 13 separate mode-path options, permitting the estimation of separate trip tables for each option. These separate tables allowed analysis to occur with the trip tables before assignment to the networks. This process provided a greater degree of precision in refining forecasts. It also provided an opportunity for insights into travel behavior that could not be easily achieved when the final decision on modes and submodes was left to the network assignment process. Finally, the nesting feature of the mode-path choice model allowed the grouping of those alternative mode-path options that most closely compete. Within each nest, the model estimates the probability that each alternative in the nest will be chosen.

In addition to the need to analyze the multipath options available, the opportunity to evaluate transit service capacity is also important. This evaluation occurred outside the model process in an iterative fashion through service equilibration. The model did not consider capacity constraints such as delays caused by crowded trains or delays caused by waiting for the next train if the first is full.

Nonwork travel patterns were modeled using a conventional approach. Nonwork distribution was estimated with a gravity model, which uses the person trips to and from each zone produced by trip generation, the zone-to-zone minimum time paths from the highway network, and friction factors indicating willingness to travel a certain distance. *K*-factors were introduced into the model to compensate for crossing volumes of the bridge between New York and New Jersey, which carried more trips than the model predicted. The model was unable to account for the effect of bridge crossing on travel patterns. Because it was assumed that nonwork trips are generally less likely to use transit than home-based work trips, a gamma function of travel time was used to estimate nonwork trips as a share of work trips. The gamma function assumes there is a progressive unwillingness to use transit for nonwork trips as the length of the trip increases. The gamma function used distance as the prime variable in explaining variation.

Model parameters for this initial HBLRTS model (*3*) were estimated using 1980 and 1983 transportation and land use data, including data from the 1980 U.S. census. Validation was performed using available 1986 and 1989 observed data.

Current Status of Model

The initial HBLRTS model was used to evaluate alternative transportation investment proposals and estimate their associated traffic and environmental impacts. Once a locally preferred alternative was selected, refined forecasts were needed for a final environmental assessment. After a model refinement and upgrade process, the initial model was transformed into its current version.

Specific model refinements include network, zone, and land use changes as well as enhancements to model structure and parameters. An extensive update of both the highway and transit networks resulted in the receipt of more highway detail required for more precise rail, bus, and ferry mode analysis. All state highway facilities and major county road facilities are coded in the highway network. In addition, many local arterials are used in the network, especially in the urbanized areas within New Jersey. In Hudson and Bergen counties, there is even more local detail to capture very localized complexities. Additional transit detail has led to more accurate line-haul and transfer volumes. Because the previous model indicated significant interaction between the proposed new light-rail transit (LRT) and other transit modes, particularly at major transit interchanges, detailed modal analysis is now provided at these major transfer hubs.

Accompanying changes were also made to the model's zone structure. Zones within Hudson and Bergen counties are now all based on census tracts, and some zones, particularly in the waterfront development areas, are as fine as actual development sites. This level of detail became necessary to evaluate the impact of alternative LRT alignments in and around actual or planned developments.

Both base- and future-year land use data were updated. The 1990 census, the 1990 All Modes Trans-Hudson Survey, and 1990 statistics on employment and population were used to develop and calibrate a 1990 base for the refined HBLRTS model. The source of land use in 2010 was regional forecasts prepared by Urbanomics for NJDOT and the New Jersey Office of State Planning. In addition, waterfront development expectations were updated and incorporated into the 2010 forecasts.

Model parameters and structure were reviewed, and four important modifications occurred. First, a distinction that was made in the mode-choice model between long and short drives to transit was omitted and replaced by one "drive-to-transit" definition. This new definition avoids a sudden shift at the arbitrarily defined breakpoint between long and short and instead relies more on observed park-and-ride catchment areas for the various transit modes revealed in the 1990 All Modes Trans-Hudson Travel Survey. Next, the modal definitions for trans-Hudson service were expanded. Since ferry has become a viable trans-Hudson alternative, it has been added to the model structure as a separate mode. This change enables the analysis of LRT-to-ferry transfers as an alternative to LRT-to-Port Authority Trans-Hudson (PATH) for trips destined to midtown or lower Manhattan.

The nonwork model was also modified by replacing a gamma function with a simple look-up table of factors based on the 1990 All Modes Trans-Hudson survey. The current approach to modeling nonwork trip patterns recognizes that the number of observations for nonwork trip purposes is not as robust as that for work trip purposes; therefore, a calibrated nonwork logit model would be less robust. Since the work model is calibrated from a robust data base, the results of the home-based work mode-choice model are more reliable, and pivoting off such a model limits the magnitude of error in forecasting transit share for nonwork purposes. Inherent in this current approach is the assumption that the main difference in mode shares for nonwork is due to the inherent difference in trip purpose between work and nonwork travel. This difference is captured by pivoting off the home-based work mode-choice model using mode shares from the 1990 All Modes Trans-Hudson survey to obtain nonwork travel.

Stated-Preference Research

The last model enhancements were improvements to mode-choice coefficient estimates. Under the AA/DEIS model version, the value of time was extremely high, in the vicinity of $45/hour. This value of time implied that riders were relatively insensitive to travel costs as compared with travel times. Further, riders also appeared insensitive to the number of transfers. Since both results seemed counter to past findings, a stated-preference survey (SPS) (*4*) was initiated to assist in refining the model. The SPS was also utilized to challenge the overall nesting structure of the model and to develop a "mode bias" constraint for the LRT mode.

The stated-preference data generally support the model specification, result in a value of time of $15/hour, and reveal that transfers have a significant perceived penalty. The transfer penalty was found to be equivalent to approximately 10 min of in-vehicle travel time and increasing in marginal value for each additional transfer. An additional finding of the SPS is that the LRT mode bias constant is very similar in value to the PATH constant and is therefore a reasonable surrogate for the "new LRT mode" constant. Otherwise, statistical estimation of model coefficients with the stated-preference data produced values very close to those in the original mode-choice model.

Recommendations from the SPS are incorporated into the current HBLRTS model, though model coefficients were estimated using approximately 4,100 revealed-preference observations from the 1990 All Modes Trans-Hudson Survey. The number of transfers is included as an explicit variable with increasing marginal disutility, and the value of time estimated by the new model is similar in value to the SPS value of time. As a result, the current HBLRTS model reflects greater sensitivity to travel cost and a greater resistance to travel paths that increase the number of transfers required. The expected outcome of the SPS was a reduction in LRT use by trans-Hudson commuters because of the new sensitivity to transfer and costs.

The model results mirror this expectation as follows:

	HBLRTS Market Share (%)	
Market Area	*Original Model*	*Current Model(5)*
Trans-Hudson	51.3	48.9
West-of-the Hudson	48.7	51.1

Market and Land Use Analysis

Description of Market Area

The New Jersey Hudson River waterfront is in the stages of major redevelopment, with far-reaching potential for waterfront municipalities and the state in terms of jobs and revenues. Historically, the waterfront housed heavy industry and railroad-related uses, but over the past few decades, industrial and railroad use vacated the waterfront properties, leaving hundreds of acres of abandoned and rusting rail yards, decaying piers, and remnants of warehouses and factories.

During the past several years, interest in the waterfront has been rekindled and redevelopment is occurring, but primarily for nonindustrial or residential uses. Developers seeking to capitalize on the region's housing and office markets have proposed a number of waterfront projects that include office buildings, apartment houses and condominiums, retail centers, restaurants, marinas, parks, and entertainment and recreation centers. Collectively, these projects could create a whole new city along the waterfront.

In nearly all socioeconomic categories, the immediate study area is divided into two distinct parts: the Bergen County section and the Hudson County section. The Bergen County municipalities are generally more affluent (1990 median household income of $49,249 versus $30,917 in Hudson County) but have similar household size (2.67 per household in Bergen County and 2.64 per household in Hudson County); working residents tend toward white-collar, professional occupations, whereas Hudson County was more blue collar. Housing values and median rents in the Bergen towns far exceed those in Hudson County. The Hudson County area is more racially and ethnically diverse, and its residents are younger.

Overall, the area population for Bergen and Hudson counties decreased between 1980 and 1990 by 2.4 percent and 1 percent, respectively. However, employment grew respectively by 22 and 9 percent between 1980 and 1990. Growth is expected in employment and population in both counties through the year 2010. Bergen County is projected to grow in employment by about 1 percent per year and is expected to remain about the same in households to the year 2010. Hudson County's household growth is expected to be 0.898 percent per year to the year 2010. Primarily because of the substantial expected waterfront development, the number of jobs available in Hudson County will grow by 1.2 percent through the year 2010.

Along the waterfront development areas, the 1990 employment level was 22,651 and is expected to grow at 9 percent per year to 43,475 in 2000 and then slow down to 6 percent per year through the year 2010. The number of housing units in 1990 was 10,437 and will grow to 29,181 by 2010.

Development Forecasts

A significant amount of the land surrounding the LRT alignment is vacant today, especially in the core sections of the alignment in downtown Jersey City, Hoboken, and Weehawken, as well as nearby sections of West New York along the waterfront. Although major development plans have been proposed for most of the vacant land, future development patterns are not really known today. The recent decision of the cotton, sugar, and other commodity exchanges to remain in Lower Manhattan instead of relocating 3,200 jobs to Colgate illustrates the volatility associated with future land use forecasts and development patterns. However, estimates of future development at waterfront sites were developed for 2000, 2005, and 2010 to enable the determination of future LRT ridership for those years. The forecasts include estimates of future office space, retail space, and housing units, which have been converted into office jobs, retail jobs, and resident population.

Several sources (6, Appendix D) were used to develop these forecasts to take into account both current conditions in the Hudson River waterfront development environment and current thinking about the economic growth potential in the New York metropolitan area, including Manhattan and Hudson County. These sources were used to develop estimates of total future growth for the area and estimates of growth for each of the individual developments in the waterfront area.

Demand Analysis

Application of the refined HBLRTS model presents an opportunity to assess its reasonableness. In addition, by varying assumptions in the model, it can be shown how sensitive the model is to these changes and the level of confidence of the model. These issues will be addressed by providing a benchmark patronage forecast for review and analysis, various sensitivities and elasticities of alternative model assumptions, confidence intervals around the benchmark, and finally a comparison of the elasticities against local and regional experience.

Benchmark Description

The 2010 benchmark LRT system used for this analysis is the locally preferred alternative, which has two branches, the Bayonne Branch and the Westside Branch (Figure 1). The Bayonne Branch begins at 5th Street in Bayonne and converges with the Westside Branch at the Gateway Park-Ride at Liberty State Park in Jersey City. The Westside Branch begins at Route 440 in Jersey City. In this benchmark system, both branches are scheduled to operate on a 9-min headway and terminate at the Vince Lombardi Park-Ride in Ridgefield. This operation produces an effective headway of 4.5 min between the Gateway Park-Ride and Vince Lombardi LRT stations. The assumed LRT fare is a flat rate of $1.00 with no discounting for intermodal transferring and multiride tickets or other discounts such as that for senior citizens.

The bus service for this benchmark system assumes modifications to both NJ Transit and private carrier routes to feed the LRT service and has not been fully dimensioned in cost or difficulty of implementation, but barring any constraints, it is "feasible" (7).

In addition to bus feeder service, the benchmark sys-

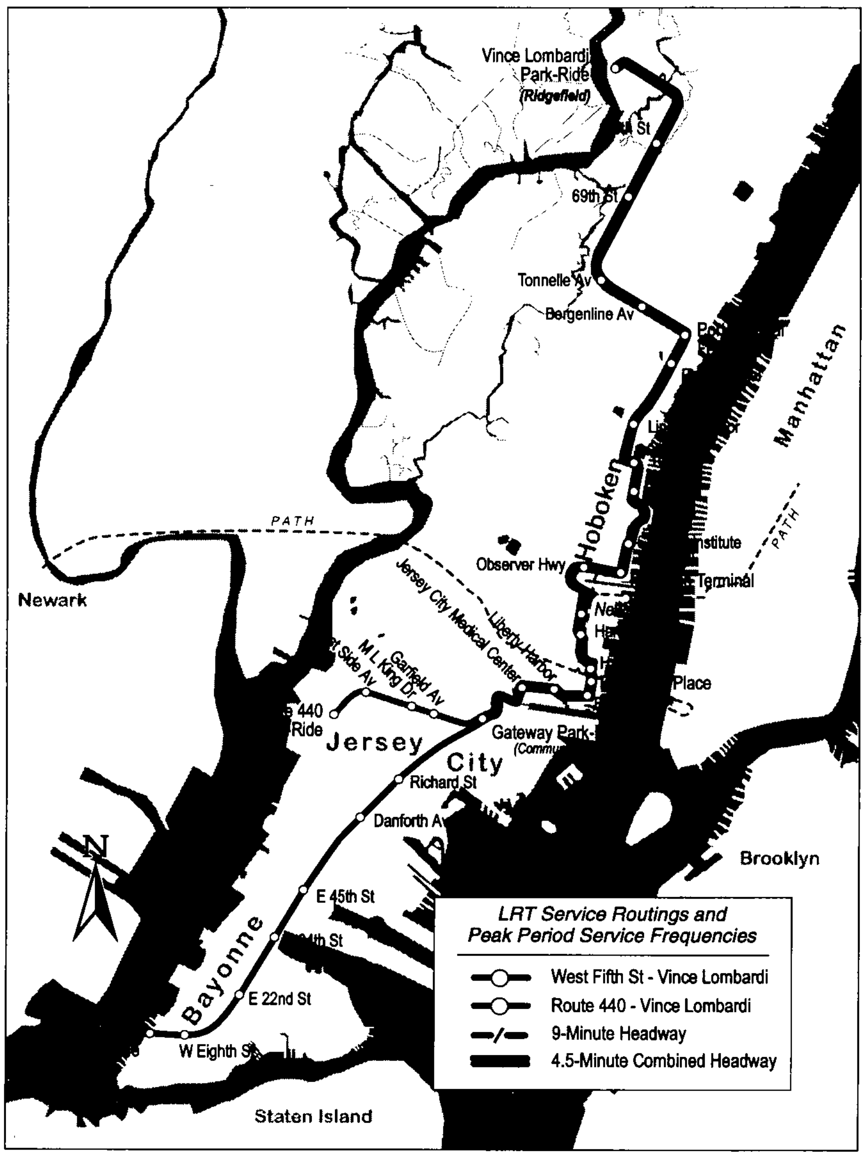

FIGURE 1 LRT alignment.

tem features a series of LRT park-and-ride or "drive-to-LRT" locations. There are 13 LRT park-and-ride locations among each of three branches: Westside, Bayonne, and Northern. Although projected demand for spaces at Liberty State Park would surpass capacity, there is no occurrence of serious undercapacity with respect to the number of daily parkers and the availability of parking spaces. Park-and-ride locations at 5th Street, Liberty State Park, and Vince Lombardi would represent more than 60 percent of the total parking demand. On the basis of nominal parking fees, the minimum expected revenue that the LRT park-and-rides would generate is slightly more than $2.3 million.

Market Share Summary and Patronage Forecast

The total patronage projected for the 2010 benchmark LRT system is 90,200 daily LRT riders. Approximately 48 percent of this patronage is the trans-Hudson market and the remaining 52 percent remain west of the Hudson. The expected annual revenue generated by this patronage is approximately $27 million. The combined revenue generated by LRT ridership and the $2.5 million additional revenue expected from park-and-ride lots brings the total expected LRT revenue to $29.5 million.

When compared with other modes in the region, the benchmark LRT system captures a significant share of transit trips. Approximately 10 percent of all transit trips beginning or ending west of the Hudson and around 6 percent of the transit trips into New York are made on LRT. For transit trips with destinations only to Hudson County, 24 percent, or 43,000, are made on LRT, and transit trips originating in Hudson County have a 20 percent LRT share, or 60,000 LRT riders. Finally, the highest LRT transit share is for intra-Hudson County trips at approximately 27 percent, reflecting 36,400 trips on LRT.

The principal origin markets targeted for the HBLRTS can be defined as Staten Island, southern Hudson County, downtown Jersey City, northern Hudson County, northern Bergen County, and southern Bergen County. Over 40 percent, or 38,000, of all benchmark LRT trips have destinations in either midtown or lower Manhattan. Approximately 28 percent, or over 25,000, are destined to new development areas along the waterfront—downtown Jersey City and other parts of the waterfront in Hoboken or Weehawken.

Southern Hudson County

Although close to 30 percent of the LRT trips that begin south of Hoboken go to Manhattan, over half of the LRT trips from these areas involve local trips between or within Staten Island, Bayonne, southern Jersey City, and downtown Jersey City. This result reflects a significant amount of short-distance, local LRT trips. The LRT serves residents of southern Hudson County well by affording a viable alternative for making local trips, the largest percentage of which occurs in downtown Jersey City. Of the total 7,050 trips originating in downtown Jersey City, approximately 60 percent remain in the downtown area. When the entire waterfront is considered, 8,666 of the 15,339 trips that would originate in the waterfront are local waterfront LRT trips.

Northern Hudson County

In contrast to southern Hudson County, approximately 9,215 LRT trips, representing over 50 percent of the 16,665 LRT trips from northern Hudson County markets, are Manhattan-destined trips, whereas 5,149, slightly less than 30 percent, reflect local or waterfront trips. The largest market for trans-Hudson LRT trips is Bergen County. Over 80 percent, or 9,981 of the LRT trips from this market, end in Manhattan locations.

Comparison with Other Scenarios

Patronage forecasts produced for the LRT benchmark system were systematically compared with results from over 20 different scenarios (6, Appendix F) selected to demonstrate the importance of key variables: LRT run time, LRT frequency, fare policies, and land use assumptions. In addition, a 1990 base year along with a future-year build scenario were selected to demonstrate growth and diversion impacts. The results of these scenarios are shown in Table 1. The scenarios are defined as follows:

1. 1990 base year: no build assumptions, only existing conditions,
2. 2010 build without LRT: all build assumptions such as heavy rail in major corridors but no LRT,
3. 2010 baseline: build assumptions with LRT,
4. Fare: increase in LRT fare from $1 to $2,
5. Frequency: decrease frequency from 9 to 12 min,
6. Run time: increase run time on LRT alignment in mixed traffic,
7. 1990 land use: assumes all build assumptions including LRT but no economic growth, and
8. Development: assumes 100 percent development near LRT stations.

The analyses for the scenarios that did not involve land use changes were performed without rerunning the residential location model. The results thus reflect mode-choice and network equilibration effects only.

TABLE 1 Benchmark and Selected LRT Trips by Market Type

Market:	TRIPS WITH DESTINATION IN HUDSON COUNTY							
		2010						
		BUILD	2010					
	1990	WITHOUT	LRT	LRT	LRT	LRT	LRT - NO	LRT -DEVOLPMENT
MODE	BASE	LRT	BASELINE	FARE	FREQ	RUNTIME	GROWTH	GROWTH
Total Walk to Transit	77.4	136.0	124.2	126.2	126.0	126.2	84.8	141.0
Total Drive to Transit	10.2	22.0	15.0	15.2	15.4	15.4	8.4	18.2
Walk to LRT	0.0	0.0	37.8	33.0	33.8	34.0	17.4	44.8
Drive to LRT	0.0	0.0	5.2	4.8	5.0	5.0	3.4	5.6
Total LRT	0.0	0.0	43.0	37.8	38.8	39.0	20.8	50.4
Total Transit	87.6	158.0	182.2	179.2	180.2	180.6	114.0	209.6
Auto	1096.0	1336.0	1314.0	1318.0	1316.0	1316.0	1094.0	1260.0
Total Trips	1183.6	1494.0	1496.2	1497.2	1496.2	1496.6	1208.0	1469.6
Market:	TRIPS WITH ORIGIN IN HUDSON COUNTY							
		2010						
		BUILD	2010					
	1990	WITHOUT	LRT	LRT	LRT	LRT	LRT - NO	LRT -DEV
MODE	BASE	LRT	BASELINE	FARE	FREQ	RUNTIME	GROWTH	GROWTH
Total Walk to Transit	152.6	220.0	196.4	200.0	199.2	199.6	146.4	209.8
Total Drive to Transit	43.6	62.0	49.2	50.2	50.0	50.2	35.4	50.6
Walk to LRT	0.0	0.0	54.0	47.0	48.8	48.8	30.4	60.0
Drive to LRT	0.0	0.0	6.6	6.0	6.2	6.2	4.8	6.8
Total LRT	0.0	0.0	60.6	53.0	55.0	55.0	35.2	66.8
Total Transit	196.2	282.0	306.2	303.2	304.2	304.8	217.0	327.2
Auto	1188.0	1428.0	1408.0	1412.0	1410.0	1410.0	1182.0	1260.0
Total Trips	1384.2	1710.0	1714.2	1715.2	1714.2	1714.8	1399.0	1587.2
Market:	HUDSON COUNTY TO HUDSON COUNTY TRIPS							
		2010						
		BUILD	2010					
	1990	WITHOUT	LRT	LRT	LRT	LRT	LRT - NO	LRT -DEV
MODE	BASE	LRT	BASELINE	FARE	FREQ	RUNTIME	GROWTH	GROWTH
Total Walk to Transit	54.4	100.0	90.4	92.0	92.2	92.0	62.0	101.2
Total Drive to Transit	4.6	12.0	6.0	6.2	6.2	6.4	3.0	7.4
Walk to LRT	0.0	0.0	32.6	28.2	28.8	29.2	13.2	39.0
Drive to LRT	0.0	0.0	3.8	3.4	3.6	3.6	2.6	4.0
Total LRT	0.0	0.0	36.4	31.6	32.4	32.8	15.8	43.0
Total Transit	59.0	112.0	132.8	129.8	130.8	131.2	80.8	151.6
Auto	738.0	926.0	911.0	912.0	912.0	912.0	738.0	870.0
Total Trips	797.0	1038.0	1043.8	1041.8	1042.8	1043.2	818.8	1021.6
Market:	TRIPS TO NEW YORK CITY -- INCLUDES STATEN ISLAND							
		2010						
		BUILD	2010					
	1990	WITHOUT	LRT	LRT	LRT	LRT	LRT - NO	LRT -DEV
MODE	BASE	LRT	BASELINE	FARE	FREQ	RUNTIME	GROWTH	GROWTH
Total Walk to Transit	292.8	370.0	351.6	353.6	352.4	353.0	268.0	351.4
Total Drive to Transit	219.0	300.0	285.2	286.6	285.6	286.0	213.8	282.8
Walk to LRT	0.0	0.0	28.0	24.6	26.0	25.4	23.0	27.4
Drive to LRT	0.0	0.0	15.2	13.2	14.2	13.8	12.4	15.0
Total LRT	0.0	0.0	43.2	37.8	40.2	39.2	35.4	42.4
Total Transit	511.8	670.0	680.0	678.0	678.2	678.2	517.2	676.6
Auto	1452.0	1842.0	1838.0	1840.0	1840.0	1840.0	1440.0	1840.0
Total Trips	1,963.8	2,512.0	2,518.0	2,518.0	2,518.2	2,518.2	1,957.2	2,516.6

Note: Two directional, 24-hr service; values are in thousands.

1990 Base Year

The primary destination markets, trans-Hudson and Hudson County, are evaluated. Between the 1990 base year and the 2010 LRT benchmark, the market share of total transit increases for trips destined to Hudson County, originating in Hudson County, as well as for intra-Hudson County and remains relatively constant for the trans-Hudson market.

The direction and magnitude of change in automobile versus transit shares are expected. Since there already exists an array of transit services into Manhattan, the transit-to-automobile share is not expected to change significantly with development of the HBLRTS. Instead, shifts between transit modes are more likely to occur in the Manhattan-destined trip market. For instance, modal shifts between PATH and ferry will occur because ferry is now competing with PATH, and the LRT will serve as a feeder to both systems.

Expected future development along the waterfront, even without a seamless north-south transit distributor along the waterfront, explains the increase in transit shares for trips to, from, and within Hudson County. The reasonable magnitude of the increase in trips to, from, and within Hudson County, respectively 5, 4, and 6 percent, reflects existing PATH and local bus competition. As a result, the LRT would divert some PATH and bus users but would also attract some automobile users who are currently not well served by existing transit services.

2010 Build Without LRT

The major difference between the 2010 LRT benchmark and the 2010 build without LRT scenarios is the change in automobile, PATH, and Port Authority Bus Terminal (PABT) bus volumes. As shown in Table 1, the 2010 LRT benchmark would decrease 24-hr daily automobile volumes by 22,000 for trips destined to Hudson County, by 20,000 for trips originating in Hudson County, by 15,000 for intra-Hudson County trips, and by 4,000 for Manhattan trips. Table 2 shows that 24-hr daily PATH volumes would increase by more than 20,000 trips.

This last result is the effect of the LRT-to-PATH relationship, which becomes evident when the LRT is included. What also shows up is the reduction in the use of PABT buses to enter Manhattan because commuters would exercise the option to use LRT-to-PATH or LRT-to-ferry routes. For instance, at Hoboken Terminal, in the 2010 build without LRT scenario, there are approximately 48,000 daily transfers to PATH, and in the 2010 LRT benchmark, which includes the LRT, there are around 72,800 daily transfers to PATH. The additional PATH transfers generated in the LRT benchmark are a result of the LRT.

TABLE 2 Ridership Boardings by Mode

MODE	1990 BASE 24-HR ONE-DIR	2010 BUILD WITHOUT LRT 24-HR ONE-DIR	2010 BUILD WITH LRT 24-HR ONE-DIR
Hoboken Rail	32,500	61,047	60,294
Newark Rail	50,083	77,810	77,182
Ferry			
Hoboken	1,635	2,329	2,147
Port Imperial - Midtown	4,431	6,681	7,772
Port Imperial - Downtown	53	178	46
Colgate	na	1,156	1,133
PATH (Trans Hudson)			
North Tunnel	39,869	42,437	50,675
South Tunnel	53,739	72,456	75,478
Total PATH:	93,608	114,892	126,152
Bus			
Route 9	8,401	12,057	12,326
PABT (Trans Hudson)	83,258	91,644	86,632
LRT	na	na	45,617

Land Use Impacts

The impacts of various land use assumptions can be observed best by evaluating impacts in specific markets. Two land use scenarios were analyzed. The first scenario assumed that there would be no economic growth in the region but that all capital rail improvements would be made, inclusive of the LRT. The other scenario assumed that 100 percent of proposed development would occur in or near the vicinity of LRT stations.

No Growth

Even in the absence of economic growth, the LRT would still generate over 60,000 daily trips. Market-specific impacts of importance include the following:

1. A diversion from automobile to transit would occur as compared with the 1990 base year. There would be 2,000 and 6,000 fewer daily automobiles for trips with destinations or origins, respectively, within Hudson County, and 12,000 fewer automobiles into New York. Because the 1990 base year and the no growth scenarios assume the same economic conditions, this result clearly demonstrates that an LRT option greatly benefits current commuters.

2. When compared with the 2010 benchmark scenario, the no growth scenario results in an increase in the portion of LRT trips that go into Manhattan from

43 to 54 percent and a corresponding decrease in the portion of LRT trips to the waterfront. In addition, approximately 6,700 of the 30,000 loss in LRT trips caused by no growth occurs in the Manhattan trans-Hudson market.

3. An additional 20,500 reduction in LRT trips along the waterfront occurs in the absence of growth. This loss accounts for slightly over two-thirds of the difference in LRT ridership between the 2010 LRT benchmark and the 1990 no growth scenarios. The remaining trips would be lost to and between other locations.

100 Percent Development near LRT Stations

An expected result is that greater development within waterfront locations at or near LRT stations would shift the share of LRT trips bound for Manhattan versus those bound for the waterfront as the New Jersey Hudson River waterfront increases its share of housing and jobs in the region. A comparison between the 2010 LRT benchmark and 100 percent development scenarios verifies this expectation. Although the net gain in LRT trips is 6,800, 100 percent development around LRT stations increases LRT trips to the waterfront by more. In fact, LRT trips to waterfront locations increase by approximately 9,000 as other locations realize a net loss in LRT trips. Conversely, LRT trips from waterfront locations increase by more than 3,000. These results demonstrate the impact of transit accessibility in the choice of work and residence locations.

Fare

Compared with the 2010 LRT benchmark scenario, a \$1.00 increase in the LRT fare causes a 12 percent decrease in ridership but an increase in revenue of 76 percent, or \$20.4 million. The changes are evenly distributed throughout the various markets as well as among the various LRT boarding segments. Daily weekday LRT trips into Manhattan decrease by 4,800, but annual revenue increases by around \$8.7 million. LRT trips into waterfront locations decrease by 3,000 but revenue increases by approximately \$5.8 million. Total annual revenue increases by \$20.4 million and daily weekday LRT ridership decreases by 11,000.

Frequency

Decreasing frequency from 9 to 12 min over the 2010 LRT benchmark has the effect of reducing overall LRT ridership by approximately 8 percent, or 7,400 daily riders, and produces a corresponding 9 percent decrease in revenue, or \$2.2 million. The distribution of LRT ridership to and from targeted markets remains relatively constant as compared with the 2010 LRT benchmark. The change in LRT frequency has less impact on ridership and fares than a change in LRT fare policy, and much less impact than that resulting from a change in economic growth.

Run Time

An increase in LRT run time decreases LRT ridership only slightly more than a decrease in frequency: an additional 900 riders would be lost accompanied by an additional \$200,000 loss in revenue. The effects of the change in LRT run time also occur proportionately as the market shares remain relatively constant against the 2010 LRT benchmark.

Sensitivity of Forecasts to Policy

Over 20 alternative policy assumptions were made to produce different LRT scenarios. Table 3 shows some of these scenarios and the associated policy assumptions, ridership result, percentage change over the LRT benchmark, and elasticity where appropriate. The impact of the LRT fare policy is roughly symmetrical. Total LRT riders have an elasticity of –0.12 when fare is either increased or decreased. However, for trans-Hudson only LRT riders, the fare elasticity ranges from –0.18 to –0.25. For intra-New Jersey LRT riders the elasticity is –0.12. This means that trans-Hudson riders are more sensitive to changes in fare policy, primarily because this market has more transit options, and the absolute dollar change of the total cost is greater for this market than it is for intra-New Jersey riders (i.e., trans-Hudson riders generally pay multiple fares and have a higher total fare).

The park-ride fare policy is not symmetrical. When only drive-access trips to the LRT are considered, elasticity increases to around 0.08 for drive-access LRT riders (Table 4). The elasticity for a frequency policy is slightly greater when the wait time is shortened: −0.24 versus −0.25.

All elasticities move in the expected direction. The greatest ridership change occurs when assumptions regarding economic growth are changed. Changes in fare policy have the next most significant impact, although not as substantial as changes in growth assumptions. LRT run time and frequency assumptions have the least impact within the range explored. LRT ridership is not greatly affected by policy changes on other modes except in the instance of feeder buses, in which case the extent to which feeder bus service is within the control or influence of the LRT operator will affect ridership and revenue benefits expected from the LRT system.

TABLE 3 Sensitivity and Elasticity

Scenario No.	Description	Ridership	% Change	Elasticity
0	Baseline Scenario	90,167		
1	Increase LRT fare: $2.00	79,149	-12.22	-0.12
2	Decrease LRT fare: $0.50	95,381	5.78	0.12
3	Employ distance based LRT fare:	86,881	-3.64	n/a
4	Increase non-LRT fare: PATH $2.00	86,043	-4.57	0.05
5	Increase non-LRT fare:Ferry 25%	89,645	-0.58	-0.02
6	Increase non-LRT fare: Bus 25%	90,839	0.75	0.03
7	Increase LRT frequency: 12 min	82,808	-8.16	0.24
8	Decrease LRT frequency: 6 min	97,566	8.21	0.25
9	Increase LRT park-ride cost 100%	88,075	-2.32	-0.02
10	Decrease LRT park-ride cost: 100% (free parking)	91,707	1.71	0.02
11	Increase non-LRT park-ride cost: PATH 25%	90,449	0.31	0.01
12	Increase non-LRT park-ride cost - Ferry 25%	90,081	-0.10	0.00
13	Change feeder bus headway: NJ Transit only	80,224	-11.03	n/a
14	1990 landuse and 2010 network	60,112	-33.33	n/a
15	Increase LRT run time: non fixed guideway segment	81,917	-9.15	n/a
16	Increase auto highway and "drive-to" time 10%	89,707	-0.51	-0.05
17	Increase Hudson River Crossing Tolls: 25%	90,903	0.82	0.03
18	Increase auto parking cost in Waterfront downtown:25%	90,185	0.02	0.00
19	Different regional forecasts of population &employmt	97,271	7.88	n/a
20	100% development at projects adjacent to LRT station	96,976	7.55	n/a

Note: Baseline scenario—9-min frequency, $1.00 fare, feeder bus plan.

TABLE 4 Sensitivity and Elasticity by Market Type

	TRANS-HUDSON LRT/PATH RIDERS			
Scenario	Description Scenario	Ridership	% Change	Elasticity
0	Baseline Scenario	47,121		
101	Increase Trans-Hudson Total Transit Fare:$1	41,325	-12.30	-0.25
	DRIVE ACCESS TRIPS ONLY			
No.	Description	Ridership	% Change	Elasticity
0	Baseline Scenario	21,759		
109	Increase LRT park-ride cost 100%	19,972	-8.21	-0.08
110	Decrease LRT park-ride cost: 100% (free parking)	23,780	9.29	0.09

Note: Baseline scenario—9-min frequency, $1.00 fare, feeder bus plan.

Sensitivity of Forecasts to Model Sampling Error

It is generally not possible to specify a precise confidence interval for forecasts from a travel demand modeling system such as that developed for HBLRTS. Even for a single component such as a statistically estimated mode-choice model, there are several possible sources of error, not all of which can be quantified. A confidence interval representing sampling errors can in theory be constructed for the HBLRTS mode-choice model. To do that for the full model requires a relatively complex set of calculations. A simple alternative is to estimate the range in forecasts that would result from variations in the individual model coefficients within their statistical confidence levels.

Table 5 shows the changes in LRT forecasts that result from variations in mode-choice model coefficient values within 2 standard deviations from the estimated values. Results are shown for each of the model variables and for the structural parameters of the nested logit model. They are also shown both with and without iteration through the residential-choice model (fixed versus nonfixed trip tables). The greatest ranges in estimates come from the transfer variable and the coefficient for the nest

TABLE 5 Sampling Error

Coefficient Name	Coefficient Value	Standard Error (SE)	Original Model Result	Fixed Person Table +2*SE	Fixed Person Table -2*SE		Non-Fixed Person Table +2*SE	Non-Fixed Person Table -2*SE
Transfer	-0.423400	0.0546	90,167	93,494	86,086		94,955	85,804
Cost/Income	-0.007361	0.000587	90,167	87,496	91,622		88,343	91,681
In-Vehicle	-0.047360	0.00212	90,167	88,515	90,776		87,149	92,766
Emp Density	-0.001398	9.06E-05	90,167	88,093	91,173		88,032	92,131
Nest 1	0.560500	0.0211	90,167	84,605	95,423		83,538	97,437
Nest 2	0.794600	0.0621	90,167	90,196	88,798		90,554	89,122
Nest 3	0.283000	0.0252	90,167	87,131	92,423		86,736	93,776
Nest 4	0.493300	0.0404	90,167	90,569	88,571		90,930	88,744

that includes walk to LRT. Generally, however, the sampling errors from individual coefficient values result in only approximately 5 percent variations in forecast LRT patronage.

Local and Regional Experience

LRT fare elasticity ranges from −0.18 to −0.25 for trans-Hudson commuters and is −0.12 for intra-New Jersey commuters as compared with the elasticities on local or interstate bus and rail, which fall within a range of −0.2 to −0.3. This result can be attributed to the fact that roughly 55 percent of the LRT passengers transfer to another mode to complete the entire trip, and therefore the actual change in fare is less.

The overall PATH elasticity estimated from the model is very close to historic PATH elasticities calculated by Regional Plan Association (RPA) in 1989. Based on actual ridership data, these elasticities were between −0.04 and −0.06. The 95 percent confidence interval indicated that the elasticity could range up to −0.19.

The fare elasticity of the New York City subway system appears close to the LRT elasticity. Charles River Associates estimated a fare elasticity of −0.166 covering the period 1975–1984. Other subway elasticities range from −0.09 to −0.209.

The model's elasticity of ±0.245 is almost an exact match to RPA's historic data on subway frequency of 0.24 for an increase in service frequency.

Conclusions

Forecasting experiments are shown to illustrate the overall sensitivity of model forecasts to policy variables and possible future scenarios. The refined and reestimated HBLRTS model is appropriately sensitive to cost, transfers, and frequency. Patronage results are within reasonable ranges and generally have a 95 percent confidence level. The LRT elasticities are consistent with historic New York subway, PATH, local bus, and interstate bus experience. Major findings of the analysis are as follows:

- Important destination markets for the HBLRTS are Manhattan and waterfront locations. Respectively, these destination areas account for approximately 42 and 28 percent of the LRT trips.
- Important origin markets for the HBLRTS include Staten Island, Bayonne, southern Jersey City, the waterfront, northern Hudson County, and Bergen County. Combined, these areas are the source of over 74,000, or 82 percent, of the total 90,167 LRT trips.
- Forty percent of the HBLRTS ridership is a strong, local, intra-Hudson County commutershed. Of the total 90,167 LRT riders produced by the 2010 LRT benchmark scenario, 36,400 are intra-Hudson County trips.
- Southern Hudson County is an important LRT market for waterfront-destined trips, whereas northern Hudson County and Bergen County have predominately LRT riders for New York–destined trips. Both southern and northern Hudson County are also strong local LRT markets.
- Expectation regarding employment growth is the most critical factor for projected HBLRTS ridership and revenue. Comparing a model run that assumed 2010 employment and population growth projections with a model run that assumed only 1990 economic conditions but 2010 transportation facilities shows a variance of 30,000 LRT riders over the 2010 benchmark result.
- Economic development around LRT stations will shift the share of Manhattan- versus waterfront-bound LRT trips. When 100 percent development is assumed around LRT stations, the share of commuters to Manhattan fell from 0.43 to 0.39 and the share of trips to the waterfront increased from 0.28 to 0.36. In addition, the 100 percent growth assumption resulted in an additional 20,500 LRT riders over the 2010 benchmark scenario.
- Four other policy variables that are important in projecting LRT ridership and fare levels are, in order

of importance, LRT fare, LRT run time, and LRT frequency.

- An LRT feeder bus system will enhance patronage of the system. The ability to control and influence the feeder service will affect the degree and consistency to which this enhancement can be accomplished.
- LRT fare elasticity is higher for trans-Hudson commuters using the LRT than it is for intra-New Jersey LRT riders.
- All LRT elasticities move in the expected direction and are consistent with historical local and regional experience.

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