Feasibility Study on Transit-Oriented Development, Using Urban-Form and Non-Urban-Form Variables

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Paper Abstract

Transit-Oriented Development, known as a form of walkable, mixed-used, location-efficient development with convenient transit service, has now become a hot topic among planners, architects and policy-makers in the U.S. Existing research on transit-oriented development lacks quantitative interpretations, making it difficult for practitioners to implement projects. The author is developing a quantitative approach to understand transit -oriented development, and to assess the feasibility of such development. When searching the meaningful variables to do the analysis, the hypothesis, that mixed land use and high density would increase the financial return from the developments is tested. After examining existing measurements of related Urban-Form and Non-Urban-Form variables, specifically Frank & Pivo's Entropy Index model in gauging the land use heterogeneity, the author improves the current model to measure certain required variables by using OLS regression analysis with the assistance of current GIS and GPS technology. The quantifiable results are useful for practitioners and researchers.

Introduction:

Rapid population growth, urban sprawl, suburbanization and traffic congestions cost people more and more time on the road. After housing, transportation is now the second largest expense for American families (Candy, 2003). Inefficient transportation in the urban areas of the United States has been effectively restricting many American families' access to the resources they need to increase their wealth. In many areas of the United States, traffic woes have generated a cohort of individuals who are drawn to the idea of living near public transit and enjoying a less stressful commute to work (TCRP 2002). While the American love affair with the automobile is not yet over, concerns about the negative effects of automobiles –on the physical environment, on public health, on the quality of life, and on the relationships among people in the community –have led to policies and projects that promote more public transit use, including heavy and light rail, bicycle paths and public walkways. The renewed interest in transit use and transit investment, together with the resurgence of investment in America's downtown areas, calls for a diversification of real estate projects and a type of development know as transit-oriented development (TOD), a form of pedestrian-friendly, mixed-used, and location-efficient development with convenient transit service (Belzer and Autler, 2002).

The Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 and the Transportation Equity Act for the 21st Century (TEA –21) in 1998 laid the groundwork for building safe, environmentally–sound, transit-oriented communities. Several federal initiatives, such as the location efficient mortgage (LEM) program, underwritten by Fannie Mae, have also sought to leverage TOD. The shrinking household size and the increasing share of foreign immigrants in the United States have contributed to the rising popularity of TOD. Growing numbers of singles and single-parent families, childless couples, and “empty-nesters” seeking to downsize their living quarters, along with influxes of foreign immigrants coming from countries with a heritage of transit –oriented living, have created ready-made consumer markets for TODs (Calthorpe 1993). Furthermore, a receptive policy environment, together with changing demographic characteristics in favor of TOD, have heightened public interest in TOD as a means of redressing a number of urban problems, such as traffic congestion, affordable housing shortages, air pollution, and incessant urban sprawl (TCRP 2002).

A review of international trends also uncovers latent factors that challenge the conventional strategy of building more highways, and which may further catalyze the United States’ transition from an auto-dominated country to a more transit-dependent society. In China and India, together home to 2.3 billion people, motor vehicle use is skyrocketing. Car sales in China increased seventy three percent in 2003 alone, and by 2030 China is projected to have more motor vehicles than the U.S. (INFORM Reports 2004). As a consequence of such enormous transportation growth, China and India are vying with the United States for rapidly dwindling oil reserves. The foreseeable shortfall of oil supply in the near future, and the resultant significant rise in gasoline prices, would likely change people’s view of public transit as an alternative transportation mode in the United States, a shift that could create a vast market worldwide for TODs in the long run.

Despite the nuances in defining TOD by different transit authorities, successful pilot cases in Portland, Oregon, San Francisco, California, Dallas, Texas, Denver, Colorado, and Atlanta, Georgia, have illustrated various implementations of TOD principles throughout the country. Noticeably, financial support from the government at various levels has played a very important role in guaranteeing the actual completions of these projects. However, the nation's switch from highway-dominated development to transit-oriented development comes at a time when financial resources at every level — federal, state, and local — are shrinking. Looming deficits and unanticipated expenditures brought on by the September 11th attacks threaten the financial stability of most domestic programs. In spite of the appealing aspects of TOD, critics raise doubts about the financial feasibility of putting the "idealistic" theory into practice, further jeopardizing the possibility of widespread implementation of TOD principles. To date, record has shown some failed TOD cases. Laguna West, for instance, was originally touted as a TOD prototype for the suburbs of Sacramento, but a downturn in the real estate market led to eventual bankruptcy (TCRP 2002). Anticipated TODs in some parts of the United States have failed to break ground because of unrealistic market expectations (TCRP 2002).

On one side, concerns about financial loss from "risky" TODs discourage governments and public transit authorities from providing more funding for such development. Locational liability of the areas covered by existing transit system, delay of station-area development, non-supportive government policies including exclusionary zoning and suburban-like building codes, difficulties in cross-jurisdictional cooperation, insufficient consideration of the real estate market, and lack of market feasibility studies, all contribute to hesitant public involvement in spurring TODs (Porter 1997). On the other side, private developers, another major financial source for transit-oriented developments, make decisions based primarily on the real estate market rather than the presence of transit. Although separately confronted with their individual financial barriers, public-private partnerships are emerging as a promising way of implementing TODs.

Mixed-used transit-joint development (TJD), defined in the recent literature as a subset of TOD, represents the most frequently discussed scenario for public-private partnership in TOD projects (TCRP 2004). In addition to the pioneering TJD practice of the Washington Metropolitan Area Transit Authority (WMATA) and San Francisco's Bay Area Rapid Transit District (BART), various other transit agencies in the United States have also been implementing TJD projects. Often occurring on a transit agency's property, these TJDs can be further categorized based on their lease types and financial agreements, including ground lease, air-rights lease, operational cost sharing, construction coast sharing, station connection-fee programs, or other initiatives that promote real-estate development at or near transit stations to the mutual benefit of public and private interests (TCRP 2004).

A growing body of literature shows the financial benefits of TJDs. The challenge that remains is how to create partnerships that allow those benefits to translate into profitability for both the private sector (the developer), and the public sector (the transit agencies) that are often the landowners of such developments. There are several keys to the negotiation of a successful private-public partnership for TJD projects:

- Quantification of the increases in property values, resulting from both the transit connection and TJD arrangements.
- Calculation of the financial benefits from increased ridership associated with TJDs.

Theory maintains that the savings in travel-time and enhanced accessibility conferred by TJD should get capitalized into higher land values and market rents. Numerous studies have also demonstrated that all else being equal, being adjacent to rail stations raises property values, though to varying degrees (TCRP 2002). However, the effects of TJDs themselves and their major characteristics (particularly high-density and mixed land-use) on real estate values, controlling for proximity to transit, has been examined only sparingly (TCRP 2002).

This paper answers the following general question: What financial benefits would TJDs' major characteristics, specifically high-density and mixed land-use, bring to a project? This broad question is answered by considering the following related questions:

- To what extent will high-density and mixed land-use increase the property values of TJDs?
- Will an increase in the density and the level of land-use mix of TJDs bring a higher transit ridership?
- What is the impact of other factors, including the household income level of the neighborhood around TJDs, on the financial return?

These questions are addressed through two regression analyses. One multiple regression model was used to examine the effects of TJD projects' major characteristics, high-density and mixed-use, on real estate values, controlling for proximity to transit. Household income level was also included in this regression model to understand its role in the feasibility of TJD projects. Another multiple regression model was developed to understand the relationship between transit ridership and TJD arrangements under certain socio-economic situations.

How do people define TOD?

Although varying in scope and specificity, most TOD and TJD definitions share several common elements, including high-density and mixed land-use. A sample of TOD definitions can be found in the literature:

> "Development within a specified geographical area around a transit station with a variety of land uses and a multiplicity of landowners" (Salvensen 1996).

"A mixed-use community that encourages people to live near transit services and to decrease their dependence on driving" (Still 2002).

"A compact, mixed-use community, centered around a transit station that, by design, invites residents, workers, and shoppers to drive their cars less and ride mass transit more. The transit village extends roughly a quarter mile from a transit station, a distance that can be covered in about 5 minutes by foot. The centerpiece of the transit village is the transit station itself and the civic and public spaces that surround it. The transit station is what connects village residents to the rest of the region…The surrounding public space serves the important function of being a community gathering spot, a site for special events, and a place for celebrations—a modern-day version of the Greek agora" (Bernick and Cervero 1996, p. 5).

"A mix of residential, retail and office uses and a supporting network of roads, bicycle and pedestrian ways focused on a major transit stop designed to support a high level of transit use. The key features of TOD include (a) a mixed-use center at the transit stop, oriented principally to transit riders and pedestrian and bicycle travel from the surrounding area; (b) high density of residential development proximate to the transit stop sufficient to support transit operations and neighborhood commercial uses within the TOD; and (c) a network of roads, and bicycle and pedestrian paths to support high levels of pedestrian access within the TOD and high levels of transit use" (Oregon Revised Statutes, Section 307-600-1: www.leg.state.or.us/95reg/measures/hb3100.dir/hb3133.en.html).

Calthorpe frames modern design theory of TOD with its practical implications in *The Next American Metropolis: Ecology, Community, and the American Dream*, by providing both quantifiable guidelines and quality urban design projects as examples of TOD. Based on a well-defined TOD concept (Figure 1),[1] Calthorpe further delineated TOD as a mixed-use (residential, retail, office, open space, and public uses) community within an average 2,000-foot walking distance of a transit stop and core commercial area.

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[1] TOD concept is simple: moderate and high-density housing, along with complementary public uses, jobs, retail and services, are concentrated in mixed-use developments at strategic points along the regional transit system.

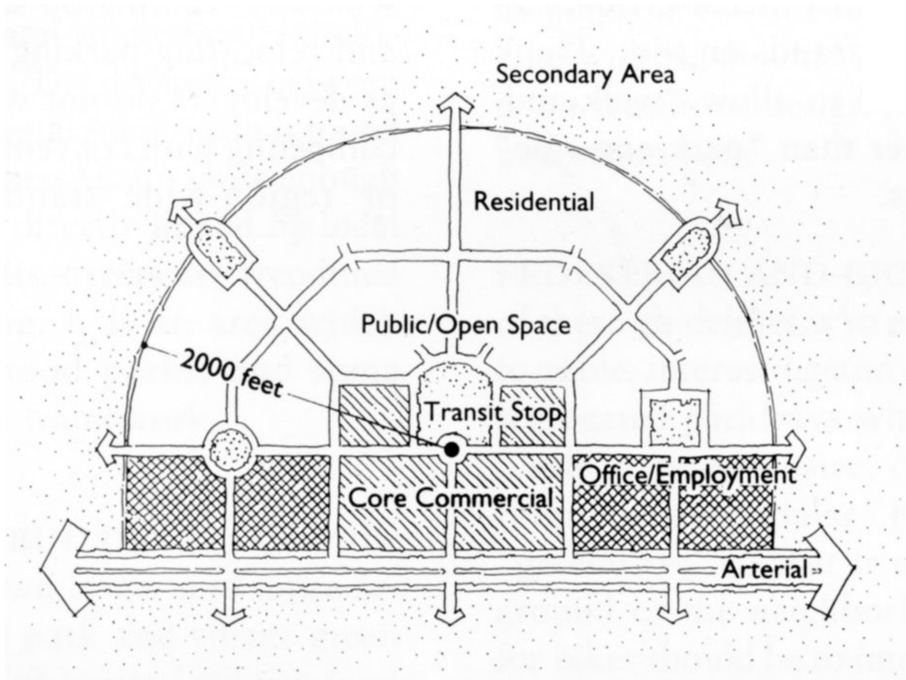

Figure 1: Calthorpe’ s diagram of TOD (Source: Calthorpe 1993)

Commercial areas, residential areas, public spaces, and secondary areas are the four major required components of Calthorpe’s TOD design. A mixed-used core commercial area located adjacent to a transit stop is required to provide at a minimum convenience retail and local offices at a minimum, while larger core areas could have more flexible combinations including major supermarkets, restaurants, service commercial, entertainment uses, comparison retail, second-floor residential, and employment-intensive office and light industrial uses. Although noting the variances in the size and location of TOD projects, Calthorpe strictly defines the ratio of the commercial core areas to the total area of the project. Whether this area functions as community center, neighborhood center, or convenience center, at least ten percent of the total TOD site area and a minimum of 10,000 sq-ft of retail space adjacent to the transit stop are designated as the commercial core area according to Calthorpe’ s design guidelines (Figure 2).

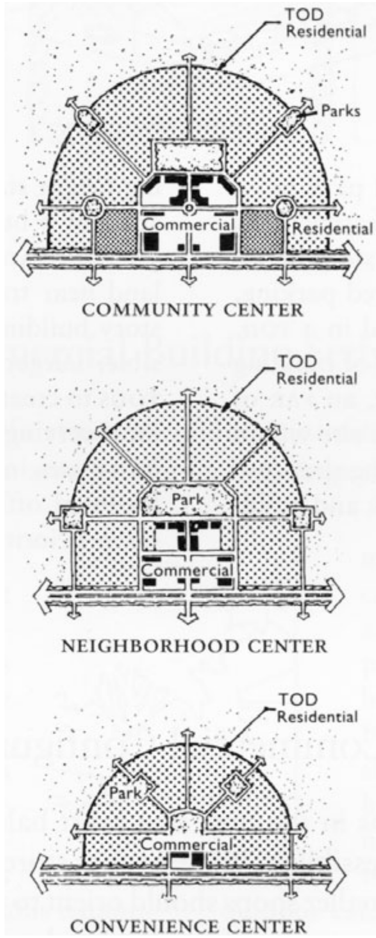

Figure 2: TODs with different core commercial areas sizes and locations (Source: Calthorpe 1993)

Parks, plazas, greens, public buildings, and public services can all be used to serve residents and workers in TODs and neighboring areas as the "Public Uses" component. To Calthorpe, all TODs must be mixed-use and contain a minimum amount of public, core commercial and residential uses (Figure 3). Vertical mixed-use buildings are encouraged, as a bonus to the basic horizontal mixed-use requirement.

USE	NEIGHBORHOOD TOD	URBAN TOD
Public	10% - 15%	5% - 15%
Core/Employment	10% - 40%	30% - 70%
Housing	50% - 80%	20% - 60%

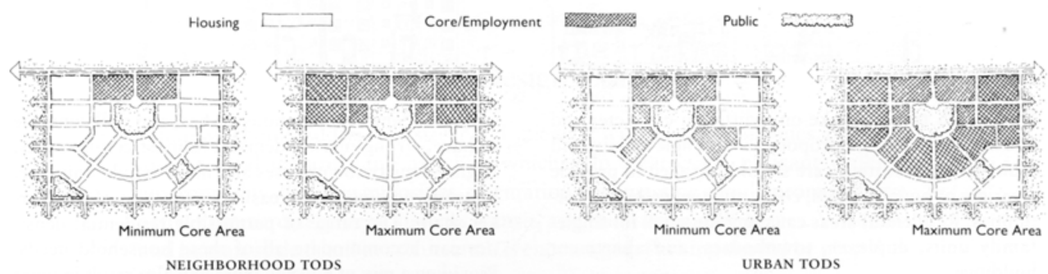

Figure 3: Minimum amount of public, core commercial and residential uses in TODs (Source: Calthorpe 1993)

Findings from the literature review about how people define TJD informed the choices of study area and related variables for the regression analysis in this research:

1. Because of rail agencies' greater institutional capacities and planning resources, most TJD cases available for scrutiny are initiated by rail agencies (TCRP 2004). Another reason for choosing properties around rail systems for this study is that existing studies have demonstrated that adjacency to rail stops has a much more significant impact on property values than adjacency to bus stops (TCRP 2002).
2. Since Calthorpe delineated TOD as a mixed-use community within an average 2,000-foot walking distance of a transit stop and core commercial area, parcels within a 2,000-foot distance from rail stations were selected for this research.
3. Most existing feasibility analyses focus merely on studying the financial return from the increase in real estate values of TJD properties. As a result, projects were predicated on a purely financial rationale rather than a broad vision of how transit could work in tandem with surrounding development (Belzer and

Autler 2002). Increasing evidence, however, shows that TJD can yield more benefits than merely increased land value, including growing transit ridership, an important factor for transit agencies to consider when exploring partnerships with private developers. Therefore, both the increase in real estate values of TJD properties and the ridership increase produced by TJD projects were calculated in the study using two multiple regression models.

4. Nelson’s study in Atlanta, Georgia, shows that elevated transit stations have positive price effects on homes in lower income neighborhoods and negative price effects on homes in higher income neighborhoods within a region approximately 2.7 mi east to west by 1.7 mi north to south in DeKalb County (Nelson 1992). Therefore, the household income level and the housing information of the neighborhoods surrounding rail transit stations were introduced into the model as its non-urban-form variables.

How do people measure the level of land-use mix?

Mixed land-use is a very important characteristic of TJD projects according to most TOD and TJD theories. In order to understand the relationship between mixed land-use and the financial return from TJDs including the increases in the property values and in the transit ridership, the level of land-use mix of a TJD community needs to be measured quantitatively. The two most common ways of measuring level of land-use mix (land use heterogeneity) are Frank & Pivo’ s Entropy Index and Cervero & Kockelman’ s Dissimilarity Index:

1. Frank & Pivo’s Entropy Index: Frank and Pivo developed an entropy index to describe the evenness of the distribution of built square footage among seven land-use categories. According to their paper in “Transportation Research

Record 1466," the entropy index was based on the following equation (Frank and Pivo, 1994):

Level of land-use mix (entropy value)

= - [single family • log (single family)] + [multifamily • log (multifamily)]

+[retail and service • log (retail and service)] + [office • log (office)]

+[entertainment • log (entertainment)] + [institutional • log (institutional)]

+ [industrial/manufacturing • log (industrial/manufacturing)]

2. Cervero & Kockelman's Dissimilarity Index: the land-use mix index developed by Cervero and Kockelman may also be called a "dissimilarity index" since it is based on "points" awarded to each actively developed hectare based on the dissimilarity of its land use from those of the eight adjacent hectares. The average of these point accumulations across all active hectares in a tract is the dissimilarity or mix index for the tract (Kockelman 1997):

$$\text{Dissimilarity Index} = \text{Mix Index} = \sum_k \frac{1}{K} \sum_i^8 \frac{X_{ik}}{8},$$

where K = Number of Actively Developed Hectares in Tract and

and $X_{ik} = 1$ if Central Active H'ectares Use Type differs from

that of a Neighboring Hectare ($X_{ik} = 0$ otherwise).

The Dissimilarity Index, developed by Cervero and Kockelman using the data consist of dominant land uses assigned to 1-hectare squares of land, has its limitation in measuring land use heterogeneity below the scale of a hectare. In order to understand the relationship between the level of land-use mix and increases in property values at the parcel level, Frank & Pivo' s Entropy Index, was deemed more suitable for this research.

In Frank and Pivo's paper, their equation resulted in the development of a normalized value between a minimum of 0 and 0.845 (Frank and Pivo, 1994). However, proportions of each land use among all the land uses are always smaller than 1, which may result in a negative value for the entropy value according to calculation of Frank and Pivo' s Entropy Index. Therefore, an improved calculation of the level of land-use mix is developed based on Frank and Pivo's Entropy Index for this research:

Level of land-use mix = -A / LN (N)

Where:

A= Σ {b(n)/a * LN [b(n)/a]}

With b(n)/a = proportion of building floor area of each land use among total square feet of all the land uses present in a buffer (when building floor area of one specific land use equals to 0, value of 0.01 will be given for its calculation);

N = Number of land use categories used in the research.

Research Methodology:

A case study of the parcels within a 2,000-foot distance from MARTA's rail stations in the Atlanta Metropolitan area utilized meaningful urban-form and non-urban-form variables for the regression analysis.

In this research, "Population Density", "Average Floor Area Ratio", "Level of Land-Use Mix", "Median Household Income", "Per Capita Income", "Total Housing Units inside the Census Block Group", "Median Number of Rooms per Housing Unit", "Number of the Workers Using Transit for Traveling", and "Average Travel Time to Work" were calculated from the census data at the block-group scale. "Square Footage of the Property", "Acreage" and "The Year When the Building was built" were obtained from the parcel data. All these independent variables were used to develop the first multiple regression model to understand the impacts of TJD's characteristics on the property value under certain socio-economic conditions (Figure 4).

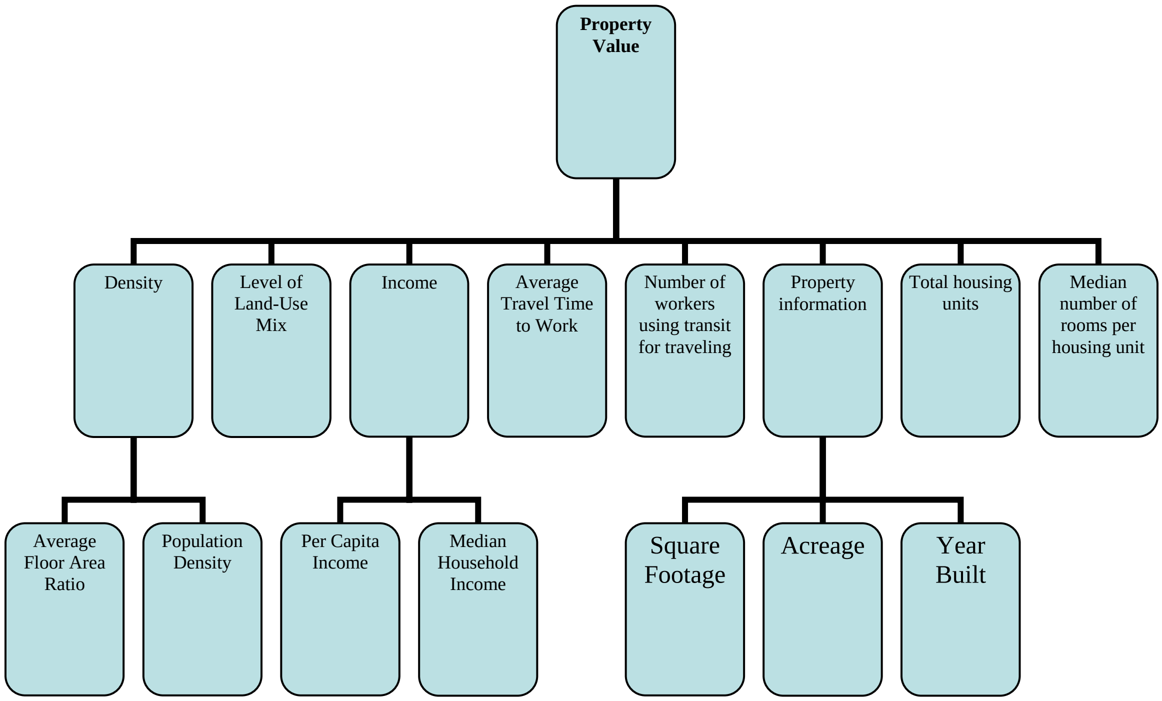

Figure 4: Conceptual Model One

Similarly, "Population Density", "Average Floor Area Ratio", "Level of Land-Use Mix", "Median Household Income", "Per Capita Income", "Total Housing Units inside the Census Block Group", "Median Number of Rooms per Housing Unit", "Average Travel Time to Work", "Square Footage of the Property", "Acreage" and "The Year When the Building was built" were used as independent variables to understand their relationship with "Number of the Workers Using Transit for Traveling" (Figure 5).

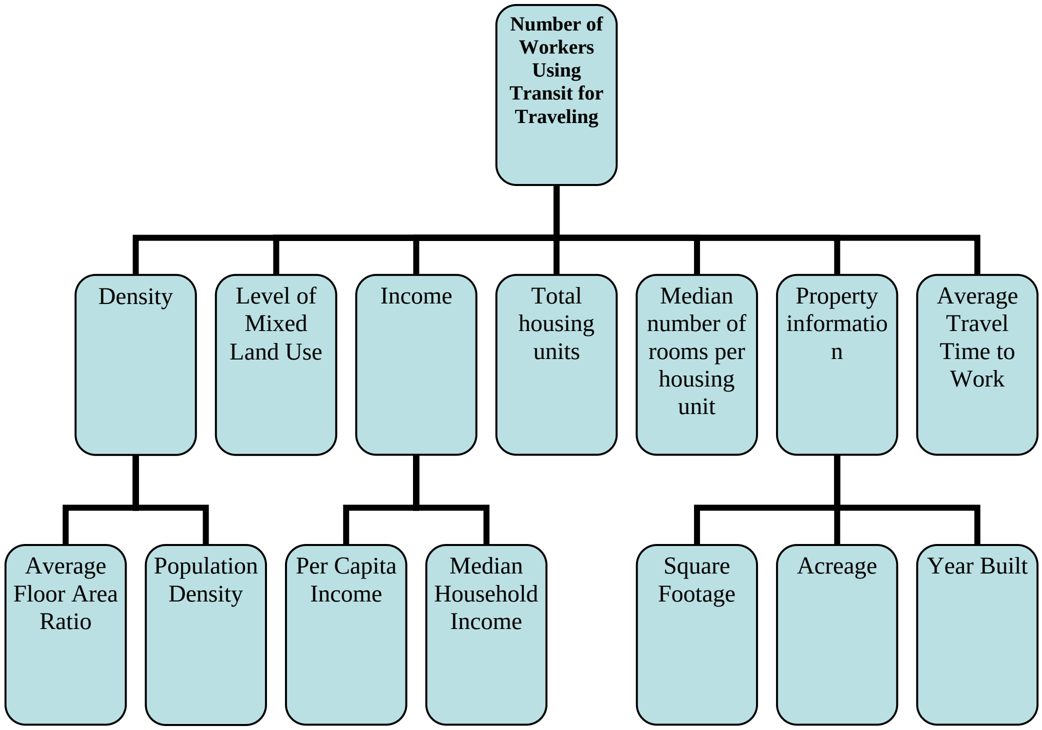

Figure 5: Conceptual Model Two

Data Analysis:

Land use, density and design are all crucial to the success of TJD projects. Land use and density of projects are more often used to identify TOD and TJD projects, as it is almost impossible to quantify various community designs. Density and level of land-use mix were therefore introduced as the urban-form variables in this research.

Density can be defined in at least two ways: how dense the built areas are clustered within an area, and how the population who use the space is clustered within an area. Therefore both “average floor area ratio” calculated from parcel data and “population density” calculated from US Census data were introduced to the regression analysis. An improved calculation of the level of land-use mix was developed based on Frank and Pivo’s Entropy Index for this research:

Level of land-use mix = -A / LN (N)

Where:

$A = \Sigma \{b(n)/a * LN [b(n)/a]\}$

With b(n)/a = proportion of building floor area of each land use among total square feet of all the land uses present in a buffer (when building floor area of one specific land use equals to 0, value of 0.01 will be given for its calculation);

N = Number of land use categories used in the research.

When calculating the level of land-use mix of the parcels inside each 2000 feet buffer around transit stations using the Entropy Index, various land uses of the parcels were grouped into 11 categories for this research: “Office”, “Institutional”, “Recreational”, “Single Family”, “Multifamily”, “Parking/TCU”, “Commercial”, “Park/ Open Space”, “Industrial”, “Vacant”, “Unknown/ Other.”

The income level and housing information of the neighborhoods surrounding transit stations were therefore introduced into the model as its non-urban-form variables. Information on “Median Household Income”, “Per Capita Income” obtained from US Census data were used for regression analysis as income-related variables. Information on “Total Housing Units” and “Median Number of Rooms per Housing Unit” were introduced into the regression analysis as housing-related variables.

To MARTA, increases in ridership mean increases in its operating revenue, which is an important component in MARTA’s decision-making for TJD projects in Atlanta. Information on “Number of Workers Using Transit for Traveling” was obtained from US Census data. And the “Average Travel Time to Work” was calculated from the information provided by the US Census data.

Description of case study area:

The Atlanta Metropolitan area in Georgia is one of the fastest growing areas in the southeastern United States. Covering a much bigger area than the City of Atlanta, the Atlanta Metropolitan area has a population of more than four million, which makes it one of the largest metropolitan areas in the southeastern United States (Figure 6).

Figure 6: Transportation Access to the Atlanta Metropolitan area (Source: http:// www.MapQuest.com)

The Metropolitan Atlanta Rapid Transit Authority (MARTA), formed as a joint public instrumentality of the City of Atlanta and the counties of Fulton, DeKalb, Cobb, Clayton, and Gwinnett, operates a bus and rapid rail transportation system in the region. As one of the TJD projects around MARTA's rail stations, Lindbergh City Center has been the subject of several earlier studies (Dumbaugh 2004). A region-wide feasibility study on the TJD projects around MARTA's rail stations, however, has not been done before.

MARTA's rail system consists of 47.6 miles of operational double track and thirty-eight fully-functioning stations. The rail system has lines running both east-west and north-south. The main lines intersect at the Five Points Station, located in Atlanta's Downtown Business District (Figure 7).

Figure 7: MARTA's Rail Map (Source: MARTA)

MARTA operates under severe financial constraints, as it is the only large metropolitan transit system in the nation that receives no money from state government (Feigon, Hoyt, and Ohland 2004). Any increase in ridership means an increase in its operating revenue. As young professionals began returning to live in the city core in the 1990's, MARTA recognized that there was a market for TOD around its rail stations (Feigon, Hoyt, and Ohland 2004).

Results and discussions:

In this research, two separate linear regression models were used in order to understand the roles the urban-form and the non-urban-form variables plays in deciding the feasibility of TJD projects. Those urban-form and non-urban-form variables, together with related property information (Table 1), were used as independent variables in the first multiple regression model to understand the impacts of TJD arrangements on the property value (taxable value of the property) under certain socio-economic conditions.

	Mean	Std. Deviation	N
Taxable Value	421035.565273	3382489.5618903	4688
Acreage	.348795	.9923584	4688
Average Travel Time	31.115570	8.3806150	4688
Square Footage	10310.802901	50654.2334957	4688
Total Housing Units	496.231655	328.8233493	4688
Median Num of Rooms per Housing Units	4.538289	1.3922763	4688
Level of Land-Use Mix	.590935	.1351577	4688
Population Density	7373.928775	7597.4111458	4688
Average Floor Area Ratio (FAR)	22088.698166	58819.4452637	4688
Median HH Income	30117.067193	25713.4279892	4688
Per Capita Income	18677.457765	17288.5931482	4688
Year Built	1940.415316	46.1487802	4688

Number of workers using transit for traveling	77.512799	47.6354418	4688

Table 1: Descriptive statistics of the variables used in the first regression model

In SPSS 12.0, step-wise regression method was used to eradicate the multi-co linearity of the model. Four independent variables were selected out as the variables playing a significant role in deciding the property value (taxable value of the property) of the parcels in the study areas in the Atlanta Metropolitan area: “square footage of the buildings on the property”, “acreage of the parcel”, “population density”, “total housing units in the census group block to which specific parcels belong.” A model with an adjusted R-Square value of 0.394 was constructed.

Contrary to the hypothesis of most TOD theories, the level of land-use mix and the average floor area ratio, two of the most commonly used identifying variables, were excluded from the model due to their insignificant impact on property value. Population density, another identifier of density, played a significant role in deciding the property value in this model, although its coefficient calculated from the linear regression model was negative, and thus different than expected (Table 2).

Independent Variables	Unstandardized Coefficients
(Constant)	76509.977
Square Footage	46.431
Acreage	-506030.460
Population Density	-14.868
Total Housing Units	306.133

Table 2: Coefficients of the independent variables with the "taxable value of the property" as its dependent variable

The second multiple regression model was used to understand the impacts of the urban-form and non-urban-form variables, and related property information on the transit ridership within the study region including TJD projects and potential TJD sites in the Atlanta Metropolitan area (Table 3).

	Mean	Std. Deviation	N
Number of workers using transit for traveling	77.512799	47.6354418	4688
ACREAGE	.348795	.9923584	4688
Average Travel Time	31.115570	8.3806150	4688
Square Footage	10310.802901	50654.2334957	4688
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Per Capita Income	18677.457765	17288.5931482	4688
Year Built	1940.415316	46.1487802	4688

Table 3: Descriptive statistics of the variables used in the second regression model

In SPSS 12.0, step-wise regression method was used to eradicate the multi-co linearity of the model. Ten independent variables were selected out as the variables playing an important role in deciding the transit ridership in the study areas in the Atlanta metropolitan area: “average travel time”, “median number of rooms per housing unit”, “total housing units in the census group block specific parcels belong to”, “per capita income”, “level of land-use mix”, “population density”, “average floor area ratio”, “property value (taxable value of the property) of the parcels”, “acreage of the parcel”, and “square footage of the buildings on the parcel.” “Property value (taxable value of the property) of the parcels” was then removed because of multi-co linearity. And a model with an adjusted R-Square value of 0.519 was constructed.

Although the variables indicating the density (“population density” and “average area floor ratio”) and the level of land-use mix played significant roles in deciding the number of workers using transit for traveling in the linear regression model, level of land-use mix was negatively related to the “number of workers using transit for traveling”, partly rejecting some of the TOD theories that increasing the level of land-use mix would result in an increase of number of workers using transit for traveling (Table 4). A higher population density in this regression model resulted in an increase of number of workers using transit for traveling, which supports most of the hypotheses for TOD/ TJD research and the TOD/TJD theories.

Independent Variables	Unstandardized Coefficients: B
(Constant)	38.563
Average Travel Time	1.860
Median Num of Rooms per	-1.810

Housing Units	
Total Housing Units	.071
Per Capita Income 1999	-.001
Level of land-use Mixed	-49.632
Population Density	.001
FAR	-5.710E-05
Acreage	-2.328
Square Footage	4.760E-05

Table 4: Coefficients of the independent variables with the “number of workers using transit for traveling” as its dependent variable

This research was carried out to understand the financial benefits brought by TJDs' major characteristics, specifically high-density and mixed land-use. Financial benefits, including increases in property values and in transit ridership, are often assumed for TJDs with a higher density and a greater level of land-use mix in previous studies (Belzer and Autler 2002).

The results of this research, however partly reject the hypothesis that a higher density and a greater level of land-use mix bring a higher financial return, particularly in the case of the TJD projects in the Atlanta Metropolitan area, Georgia, a growing urban area in the United States. On one hand, “population density” played a significant role in determining the property value of the parcels in the study region, while the “level of land-use mix” played an insignificant role in determining property value. On the other hand, two indicators of density, “population density” and “average area floor ratio”, also had significant impacts on the number of workers using transit for traveling in the study region. An increase in the level of land-use mix, however, resulted in a decrease in the number of workers using transit for traveling, an important factor in the success of TJD projects. Contrary to Nelson's results on the relationship between the income level and the property value of the parcels around the transit stations in DeKalb County, Georgia (Nelson, 1992), variables indicating income level did not play a significant role in determining property value in the regression analysis for this research.

Based on the results of the case study in the Atlanta Metropolitan area, a higher level of land-use mix is unlikely to make TJD projects more financially successful. It is also difficult to reach the conclusion that higher densities would bring a higher financial return to the TJD projects in the study region, because a higher population density results in a decrease in the property value and an increase in the numbers of workers using transit for traveling at the same time. Furthermore, the numbers of workers using transit for traveling is just one component of the transit ridership, for people may take transit with other purposes than merely going to work. Previous study also indicate that population density may be a proxy to other locational factors (Steiner 1997). In another word, changes in property value associated with changes in population density may be caused by locational differences among the transit stations in the study region.

But before drawing the conclusion that increases in the level of land-use mix and density will not necessarily make TJD projects more feasible in the Atlanta Metropolitan area, Georgia — which is contrary to the related theories — several factors must be considered.

First, mixed land use in the TOD theory stands for well-connected mixed land use with quality urban design (Calthorpe 1993). Parcels with various land uses and densities in the study region may just be juxtaposed without a considerate design for TJD purposes. It is accepted that land use, density and designs are all crucial to the success of TJD projects. Difficulties in quantifying various unique designs of TJD projects has resulted in a lack of discussion of design elements and their interrelation with land use and density in most quantitative TJD and TOD researches. Emphasis on land use and density may have obscured the potentially prominent role of actual design in deciding the success and feasibility of TJD projects.

Second, TJD or TOD is not the panacea for all urban problems in the United States. Employment and other economic factors in many senses play a much more important role in shaping urban development than transit systems. Although the Atlanta Metropolitan area, with seven percent of its households in the year of 2000 having no access to a car, truck, or van for private use according to the US census data, has a market for TJD projects, decades of unplanned urban sprawl have created an urban pattern that makes the change towards mixed-used development expensive and difficult.

Third, by comparing several socio-economic characteristics of the study region with other parts of the United States, some unique factors of the study region may make the implementation of TJDs in the Atlanta Metropolitan area more difficult than in some other parts of the United States:

- The Atlanta Metropolitan area has a smaller age cohort of over sixty-five years old, who are possibly more likely to be the transit riders (Table 5).

Age Category	Atlanta Metropolitan area	The United States	San Francisco County, California	Washington, D.C.
65 and over	7%	12%	13%	12%
45 to 64	21%	22%	22%	23%
25 to 44	36%	30%	41%	34%

18 to 24	9%	9%	9%	10%
Under 18	27%	26%	15%	21%

Table 5: A comparison of the percentage of population in each age category (Source: Census 2000 Supplementary Survey)

- Both San Francisco County and Washington, D.C., where most successful TJDs have been reported, have lower percentages of married-couple families and a higher percentages of people living alone than the Atlanta Metropolitan area (Table 6).

Type of household	Atlanta Metropolitan area	The United States	San Francisco County, California	Washington, D.C.
Married-couple families	48%	51%	31%	21%
Other families	19%	17%	14%	23%
People living alone	25%	26%	38%	47%
Other non-family households	7%	6%	17%	9%

Table 6: A comparison of the percentage of different types of household (Source: Census 2000 Supplementary Survey)

- Both San Francisco County and Washington, D.C., where most successful TJDs have been reported, have lower percentages of single-unit structures and a higher percentages of multi-unit structures than the Atlanta Metropolitan area (Table 7).

Type of housing unit	Atlanta Metropolitan area	The United States	San Francisco County, California	Washington, D.C.
Single-unit structures	66%	66%	33%	39%
In multi-unit	29%	27%	67%	60%

structures				
Mobile homes	4%	8%	0%	0%

Table 7: A comparison of the percentage of different types of housing units (Source: Census 2000 Supplementary Survey)

Fourth, a linear relationship between the dependent and independent variables is assumed in the regression models. In reality, the relationships among them are much more complicated than the model. Besides, many other factors like the interactive items among the variables are not considered in the model either. All of these factors together create a gap between the regression models and reality (Figure 12).

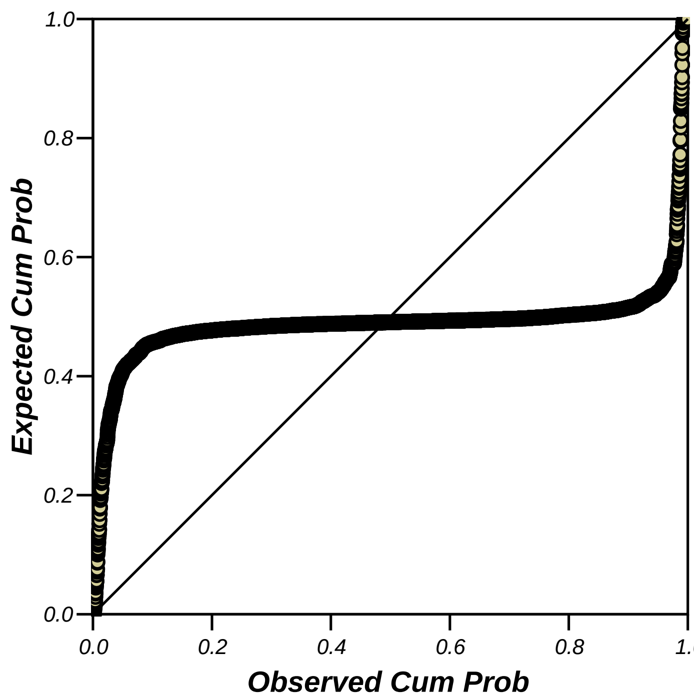

Figure 8: Difference between the expected cumulative probability and the observed cumulative probability in the first regression model for the case study

Finally, the new formula used to calculate the level of land-use mix in this research still leaves room for further discussions and improvements:

- Some researchers calculated "N" in the equation as the number of different land uses that are not vacant. In order to calculate the level of land-use mix for all the parcels inside all the buffers in the study region, a same "N" value (the maximum number of different land uses) is applied to the calculation. There are some values for the parcels inside some of the buffers are zero, for some groups of parcels around certain stations do not have all the categories of the land uses. Zero then is treated as 0.01 to let it working for LN function. Some but insignificant differences are created from doing this.

- The equation uses the square footage of the buildings on the parcels instead of the acreage of the parcels for the calculation. However, there are some land uses that are functional even if there is no building on them, including the parking space, open space and parks, which actually are important components according to Calthorpe's theory of TOD (Calthorpe 1993).

- The vacant lands designated for some specific land use are not included in the calculation of the level of land-use mix. But in a rapidly changing and growing urban area like the Atlanta Metropolitan area, those lands may have some hidden impacts on the overall performance of the TJD projects.

Conclusions and areas for further research

Advocates of TJD assume that increases in the density and level of land-use mix will bring greater financial return to both private developers and transit agencies. This research was carried out to understand the financial benefits brought from TJDs' major characteristics, specifically high-density and mixed land-use.

Findings in the literature review identified the increases of the property values and in the transit ridership as two of the major financial benefits of TJDs. A case study in the Atlanta Metropolitan area selected parcels inside a 2,000 foot buffer around MARTA's transit stations for regression analyses. Two regression models were constructed for the study.

Using meaningful urban-form and non-urban-form variables, these two regression models were used to address several questions:

- To what extent will high-density and mixed land-use increase the property values of TJDs?
- Will an increase in the density and the level of land-use mix of TJDs bring a higher transit ridership?
- What is the impact of other factors, including the household income level of the neighborhood around TJDs, on the financial return from TJDs?

However, the results of this research partly reject the hypothesis that a higher density and a greater level of land-use mix bring a higher financial return to TJD projects, specifically in the Atlanta Metropolitan area, Georgia, a growing urban area in the United States. Based on the results of the case study, the level of land-use mix played an insignificant role in determining the property value. Furthermore, an increase in the level of land-use mix resulted in a decrease in the number of workers using transit for traveling. It is also difficult to reach the conclusion that a higher density would bring a higher financial return to the TJD projects in the study region, because a higher population density results in a decrease in the property value and an increase in the numbers of workers using transit for traveling at the same time.

Different from Nelson's results on the relationship between the income and the property level of the parcels around the transit stations in DeKalb County, Georgia (Nelson, 1992), variables indicating the income level do not play a significant role in deciding the property value in the regression analysis for this research.

Before any conclusion that increases in the level of land-use mix and density will not necessarily make TJD projects more feasible in the Atlanta Metropolitan area can be drawn, several factors were discussed:

- Mixed land use in the TOD theory stands for well-connected mixed land use with quality urban design (Calthorpe, 1993). Parcels with various land uses and densities in the study region may just be juxtaposed without a considerate design for TJD purposes.

- TJD or TOD is not the panacea for all the urban problems of the United States. Employment and other economic factors in many senses play a much more important role in shaping urban development than transit systems. Decades of unplanned urban sprawl have created an urban pattern that makes the change towards mixed-used development costly.

- There may be several unique social-economic characteristics of the study region making the implementation of TJDs in the Atlanta Metropolitan area more difficult than in some other parts of the United States.

- A linear relationship between the dependent and independent variables is assumed in the regression models. In reality, the relationships among them are much more complicated than the model.

- The formula used to calculate the level of land-use mix in the research still has several points for further discussions and improvements.

At last, it is also noticeable that reasons for pursuing TJD projects with growing concerns over environmental, economical, and social sustainability goes far beyond the calculation of the financial returns from TJD projects. As a way of smart growth, TJD projects offer the hopes, if only to a modest degree, of relieving traffic congestions, air pollution, energy depletion, and social disintegration of the neighborhoods.

Land use, density and designs are all crucial to the success of TJD projects. However, it is often mistakenly assumed that mixed land use and high-density alone enable higher financial return from TOD and TJD projects. While greater financial return is probably more likely if projects are designed to take advantage of the benefits provided by these other two characteristics, mixed-use and high density are not determinative in and of themselves. Land use and density of projects are more often used to identify TOD and TJD projects rather than design, but experience shows that actual design of projects may have played a major role in deciding their success.

The roles that land uses, density and designs, together with the interactive effects among them, are playing still need further research towards a better and comprehensive understanding.

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