Quantifying Transportation Benefits of Transit-oriented Development in New Jersey

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ABSTRACT

The cost of transportation plays an important role in residential location choice. Reducing transportation costs not only benefits the user but also improves the performance of the system as a whole. A direct impact of transit-oriented development (TOD) is the change in out-of-pocket costs for users, as well as the changes in costs of externalities and agency benefits. The prime mover for these changes is the shift in population when TOD is built near train stations, and the induced mode shift from driving to transit. In this study, several sites throughout New Jersey are evaluated to determine the cost of driving versus the cost of using rail transit to major employment destinations in New Jersey and New York City. Driving costs are composed of vehicle operating costs (including fuel, wear and tear, and depreciation), value of time is based on the highway travel time from origin to destination, parking cost, and cost of externalities such as air and noise pollution, road maintenance, and accidents. Transit costs are composed of fares, parking costs, value of travel time, waiting time, and transfer time. The likely changes in population resulting from the TOD are used to estimate changes in highway and transit trips. The costs are compared to derive the net benefit for transportation system users, as a result of TOD development. We observe that generally, TOD results in financial benefits to the user and for the transportation system.

INTRODUCTION

Transit-Oriented Development (TOD) can directly benefit a transit agency through increases in ridership and revenues. It can also have a positive impact on society at large by reducing auto usage and reducing the volume of vehicles and congestion on the highway network.*(1)* As a 2008 Transit Cooperative Research Program (TCRP) report shows, TOD led to the need for an estimated 188,300 fewer lane-miles of construction, (as well as the related lane-miles' long-term maintenance).*(2)* This analysis seeks to examine how TOD affects both the costs of travel for individuals, network effects, the benefits to the transit agency and external costs to society. This is done for a sample of train station areas in New Jersey using a regional travel demand model for North Jersey.

Measuring the effects of a TOD on highway network congestion is a critical component of fully understanding the precise impact of a TOD. For example, TOD evaluations have shown that TOD can reduce highway transportation costs and externalities such as road maintenance and infrastructure expenses, as well as reduce air and noise pollution and fuel consumption.*(2)* The impact of TODs, at the user-level, can indirectly be interpreted by the importance that users give to transportation cost when making housing location choices. Weisbrod et al. compared and estimated the effect of various trade-offs made by families at the time of changing their residential location. The author estimated that a 5% reduction in commute time has the same effect as a 1.5% decrease in rent or 28% reduction in home value. (3) Other studies show the importance of transportation costs on location choice. Findings include housing closer to subway lines and bus stops in New York City are more likely to be chosen (4), zones located closer to transit facilities have more employment (5), and residential choice is positively correlated with the number of subway stations in the zone (6).

The impact of TODs has revealed both short and long term benefits. Several different approaches to measuring these benefits have been attempted, ranging from analysis of travel survey data to complex modeling of demographics and mode usage. As opposed to using localized travel survey data a regional transportation and travel demand model can provide estimates of overall regional impacts. These models utilize regional demographic data to predict travel demand, mode, and route choice throughout a region. Cervero pointed out that travel demand models are not without their weaknesses in evaluating the impact of a TOD, however, he has also illustrated methods to overcome these weaknesses, including modified vehicle ownership in TODs that affect trip generation and mode choice and methods to post-process model results.*(1)* In addition to the traditional trip generation and attraction variables of household size, income, auto ownership, and employment, Cervero also suggests that land use variables such as employment density, ease of walking access, and a land use mix measure be included in models. Traditional travel demand models may miss the detailed spatial context that affects travel behavior in more compact developments, such as TODs. In this paper, parallel analysis of walking, transit use, and driving frequency addresses these issues at the individual level and with detailed spatial data.

One of the solutions proposed by Cervero et al. (2004) involves post-processing the outputs of the four-step modeling process using elasticities based on some of the spatial and urban design variables. Alternatively, models can also be used to capture the finer-grained/local variables that may influence transit ridership. Examples of such approaches can be found in several references. *(7-9)* Another alternative or modified four-step modeling process, as proposed by Kaneko and Fukuda, estimates the effect of TOD on both land use and traffic volume. *(10)* Their equilibrium model combines a trip distribution model, a modal choice model, and a trip assignment model to represent the constraint of allocated population and employment in each zone of a land use plan proposed by a TOD policy.

In order to measure the impact of TOD in Austin, Zhang redistributed population and employment growth in Austin's four-step travel demand model. *(11,12)* The model used area, population, employment density, and household size to estimate employment and population gains. Zhang re-estimated mode choice for two scenarios of TOD development and calculated the shift in percentage of trips by mode. The model predicted increasing losses for single occupancy vehicle (SOV) trip share and gains for transit trip share based on the increasing level of TOD development. After mode choice was estimated, highway and transit assignment models were run based on the new demand levels. He was able to estimate a significant drop in person-miles traveled by automobile and an increase in person-miles traveled by transit associated with the TOD.

An analysis was done that used the North Jersey Regional Transportation Model-Enhanced (NJRTM-E), a travel demand model for Northern New Jersey, to estimate the impact of TOD in Bloomfield, NJ. *(13)* The project called for additional development including increased parking capacity at the Bloomfield rail station, with a resulting increase in rail transit trips. The benefits due to TOD at the Bloomfield train station were modeled by shifting auto trips to transit trips, and the estimated benefits of the project included the reduction of vehicle congestion, vehicle operating costs, vehicle accidents, air and noise pollution, and maintenance costs at the network level.

In this paper the NJRTM-E travel demand model and NJ Transit rail schedules are used to estimate the transit and highway costs for users traveling from TOD locations to their primary commuter destination. The change in population and ridership are estimated from the NJRTM-E model. Subsequently the changes in costs are estimated with base and changed population. Finally, the average and marginal benefits of changes in population is estimated at each TOD.

METHODOLOGY

Understanding the network-level impact of a TOD is an important aspect of its presumed benefits. Regional transportation planning models are a potential platform for analyzing these effects, since they consider demographics, estimate mode usage, and assign traffic according to users' best options. Network traffic flows are obtained from a traffic assignment model and transit usage from the mode choice component of the model. The potential benefits of TODs (and greater transit access) in communities are estimated by the changes in various cost categories, such as congestion, vehicle operations, accidents, air and noise pollution, and maintenance costs at the network-level.

Key Outputs from Network Analysis

The transportation demand model is based on the traditional four-step process of trip generation, trip distribution, mode choice, and highway/transit assignment. The output of the transportation demand model includes trip-level metrics, number of trips between different origins and destinations based on the mode chosen by the user, and network-level metrics such as link volumes, speeds and travel times.

Evaluation of network costs due to TOD

The network-level costs are estimated by quantifying the impact of mode trip generation/distribution and mode shift changes from the highway assignment results. Model outputs are quantified using the methodology presented in (*13*).

Estimation of changes in trip costs due to TODs

Some trips are expected to change due to TODs. This can be via mode shift, or even if a mode is not shifted, the paths taken by a trip-maker can change because of shorter travel times or reduced travel costs, estimated by equilibrium traffic assignments. If the travel times and distances are known, then the marginal costs for the links, both before and after TOD impacts, can be calculated for the entire path. The change in marginal cost for an entire trip due to a path shift or, if the trip shifts to the transit mode, is only the trip fare and the marginal impact to the operation and maintenance costs of the transit system.

NJRTM-E Model

For the purpose of transportation planning in Northern and Central New Jersey, a sophisticated estimation model was developed. The NJRTM-E was specifically developed to satisfy the different needs of the North Jersey Transportation Planning Authority (NJTPA), New Jersey Transit, and New Jersey Department of Transportation (NJDOT). NJRTM-E encompasses the transportation links from 40 counties in the states of New Jersey, New York, Connecticut and Pennsylvania that are under the purview of NJTPA. For transit network modeling, the NJRTM-E adopts existing transit networks from the NJ Transit Regional Transit Model. The primary purpose of the transit network is to develop estimates of the time and cost variables for peak and off-peak periods as required for the mode choice model and to load trips within the transit assignment process. *(16-18)*

A variety of transit modes are included as a part of the NJRTM-E transit network. There are ten modes to represent the actual transit services provided in the region. Five modes are non-transit modes that provide access and transfer linkages for transit users. Two different access related modes, auto-access and walk-access, are used in NJRTM-E. The network output is produced for 55,230 road links. The metrics such as link volume, link speed, distance, and number of lanes are used in the evaluation of network effects.

Mode choice is an important aspect of the NJRTM-E model. The structure of the mode choice model is a nested-multinomial logit model. The series of nests are for instance, "transit vs. auto" or "walk access vs. drive access to transit". The utility of a mode a (auto, rail, bus, subway, walk) can be represented as:

$$U_a = c_1 * Distance_a + c_2 * \ Fare_a + c_3 * InVehicleTime_a + \cdots + C_a \qquad (1)$$

$Distance_a$ is the length of travel in mode a, $Fare_a$ is fare paid for mode a, $InVehicleTime_a$ is time spent in the vehicle for mode a, $c_1, c_2, c_3, \ldots$ are weights for each parameter in the utility.
All components of Out-of-vehicle time (walk time and waiting time) were weighted 1.5 times transit in-vehicle time and 2.0 times commuter rail in-vehicle time. Vehicle to transit transfer time was weighted as 1.5 times transit in-vehicle time and 2.0 times commuter rail in-vehicle time. *(16-18)* The utility for auto mode is similar to one shown in equation (1) but without parameters such as Fare, etc.

Analysis of Transportation Impacts

The results of the model are processed using ASSIST-ME, a tool developed to post-process highway assignment results from transportation planning models. ASSIST-ME is a GIS-based full cost estimation tool that can, among its other capabilities, be used to estimate the recurring annual benefits of transportation projects. ASSIST-ME was developed to estimate the reductions in various costs of highway transportation using cost reduction models specific to New Jersey, or national data if NJ-specific data is unavailable. *(15)*

By estimating marginal costs, the effect of removing trips from the highway network (due to a shift to transit) on the entire highway network can be determined. After the total cost functions are calculated, marginal cost functions can be derived for each cost category, and similarly determined. The sum of marginal costs then equate to the full marginal cost of a trip between an origin and destination. By isolating trips that would potentially shift to transit, the reduction in these marginal costs represents the benefits to TODs. The *full marginal cost* (FMC) is defined as the cost of an additional increment of output.

Ozbay et al. define a "trip" as the major output measure. *(19)* In other words, FMC is defined and calculated as "cost per trip." Although "trip", as a final output of highway transportation, is not as standard a measure as vehicle-miles or vehicle-hours, it has several desirable attributes (e.g., trip distance, time of the day, highway functional categories on a route, degree of urbanization, and climate) for the calculation of cost of externalities due to the trip. These costs enable us to better understand the policy implications of additional travelers on the road network. Moreover, the concept of a trip is a natural measure when dealing with transit costs.

ASSIST-ME Assumptions

Various cost categories are derived using the ASSIST-ME model. These include the following:

- Out-of-pocket + Travel time (OOP + TT) costs
  - Vehicle Operating cost
  - Congestion cost
- Cost of externalities (Ext.)
  - Accident Cost
  - Air pollution cost
  - Noise cost
  - Maintenance cost

The assumptions underlying the calculation of each cost category in ASSIST-ME are available in prior reports *(13,19,20)*. Using ASSIST-ME, the shift in trip paths and the costs for the trips can be easily calculated. The travel times and marginal costs before and after the introduction of a TOD in the modeling process can then be compared to estimate the overall impact of a TOD on the network.

Value of Time

Value of time is a critical component of both mode choice and quantification of network impacts. In the NJRTM-E model, value of time is constant region-wide. In actuality, it varies by trip-maker. For the purposes of this study, value of time is averaged by location rather than region-wide, so that the effect of TOD in two locations, even if the development is of a similar nature, can have different impacts.

In general the VOT varies by vehicle class. For cars, Small and Verhoef conclude that the average VOT widely used in practice is about 50% of the gross wage rate. *(21)* Based on this evaluation, using the U.S. Bureau of Labor Statistics 2009 for New York-Newark-Bridgeport, the VOT can be estimated to range from $13.28 to $16.83/h (using the mean hourly wages of $26.56 to $33.66). *(22)* The most recent empirical results obtained from travel survey data for users of Port Authority of New York & New Jersey facilities estimated VOT around $16.50/hr for E-ZPass peak users, and around $15.15/hr for E-ZPass off-peak users. *(23)*
However, in New Jersey, household income at TOD locations varies greatly. Thus the NJTransit on-board survey is used to obtain the household incomes based on users' origin (municipality) and destination (NYC, Newark, etc.). For further details, the readers are directed to the detailed report of this study (*24*).

TOD Site Selection

Transit is heavily used in New Jersey for daily commutes. The major destinations i.e. employment centers are New York City, Newark, Jersey City, and Hoboken. as The analysis conducted here focuses on stations in the following municipalities: Collingswood, Cranford, Metuchen, Morristown, New Brunswick and Rahway that have received substantial TOD investment; in addition, stations in two other municipalities –Newark Broad Street, and Plainfield have had less new development. In this study, seven stations were selected in consultation with staff from New Jersey Transit.[1] Figure 1 displays the geographic location of the stations. An on-board survey was conducted by NJ Transit to study the travel behavior of users of these stations. This survey was collected from 33,365 NJ Transit rail users from all over New Jersey in 2007. These stations represent a broad range of different demographic characteristics from the survey. Metuchen and Cranford are relatively affluent areas, while Plainfield, New Brunswick and Newark are relatively low income. These stations are on different transit lines including the Northeast Corridor line (Metuchen, New Brunswick, Rahway), Morris & Essex line (Morristown), and Raritan Valley (Cranford, Plainfield) line. Most are commuter rail lines, the exception being Newark Broad St. which is served both by commuter rail and the Newark subway (a light rail line). The distribution of destinations in the daily commute of users using these train stations can be seen in Figure 2. The value of time for this study is determined as the average hourly income of users traveling from each TOD location to a particular destination. Typically, the users travel by four major modes in the region, namely, vehicle, rail, bus and Port Authority Trans-Hudson (PATH) trains.

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[1] The full study on which this paper is based analyzed eight stations for many other attributes of TODs. The eight station was Essex St. in Jersey City. (*24*)

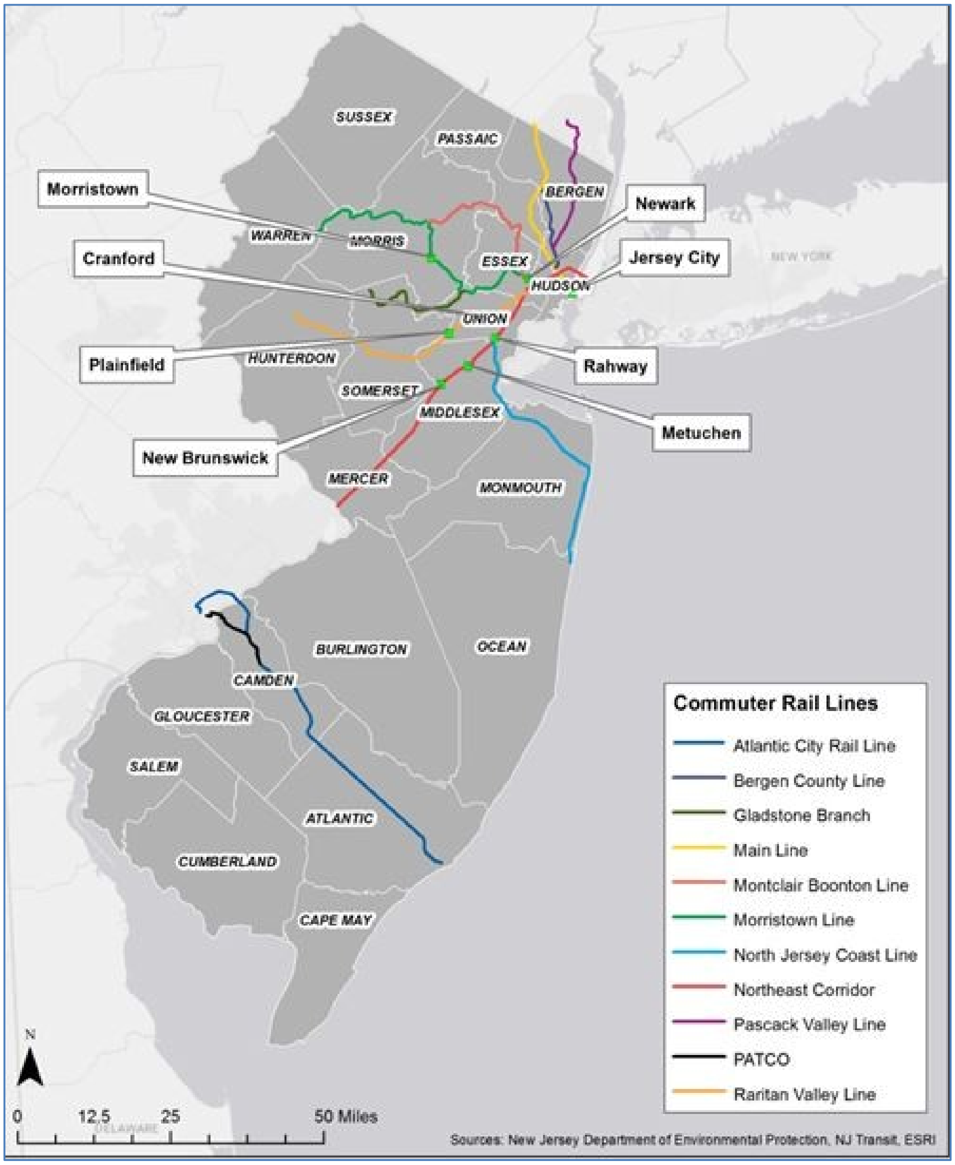

Figure 1 Map of station locations and NJ Transit rail lines (*24*)

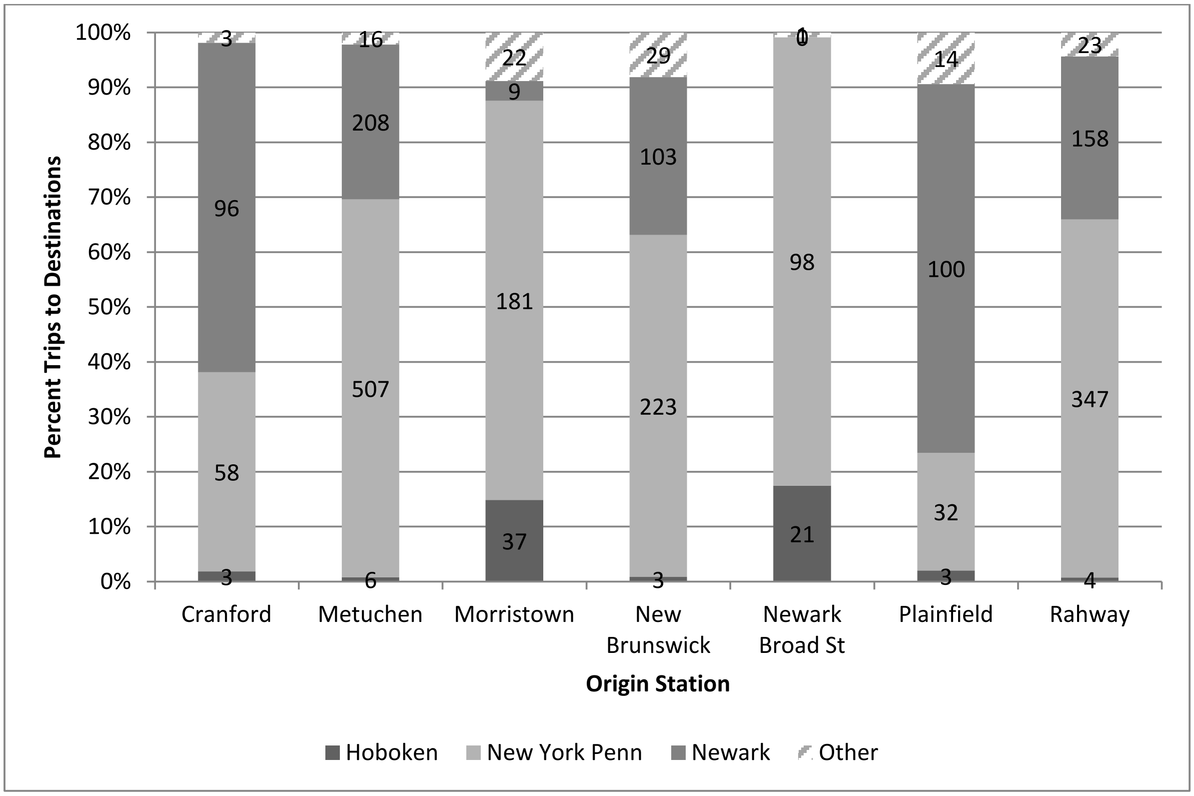

Figure 2 Distribution of users' origins and destinations for select stations based on NJ Transit Surveys

NJRTM-E MODEL OUTPUT AND COST ANALYSIS

The NJRTM-E model is used to estimate three primary metrics to evaluate the merit of TODs. These metrics are:

1. Total number of trips
2. Transit ridership
3. Travel time and Travel costs

A direct impact of a TOD is the increase in population where it is located. The mode chosen by new and existing trips determines the ridership at each train station, estimated by the mode choice model incorporated into the NJRTM-E model. The output of the planning model provides estimates of link volumes, speeds, and travel times for highway users, which are used to estimate the total cost and cost savings of deferred auto trips.

On-board survey data provided by NJ Transit is used to estimate the cost of trips made by rail transit commuters originating from the TOD stations. The trip for each user is constructed using various modes involved in the transit trip. Key data extracted from the survey include origin of commuters (at the municipality level) their selected train station, mode of access to train station, and final destination beyond disembarking station. The following steps are performed to calculate the user-level rail transit costs (see (*24*) for more details):

1. Transit travel times are determined by the NJ Transit scheduled travel times during the AM Peak period from origin to destination.
2. For transit users, the NJ Transit trip leg is often preceded and succeeded by home-to-station and station-to-office/destination trip segments, respectively by walk, NYC subway or PATH.
3. The NJRTM-E model-based walk times are gathered for municipalities corresponding to the users' origin to train stations, and further refined using Google Maps ® estimated walk times. An average of 2.5 minutes is assumed for wait times for each leg of the trip, as well as 5 minutes if a transfer is required.
4. For drive-to-transit commuters, drive time from origin to the train station is based on origins chosen from survey data and estimated using NJRTM-E highway assignment for travel times, and parking cost is determined by the lowest monthly parking fees listed on www.njtransit.com.
5. A value of time assumption is required to monetize travel time into a cost. The value of time for users is taken from the average annual income of respondents in the survey data, divided by 2,000 hours per year.
6. To convert travel time, walk time, wait time, and transfer times into a cost, the work of Wardman (*26*) and Liu et al. (*27*) are used.
7. Finally, the costs are calculated as a weighted average, weighted by the number of users utilizing each station for each origin and destination pair derived from the NJ Transit on-board survey.

Estimating Population change in TOD station areas

To examine the impact of growth near train stations and of additional TODs, we assume that population shifts from more distant areas (out to 2 miles from the station) to areas closer to the station. The increase near the station is within a 0.5 mile radius. The changes in population resulting from a TOD are very difficult to predict. To this end, we studied the location choice of people from the NJ Transit on-board survey to determine changes in population. From the survey data, we studied the number of people moving closer to the TOD stations each year and estimated the maximum expected increase in population around the TOD locations. Thus, using our seven targeted TOD stations, we use the maximum expected increase in population for traffic-analysis zones within the 0.5 mile radius as 2,000, except for Newark where population is increased by 10,000, owing to the relative size of the existing cities and projected increases. The equivalent population is reduced in the outer traffic-analysis zones within a 0.5 mile to a 2 mile radius.

The change in population in each traffic-analysis zone is allocated based on their population. The population increase for zones within the 0.5 mile radius around the TOD station area is calculated as follows.

$$P'_i = P_i + \frac{\Delta P * P_i}{\sum_{i=1}^{j} P_i} \tag{2}$$

Where,

$P_i = Population\ for\ Zone_i(\ 1\ to\ j, number\ of\ zones\ within\ 0.5\ mile\ radius\ around\ TOD)$
$\Delta P = Increase\ in\ population\ (10{,}000\ for\ Newark\ , 2{,}000\ for\ other\ TODs)$
$P'_i = Increased\ Population\ for\ Zone\ i$

The population decrease for zones in the 0.5 to 2 mile radius around the TOD station area is calculated by using an equation similar to (2). Based on this estimation approach, the percent population change calculated for the inner and outer zones is shown below in Table 1.

Table 1. Population Change by Shift Scenario for TOD Zones

	0.5 Mile Radius				0.5 to 2 Mile Radius		
	Number of Zones	Zonal Population	Δ Pop	%Δ Pop	Number of Zones	Zonal Population	%Δ Pop
Cranford	5	22748	2000	8.79%	18	92355	-2.17%
Morristown	4	19713	2000	10.15%	8	31952	-6.26%
Metuchen	4	13938	2000	14.35%	15	69534	-2.88%
New Brunswick	7	38628	2000	5.18%	22	78138	-2.56%
Newark (Broad St)	14	29847	10000	33.72%	75	229029	-4.37%
Plainfield	2	9753	2000	20.51%	23	110811	-1.80%
Rahway	5	23880	2000	8.38%	16	63965	-3.13%

The change in population in each traffic-analysis zone is used as an input to the NJRTM-E model and the four step model is re-run. By comparing the number of trips between the base model and this scenario with a shift in population location, the change in trips for each mode are estimated.

The total number and percent change in trips that are generated for the inner zones within 0.5 miles of each TOD station area are shown in Table 2(a) (for the AM peak period). As this is a population increase within these zones, in general, all trips increased except bus trips for Cranford and Plainfield, and PATH trips for New Brunswick, Metuchen and Plainfield. In the case of PATH trips for New Brunswick and Metuchen, since the total number of trips for the base case is low, the percent change is large.

Table 2. (a) Total Daily Numbers after Shift in Population and Percent Changes in Trips by Mode during AM Peak Period from 0.5 miles around TOD Station Areas

TOD	Car	Rail	Bus	PATH
Cranford	12017.2	1189.6	671.8	139.5
Metuchen	6593.4	1298.9	78.9	5.5
Morristown	10368.7	899.7	160.6	23.8
Newark BS	10756.2	721.7	6541.4	3556.6
New Brunswick	13023.1	2158.0	1244.5	3.6
Plainfield	3206.7	1008.5	128.4	0.8
Rahway	11706.5	979.7	312.9	195.7
% Change from Base				
Cranford	5.07%	14.76%	-6.34%	46.56%
Metuchen	8.67%	9.01%	9.66%	-38.05%
Morristown	3.88%	4.73%	4.78%	9.17%
Newark BS	11.15%	9.45%	11.22%	16.33%
New Brunswick	2.91%	6.00%	1.10%	-45.36%
Plainfield	11.01%	15.94%	-5.87%	-6.10%
Rahway	3.11%	1.35%	10.94%	8.21%

(b) Total Daily Numbers after Shift in Population and Percent Change in Trips by Mode during AM Peak Period for 0.5 To 2 miles around TOD Station Areas

TOD	Car	Rail	Bus	PATH
Cranford	45336.9	3277.6	3015.3	1030.6
Metuchen	33762.5	3867.2	354.2	125.2
Morristown	21467.9	1500.6	138.0	102.3
Newark BS	33410.4	2724.6	27139.4	24109.1
New Brunswick	65293.8	3596.6	1462.1	32.1
Plainfield	50374.3	7024.0	1154.1	253.1
Rahway	28082.4	2068.1	806.1	615.1
% Change from Base				
Cranford	-1.26%	2.23%	-7.78%	11.02%
Metuchen	-1.59%	-0.01%	-2.63%	-35.60%
Morristown	-3.69%	-7.02%	-6.76%	-7.57%
Newark BS	-1.15%	-1.31%	-2.25%	-3.19%
New Brunswick	-2.20%	0.30%	-5.61%	-40.60%
Plainfield	-1.06%	3.21%	-14.22%	-9.26%
Rahway	-0.87%	1.38%	-8.63%	-5.42%

The key result for the reduction in population within the outer zones (Table 2(b)) is the drop in car usage. In spite of the decrease in population, rail trips increase for Plainfield, Rahway and Cranford. Rail trips for Morristown decrease about 7 percent. All PATH trips decrease, except for Cranford, and bus trips decrease. The net change in trips when the changes in the inner zone and the outer zone are summed together shows a net increase in rail (and PATH) ridership and reductions in car usage. Bus usage also has a net decrease, because the train is now more accessible.

Total NJ TRANSIT Rail Ridership Changes

Ridership on the train at each TOD station is another metric that is useful for measuring the benefits of TOD. Changes to ridership are different from changes to the number of trips taken on the train at each TOD station location. The difference is that the ridership numbers indicate not only trips from within the TOD but also drive-access trips arising from outside the TOD area 2-mile radius.

The changes to ridership at each TOD train station when there is a population shift is shown in Table 3. Morristown is the only station where a reduction is observed. This could be due to the shift in mode to other modes due to the slightly lower highway cost as compared to the train from Morristown (Table 4 and Table 5). The train station with the largest percent increase in boardings is Newark Broad Street.

Table 3. Change in Boardings for Population Shift in TOD Locations

PEAK Volume	Boarding Volume for All Destinations			
Station	Base	Shifted	Difference	% Difference
Cranford	1332	1507	175	13.14%
Newark Broad St	667	758	91	13.64%
Metuchen	3946	4100	154	3.90%
New Brunswick	9590	9774	184	1.92%
Plainfield	4272	4502	230	5.38%
Morristown	2563	2535	-28	-1.09%
Rahway	2941	3003	62	2.11%

Cost Estimates

The cost functions and inputs in *(13,19,20)* are used to estimate costs after processing the planning model output of NJRTM-E with ASSIST-ME. From the distribution of destinations in Figure 2, it can be seen that trips to New York City (NYC) form 62-82% of the transit commuter trips. NYC receives 63% of all rail transit trips from New Jersey. Hence, in this study, we use trips bound to NYC as a representative trip for cost calculations.

The average cost of using the train for commuting from TOD stations to NYC is calculated by using the seven-step procedure described previously. The out-of-pocket (OOP) costs and monetary value of travel time (TT) costs are shown in Table 4.

Table 4. Rail Transit Out-of-pocket and Travel time Costs

TOD	OOP	OOP + TT

Cranford	$ 11.10	$ 163.67
Metuchen	$ 16.42	$ 163.03
Morristown	$ 20.86	$ 239.02
New Brunswick	$ 19.42	$ 130.60
Newark BS	$ 11.22	$ 92.52
Plainfield	$ 14.26	$ 128.91
Rahway	$ 14.05	$ 116.78

The average cost estimates for the NJRTM-E output for TOD to NYC trips for the year 2010 with population shift at the TOD locations and change from the base case are shown in Table 5(a). Change from Base case represents the percent change in sum of all costs between scenarios with change in population in the TAZ's around each TOD train station as shown in Table 2. Average cost of travel time (TT), average cost of externalities namely, accidents, air pollution (AP), noise and maintenance costs are also shown.

The marginal cost estimates for the NJRTM-E output for TOD to NYC trips for the year 2010 at the TOD locations and the change from the base case are shown in Table 5(b). Marginal cost refers to the cost incurred by adding one more vehicle to the trip. We assume that the additional vehicle trips will not cause link volume to exceed capacity. Hence, in Table 5 (b), the marginal cost of congestion only involves regular congestion costs and not the hypercongestion cost mentioned in Ozbay et al. (2007). (*13*)

Since local vehicle trips in Newark and Cranford are increased more when compared to other TODs, local links may be affected more due to this increase compared with the increase in vehicle trips to NYC.

Table 5. (a) Average Costs per One-Way Highway Trip from TOD to NYC Estimated from NJRTM-E Output for 2010 with Population Shift

TOD	Avg. Travel Time (min)	TT	Accident	AP	Noise	Maintenance	% Change from Base
Cranford	78.6	$ 40.73	$ 0.13	$ 0.72	$ 0.02	$ 0.01	1.99%
Metuchen	105.4	$ 46.97	$ 0.11	$ 1.00	$ 0.02	$ 0.01	-0.05%
Morristown	112.2	$ 49.40	$ 0.12	$ 0.99	$ 0.02	$ 0.00	0.20%
New Brunswick	109.7	$ 52.61	$ 0.11	$ 1.12	$ 0.02	$ 0.02	-0.36%
Newark Broad St	75.7	$ 30.43	$ 0.09	$ 0.47	$ 0.01	$ 0.00	1.02%
Plainfield	109.5	$ 56.70	$ 0.17	$ 0.96	$ 0.02	$ 0.01	-1.26%
Rahway	82.0	$ 37.52	$ 0.09	$ 0.75	$ 0.02	$ 0.01	-0.96%

(b) Marginal Costs per One-Way Highway Trip from TOD to NYC Estimated from NJRTM-E Output for 2010 with Population Shift

TOD	OOP + TT	Externalities	% Change from Base
Cranford	$40.50	$2.15	2.22%
Metuchen	$46.78	$2.54	0.56%
Morristown	$49.20	$1.44	-0.47%
New Brunswick	$52.40	$2.48	0.50%
Newark Broad St	$30.19	$3.28	1.91%
Plainfield	$56.34	$4.03	-0.59%
Rahway	$37.35	$2.03	-1.37%

Ideally, the expected result is that average cost decreases when average cost is lower than marginal cost and vice versa. But, in the authors' opinion, there are network effects due to the changes in population far away from the location of change. Additionally, there could be interactions between changes in population at different TODs. These could be the reasons for any counter-intuitive results in Table 5.

Benefit for Train Users

The previous section presents the analysis of average transit and highway costs for the TOD locations. The cost of a transit trip by using the train is lower than the cost of a highway trip. The cost saved by the user who uses the train as opposed to the highway to travel from the TOD to NYC and back is shown in Table 6. The benefit using OOP (OOP+TT) is benefit calculated using OOP (OOP+TT) cost shown in Table 5. These costs show the benefit that the user incurs by opting to travel by train for their commute from the TOD location. In the calculation of yearly benefit, we assumed that there are 260 workdays.

Table 6. User-benefit for Using Train Instead of Car for Commute to NYC ($ per user)

TOD	Benefit per Round Trip using OOP	Benefit per year using OOP	Benefit per Round Trip using OOP + TT	Benefit per year using OOP + TT
Cranford	$5.79	$1,505.61	-$59.64	-$15,506.44
Metuchen	$13.71	$3,564.47	-$4.22	-$1,097.50
Morristown	-$0.16	-$42.38	-$107.34	-$27,909.43
New Brunswick	$33.83	$8,796.13	$4.37	$1,136.20
Newark Broad St	$22.57	$5,868.58	$43.34	$11,269.34
Plainfield	$8.06	$2,095.41	$25.72	$6,687.42
Rahway	$11.84	$3,077.91	-$23.61	-$6,139.86

From Table 6 it can be inferred that for a user in Cranford, if she uses the train instead of a car for her commute, she can save about $6 per day and $1,500 per year. However, if we consider the total travel time from Cranford the estimated benefit is negative. The train travel from Cranford involves transfer at Newark Penn Station, hence the total travel time includes the wait, walk and transfer times. The value-of-time for wait and transfer times are greater than 1. Hence the value of travel time from Cranford is lower for highway travel as compared to train travel.

Thus there are no benefits for the user to travel by train instead of car. However, for Metuchen, New Brunswick, Newark and Plainfield there are significant positive out-of-pocket benefits.

Note that a transfer is required for users traveling from Cranford or Plainfield to New York, whereas there is no transfer required for users traveling to Newark. The rest of the trips considered from Cranford and Plainfield, using the NJTransit survey, are bound to Newark. The percentage of transit trips to Newark from Plainfield is 25%. The same from Cranford is only 11%. This means that the effect of transfer time and its value will affect 89% of transit trips from Cranford and only 75% of trips from Plainfield. Additionally, the value-of-time for users in Cranford is 45% higher than those in Plainfield. Due to the higher VOT for transfers in a transit trip, the benefits calculated based on OOP + TT are much lower for Cranford when compared to Plainfield.

In contrast, for New Brunswick, the economic benefit (out-of-pocket cost) to the user when they take the train as opposed to a car for their commute is $34 per day; the total benefit (out-of-pocket + travel time cost) is $4.40 per day. Thus the yearly benefit when considering the total cost to the user is $1,140 per year.

Net Marginal Benefit for the Population Shift

The net trip changes from the population shift estimates are shown in Table 2. If the TOD had not been implemented, the new trips due to the population shift would use the highway. Each of these new trips could be seen as an additional trip on the existing highway network. Thus, the benefit in implementing the TOD can be quantified using the increase in the highway costs. In other words, to quantify the impact of trip change we can use the marginal cost for the population shift scenario and multiply it by the number of new rail and PATH trips. The marginal benefit due to the increase in PATH trips could be estimated in a similar way. Moreover, if there is a reduction in the number of vehicle trips to NYC due to the population shift, this could be assumed to be the marginal benefit for TODs.

The marginal costs for each TOD, shown in Table 5(b), are used to quantify the benefits due to new rail trips to NYC. Table 7 shows the daily benefits if new rail and PATH trips do not use highways and benefits due to reduced highway trips. Since there are no new train trips from Morristown for the scenario with new trips estimated from the population shift, the increase in costs is zero.

From Table 7, Plainfield has the maximum marginal benefit of $16,167 per day for the increase in rail trips. Cranford has a marginal benefit due to the increase in PATH trips of about $5,300 per day. Morristown has no net benefits due to a decrease in the number of rail trips

Table 7. Total net marginal daily benefits for peak period due to increase in rail, PATH and decrease in vehicle trips to NYC

	Marginal Benefits due to OOP + TT		
TOD	**Rail**	**PATH**	**Vehicle**
Cranford	$8,472.13	$5,259.59	$ 0.00
Metuchen	$2,072.75	$ 0.00	$1,825.59
Morristown	$ 0.00	$ 0.00	$343.70
Newark Broad St	$2,476.02	$ 0.00	$ 0.00
New Brunswick	$2,688.91	$ 0.00	$1,262.40
Plainfield	$16,166.81	$ 0.00	$2,396.52
Rahway	$1,020.54	$ 0.00	$1,131.00

CONCLUSIONS

TOD has been cited as a means of reducing the cost of transportation, which is a crucial factor in people's residential location choice. A direct impact of TOD is the increase in population near a transit station. This analysis attempts to examine how focusing population around transit stations can lead to benefits for the transportation system at seven train stations in New Jersey where TOD has been or will likely be undertaken. The analysis was based on shifting population currently living within 0.5 to 2.0 miles from the station to live within 0.5 miles of the station and evaluating the network-wide transportation impacts from a regional travel demand model. The model, NJRTM-E, is used to estimate the number of new trips generated due to the population location change and their mode choice. The cost model, ASSIST-ME, is used to estimate various costs, both out-of-pocket and external.

The shift of population closer to the train station results in net increases in rail (and PATH) ridership and reductions in car usage. Bus usage also has a net decrease, because the train is now more accessible. This resulted in a 2-13% increase in boardings at train stations, depending on the location considered, except for Morristown.

We see increased financial benefits for the commuter cost particularly for NYC trips, and some minor reductions in external costs. The costs include average cost of travel time, average cost of externalities namely, accidents, air pollution, noise and maintenance costs. The change in costs when the user who uses the train as opposed to the highway for a commute trip to NYC shows the benefit that the user incurs. These benefits vary from $6-$34 per trip for various TODs. This translates to $1,500-$8,800 per year for trips to NYC (as seen from Table 6).

The marginal effect of the increase in trips due to a shift in population can be quantified using the increase in the highway costs if these new rail trips had instead used the highway network. To quantify the impact of the trip change we estimated the marginal cost of the population shift scenario and multiplied it by the change in rail, PATH or vehicle trips. The total marginal daily benefits vary between $1,000 and $16,000. The total marginal daily benefits of increased PATH trips are between $2,500 and $5,200. The total marginal daily benefits of increased train trips are between $350 and $2,400.

All these results are sensitive to assumptions embedded within the model and should be interpreted with care. The changes modeled are relatively small for a regional travel demand model that is generally used to estimate larger regional changes in the transportation system. The cost model (ASSIST-ME) is used to estimate external cost changes and is based on various modeling assumptions that may not hold for specific cases.

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