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Transport, Energy and Environmental Benefits of Transit-Oriented Development Strategies

APEC Transportation Working Group

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** Final Report **

TPT 04/2010

Transport, Energy and Environmental Benefits of Transit-Oriented Development Strategies

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Executive Summary

The present report addressed questions raised by APEC and the Intermodal and ITS Experts group and the Group of Experts on Energy Efficiency and Conservation, Energy Working Group (EWG) from APEC on the "Transport, Energy and Environmental Benefits of Transit Oriented Development Strategies" in Asia Pacific Economic Cooperation economies.

The report was designed to:

- Assess the "energy, transport and environmental benefits of transit-oriented development (TOD) strategies"
- Evaluate TOD "in terms of reduced oil imports, pollutants and greenhouse gas emissions, and reduced travel times"
- Encourage TOD "Through a better understanding of these benefits, … throughout the APEC region"
- Provide case studies of TOD to demonstrate these concepts

In order to calculate indices that could assist in evaluating the impact of TOD on the environment, energy use, GHG emissions and transportation, a number of sources and factors were considered. After a thorough review of the literature a number of metrics were identified. These metrics were presented to TPT and EWG members and international experts at the Commission on Energy and Environmental Development (CEEDS)[1] workshops held in San Francisco in September 2011 and Singapore in Jan 2012. In addition, a workshop was also held on April 11, 2013 in Ho Chi Minh City, Viet Nam that was attended by APEC Transportation Working Group members and a number of international and regional experts to discuss the these case studies and analyses. Comments and suggestions gleaned from that discussion are also incorporated into this report. As a result of these discussions the final list of metrics was adopted to best address the questions.

To obtain the CO_2 reductions, the average CO_2 emission factors for passenger vehicles and the various modes of transportation provided in the TOD zones selected for study were calculated. According to the US Environmental Protection Agency (EPA) the average emission factor for a passenger vehicle can be produced by two important parameters provided by the EPA:[2] In addition, census data provided the estimates for the numbers of persons residing and working in the selected TOD zones. The majority of the sites selected for analysis were included in the TOD Database maintained by the Center for Transit-Oriented Development. Additional sites were selected based on recommendations included in the original statement of work from APEC. Utilization of public transport, non-motorized transport and public transportation was also determined from databases and other published reports.

[1] http://esci-ksp.org/wp/wp-content/uploads/2012/09/Final_Report_CEEDS_Phase_3-EE-URBAN-PASSENGER-TRANSPORTATION.pdf

[2] http://www.epa.gov/oms/climate/documents/420f11041.pdf

Subsequent analyses and calculations revealed that there was a significant reduction in overall Green House Gas (GHG) emissions and CO_2 emissions associated with living and working in transit oriented development zones as compared to non-TOD or adjacent regions. CO_2 emissions associated with transit oriented development at the sites studied show that, on the average, transit oriented development reduced CO_2 emissions a little over 11% annually. It should be noted however, that CO_2 emissions reductions vary according to population density. In addition, policies that encourage use of non-motorized transport and public transportation are likely to also contribute to the reduction in CO_2 emissions associated with transit oriented development.

There appeared to be strong relationships between use of public transportation, non-motorized transport and overall GHG emissions reductions. Strong relationships were also found between population density, use of public transportation and overall GHG and CO_2 emissions. In addition to GHG reductions, the report also calculated indices for the various TOD zones that demonstrated the significant reduction in vehicle miles traveled (VMT) as well as decreases in fuel consumption in terms of numbers of gallons of gasoline and barrels of crude oil imported.

These findings are not surprising and are corroborated by the work of others[3] who have argued that "TOD and green urbanism" along with higher densities, improve resource use efficiency. Nevertheless, it is important to recognize that the analyses conducted here document dramatically the positive impact of transit oriented development on the reduction of GHG.

The lessons learned from these analyses clearly indicate that TOD has a number of benefits. The increases in walking and use of public transportation result in decreases in GHG emissions. In addition, TOD associated with reductions in automobile use which also lead to reductions in GHG emissions. Accordingly, a number of recommendations were discussed that would encourage further transit oriented development and also maximize the environmental and sustainable aspects of TOD:

1. TOD appears to have a substantial impact on the reduction of GHG.
2. TOD is associated with greater use of public transport and non–motorized travel.
3. TOD needs policies that significantly encourage the use of public transportation.
4. TOD environmental impact best if policies also encourage more efficient transit.
5. TOD environmental impact improves when incentives encourage bicycle use and walking.
6. TOD benefits are more likely if motorcycle use is also decreased.
7. TOD based transit stations should be intermodal to maximize use of public transportation.
8. TOD benefits from zoning laws that encourage greater density.
9. TOD impacts increase if employment opportunities are nearby.
10. TOD research would be enhanced by development of a global TOD database.

[3] http://www.its.berkeley.edu/publications/UCB/2010/VWP/UCB-ITS-VWP-2010-7.pdf

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Project Overview

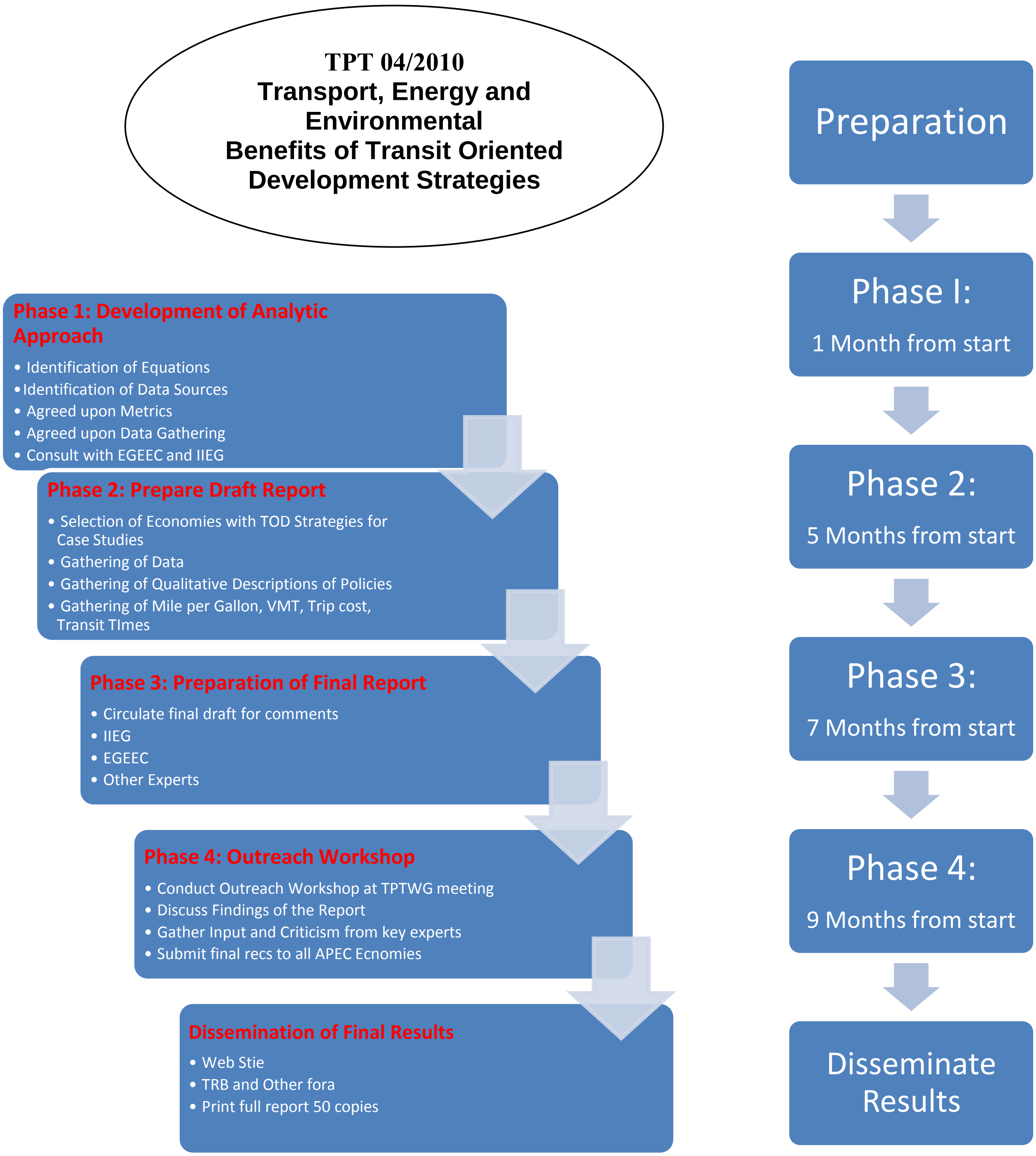

Figure 1. Conceptual Overview of Project

Introduction

The present report is designed to addresses the questions raised by APEC and the Intermodal and ITS Experts group on the "Transport, Energy and Environmental Benefits of Transit Oriented Development Strategies" in Asia Pacific Economic Cooperation economies. This report was commissioned by the APEC by the Intermodal and ITS Experts Group, Transportation Working Group (TPT-WG) and the Group of Experts on Energy Efficiency and Conservation, Energy Working Group (EWG) from APEC.

The key objectives addressed in this report are:

- To assess the "energy, transport and environmental benefits of transit-oriented development (TOD) strategies to assist APEC economies in shifting passenger transport from energy-intensive automobiles to energy-economizing modes like public transit, light rail, buses, bicycles and walking."
- To evaluate TOD "in terms of reduced oil imports, reduced pollutants and greenhouse gas emissions, and reduced travel times for the APEC economies that have adopted them."
- To encourage TOD "Through a better understanding of these benefits, … throughout the APEC region, especially in developing economies where transport infrastructure and oil use are expanding rapidly."

The underlying assumption of this project is that transportation today is highly dependent on oil consumption. Clearly and by far the greatest user of oil in APEC economies, is from transportation. This increase in oil consumption has closely followed the movement of population towards urban settings such that greater and greater quantities of fossil fuel have been consumed in the support of urban and metropolitan based transportation. As population and access to automobiles has increased, more frequent use of automobiles and vehicle trips have occurred also increasing the consumption of oil. Consequently, the recent focus on the development of urban based transit oriented development is now seen as a possible contributor to the reduction of automobile traffic and an increase in alternative and more fuel efficient modes and methods of transportation. Unfortunately, as noted in the APEC TPT RFP for this project:

> "there is no systematic understanding across the APEC region of the extent to which transit oriented development strategies can shorten travel times, reduce energy needs and costs for consumers and businesses, and limit atmospheric emissions of urban air pollutants and carbon dioxide."

Accordingly, it is hoped that the results of this report will provide transport, energy and environmental ministers with a clearer understanding of how transit-oriented development strategies might contribute to the reduction of energy needs and oil imports, as well as reducing the overall carbon footprint of transport in APEC economies. In addition, it is hoped that the results of the project will broaden and accelerate investments in transit-oriented development, thereby limiting upward pressure on pedestrian and freight transit times and costs, oil prices, oil import dependency, and global carbon emissions.

To address the questions raised, an analytic approach assessing the local transport, energy and environmental benefits of transit oriented development strategies was developed. The approach drew upon a number of sources for calculating the potential for TOD strategies to reduce transit times and costs, and to limit and curb greenhouse gas emissions. Initial case examples that were subjected to the analyses were drawn from various APEC economies that have adopted TOD strategies, drawing upon examples identified in the *Survey of Policies and Programs that Promote Fuel–Efficient Transport* (May 2008) and follow-up workshop (March 2009). Specifically, locations and TOD programs such as the Auckland Urban Living Program in New Zealand, bicycle lanes in Chinese Taipei, and integrated transportation planning in the city of Portland, Oregon in the United States. Additionally, TOD projects in Denver, Colorado (USA), Tianjin China and Korea were also examined to identify further examples of how urban development has occurred around a core of highly efficient passenger mass transit systems in APEC economies. The report addresses how such strategies have reduced passenger movements and freight shipment transit times and costs, curbed automotive fuel requirements, and limited emissions of carbon dioxide and other pollutants.

APEC Rationale

The rationale for the project stems from statements and instructions provided by the APEC Ministers in various communicates over the last several years. APEC Ministers in 2008 encouraged greater cooperation between the Energy Working Group and Transportation Working Group in assessing approaches to fuel-efficient transport. The Draft Declaration for the Sixth APEC Transportation ministerial in 2009 affirms that the Transportation Working Group should collaborate with the Energy Working Group on projects of mutual interest.

An additional basis for this project stems from recent developments and concerns expressed by various leaders and energy ministers who met at the 7th Annual Energy Ministers Meeting in Gyeongju, Korea to discuss the oil import issues. Since transport is highly dependent upon energy efficiency and the use of primarily oil related energy technologies, the transport sector is particularly sensitive to fluctuations in the price of energy. Additionally, the use of oil is dependent upon the technologies selected and most appropriate for the infrastructure configuration of the local economy.

The Asian Development Bank (ADB) has argued that greenhouse gas (GHG) emissions affect climate change. Moreover, in 2009, transportation accounted for 23% of GHG emissions globally. It is estimated that by 2035 transportation will be largest GHG source of global emissions (46%), and by 2050 will have risen to 80%. In 2006, Asia produced 19% of total worldwide transport–sector related CO_2 emissions and by 2030 Asia's share will increase to 31%.[4]

The APEC region has seen dramatic economic success and a significant increase in the use of petroleum based energy supplies to fuel its expansion. Concern over the impact that these developments have had on the environment in addition to the sustainability of such growth has

[4] http://www.adb.org/sectors/transport/key-priorities/climate-change

prompted an interest in reducing emissions and oil consumption. It is imperative that the APEC economies address issues related to energy conservation and deployment. In particular, it is the long term goal of this project that the implementation and utilization of various transit oriented development strategies will lead to reduced fuel consumption and decreased carbon emissions. This may be achieved in part as a result of the identification of effective policies that are designed to promote transportation while at the same time reducing energy usage and increasing energy efficiency.

At the 7th Annual Energy Ministers Meeting in Gyeongju, Korea participants also agreed that an effective response to growing oil import dependency for the region as a whole requires a mix of demand-and supply-side measures, including increased energy efficiency in transport. Since transport is highly dependent on oil and by far the greatest user of oil in APEC economies, more fuel-efficient transport is essential to curbing oil dependency. Transit oriented development strategies for shifting individual transportation choices to less energy-intensive transport modes may lead to increased transport energy efficiency.

At the 8th Meeting of APEC Energy Ministers in Darwin, Australia in May 2007, APEC Energy Ministers encouraged APEC economies to individually set goals and formulate action plans for improving energy efficiency on an overall and/or sector basis. As a result, in the Sydney Declaration of September 2007, APEC Leaders agreed to work towards achieving an APEC-wide regional aspirational goal of a reduction in energy intensity of at least 25% by 2030 (with 2005 as the base year). To this end, APEC economies were encouraged to set individual goals and action plans for improving energy efficiency, reflecting the individual circumstances of each economy.

APEC Ministers in 2008 again encouraged greater cooperation between the Energy Working Group and Transportation Working Group in assessing approaches to fuel-efficient transport. The Draft Declaration for the Sixth APEC Transportation ministerial in 2009 affirms that the Transportation Working Group should collaborate with the Energy Working Group on projects of mutual interest.

At the 2010 APEC Energy Ministerial Meeting of APEC Energy Ministers in Fukui Japan, Ministers declared their position on low carbon paths to energy security and identified the need for cooperative energy solutions for a sustainable APEC. The Ministers also called for more efficient use of energy and a cleaner energy supply to boost energy security, grow APEC economies and lower emissions. The Ministers committed to further strengthening the Energy Security Initiative (ESI) endorsed by the APEC Leaders in 2001 and to undertaking new measures to build upon it. In addition, they noted the need for fuel-efficient vehicles using lightweight materials and other advanced technologies that can greatly reduce both oil consumption and carbon emissions. Most relevant to the current proposal, the Ministers instructed the EWG to conduct a series of workshops on the potential fuel and carbon savings from: electrification of the transport sector, the use of more energy efficient freight transport, the effects of transit-oriented development and the development of other energy efficient transport strategies, in cooperation with the TWG.

Thus, the present project is an outgrowth of these Ministerial statements in that the objective is to pursue the identification of best practices and policies that will promote the more efficient and effective use of energy in the transport sector.

APEC Cooperative Energy Efficiency Design Project (CEEDS)

The APEC Cooperative Energy Efficiency Design for Sustainability (CEEDS) project was focused on reviewing energy-efficient urban passenger transportation. The project was sponsored by the Asia Pacific Economic Research Centre (APERC) with additional support from the Ministry of Energy and Transportation from Japan.

Results of two workshops held by the CEEDS organizers resulted in a report posted on the CEEDS web site.[5] The report identified a number of key recommendations and support for a strategy thought by workshop participants to be useful in promoting energy efficient transportation. The discussion at the workshops identified areas of concern relative to: 1) energy efficient transport as a cornerstone for achieving energy efficiency 2) the need for energy efficient urban design and 3) the need to focus on transit oriented development and livable communities. The workshop participants concluded that a policy approach that emphasized the strategy of "*Avoid – Shift – Improve*", originally proposed by Dalkmann and Brannigan (2007), was quite helpful in thinking about ways to improve energy efficient urban transportation.

Table 1. Avoid-Shift-Improve (ASI) Strategy.

Avoid	Shift	Improve
"travel with carbon footprint"	"to sustainable low carbon alternatives"	"efficiency of transport with technology & choice"

Adapted from: Dalkmann and Brannigan (2007) and Sakamoto (2012)[6],

The "Avoid" policy emphasized the need to reduce reliance upon motorized vehicles for transport primarily through the use of land use and transportation planning such as TOD. The report included a recommendation on key principles for energy efficient TOD namely:

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[5] http://esci-ksp.org/wp/wp-content/uploads/2012/09/Final_Report_CEEDS_Phase_3-EE-URBAN-PASSENGER-TRANSPORTATION.pdf

[6] Sakamoto, K. (2012). Overview of policy interventions for GHG mitgationin transport. UNECE Internation Expert Meeting on the Assessment of CO emissions in Trasport Geneva Switzerlnd April 24, 2012. http://www.unece.org/fileadmin/DAM/trans/doc/themes/07_-_Sakamoto__ADB__-_Overview_of_policy_interventions_for_GHG_mitigation_in_transport.pdf

> Key principles for effective TOD include planning for mixed urban uses; providing and promoting convenient mass transit options; maximizing intermodal connectivity of transit hubs; charging for vehicles coming into cities; and developing bicycle networks and neighborhoods that promote walking. Other proven practices include changing zoning laws around mass transit stations and transforming underused/badly designed areas in cities into more attractive, vibrant urban areas. The workshop discussions also highlighted the need to create dense networks of streets and paths, use smaller city blocks, and regulate parking and road use. (CEEDS, page 6)[7]

With respect to the "Shift" aspect of policy the workshop participants recommended that policy should recommend a *shift* to more energy efficient modes of travel by promoting and increasing the use of public transportation.

The "Improve" aspect of policy that the workshop participants endorsed referred to the need to improve vehicle efficiency and energy utilization to reduce the amount of GHG. Examples of ways of addressing these goals would be to adopt more stringent fuel efficiency and economy standards, the use of fiscal incentives to encourage more efficient vehicles, and education of consumers regarding the efficiency of various vehicles. In addition, reducing congestion and increasing the use of electric vehicles. Additional work on the "*Avoid – Shift – Improve*"[8] strategy was also conducted by Dalkmann and Brannigan (2007).

A recent report by Huizenga and Baker (2010) published by the Asian Development Bank suggests that the "*avoid-shift-improve*" approach has influenced a number of transport policies and programs that can or may lead to reductions in GHG emissions from both passenger and freight transport. They reported on three Asian cities considering transportation programs that would target carbon emissions. However, most of the cases examined were reviewing bus rapid transit, traffic demand management or bus route redirection or modification. None of the cases examined in Jakarta, China, Mexico or Brazil addressed transit oriented development.[9]

TOD in the Past Twenty Years

When BART opened in 1974, many suburban Bay Area communities allowed the zoning around the station to revert to limited use or low value in the areas directly adjacent to the station. When the D.C. Metrorail system opened in 1976, urban planners, The Washington Metropolitan Area Transit Authority and nearby local governmental agencies took a more active approach in identifying development strategies in the immediate areas around their stations and have since become a national model for suburban "transit-oriented development." (Urbanist, 2010). [10]

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7 http://esci-ksp.org/wp/wp-content/uploads/2012/09/Final_Report_CEEDS_Phase_3-EE-URBAN-PASSENGER-TRANSPORTATION.pdf

8 Dalkmann, H. and C. Brannigan (2007). *Module 5e. Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities.* GTZ.

9 Huizenga, C. & Baker, S. (2010). *Climate Instruments for the Transport Sector: Considerations for the Post 2012 Climate Regime*. Published by Asian Development Bank and Inter-American Development Bank.

10 The Urbanist (2010). "Thriving TOD" January 2010.

In contrast to BART and most other U.S. regional rail systems, many suburban D.C. Metrorail stations are immediately surrounded by a dense building pattern. Often made up of office buildings with increasing amounts of residential and retail, these station areas contrast with the low-density suburban form nearby. In contrast, the development around some BART stations like North Berkeley, Ashby, Fremont and MacArthur has not changed since the 1970s. In Arlington Virginia outside DC, employment in the corridor has gone from 30,000 to 80,000 jobs since 1972. This corridor would cover 14 square miles if it were developed at typical suburban population densities. However, nearly two thirds of all jobs and 40 percent of new housing have been built near Metro stations. In addition, 75 percent of new development in Arlington County has occurred near the metro stations.[3]

According to the Masoumi (2011)[11] site, Peter Calthorpe introduced the concept of TOD or Transit Oriented Development as we know it today in his book titled *The Next American Metropolis* published in 1993[12]. TOD refers to the high-density and mixed-use land development centering on a transit station, typically a rail station. Masoumi[13] summarizes the main characteristics and goals of TOD as follows:

1. Organize growth on a regional level to be compact and transit-supportive.
2. Place commercial, housing, jobs, parks, and civic uses within walking distance of transit stops.
3. Create pedestrian-friendly street networks which directly connect local destinations.
4. Provide a mix of housing types, densities, and costs.
5. Preserve sensitive habitat, riparian zones, and high quality open spaces.
6. Make public spaces the focus of building orientation and neighborhood

Parker published a research report and noted that: “Transit-Oriented Development (TOD) is moderate to higher density development, located within an easy walk of a major transit stop, generally with a mix of residential, employment and shopping opportunities designed for pedestrians without excluding the auto. TOD can be new construction or redevelopment of one or more buildings whose design and orientation facilitate transit use”.[14]

Since 1993, a number of studies and projects have been completed throughout the U.S. and Canada which are well documented and researched by the publications of the Transit Cooperative Research Program (TCRP) under the Transportation Research Board (TRB), National Research Council that are described as Transit Oriented Development (TOD). The main design principles usually associated with the development of these projects are usually: Density, Distance, Diversity, Design, and Destination Accessibility.

[11] http://urban-research.blogspot.com/2011/01/some-definitions-for-transit-oriented.html
[12] Calthorpe, P. (1993). The next American metropolis: ecology, comuity and the American dream. Princeton Architectural Press.NY, NY.
[13] Masoumi, Op cit.
[14] Parker T., McKeever, M., Arrington, G. B., Smith-Heimer, J. (2002), “Statewide Transit-Oriented Development study: Factors for Success in California”, Final Report, California Department of Transportation.

TOD and the Environment

The economic, operational and environmental benefits of using transit oriented development investments to facilitate the goals of livability and sustainability are thought by numerous experts to warrant considerable investment and investigation. One significant improvement in the area of energy efficient transport is the development of facilities in close proximity to more efficient transportation modes in order to reduce fuel consumption, promote the use of alternative energy sources while facilitating the most efficient movement of passengers from point to point.

Various reports have begun to demonstrate the economic and environmental benefits of transit oriented development. For example, a recent popular news magazine article stated:

> "Transit Oriented Development as an approach to combat traffic congestion and protect the environment has caught on all across the country. The trick for real estate developers has always been identifying the hot transportation system. Today, highways are out; urban transit systems are in." -The Urban Land Institute (ULI)[15]

A recent report published in Oregon [16] (www.oregon**metro.gov**) has noted that the transit oriented development efforts have resulted in improvements such as:

- increased transit use by creating places for people to live and work within walking distance of high quality transit. Each year, over half a million more travel trips are made by transit, rather than by car, as a result of projects built with TOD program funding.
- increased housing choice and affordability by attracting compact residential development near transit and walkable urban centers. The 2,100 housing units constructed to date serve a diverse range of households: 531 units are restricted for households earning up to 60 percent of the area median family income; and 703 of the market rate units are affordable to households earning up to 80 percent of the area median family income.
- In Oregon, mixed-use TOD projects completed to date include 106,806 square feet of retail and 140,737 square feet of office space. Well-designed, mixed-use buildings with retail, restaurants and offices contribute to placemaking by generating more pedestrian activity, strengthening the customer base, and introducing amenities for urban living.
- The Metro Portland TOD program stimulates private and public investment by helping to offset the higher costs of compact development. The 20 TOD projects

[15] http://www.transitorienteddevelopment.org/
[16] http://library.oregonmetro.gov/files//tod_annual_report_2009-2010.pdf

completed to date have leveraged more than $300 million in total development activity.

- TOD projects completed to date required a total of only 44 acres. If developed conventionally, they would have used 366 acres. Compact development helps preserve farms and forestland.[17]

TOD and Modal Shift

Transit oriented development strategies are also designed to produce shifts from automobiles to walking. One report suggested that "The greatest mode shift is not from automobile to public transit, it is to walking, as illustrated in the figure below. In total, residents of neighborhoods with good transit and mixed land use drive less than half as much on average as residents elsewhere." [18]

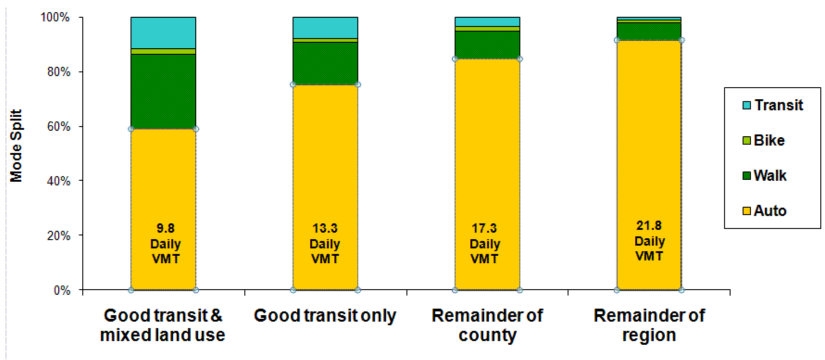

Figure 2. TOD Impacts on Modes in Portland Oregon (Source: Ochland & Poticha , 2006)[19]

Urban Energy Use

Research by Newman and Kenworthy (1999) shows that there is a distinct relationship between urban density and energy consumption. While there are differences in energy consumption across the globe, the relationship appears to be somewhat curvilinear in that energy use increases significantly based on location. Data suggest that energy consumption in the US is greater in cities with lower population densities than that of Asian cities with higher population densities. As can be seen in Figure 3, Hong Kong, with 300 persons per hectare uses less than 20 billion joules of energy while Houston, Phoenix and Detroit with less than 20 persons per hectare use over 80 billion.[20]

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[17] http://library.oregonmetro.gov/files//tod_annual_report_2009-2010.pdf
[18] http://www.planetizen.com/node/39133
[19] http://www.planetizen.com/node/39133
[20] Newman, P. & Kenworthy, J. (1999). Sustainability and cities: Overcoming Automobile dependence. New York: Island Press.

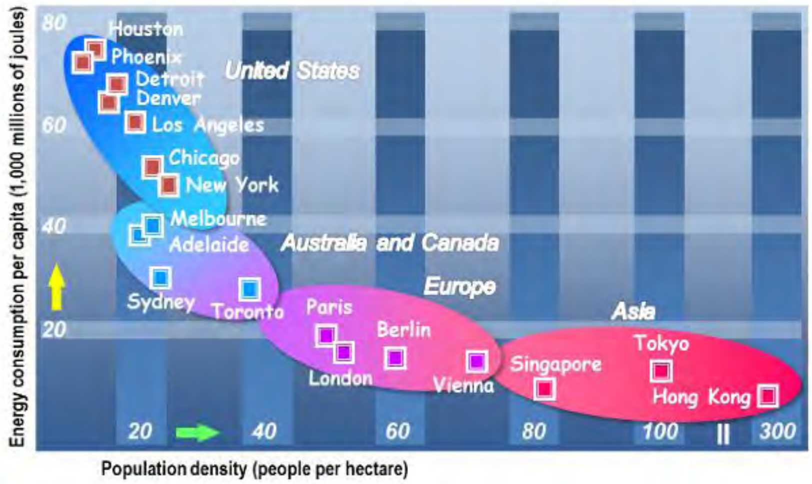

Figure 3. Urban Energy use in Asian and North American. Newman & Kenworthy (1999).

A study by Dhakal (2009)[21] examined the contribution of urban centers to the overall energy consumption. In this study, it was determined that while urban areas contain only 40% of the population of China, they make up 84% of China's commercial energy usage. The 35 largest cities in China, which contain only 18% of the population, account for 40% of China's energy uses and CO_2 emissions. In four key cities, the per capita energy usage and CO_2 emissions have increased dramatically. In addition, while progress was made in reducing the carbon emissions in Chinese cities during the 1990s, in the last few years it has either been slowed further or completely reversed.

Zhang et. al. (2011) examined the energy consumption of 30 provincial capital cities of mainland China in 2005. Cities with the highest total energy consumption were found in the economically developed regions such as the Beijing-Tianjin Area, the Yangtze River Delta and the Pearl River Delta. However, per capita energy use was found to be significantly higher in the Mid-and-Western regions. The energy intensive cities are mainly located in the northwest, while the cities with higher efficiency are in southeast areas. In light of this great variance in urban energy consumptions, a more effective regional and management system is needed to effectively address the ongoing energy strategies and targets in China.[22]

[21] Dhakal, Shobhakar, 2009. "Urban energy use and carbon emissions from cities in China and policy implications," Energy Policy, Elsevier, vol. 37(11), pgs. 4208-4219, November.

[22] Zhang L., Yang Z., Liang J., Cai Y. Spatial Variation and Distribution of Urban Energy Consumptions from Cities in China. *Energies*. 2011; 4(1):26-38.

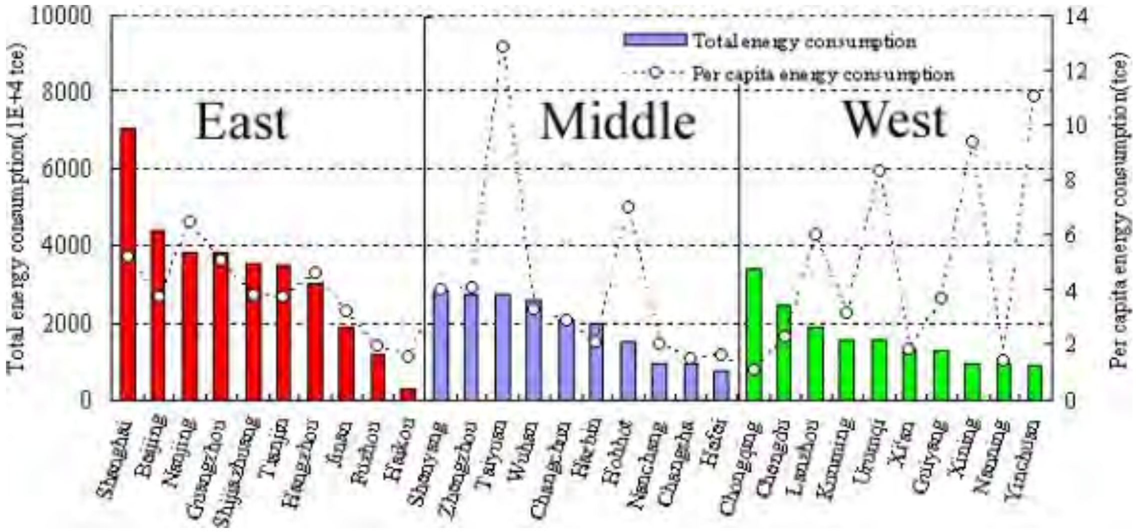

Figure 4. Total Energy Consumption in Various Regions.

The total GHG emissions by source have been calculated by various authors. Recent reports suggest that passenger transportation accounts for 60 to 70% of energy consumption from transportation activities. Single passenger vehicles are the primary mode of transportation in the US but have had a history of poor energy efficiency. Improvements have been seen since the 1970's following the introduction of fuel efficiency standards. The United States has one of the highest levels of car ownership in the world with one car for every two people, and with about 60% of all American households owning more than one vehicle, and with 19% owning three or more. [23]

TOD and Energy Use

According to a recent peer-reviewed report[24] supported by the EPA, transit-oriented development is the key to cutting energy consumption — even more so than Energy Star construction or green cars.

The report, *Location Efficiency and Housing Type—Boiling it Down to BTUs,* is summed up in the attached graph. The study examines the energy implications of the following scenarios:

1) Conventional suburban development (CSD) versus transit-oriented development (TOD)
2) Green building (Energy Star), versus conventional construction
3) Single-family versus multifamily residential units
4) Green versus conventional automobiles

[23] Rodrigue, J-P *et al.* (2012) *The Geography of Transport Systems*, Hofstra University, Department of Global Studies & Geography, http://people.hofstra.edu/geotrans.
[24] http://epa.gov/smartgrowth/location_efficiency_BTU.htm

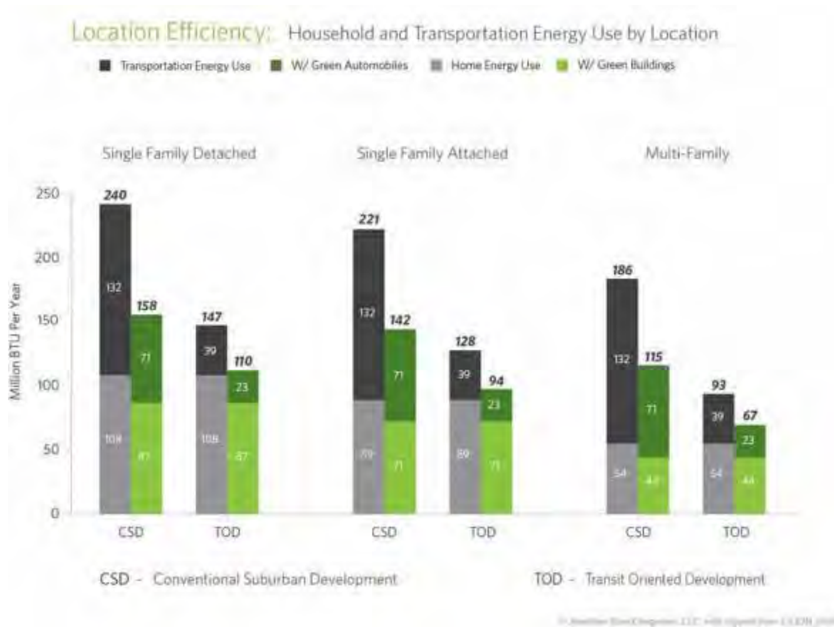

Figure 5. Energy Use for Residents.

The most significant factor determining energy usage was found to be going from conventional suburban to transit-oriented design. Changing to TOD resulted in a 50 percent reduction in energy use in multifamily buildings and 42 percent and 39 percent reductions in single family attached and detached dwellings. In fact, the authors noted that the most inefficient TOD beats the most efficient CSD in this study.

TOD and VMT

Factors influencing the amount of GHG in the atmosphere are also related to the travel demand statistics. Ewing and Cervero (2001) reported that the application of three main planning factors: density, diversity and design tended to reduce total trips and total vehicle miles traveled by 3–5%. Also, conducting a comparative analysis between an automobile-oriented city and a transit-oriented city, Cervero (1996) further demonstrated that the latter has about 30% fewer total trips and vehicle miles traveled than the former. In general, the number of trips in the U.S. has been declining over the past few years. A study by Rodrigue (2012)[25] showed that there appears to be a direct relationship between the cost of fuel and the quantity of travel. When oil prices rise, vehicle usage and thus vehicle-miles traveled (VMT) decline. Additionally, VMT has been declining over time with a projection of zero in zero in the first decade of the 21st century. This may be due to the diffusion of the automobile, higher energy prices and value choices by individuals. [26] Nevertheless, TOD is seen as a significant contributor to further reductions in VMT and trips.

[25] http://people.hofstra.edu/geotrans/eng/ch8en/conc8en/ch8c1en.html
[I]Ibid.

Methodology

In order to calculate indices to assist in evaluating the impact of TOD on the environment, energy use, GHG emissions and transportation, a number of sources and factors were considered. These indices were also discussed with other TPT EWG members and international experts at the CEEDS workshops held in San Francisco in September 2011 and Singapore in January 2012.

Previous studies have utilized a wide range of measures such as:

(1) Motor vehicle miles per vehicle and miles per gallon
(2) Ton miles per gallon
(3) Percent utilization of modes
  (a) Percent use of private autos
  (b) Percent use of car pooling
  (c) Percent use of public transportation
  (d) Percent use of transit buses
  (e) Percent use of light rail
  (f) Percent use of BRT
  (g) Percent use of walking
  (h) Percent use of bicycling
(4) Fuel consumption by mode and sub mode
(5) Congestion changes
(6) Transportation and land use planning oriented to TOD

The US EPA has published formulas to calculate the amount of greenhouse gases emitted by passenger vehicles. Consultants will likely revert to those cited by the U.S. Environmental Protection Agency. The US EPA notes that:

> To translate GHG reductions into an equivalent number of cars off the road, annual emissions from a typical passenger vehicle should be equated to 5.5 metric tons of carbon dioxide equivalent or 1.5 metric tons of carbon equivalent
> (nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1001YU0.txt)
> (Note: Paste URL into web browser for best results.)

The EPA also provides guidance on estimating the amount of CO_2 produced by a gallon of gasoline:

> A gallon of gasoline is assumed to produce 8.8 kilograms (or 19.4 pounds) of CO_2. This number is calculated from values in the Code of Federal Regulations at 40 CFR 600.113-78, which EPA uses to calculate the fuel economy of vehicles, and relies on assumptions consistent with the Intergovernmental Panel on Climate Change (IPCC) guidelines. In particular, 40 CFR 600.113-78 gives a carbon content value of 2,421 grams (g) of carbon per gallon of gasoline, which produces 8,877 g of CO_2. (The carbon content is multiplied by the ratio of the molecular weight of CO_2 to the molecular weight of carbon: 44/12). This number is

then multiplied by an oxidation factor of 0.99, which assumes that 1 percent of the carbon remains un-oxidized. This produces a value of 8,788 g or 8.8 kg (19.4 lbs) of CO_2.
--- Adapted from
(nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1001YU0.txt)
(Note: Paste URL into web browser for best results.)

The EPA has provided estimates of the average fuel efficiencies and these have been estimated for cars and light trucks in the annual *EPA Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2010*. [27] Combining these estimates, metrics were generated to evaluate the effects of TOD.

Metrics used in this report

For the purposes of this report we will primarily utilize the following metrics:

(1) Percent utilization of modes
(2) Percent use of private autos
(3) Percent use of car pooling
(4) Percent use of public transportation
(5) Percent use of transit buses
(6) Percent use of light rail
(7) Percent use of BRT
(8) Percent use of walking
(9) Percent use of bicycling

And the amount of CO_2 emissions that are emitted associated with these transportation choices.

Data Sources. Gathering data to combine in the formulas was perhaps one of the most difficult aspects. For the U.S., we were able to consult the TOD database.[28] This data base provides statistics on the number of persons living in or around the various TOD locations and their average commute etc. These general numbers were used to determine the impact of the TOD on the environmental metrics of interest in the study. In order to determine the best sources of data and the impact on the environmental metrics used recommendations from several different sources were followed. Data for other locations was in some cases provided by local experts or estimated for our purposes.

[27] http://www.epa.gov/oms/fetrends.htm
[28] http://toddata.cnt.org/

Calculation of Various Metrics

CO_2 Reductions

In order to quantify one of the environmental benefits of transit-oriented development or TOD, estimated CO_2 reductions were estimated from the annual work commutes of persons living in 5 different .5 mile TOD zones.

To obtain the estimated CO2 reductions, the average CO2 emission factors were calculated for passenger vehicles and the various modes of transportation provided in the TOD zones. According to the U.S Environmental Protection Agency (EPA) the average emission factor for a passenger vehicle can be produced by two important parameters provided by the EPA:[29]

- Average carbon content value of 8.9 kg CO_2 per gallon of gasoline
- Average fuel economy of about 21 mpg for a passenger vehicle[30]

Using these values, an average emissions factor of a passenger vehicle is given as 0.43 kg CO_2 /passenger-mile:

$$(8.9\text{kg}CO_2/\text{gal}) \times ((1/21)\text{gal/mi}) = .43 \text{ kg } CO_2 \text{ per mile}$$

It should be noted that this emissions factor is represented as passenger-mile, which assumes a passenger vehicle occupancy of 1 person, which is supported by transportation census data in the United States.[31]

One of the characteristics of transit oriented development locations is the availability of alternative low emission modes of transportation such as buses and light rail systems while also encouraging the use of bicycles and walking. The CO_2 emissions resulting from these modes of transportation can be estimated as well. The average CO_2 emission for a passenger bus and a light rail system were calculated by the Federal Transit Administration in 2009. The average kg CO_2 produced per passenger-mile for a bus is estimated at 0.30 kg CO_2/passenger-mile, while a light rail averages 0.19 kg CO_2/passenger-mile.[32]

With limited data concerning modal share, bus and LRT emission factors were averaged to represent the use of public transportation as a means of travel to work. The average of the bus and LRT emission factors gives 0.24 kg CO_2 per passenger-mile. Commuting by bicycle and walking constitute zero CO_2 emissions. The relationships of the various emission factors are shown below in Figure 6.

[29] http://www.epa.gov/oms/climate/documents/420f11041.pdf
[30] http://www.epa.gov/oms/climate/documents/420f11041.pdf)
[31] http://www.fhwa.dot.gov/planning/census_issues/ctpp/data_products/journey_to_work/executive.cfm
[32] http://www.fta.dot.gov/documents/PublicTransportationsRoleInRespondingToClimateChange.pdf

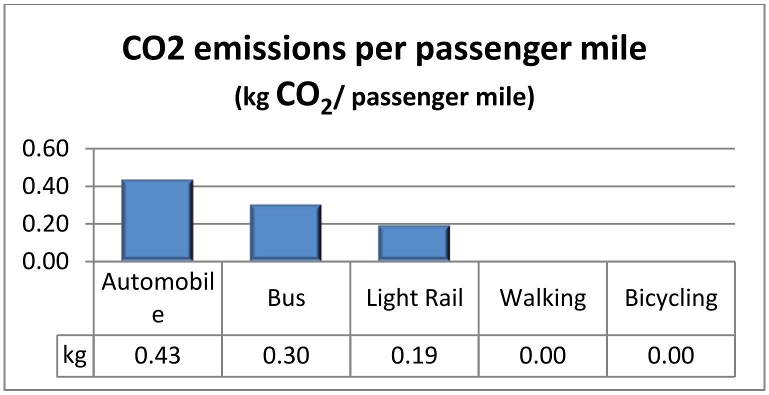

Figure 6. CO_2 Emissions per mode of transportation.[33]

To further quantify the impact of TOD on the environment, we estimated the number of persons who use the different modes of transportation in each TOD zone. Consulting the TOD database made available by the Center For Transit-Oriented Development[34], provided zone specific populations of persons utilizing these various types of transportation to commute to work. When population data and modal share data could not be found from the TOD database, other resources were referred to.

The average commute distances to work are provided below.

- **Motor Vehicle/Public Transportation**
  15 miles, according to Bureau of labor Statistics (2003)[35]
- **Bicycle**
  2 miles, according to non-motorized evaluation study (2007)[36]
- **Walking**
  0.5 miles,

With estimated population numbers of various transportation modes, the above emission factors, average commute distances by transportation method, and a baseline of 520 commutes per year {(2trips/day) x (5 days/week) x (52 weeks /year)}, the following formulas were produced to represent CO_2 emission reductions in each TOD zone.

[33] EPA (2012). "Greenhouse gas emissions from a typical passenger vehicle. EPA Office of Transportation and Air Quality. Report # EPA-420-f-11-041 (December, 2011). http://www.epa.gov/oms/climate/documents/420f11041.pdf
[34] http://toddata.cnt.org/
[35] http://www.bts.gov/publications/omnistats/volume_03_issue_04/html/entire.html
[36] http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=1588

CO_2 emission Savings for Bus/LRT Commuting

CO_2 emission Savings for Bus Commuting

Total annual CO_2 savings$_{mode}$ = [CO2 savings$_{mode}$] x [Number of trips$_{mode}$]

<u>CO_2 savings$_{bus}$</u> = [(Average trip distance $_{bus)}$ x (0.048 gallons/mile) x (8.9 kg CO_2/gal) x (# of people)] - [(Average trip distance$_{bus}$) x (0.30 kg CO_2/passenger-mile) x (# of passengers)]

<u>Number of trips$_{mode}$</u> = Based on a commute to work example:
[(2 trips/day) x (5 days/week) x (52 weeks/year)]

CO_2 emission Savings for LRT Commuting

Total annual CO2 savings$_{LRT}$ = [CO_2 savings$_{mode}$] x [Number of trips$_{mode}$]

<u>CO_2 savings$_{LRT}$</u> = [(Average trip distance $_{LRT)}$ x (0.048 gallons/mile) x (8.9 kg CO_2/gal) x (# of people)] - [(Average trip distance$_{LRT}$) x (0.19 kg CO_2/passenger-mile) x (# of passengers)]

<u>Number of trips$_{mode}$</u> = Based on a commute to work example:
(2 trips/day) x (5 days/week) x (52 weeks/year)

CO_2 emission Savings for averaged modal share for Bus and LRT Commuting

Total annual CO_2 savings$_{bus/LRT}$ = [CO_2 savings$_{mode}$] x [Number of trips$_{mode}$]

<u>CO_2 savings$_{mode}$</u> = [(Average trip distance $_{passenger\ vehicle)}$ x (0.048 gallons/mile) x (8.9 kg CO_2/gal) x (# of people)] - [(Average trip distance$_{bus/LRT}$) x (0.24 kg CO_2/passenger-mile) x (# of passengers)]

<u>Number of trips$_{mode}$</u> = Based on a commute to work example:
[(2 trips/day) x (5 days/week) x (52 weeks/year)]

CO_2 emission Savings For Walking and Bicycle Commuting

Total annual CO_2 $savings_{mode}$ = [CO_2 $savings_{mode}$] x [Number of $trips_{mode}$] x [Number of $people_{mode}$]

CO_2 $savings_{mode}$ = (Average trip $distance_{mode}$) x (0.048 gallons/mile) x (8.9kg CO_2/gal) x (# of $people_{mode}$)
Number of $trips_{mode}$ = Based on a commute to work example:
[(2 trips/day) x (5 days/week) x (52 weeks/year)]

Calculations for Estimating Congestion Reduction

To estimate the reduction in congestion that would occur as a result of changes in ridership or other activities the methodology adopted by the Texas Transportation Institute was utilized. Using the methodology outlined in the report "Intercity passenger rail: Implications for Urban, Regional, and National Mobility." Prepared by UTCM (Sperry & Morgan, 2011)[37].

In the following cases studies, vehicle miles traveled "VMT" were calculated to represent traffic congestion reductions on adjacent roadways.

Assuming:

- VMT data only accounts for estimated commutes to work with a distance of 15 miles, 2 miles and .5 mile.
- Reduction of VMT does not represent reductions of VMT on specific roadways or highways and only represents "adjacent" roadways/highways to the TOD station.
- Comparison only takes into account passenger car vehicle miles traveled and miles traveled from Bus/LRT were not included in the analysis to keep data consistent between case studies.
- The other important number that needs to be determined is the usage of the LRT/BRT, walking or bicycling. In some cases the data available for these locations is not as readily available as we would like to see. Thus, these data are at times estimated from the various databases that were available.

Calculations for Estimating Fuel Savings

- Average carbon content value of 8.9 kg CO_2 per gallon of gasoline

(xx kg CO_2) / (8.9 kg CO_2 / gallon) = (xx gallons)

[37] Sperry, B., & Morgan, C.A. (2011). Intercity Passenger Rail: Implicaitons for Urban, Regional, and National Mobility. University Transportation Center for Mobility (UCTM), Texas Transportation Institute. DOT Grant No. DTRT06-G-0044

Selection of Sites

The majority of the sites selected for analysis were included in the TOD Database maintained by the Center for Transit-Oriented Development. Additional sites were selected based on recommendations included in the original statement of work from APEC. The National TOD Database is a project of the Center for Transit-Oriented Development. Intended as a tool for planners, developers, government officials, and academics, the Database provides economic and demographic information for every existing and proposed fixed guideway transit station in the U.S.

The TOD Database consists of **4,416 existing stations** and **1,583 proposed stations** in **54 US metropolitan areas**, as of December 2011. Data are available for the transit zone which is normally a .25 to .50 mile radius of the station. The database includes data on **nearly 70,000 variables** that are accumulated from several other U.S. based data sets including the 2000 and 2010 Decennial Census, the 2009 American Community Survey, the 2000 Census Transportation Planning Package, and the 2002 - 2009 Local Employment Dynamics.

Additional sites were considered which had been referenced in previous APEC reports. For example, an Asian Development Bank report on GHG mitigation efforts in China referenced Hefei, the capital of Anhui Province, in the Peoples Republic of China. At the end of 2008, Hefei had a total of 4.87 million inhabitants, with around 2 million living in the urban center. According to the report, transit ridership has increased from 700,000 in 2003 to around 1.8 million in 2010. In addition, the number of individually owned automobiles has grown by 200-300 per day. BRT was introduced in Hefei in 2009, and three lines currently are operating with projections for seven additional BRT lines by 2020.

The Hefei case study bye the ADB focused on assessing the feasibility of developing standardized baselines (SBLs) for BRT projects. This case study employed the Activity-Structure-Intensity-Fuel (ASIF) model (Schipper et al., 2000)[38] as an analytical framework to assess which indicators influencing emissions from BRT projects are suitable for standardization. Essentially, the case study was performed using theoretical modeling data as a lead up to considering the introduction of BRT approaches. Results of the analysis were inconclusive due to the fact that, "BRT baselines largely depend on modal structure, which differs from city to city, making baselines not easily comparable across projects. In the end, no single benchmark can be developed for BRT interventions, since baseline emissions depend on many different indicators that cannot be easily aggregated into one unit." (page 75).[39] Thus Hefe was not selected as a case study site.

Similarly, Seoul, Korea, was discussed at the recent CEEDS Workshop in Singapore in Jan 2012, Rakwatin, Watanabe, & Yonemura (2012)[40] discussed the current TOD policies in Seoul, Korea.

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[38] Schipper, L., Marie-Lilliu, M., Gorham, R. (2000). *Flexing the Link between Transport Greenhouse Gas Emissions: A Path for the World Bank*. International Energy Agency, Paris, June. http://www.iea.org/textbase/nppd/free/2000/flex2000pdf

[39] Ibid.

[40] http://esci-ksp.org/wp/wp-content/uploads/2012/05/TOD-in-Seoul.pdf

Following the recent increase in the population of the suburbs of Seoul, there have been five new developments and an increase of both ownership of private automobiles and traffic congestion. As a result, the city planners have placed an increasing emphasis on the use of the bus system and the subway rail system. However, development around the rail stations is relatively limited. Instead, redevelopment efforts have been focus on the construction of buildings that will have both commercial and residential uses. The presenters called for the development of a long range plan or vision to address these issues. Additional improvements and enhancement of the transportation system including the development of additional pedestrian and bicycle friendly environments were encouraged. However, with the exception of the bicycle road and bicycle friendly environment, there do not appear to be any specific TOD projects that were outlined in the report to provided to CEEDS (2009)[41]. Consequently, Seoul was not selected as a case study site.

Site Selection Summary

In general, many cities and sites were reviewed, however, they were found to be unusable due to lack of data, lack of a transit oriented development policy or program, or lack of availability. Sites were selected for study if there was a definite policy of transit oriented development in place that could easily be obtained. The recommended sites from the RFP were examined. In short, we attempted to obtain a representative sample that was available for analysis given the research and investigative tools that were available.

Case Studies

In order to evaluate the direct impact of TOD on energy use and transportation ten different sites, two in New Zealand, four in the U.S. and one in Chinese Taipei were selected for evaluation. The criteria for selecting the sites was that 1) data be publicly available and accessible 2) the sites be predominantly mixed use urban settings 3) the site represent a different APEC economy 4) the sites have some documentation as to the plan for TOD in the surrounding area. These sites were either obtained from the TOD data base, or were mentioned in the APEC study on transportation, and provided the necessary data to perform calculations needed to asses.

Case #1 - Auckland, NZ – New Lynn TOD

The New Lynn area is the name assigned to the area just outside of Auckland NZ that is being developed with transit in mind. Based on information reported in the "Future Growth Opportunities – Urban Design Report Auckland CBD Rail Link Business Case"[42] regional planners estimate that this project has the potential to increase population to about 20,000.

[41] Kim (2009). http://esci-ksp.org/wp/wp-content/uploads/2012/05/Policy-Directions-of-Seoul.pdf
[42] http://www.aucklandtransport.govt.nz/improving-transport/city-rail-link/Documents/crl-developments-around-stations-appendix-H.pdf

New Lynn is located in Waitakere City and has been identified as a suitable TOD location. New Lynn has been classified as an existing residential/mixed use area and a future sub regional center (which is defined to accommodate 60 dwellings/ha and 300 employees/ha)[43].

The Auckland City Council is transforming New Lynn into a new cosmopolitan and metropolitan center. The New Lynn Urban Plan maps out the council's vision for the center, and acts as the master plan providing clear steps towards achieving that vision. The urban plan says New Lynn will, by 2030, be a sustainable urban center with a large transit interchange capable of serving a 20,000 residents and 14,000 workers. The completion of New Lynn's new transport interchange in September 2010 - the economy's largest-ever public transport infrastructure investment - was the first step in the area's long-awaited regeneration project.[44]

Local Board Chairman Derek Battersby says New Lynn's redevelopment is a triumph for the local community.

> "The difference these projects are making and will make to New Lynn is remarkable and we are well on our way to being able to cater for the significant population increase projected for this area in the next 50 years. We can look forward to living in a modern, vibrant and pedestrian-friendly town center with strong and consistent design, a mix of living, working and civic spaces and a growing economy."[45]

Excerpts from the New Lynn Urban Plan[46] reveal the vision and the strategic initiatives that will be taken to create the new development area. The plan is being implemented with the 2030 goals of:

- New Lynn will be a showcase of an integrated approach to delivering a TOD and urban regeneration and be a model for other projects throughout New Zealand
- The transit interchange will handle thousands of daily commuters
- 4,000 new homes will have been built showcasing a sustainable residential neighborhood
- The town center will be a high density employment hub with a mixed-used retail area and a shopping center
- Ten open spaces will be within a five minute walk of the transit interchange
- Pedestrian and cycle friendly
- A new transit connection will have been created
- Edge of town center sites will be redeveloped at higher densities

43 http://www.aucklandtransport.govt.nz/improving-transport/city-rail-link/Documents/crl-developments-around-stations-appendix-H.pdf

44

45 www.aucklandcouncil.govt.nz/EN/PLANSPOLICIESPROJECTS/COUNCILPROJECTS/Pages/newlynntransformation.aspx

46 http://www.aucklandcouncil.govt.nz/EN/planspoliciesprojects/CouncilProjects/Documents/newlynnurbanplan2010part1.pdf

- The traditional employment base will be moved towards higher value postindustrial activities
- Social infrastructure will include a new school, and a range of community facilities, housing, services and networks
- New Lynn will have a thriving evening economy, the place to see and be seen
- Clark Street extension and Veronica Street / Portage Road will relieve the town center of through traffic enabling a pedestrian focused environment in Totara Avenue West and Great North Road
- New buildings will be built to the highest environmental standards, moving towards carbon neutrality

Based on 2006 census data, the area subject to the New Lynn TOD (approximately 160 hectares) currently has a residential population of 1,941 persons (approximately 618 households)[47]. Our evaluation of the energy saving aspects of the new Lynn TOD project are based on the existing census data being compared. So, assuming 1,941 persons/ 618 households = ~3 people per home and estimating 2 people work, that gives a worker population of 1,236.

Assumptions

- 10 % of population commute by public transportation
- 5 % of population commute by walking
- 2 % of population commute by bicycle

The above percentages are estimates and reflect ridership percentages estimated from similar geographic regions like Denver, CO. Actual population percentages by modes of transportation could be higher or lower than the above numbers. A recent study by Stone (2011) found that the average use of public transport for the city was about 7% and about 5.6% use walking or bicycling. The following tables then estimate the advantage of TOD for the New Lynn TOD area as compared to the general city. Using the estimates from above, we can calculate the number of persons and trips that would be taken by the existing residents in the New Lynn TOD. With these estimates, we would expect that there is a 5% reduction in GHG obtained by living in the New Lynn TOD. If the population increases to the 20,000 projected in the planning report, we would expect to see similar significant reductions in GHG.

Based on these calculations, the combined 17 percent of the residents who live in this area utilizing low emission modes of transportation to commute to work would collectively reduce CO_2 emissions by 46 percent compared to the same number of people commuting by passenger vehicle.

[47] http://www.aucklandtransport.govt.nz/improving-transport/city-rail-link/Documents/crl-developments-around-stations-appendix-H.pdf

Looking at the overall reductions in CO_2 resulting annually we would expect to see the following results.

Table 2. GHG Reductions from New Lynn NZ TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**Kg CO_2 Emitted Annually**	**Mode**	**Kg CO_2 Emitted Annually**	**% CO_2 Reduction**
1025	PCE	3,415,464	PCE	3,415,464	**0%**
124	PT	232,128	PCE	413,188	**43.82%**
25	Bicycle	0	PCE	11,107	**0%**
62	Walking	0	PCE	6,886	**0%**
Total TOD		**232,128**		**199,054**	**46.16%**
Total Annual		**3,647,592**		**3,846,645**	**5.17%**

Note: PCE= Passenger Vehicle; PT = Public Transportation.

With a total of 199,054 kg CO_2 savings a year from worker commutes, TOD allows the population in the .8 km radius zone to reduce CO_2 emissions by a little over 5 percent per year. That is 3,981,060 kg CO_2 savings over next 20 years.

In addition, this 5.17% reduction in CO_2 is equivalent to a reduction in fuel usage of 22,366 gallons of gasoline or 1,177 barrels of crude oil.

Effects on Congestion – New Lynn

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

Table 3. VMT in the New Lynn NZ TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
1025	PCE	7,995,000	PCE	7,995,000	**0%**
124	PT	0	PCE	967,200	**100%**
25	Bicycle	0	PCE	26,000	**100%**
62	Walking	0	PCE	16,120	**100%**
Total Annual		7,995,000		**9,004,320**	**11.2%**

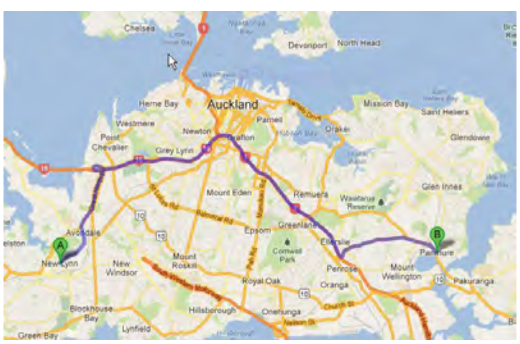
Note: PCE= Passenger Vehicle; PT = Public Transportation.

Results of these analyses clearly indicate that there is a significant reduction in VMT as a result of the TOD Zone. In fact, we can further estimate that the 11.2% reduction in VMT would likely translate into a reduction of 80,105 trips annually.

Case #2 – Auckland, NZ - Panmure Station TOD – Typology "mixed use"

Figure 7. Panmure Railway Station, Auckland, New Zealand.

Panmure Railway Station is on the Eastern Line of the Auckland railway network in New Zealand. Panmure Station is set to receive a major upgrade within the next decade in order to become a major bus-rail interchange, as part of the AMETI project.[48]



Source: maps.google.com

Source: Auckland Trasnport[49]

Figure 8. Location of Panmure Railway Station location and traffic flow.

The Auckland Manukau Eastern Transport Initiative (AMETI) is a group of transport projects for the eastern suburbs of the city. The aim is to give people living in the area transport choices by improving public transport, walking and cycling facilities, and reducing traffic congestion. Other major aims are to unlock the economic potential of the area and to promote good urban design. Severe congestion in the area is holding back the huge potential for economic growth in the area – there are a number of sites that could be key redevelopment sites if transport links are

[48] http://en.wikipedia.org/wiki/Panmure_Railway_Station
[49] http://www.aucklandtransport.govt.nz/improving-transport/ameti/Pages/AMETI-transport-strategy.aspx

improved. This means there is the potential for a large number of new jobs in the area. According to 2006 census data, the area's population remains relatively low at just over 1000 persons or approximately 350 dwellings.[50] Assuming 1000 persons / 350 dwellings = ~3 people per dwelling and estimating 2 people work that gives a worker population of 700. The population is expected to grow by 20,000 – 25,000 over the next 20 years, further increasing the pressure on the transport system.[51] However, the overall strategy[52] for the area is to:

- Give people better transport choices
- Get more people onto public transport to free up roads for freight and business traffic
- Focus road improvements on unlocking key congestion points like the Panmure town centre and the Ti Rakau Drive/Reeves Road/South Eastern highway intersection

Additionally, the hope is that these improvements will significantly affect the quality of life around the station by:

- Increasing travel options
- Increasing connectivity between communities and businesses
- Improving and reducing travel times
- Providing safety improvements including more and safe pedestrian crossings
- Offering new bicycle facilities and walkways
- Offering increased public transport services and options (e.g. a new busway)

Trains on the Eastern Line are operated by Veolia under the Maxx brand. They will soon be replaced by the AT brand, as Auckland Transport has decided to replace the Maxx brand.[9] During the day on weekdays, Panmure is served by 6 trains an hour. Three of these travel north to Britomart, two travel south to Papakura, and one of travels to Manukau. Additional services run during peak hours. The journey time from Panmure to Britomart is approximately 16 minutes.[10]

More projects which are part of AMETI are due to occur in and around Panmure Station. Among these is a major upgrade of the station and the building of new bus stops. A new building will be built over the platforms, facing Ellerslie-Panmure Highway, from where lifts and stairs will provide access to the platforms. A new bridge will be built over the railway, just north of the current Ellerslie-Panmure Highway bridge. New bus stops will be built on the bridge, which will eventually be used by the Southeastern Busway. Additionally, new bus stops for local buses will be built on a new road, which will be above and adjacent to the platforms. A new road will also run adjacent to the platforms, in a tunnel below the local bus stops. After AMETI is complete,

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50 http://www.aucklandtransport.govt.nz/improving-transport/city-rail-link/Documents/crl-developments-around-stations-appendix-H.pdf

51 http://www.aucklandtransport.govt.nz/improving-transport/current-projects/01IntegratedTravel/Pages/AMETI-Panmure.aspx

52 http://www.aucklandtransport.govt.nz/improving-transport/ameti/Pages/AMETI-transport-strategy.aspx

Panmure will become a major bus-rail interchange. Many local bus routes, and bus routes from the Southeastern Busway will terminate here, with passengers transfering onto either trains or other buses. Applying the identical assumption of estimated percent ridership as that used for the New Lynn case study, we expect to see the following results.

Based on our assumptions and calculations (Table 4), the effects of the change in use of public transportation, walking and bicycling for the Panmure TOD area results in a decrease of 46.15% of CO_2 emissions.

Table 4. GHG Reductions from Panmure TOD.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reduction**
581	PCE	1935985	PCE	1935985	0.00%
70	Bus/LRT Average	131040	PCE	233251	43.82%
14	Bicycle	0	PCE	6220	100.00%
35	Walking	0	PCE	3888	100.00%
	Total TOD	**131040**		**243359**	**46.15%**
Total Annual TOD		**2067025**		**2179344**	5.15%

Note: PCE= Passenger Car Equivalent.

Additionally, over the course of a year it would be expected that for the entire TOD area, the decrease of CO_2 due to the utilization of public transportation, walking and bicycling would be expected to reduce CO_2 emissions by nearly 5%.

In addition, this 5.15% reduction in CO_2 is equivalent to a reduction in fuel usage of 12,620 gallons of gasoline or 664 barrels of crude oil.

Effects on Congestion – Panmare Station, Auckland, NZ

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD. Additionally, the number of trips can be estimated using the NHTS Database which suggests that the average length of trip per vehicle is approximately 12.6 miles.[53] Therefore, for this data set, assuming that the average trip length is relatively similar in NZ, at about 12.6 miles per vehicle trip to work, that we would see an 11.2% reduction in trips or in the number of 45,211 trips over the course of a year.

[53] http://www1.eere.energy.gov/vehiclesandfuels/facts/2010_fotw615.html

Table 5. VMT Reductions as a result of Panmure TOD.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
581	PCE	4,531,800	PCE	4,531,800	0%
70	PT	0	PCE	546,000	100%
14	Bicycle	0	PCE	14,560	100%
35	Walking	0	PCE	9,100	100%
Total Annual		**4,531,800**		**5,101,460**	**11.2%**

Note: PCE= Passenger Car Equivalent; PT = Public Transportation.

Case #3 - Denver - Alameda Station TOD Zone – Typology - "Mixed use urban"

The Denver RTD web site describes the Alameda station as being located on the Central Light Rail Corridor. The station is situated west of Broadway at Alameda Ave. Alameda is an urban center station allowing residential, commercial, and retail uses with a small park-n-ride facility. It is designed to serve the immediate surrounding neighborhoods that offer charming quality housing, neighborhood parks, schools, and small business districts. The addition of the station adds significant value to these areas. There is tremendous opportunity for new development and the area is seeing increased interest in making Alameda Station a robust transit oriented development. To guide this redevelopment a Station Area Plan was created.

The Denver RTD TOD program utilizes Station Area/Urban Center Planning grants to assist local governments in developing plans for existing and future transit station areas and designated Urban Centers that further the region's goals and meet the needs of local communities. Seven cities that are part of the regional Mayors Caucus pooled their Private Activity Bond authority to finance the construction or rehabilitation of multifamily rental projects near existing or planned transit. Projects that meet criteria related to size, affordability and transit accessibility gain access to lower debt financing costs and to Low Income Housing Tax Credits.

The transit oriented development for the Alameda Station is outlined in the Denver Design District General Development Plan (GDP) (2008)[54] and includes the approximately 80 acres adjacent to the Alameda Light Rail Station. This project is designed to transform the previously industrial and commercial auto-oriented site into a high quality transit-oriented development that re-establishes the urban fabric of the neighborhood. The plan includes strategies for improving access in the station area for pedestrians, bikes, cars and buses through significant extensions of the street grid as well as creating mixed land use choices and densities. The GDP also provides for several million square feet of commercial (office, retail and hotel), residential and educational development.

[54] http://www.denvergov.org/Planning/HowWePlan/GeneralDevelopmentPlans/tabid/431850/default.aspx

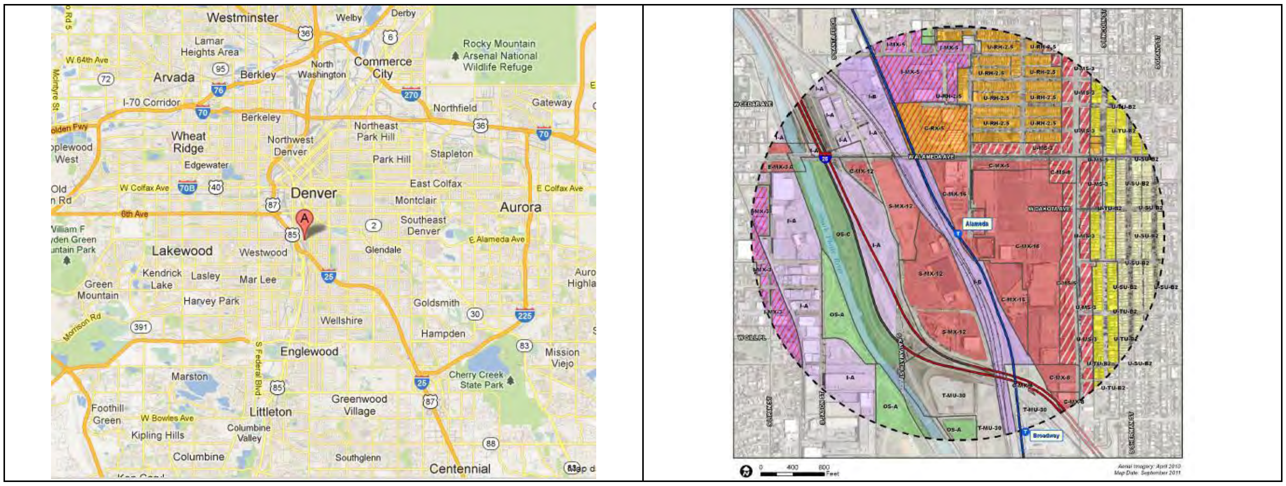


Figure 9. Location of Alameda Station Denver.

Source. http://www.denvergov.org/Portals/193/documents/Station%20Area%20Profiles/Alameda_Stats.pdf

Based on the data obtained from the TOD data base, 21% of people living in the Alameda TOD zone currently commute by public transportation, bicycle or walking[55].

In the Alameda Station TOD approximately 14 percent of the residents utilize low emission modes of transportation to commute to work. Taken together these individuals have collectively reduced CO_2 emissions by 47 percent compared to the same number of people who would be commuting only by passenger vehicle. If we consider the extent to which the entire area affects the region, generally over the course of the year we can see that the TOD currently has a small but substantial impact on the GHG emissions annually.

Table 6. GHG Reductions from from Alameda Station TOD.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**CO_2 GHG Savings from TOD**
1381	PCE	4,565,191	PCE	4,565,191	0%
150	PT	280,800	PCE	503,100	44%
40	Bicycle	0	PCE	17,888	100%
109	Walking	0	PCE	12,186	100%
Total		**280,800**		**533,174**	**47%**
Total		**4,845,991**		**5,098,365**	**4.95%**

Note: PCE= Passenger Car Equivalent; PT = Public Transportation.

55 http://toddata.cnt.org/

Examining the total CO_2 savings for a year of commuting we find that the presence of the Alameda Station TOD results in a savings of 252,374 kg of CO_2 emissions compared to a similar sample of residents not using public transportation. Thus, TOD allows the population in the .5 mile radius zone to reduce CO_2 emissions by almost 5 percent per year.

In addition, this 4.95% reduction in CO_2 is equivalent to a reduction in fuel usage of 27966 gallons of gasoline or 1472 barrels of crude oil.

Effects on Congestion – Alameda Station

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

Table 7. VMT Reductions as a result of Alameda Station - TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
1381	PCE	10,771,800	PCE	10,771,800	**0%**
150	PT	0	PCE	1,170,000	**100%**
40	Bicycle	0	PCE	41,600	**100%**
109	Walking	0	PCE	28,340	**100%**
Total Annual		10,771,800		**12,011,740**	**10.32%**

Note: PCE= Passenger Car Equivalent; PT = Public Transportation.

These calculations show that on the average there would be a 10.3% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 98,408 trips annually.

Case #4 – Denver - Louisiana-Pearl Station - Typology - "urban neighborhood"

Located at I-25 and E Louisiana Ave, 755 East Louisiana Avenue Denver, CO

The Denver RTD website describes The Louisiana-Pearl light rail station on the Southeast Light Rail Corridor near I-25 and Louisiana Ave as an urban neighborhood "walk-and-ride" station with no commuter parking. It is designed to serve the immediate neighborhoods of Platt Park, West Washington Park and Washington Park. These surrounding neighborhoods offer quality housing, neighborhood parks, schools, and small business districts.

Significant portions of the station area have been rezoned enhancing neighborhood livability to reduce automobile dependence and support transit.

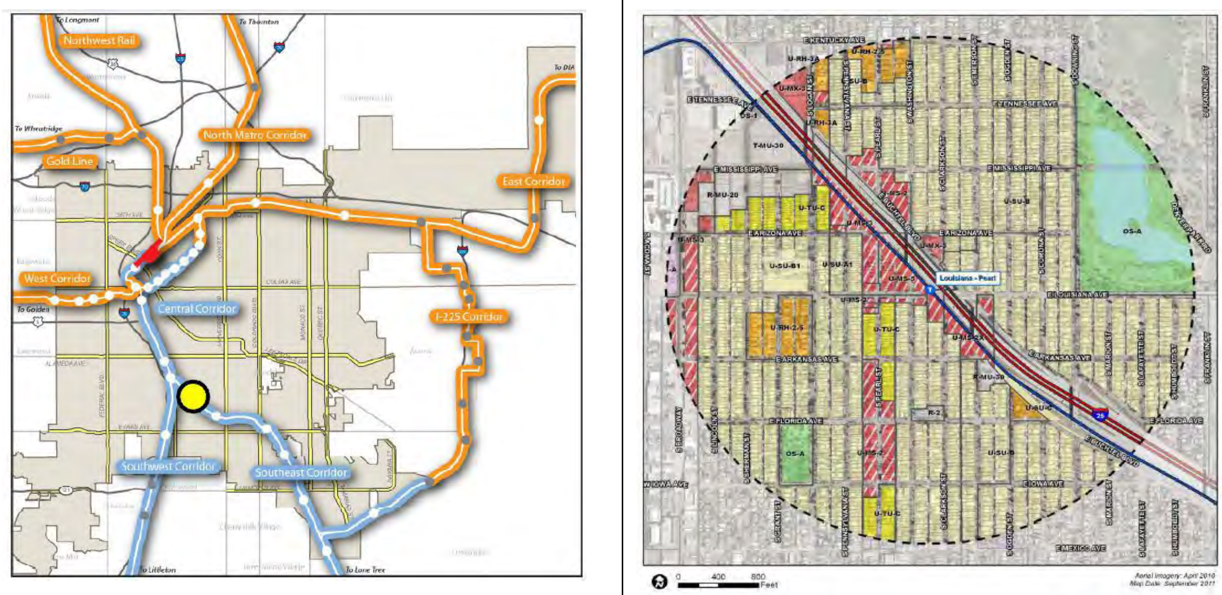


Figure 10. Location of Louisiana-Pearl Station Denver.
Source.. http://www.denvergov.org/tod/TransitCorridors/SoutheastCorridor/LouisianaPearlStation/tabid/441680/Default.aspx

The Louisiana-Pearl Station TOD area plan[56] is based on the city of Denver's Transit Oriented Development Strategic Plan of 2006.[57] These plans include detailed station area plans that outline specific directions for appropriate development, needed infrastructure investments and economic development strategies.

The Louisiana-Pearl Station is a 'walk-up' light rail transit station with easy pedestrian access and designated passenger drop-off and pick-up areas. It is embedded in a stable neighborhood that offers primarily single family housing. Consistent with the principles of the Urban Neighborhood TOD Typology, near the platform there is a vibrant mix of housing options, shopping, dining, employment and public gathering areas. Specific descriptions of the station area follow:

- Station Platform Area: The immediate station platform area is inviting and comfortable. The transit plaza draws riders to the station while providing a neighborhood gathering space made attractive with landscaping, art and appropriate lighting.
- Access: Multiple transportation choices will continue, providing access and opportunities for travel by foot, bicycle, light rail, bus or car. There is special

[56] http://www.denvergov.org/Portals/646/documents/Louisiana_Station_Area_Plan.pdf
[57] http://ctod.org/pdfs/2006TODStrategicPlanDenver.pdf

emphasis and enhancement to pedestrian-friendly and convenient access to the light rail station. Parking supplies balance business and resident needs.

- Mobility: Sidewalks provide easy access to and from the station by foot. Bike routes offer safe routes to the station and bicycle facilities provide convenient storage. Streetscape improvements create a pleasant environment.
- Reinvestment: Mixed uses and buildings respect the scale and character of the neighborhood with the greatest concentration of reinvestment occurring at Louisiana Avenue and Buchtel Boulevard South. Development provides pedestrian friendly, ground-floor uses offering goods and services to residents, workers, transit riders and visitors. There are new and diverse housing opportunities and employment for residents to live close to work, services and transit.
- Design: Building design is contextual and respects the character of the surrounding older, established neighborhoods in building orientation, massing, scale and quality of materials. Dominant front entries promote pedestrian access and connections at the street. There is an increase in sustainable design practices in accordance with Greenprint Denver.
- Housing: The stable, neighborhoods of Platt Park and West Washington Park will maintain their predominantly single family housing, tree-lined streets, sidewalks, and front yards and engaged entries. Housing reinvestment will maintain the unique neighborhood character, the long-standing tradition of high quality construction and materials and support goals of environmentally responsible design.

The detailed plan outlines and identifies specific recommended actions in the areas of land use, urban design, mobility, and parking.[58]

According to the TOD database 14% of people living in the Louisiana-Pearl TOD zone commute by public transportation, bicycle or walking[59]. Using our assumptions noted above, the estimated reduction in GHG due to utilization of public transportation, walking and bicycling versus single occupancy vehicles is approximately 48%. In other words, if the persons estimated to live in the existing TOD used traditional single occupancy vehicles for their commute to work we could expect that the current arrangement would result in an increase of almost 52% in carbon emissions.

Table 8. GHG Reductions from Louisiana-Pearl TOD area.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reductions**
2449	PCE	8,095,694	PCE	8,095,694	0%
152	PT	284,544	PCE	509,808	44.19%
62	Bicycle	0	PCE	27,726	0%
121	Walking	0	PCE	13,528	0%
Total		**284,544**		**551,062**	**48.36%**
Total Annual		**8,380,238**		**8,646,756**	**3.08%**

Note: PCE= Passenger Car Equivalent; PT = Public Transportation.

[58] http://www.denvergov.org/Portals/646/documents/Louisiana_Station_Area_Plan.pdf
[59] http://toddata.cnt.org/

Similarly, as can be seen in the table above, taking into account the entire TOD zone it is estimated that the over a one year time period that the TOD allows the population in the .5 mile radius zone, to reduce CO_2 emissions by 3 percent per year.

In addition, this 3.08% reduction in CO_2 is equivalent to a reduction in fuel usage of 29,543 gallons of gasoline or 1,555 barrels of crude oil.

Effects on Congestion – Louisiana and Pearl Station, Denver

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

Table 9. VMT Reductions as a result of Louisiana and Pearl Station - TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
2449	PCE	19,102,200	PCE	19,102,200	**0%**
152	PT	0	PCE	1,185,600	**100%**
62	Bicycle	0	PCE	64,480	**100%**
121	Walking	0	PCE	31,460	**100%**
Total Annual		19,102,200		**20,383,740**	**6.3%**

Note: PCE= Passenger Car Equivalent; PT = Public Transportation.

These calculations show that on the average there would be a 6.3% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 98,408 trips annually.

Case #5 - Seattle, WA - South Lake Union Station – Typology - "mixed use urban"

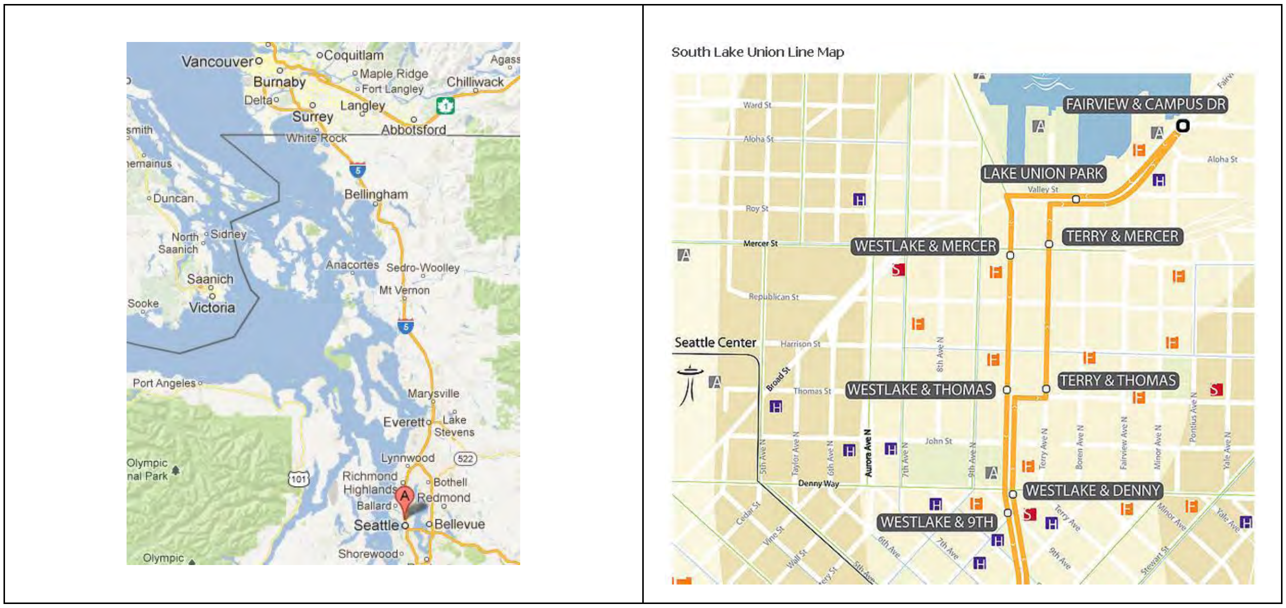


Figure 11. Location of South Lake Station Seattle.
Source: http://www.seattlestreetcar.org/slu.htm#map

According to the Seattle Transit Plan the South Lake Union (SLU) area was designated as a Mixed Use Centers (MUC)[60] which is representative of "complete neighborhoods that have the highest levels of transit connectivity to other neighborhoods with reliable, frequent service." The area is populated with office buildings, hotels, and residential towers, and with retail shops along the sidewalk. Transportation needs are served by commuter rail, light rail, streetcars, bus rapid transit, express bus and other bus services. In addition, the MUC would be characterized by shared public spaces that would include large public plazas, semi-public plazas at the base of tall buildings, and smaller pocket parks. Street walls act to define the sidewalk and street space. Paid public parking is found on most surface streets and off-street in garages. Parking maximums ensure that new buildings add to an environment that prioritizes people over automobiles

At a recent public hearing the city council laid out several key considerations for the South Lake Union (SLU) zone. The SLU area has itself been assigned a Comprehensive Plan that is designed to encourage more development and significant increases in employment and housing. The 2004 Comprehensive Plan update set twenty-year growth targets for South Lake Union at 8,000 households and 12,000 jobs, about 17% of citywide household and 19% of citywide employment growth. [61]

[60] South Lake Union Plan.
[61] http://conlin.seattle.gov/2012/11/08/south-lake-union-rezone-public-hearing/

By 2020, South Lake Union will be home to 20,000 new jobs and 10,000 new housing units. Already South Lake Union has exceeded the 1994 Comprehensive Plan growth target for jobs in this neighborhood. To prepare for this new influx of growth and to fix existing conditions like the Mercer "mess", the Seattle Department of Transportation conducted the South Lake Union Transportation Study. The study coordinates analysis and recommendations identified through the South Lake Union Neighborhood Plan, the Alaskan Way Viaduct and Seawall Project, the Mercer Corridor Project and other recent planning efforts.

The Terry Avenue North Street Design Guidelines[62] define a master-plan concept of the street so that expected incremental development will be coordinated and the permit process clear. The Guidelines lay out a concept for the street, and identify street geometrics and a palette of materials. The intent is to provide consistency where needed, but to also allow flexibility for designers within the palette of materials, since part of the street's character results from the mix of materials and uses over time.

The second imperative of the design guidelines are to ensure that traffic volumes and speeds stay low over time so that Terry Avenue North can function as a pedestrian oriented street. In a counter-intuitive manner to typical street design, traffic devices are meant to reduce and slow traffic.

To evaluate the effectiveness of the SLU TOD in reducing emissions and GHG, calculations were performed based on the estimates of population, use of public transport, walking and bicycling available from the TOD database. Approximately, 49% of workers in the South Lake Union Streetcar & Terry Ave N area use Public transportation, bicycles or walk[63].

Given these estimates, based on these calculations, the 49 percent of TOD residents utilizing low emission modes of transportation to commute to work have collectively reduced their CO_2 emissions by almost 47 percent compared to the same number of people commuting by a passenger vehicle.

Table 10. GHG Reductions from SLU Terry Ave TOD area.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reductions**
1790	PCE	5,964,566.4	PCE	5,964,566.4	0%
742	PT	1,389,024	PCE	2,472,462.7	43.82%
114	Bicycle	0	PCE	50,648.83	
845	Walking	0	PCE	93,855.84	
Total		1,389,024		2,616,967.4	**46.92%**
Total		7,353,590.4		8,581,533.77	14.31%

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

[62] http://www.seattle.gov/dpd/cms/groups/pan/@pan/@plan/@proj/documents/web_informational/dpds017395.pdf
[63] http://toddata.cnt.org/

Taken together, over the course of one year, a total reduction of 14% or 1,227,943.37 kg CO_2 would be obtained by the residents in the .5 mile radius TOD around the SLU Terry Avenue Station.

In addition, this 14.31% reduction in CO_2 is equivalent to a reduction in fuel usage of 137,971 gallons of gasoline or 7,262 barrels of crude oil.

Effects on Congestion – Seattle, WA - South Lake Union Station

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

Table 11. VMT Reductions as a result of South Lake Station - TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
1790	PCE	13,962,000	PCE	13,962,000	0%
742	PT	0	PCE	5,787,600	100%
114	Bicycle	0	PCE	118,560	100%
845	Walking	0	PCE	219,700	100%
Total Annual		13,962,000		20,087,860	**30.5%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

These calculations show that on the average there would be a 30.5% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 486,179 trips annually.

Case #6 – Seattle, WA - Beacon Hill Station – Typology - "mixed-use neighborhood"

The North Beacon Hill Neighborhood Plan describes "a well-defined urban village anchored by a new library and commercial/retail core accessed by efficient, pedestrian friendly public transportation."[64] In support of this vision, the Beacon Hill light rail station will be located in the heart of the North Beacon Hill business district that includes local businesses in a well-established residential neighborhood. The development of the light rail station and the surrounding area will strengthen the existing business district, create opportunities for new homes, and add open space and public art to the neighborhood. The station entrances are envisioned as "signature buildings' that will reflect Beacon Hill's community pride and cultural and ethnic diversity.

The results of surveys provided by the TOD Database indicate that approximately 46% of workers in the Beacon Hill TOD zone use Public transportation, bicycles or walk.[65] Given these estimates, based on these calculations, the 46% of residents utilizing low emission modes of transportation to commute to work have collectively reduced their CO_2 emissions by 45% compared to the same number of people commuting by passenger vehicle.

Table 12. GHG Reductions from Beacon Hill TOD area.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reduction**
2194	PCE	7310759	PCE	7310759	0
1465	Bus/LRT	2742480	PCE	4881614	43.82%
247	Bicycle	0	PCE	109739	100.00%
190	Walking	0	PCE	21104	100.00%
TOD Total		**2742480**		**5012457**	**45.29%**
TOD Zone Total		**10053239**		**12323216**	**18.42%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

Taken together, over the course of one year, a total reduction of 18.42% or 2,269,977 kg CO_2 would be obtained by the residents in the .5 mile radius TOD around the Beacon Hill Station.

In addition, this 18.42% reduction in CO_2 is equivalent to a reduction in fuel usage of 255,054 gallons of gasoline or 13,424 barrels of crude oil.

Effects on Congestion – Seattle, WA – Beacon Hill Station

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

[64] http://www.seattle.gov/transportation/ppmp_sap_neigh.htm#beacon
[65] http://toddata.cnt.org/

Table 13. VMT Reductions from Seattle, Beacon Hill Station TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
2194	PCE	17,113,200	PCE	17,113,200	**0%**
1465	PT	0	PCE	11,427,000	**100%**
247	Bicycle	0	PCE	256,880	**100%**
190	Walking	0	PCE	49,400	**100%**
Total Annual		**17,113,200**		**28,846,480**	**40.7%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

These calculations show that on the average there would be a 40.67% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 931,213 trips annually.

Case #7 - Taipei City, Chinese Taipei - Xinbeitou – Typology - "urban residential"

The Taipei Metro **Xinbeitou Station** is the terminal station on the Xinbeitou Branch Line located in the Beitou District, Chinese Taipei. The location of the station used to be the terminal station for the now-defunct TRA Xinbeitou Line.[66]

The location of the station is in a residential section of the city that has experienced continuous growth and development for over 100 years. Xinbeitou had the highest ranking of public facilities in the area. Land use in the Xinbeitou station area is designated as mixed residential and commercial and has been densely developed as a residential and recreational area for 100 years because of its hot springs resources.[67]

66 http://en.wikipedia.org/wiki/Xinbeitou_Station

67 Lin, J., & Jen, Y. (2009). Household attributes in a transit-oriented development. Journal of Public Transportation, vol 12, no 2,

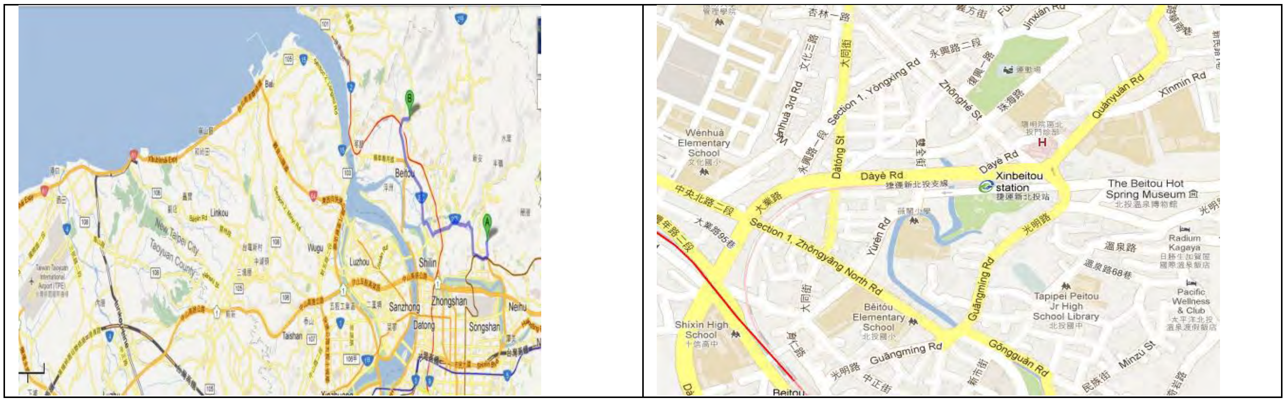


Figure 12. Location of Xinbeitou Station Chinese Taipei

The area is just outside the central city also called the Beitou District, and is the northernmost of the twelve districts of Taipei City, Chinese Taipei. The historical spelling of the district is Peitou. The name originates from the Ketagalan word Kipatauw, meaning witch. Beitou has two faces. Old Beitou is the area where the local people have lived and worked for over a century and is located around the Beitou MRT Station and Beitou Market, while Xin Beitou (New Beitou) is the area around the Xin Beitou MRT Station and Qinshui Park that was developed as a hot spring resort during the Japanese era (1895-1945). The area is served by the rail line and several bus routes. In addition there are several schools, hospitals, hotels, and a university nearby. Not a commercial center but rather a mixed use residential area, it is fairly densely populated. Xinbeitou has, visible from the MRT station, McDonald's, KFC, Starbucks, the local Mosburger, a sushi bar, and various Chinese Taipei eateries.[68]


Figure 13. Xinbeitou Station Satellite View.

Population data for the Xinbeitou TOD zone was not readily available. In order to estimate the population of the TOD, the population density was taken from research by Jen-Jia Lin and Ya-Chun Jen (2009), which gave a population density of 0.0246 people per m. The TOD station area was defined as the area within about 400 meters of the metro station[69] Using the population density and an average area of 502,400 m^2, the Xinbeitou TOD population was estimated to be around 12,359 persons.

Furthermore, due to lack of information, percentages of the population who utilize the metro, bike or walk to work had to be estimated. Travel mode share percentages were based off of the Analysis of Chinese Taipei transport modes and showed 46% of people traveled by private transport, 32% by mass transit, 15 % by walking, 4% by bicycle and 3% by other means[70]. It should be noted these estimates could differ from actual numbers around the Xinbeitou station as TOD can influence patronage of public transportation and increase the ease of bicycle use and convenience of walking.

[68] http://wikitravel.org/en/Taipei/Beitou
[69] http://www.nctr.usf.edu/jpt/pdf/JPT12-2Lin.pdf
[70] http://ltaacademy.gov.sg/doc/J11Nov-p60PassengerTransportModeSHares.pdf

According to the report *An Application of Social Force Approach for Motorcycle Dynamics*, private car ownership is near equal to motorcycle ownership in Chinese Taipei. [71] Due to the heavy use of motorcycles in the Chinese Taipei region, CO_2 emissions of motorcycles were included in this case study. According to the EPA, the average emissions factor of a common motorcycle is 0.352 kg CO_2 per mile. [72] For simplicity, emission factors for passenger vehicles and motorcycles were averaged at 0.39 kg CO2 per mile.

Results of the analysis of the population and ridership data reveal that the overall effect of the development area is that approximately 51% of the workers in the Xinbeitou TOD zone use public transportation, bicycles or walk. Given these estimates and based on these calculations, the 65% of TOD zone residents utilizing low emission modes of transportation to commute to work have collectively reduced their CO_2 emissions by slightly over 52% compared to the same number of people commuting by passenger vehicle.

Table 14. GHG Reductions from the Xinbeitou area.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reduction**
6056	PCE	18422352	PCE	18422352	0
3955	LRT/Bus	5861310	PCE	12031110	51.28%
494	Bicycle	0	PCE	200366	100.00%
1854	Walking	0	PCE	187996	100.00%
	TOD	5861310		12419472	52.81%
51%	**Total Annual**	**24283662**		**30841824**	**21.26%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

Taken together, over the course of one year, a total reduction of 21.26% or 6,558,162 kg CO_2 would be obtained by the residents in the immediate TOD around the Xinbeitou Station.

In addition, this 21.26% reduction in CO_2 is equivalent to a reduction in fuel usage of 736,872 gallons of gasoline or 38,783 barrels of crude oil.

Effects on Congestion – Xinbeitou, Chinese Taipei, Station TOD

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public

[71] http://www.ide.titech.ac.jp/~hanaoka/100333.pdf
[72] http://www.epa.gov/oms/models/ngm/420p04016.pdf

transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

Table 15. VMT Reductions from – Xinbeitou TOD zone.

With TOD			Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
6056	PCE	47,236,800	PCE	47,236,800	0%
3955	PT	0	PCE	30,849,000	100%
494	Bicycle	0	PCE	513,760	100%
1854	Walking	0	PCE	482,040	100%
Total Annual		**47,236,800**		**78,085,800**	**39.5**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

These calculations show that on the average there would be a 39.51% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 2,448,333 trips annually.

Case #8 – Shanghai China - Typology—"central urban"

Shanghai was not initially selected for analysis even though it is one of the most developed cities in Asia with respect to transit. Recent reports indicate that there are twelve different metro rail lines and 292 stations, with an operating route length of 437 kilometers (272 mi),http://en.wikipedia.org/wiki/Shanghai_Metro - cite_note-Shanghai-Daily-6 making the system the third longest in the world. The Shanghai Metro delivered 2.269 billion rides in 2012, making it the fifth busiest metro system in the world. It set a daily ridership record of 8.486 million on March 9, 2013. According to the latest report, by the end of 2020 the network will comprise 22 lines spanning 877 kilometers (545 mi). [73] However, despite the focus on the development of transit in Shanghai, there does not appear to be a clear goal or program for development adjacent to, or in conjunction with station development. But, because densities are so high, the lack of transit-oriented development may not matter much as there is in fact lots of transit near new development in the city.

Public transportation in Shanghai is developing. The most recent "Five Year Plan" published by the Shanghai city government identifies the "trend" of urban planning geared towards integration of transport.

> "The layout of urban space: space for urban development will achieve strategic expansion, to build a the polycentric spatial pattern with

[73] http://www.exploreshanghai.com/metro/pedia/

international influence and competitiveness, rational development and integration of the layout of the central city, to promote the comprehensive construction of suburbs, at different levels, classification, orderly fashion new towns, guide the formation of the coverage of the city domain, the integration of urban and rural urban space body. With the construction of a new suburban town, Pudong strategy to promote the Hongqiao business district development, subsequent use of the Expo site, the construction of large residential communities as well as the Shanghai Railway East Station, Disney and other major infrastructure project floor layout of urban space will occur significant adjustments.[74]"

Figure 14. Shanghai Metro System.

Shanghai city planners are actively connecting transit with the Hongqiao International Airport, 10 miles west of downtown. Abutting the passenger terminal is a rail station with 30 tracks for high-speed trains; two (soon to be three) subway lines to downtown, one of which continues to Pudong International Airport; four expressways; acres of taxis; and a planned extension of the Maglev from Pudong. However, it is unclear whether the surrounding fields will be developed with a transit orientation.[75]

The recent Shanghai Census estimates the population of Shanghai to be 23,019,200, of which 12.21 million live in the urban areas. Shanghai's population accounts for 1.1% of the Chinese population, with the average density of 2059 inhabitants per square kilometers (3854 in the urban areas). [76] From these facts, similar to our estimated calculations for the other transit oriented development areas of the world, we can assume that there is a population of roughly 12,101 in the one kilometer radius, or transit oriented development zone, around a metro station. Interestingly, recent reveals that the for central urban area, in 2012, the proportion of the

[74] http://www.shanghai.gov.cn/shanghai/node2314/node25307/node25455/node25459/u21ai639121.html
[75] http://www.spur.org/publications/library/article/learning-world-class-transit-system
[76] http://www.shanghaihighlights.com/essential/#Population

population using public transportation was about 49.9%. In addition, approximately 42.% of the central urban population can reach metro stations by walking about half a mile, in about 10 minutes. Furthermore, we have also learned that 20.9% of the central urban area use cars, 20.5% of the central urban population use motorcycles, 25.7% of central urban population uses walking or bicycling, and 33.0% use the subway. The estimates in reduction of GHG for the transit oriented area 1 kilometer in diameter around a typical central urban metro station would be about 43.8%.

Table 16. GHG Reductions from Central Urban Shanghai.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reduction**
5010.04	PC/MC	15,240,460	PC/MC	15,240,460	0
4489.68	Bus/LRT	8,404,680	PC/MC	13,655,666	38.45%
n/a	Bicycle	0	PC/MC	n/a	n/a
3110.10	Walking	0	PC/MC	315,604	100%
	TOD Total	8,404,680		13,971,271	39.84%
Total Annual		**23,645,222**		**29,213,512**	**19.95%**

Note: PC/MC = Passenger Care Equivalent/ Motorcycle.

Based on these calculations the combined 59% percent of residents living in a 1 km radius area of a station who walk or use public transportation to commute to work would collectively reduce CO_2 emissions by 39.84 percent compared to the same number of people commuting by passenger vehicle. In addition, this 19.06% reduction in CO_2 is equivalent to a reduction in fuel usage of 625,459 gallons of gasoline or 32,918 barrels of crude oil.

Table 17. VMT Reductions from - Shanghai TOD zone.

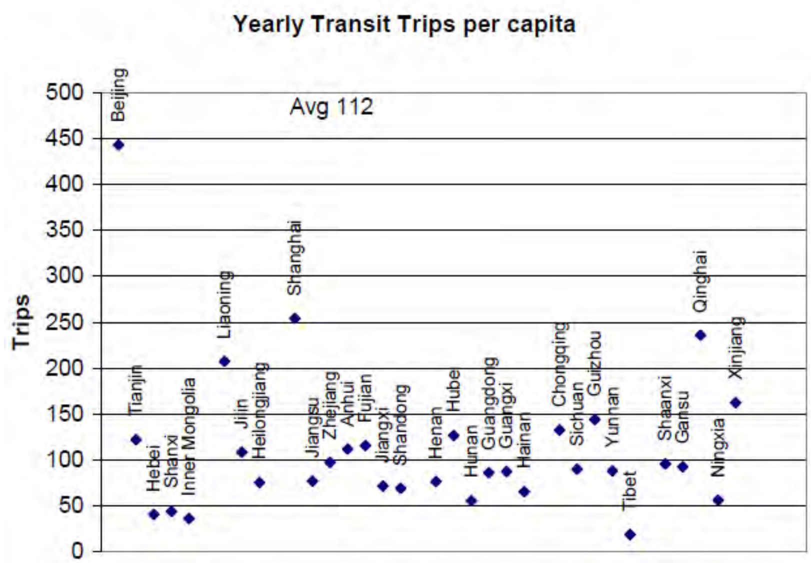
	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
5010	PCE	39,078,000	PCE	39,078,000	0%
4490	PT	0	PCE	35,022,000	100%
n/a	Bicycle	n/a	PCE	n/a	n/a
3110.10	Walking	0	PCE	808,600	100%
Total Annual		**39,078,000**		**74,908,600**	**48%**

Note: PCE = Passenger Car Equivalent.; PT= Public Transportation

These calculations show that on the average there would be a 47.83% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 2,843,698 trips annually.

Case #9 – Beijing, China - Typology—“urban residential”

According to Chen (2010)[77] the concepts associated with transit oriented development are widely endorsed by Chinese city planners. Initiated in 1985 Beijing’s integrated road transport system development program was directed at “substituting [for] private travel”. In doing so, it adopted a two-pronged strategy: (i) building mass transit and (ii) creating disincentives to car use. Intra-city public transport and rail transport appear to be the primary modal strategies for reducing car use. In addition, increased parking fees were instituted in eight central areas of the city.[78] In 1995, China established an urban public transportation policy that focused on investing in bus and urban rail projects.[79] The total number of transit trips per capita for cities in different regions is displayed in Figure 15. As expected, cities with well-developed public transportation systems, such as Beijing and Shanghai have high transit use. The central government has approved the development of metro systems in the 15 cities with populations



[80]

Figure 15. Transit Trips per Various Cities in China. From Cherry (2005).

greater than three million. (Zhang, W.B. 2003)[81]. The Beijing government decided to focus on developing a public transport plan for the new century and launched a detailed project with a

[77] Chen, Xueming. "Prospect of transit-oriented development in China." *Management Research and Practice,* vol 2, no. 1, pages 83-93.
[78] http://esci-ksp.org/?project=transit-oriented-development-in-beijing
[79] Cherry, C. (2005). China’s Urban Transportation System: Issues and Policies Facin Cities. Working Paper UCB-ITS-VWP-2005-4. http://www.its.berkeley.edu/publications/UCB/2005/VWP/UCB-ITS-VWP-2005-4.pdf
[80] Cherry, (2005). China's Urban Transportation System: Issues andPolicies Facing Cities. UC Berkley Center for Urban Transport. WORKING PAPERUCB-ITS-VWP-2005-4
[81] Zhang, W.B. (2003) “Desk Scan: China Transportation Systems”, Scoping Study for aJoint FHWA/AASHTO Scanning Mission to China. AASHTO, FHWA.

focus on the Mass Rapid Transit System (MRTS). The program relied on integration with public bus service, subway and light railway. The plan was developed in 1998 with the main objective of creating an efficient transport system in time to host the 2008 Olympics.[82] According to Chen (2010), TOD in China should be different because of its already high density urban settings. Implementing TOD around rail stations is likely to be a first step. However, he also recommends that Chinese municipalities consider the Transit-Oriented Corridor (TOC), which is the "pearl necklace-like" linear land development chaining of all nodal TODs together. The ultimate level of TOD development is perhaps the Transit-Oriented Metropolis (TOM). A TOM consists of multiple interconnected TOCs throughout the metropolitan area.[83] At this point there are few examples of TOD policies in Beijing that can be identified. Nevertheless, some estimates of the effect of the existing transit system on GHG, congestion and fuel consumption are possible.

Based on the analysis conducted, the population of Beijing is estimated to be 20,693,000 or upwards of 20 million in 2012. Further, it is estimated that about 340,000 reside in a 1 mile radius, which can use to estimate as a transit oriented development area. The results of surveys indicate that 340,000 people in a 1 mile radius area of a station, in addition, about 18.46% use cars , 5.78% use bus , 46.54% use metro , and the remaining 29.22% of residents use other modes of transportation such as bicycling and walking.

“On Friday March 8, 201, the Beijing subway daily passenger volume of the whole network for the first time exceeded 10 million people, reaching 10.276 million passengers, a new record. Among the total of 16 lines now running in the city, line 10 handles the most passengers. The subway transportation company plans to add 17 pairs of trains to thisline and red uce departure intervals from the current 2.5 minutes to 2 minutes tofacilitate traffic flow.”[84]

[82] http://esci-ksp.org/?project=beijing-mass-rapid-transit-system&task_id=650
[83] Chen, Xueming. "Prospect of transit-oriented development in China." *Management Research and Practice,* vol 2, no. 1, pages 83-93.
[84] http://english.peopledaily.com.cn/90882/8165739.html

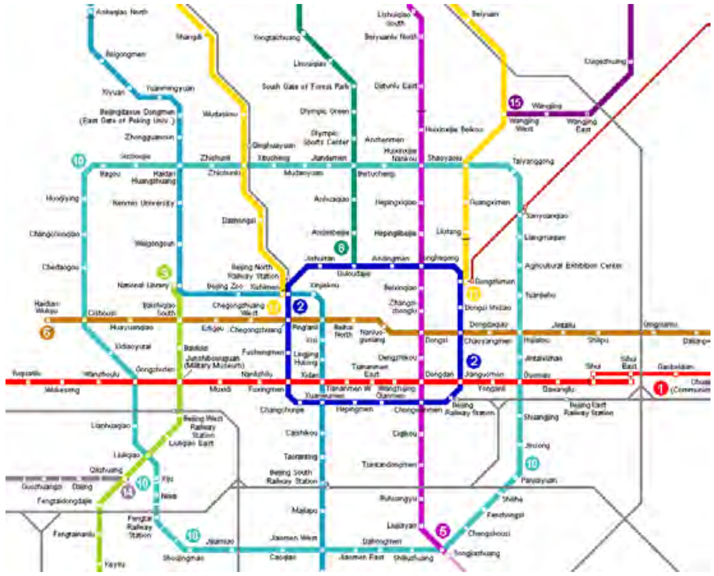


Figure 16. Map of Beijing Subway System.

Consequently, the present analysis of the likely GHG emissions that are occurring is offered.

Table 18. GHG Reductions from from - Beijing TOD zone.

	With TOD		Without TOD	
Riders	**Mode**	**Kg CO_2 emitted**	**Kg CO_2 emitted**	**% CO_2 Reduction**
62764	Car	209139690	209139690	0.00%
19652	Bus	45985680	65483608	29.78%
158236	Metro	15633717	35151178	55.52%
99348	Biking/Walking	0	0	0.00%
	Total TOD	61,619,397	100,634,786	38.77%
	Total Annual	**270,759,087**	**309,774,477**	**12.59%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

Taken together, over the course of one year, a total reduction of 12.59% or 39,015,390 kg CO_2 would be obtained by the residents in the 1.0 mile radius TOD around the average Beijing Metro Station.

In addition, this 18.42% reduction in CO_2 is equivalent to a reduction in fuel usage of 4,383,751 gallons of gasoline or 230,723 barrels of crude oil.

Effects on Congestion – Beijing

In addition to reducing GHG the effects of living in this area and utilizing public transportation or walking and bicycling, the effect on traffic congestion can also be estimated. Using the TTI approach for estimating the reduction in congestion we previously outlined, it is apparent that as a result of the TOD construction, and the increase in the use of walking, bicycling and public transportation, that there is a significant reduction in VMT, and by extension, in traffic congestion as a result of the impact of TOD.

Table 19. VMT Reductions from Beijing TOD zone.

		WITH TOD		Without TOD	
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
62764	PCE	489559200	PCE	489559200	0
19652	Bus	0	Bus	153285600	100
158236	Metro	0	Metro	1234240800	100
99348	Bike	0	Bike	25830480	100
Total Annual		**489559200**		**1902916080**	**74%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

These calculations show that on the average there would be a 74.27% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 112,171,181 trips annually.

Case #10 – Jakarta, Indonesia - Typology—"urban residential"

The ADB study[85] also looked at Jakarta, Indonesia to examine the effects of how transport demand management (TDM) might contribute to the reduction of transport emissions. Three elements of TDM were examined: electronic road pricing (ERP), parking restraint and BRT, all of which were included in the Jakarta Transport Master Plan. Results of the desktop analysis indicated that the combined TDM policies could lead to a reduction of transport demand (in the Capital Region of Jakarta) of approximately 4-5%--but up to 40% when just focusing on the central business district (CBD), where ERP would be targeted. CO_2 reductions (estimated from changes in fuel consumption) were expected to be between 20-30%. These emission reductions would translate into approximately 4-7% saving of the entire city's carbon profile, relative to the baseline in both 2010 and 2020. (Huizinga, page 60-61). However, no transit oriented development policies were examined. In fact, in a press release dated June 15, 2011 the Jakarta City Government announced a joint public private partnership study with Siemens and Deutsche Gesellschaft fur Zammenarbeit (GIZ) (German Society for International Cooperation) to provide strategic advice on development priorities for the capital city of Indonesia. The project benchmarked Jakarta against world-class cities to identify directions to develop Jakarta into "a sustainable world-class, transit-oriented metropolis."[86]

[85] Huizenga, C. & Baker, S. (2010). *Climate Instruments for the Transport Sector: Considerations for the Post 2012 Climate Regime*. Published by Asian Development Bank and Inter-American Development Bank.
[86] http://www.siemens.asia/ID/Libraries/Press_Attachment/Siemens_Press_Release_Jakarta_21_Symposium_2011_06_15.sflb.ashx

Grossly, Central Jakarta runs about 15-20,000 persons/sq-km. So looking at a 1km station radius, would mean 50-60k individuals. About 70% of that number makes most sense because the main streets are lined with large buildings, and the density often starts 100-200m away from the station.

The density comes from very tightly packed low-rise (mostly 2-story) single and multi-family dwellings on small lanes which were the original villages ('kampung') that Jakarta swallowed. These are difficult for cars to navigate, so the main motorized mode is small (125cc) motorcycles.

Ridership at a single station for the BRT (there is no 'metro' in Jakarta at the moment) ranges up to about 2500/hr at the terminal stations. An active station on the line might see about 500/hour. These are peak hour estimates, which covers about 6-hours of the day. So, that might result in 5000 to 6000 riders/day out of a pool of 40,000 residents. Two emissions scenarios one focusing on passenger vehicle use and the other on motorcycle use. This was done based on the information received from John Ernst on the relative use of motorcycles over passenger vehicles. According to the EPA, the average emissions factor of a common motorcycle is 0.352 kg CO_2 per mile and 14% of population use BRT.

Table 20. GHG Reductions from from Jakarta, Indonesia TOD zone.

	With TOD		Without TOD		
Riders	**Mode**	**Kg CO_2 emitted**	**Mode**	**Kg CO_2 emitted**	**% CO_2 Reduction**
34500	PCE	114959520	PCE	94723200	0
5500	Bus	12870000	PCE	15100800	15%
n/a	Bicycle	0	PCE	n/a	
n/a	Walking	0	PCE	n/a	
	TOD Total	12870000		15100800	29.7%
	Total Annual	127829520		133286400	**4%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

Based on these calculations the combined 14 percent of residents living in a 1 km radius area of a BRT station to commute to work would collectively reduce CO_2 emissions by 29 percent compared to the same number of people commuting by passenger vehicle.

Table 21. VMT Reductions from Jakarta, Indonesia TOD zone.

	With TOD		Without TOD		
Number of People	**Mode**	**VMT annually**	**Mode**	**VMT Annually**	**% VMT Reductions**
34500	PCE	269,100,000	PCE	269,100,000	0%

5500	PT	0	PCE	42,900,000	100%
n/a	Bicycle	n/a	PCE	n/a	n/a
n/a	Walking	n/a	PCE	n/a	n/a
Total Annual		269,100,000		**312,000,000**	**13.8%**

Note: PCE = Passenger Car Equivalent; PT = Public Transportation

These calculations show that on the average there would be a 13.8% reduction in VMT which would have a similar reduction in traffic congestion. Using the NHTS averages then, we would expect a reduction of nearly 2,843,698 trips annually.

Comparative Analyses

Table 22. Comparisons of GHG Reductions in various TOD Zones.

Location	% Not Using Autos	Kg CO_2 Savings	% CO_2 Annual Reduction
Xinbeitou, Chinese Taipei	52%	6,558,162.00	21.26%
Shanghai, China	39%	13,971,271	19.95%
Beacon Hill Station, WA	46%	2,269,977.22	18.42%
South Lake Station, WA	49%	1,227,943.39	14.31%
Beijing, China	38%	100,634,786	12.59%
New Lynn Station, NZ	17%	199,053.50	5.17%
Panmure Station, NZ	15%	112,318.75	5.15%
Alameda Station, CO	18%	248,902.37	4.85%
Jakarta, Indonesia	29%	133286400	4.00%
Louisiana Station, CO	12%	262,929.89	3.02%
Average	**32%**	**25,877,174.41**	**11%**

Green House Gas Reductions

The results of the analyses summarized in Table 22 indicate GHG reduction benefits ranging from a low of 3.02% around the Louisiana station to a high of 21.26% near Xinbeitou, Chinese Taipei. Taking the percentage of the population of the TOD zone which utilizes public transportation, transit or BRT, bicycling, or walking as a percentage of the total population of the area reveals that the savings are closely related to the use of alternative forms of public transportation. Reasons for the differences in CO_2 reductions also appear to be related to the extent to which the residents of the TOD zone utilize public transportation, walking or bicycling.

Beacon Hill in Seattle and Xinbeitou in Chinese Taipei appear to have the highest percentages of the population that are using public transportation rather than automobiles.

The other factor that seems to be present is the overall density of the population in and around the station. Louisiana and Alameda in Denver have relatively low levels of density with most one or two story and residential structures in the immediate vicinity. Whereas in Seattle, these are older neighborhoods with more densely developed infrastructure, and residential dwellings.

Noting these patterns, it is clear that there is a significant relationship between density, use of public transportation and the overall GHG and CO_2 emissions. These findings are not surprising and are corroborated by the work of others[87] who have argued that "TOD and green urbanism" along with higher densities, improve resource use efficiency". Nevertheless, it is important to recognize that the analyses conducted here document dramatically the positive impact of transit oriented development on the reduction of GHG.

Table 23. Population Density for Case Study Sites.[88]

Location	Population Density (people/acre)
Panmure, NZ	568.3
Alameda Station, CO	934.0
New Lynn, NZ	1,213.3
Denver	1,550.0
Auckland	2,000.0
Louisiana-Pearl Station, CO	2,243.7
Beacon Hill, WA	3,219.7
South Lake Union, WA	3,429.8
Jakarta, Indonesia	10,500.0
Beijing, China	11,500.0
Shanghai, China	13,400.0
Xinbeitou, Chinese Taipei	15,200.0

Traffic Congestion

TOD also has been thought to have a significant effect on the amount of traffic congestion present in urban settings. The data that we have gathered suggests that this too is a substantial effect associated with TOD. As can be seen from Table 24 reduction of VMT ranges across the various locations studied.

[87] http://www.its.berkeley.edu/publications/UCB/2010/VWP/UCB-ITS-VWP-2010-7.pdf
[88] http://www.citymayors.com/statistics/largest-cities-density-125.html

Table 24. Effects of TOD on Traffic Congestion.

Location	Reduciton in Trips	Reduction in VMT
Beijing, China	112,171,181	74.00%
Shanghai, China	2,843,698	47.83%
Beacon Hill Station, WA	931,213	40.67%
Xinbeitou, Chinese Taipei	2,448,333	39.51%
South Lake Station, WA	486,179	30.5%
Jakarta, Indonesia	312,000,000	13.8%
New Lynn Station, NZ	80,105	11.2%
Panmure Station, NZ	45,211	11.2%
Alameda Station, CO	98,408	10.3%
Louisiana Station, Denver	1617757	6.3%
Average	**43,272,208.50**	**29%**

Traffic congestion is also related to the number of trips that are taken. Various estimates of the number of trips taken in various urban settings have been made. Results indicate that over the past decade that the length of trip commute, at least to work, has increased steadily. Thus, the number of trips is an indication of the number of cars that will be on the road. Reducing number of trips and VMT will have a direct effect on congestion. Other factors of course, such as road design, highway connections, density, etc. are also related to congestion. Nevertheless, short of direct observations and more in-depth interviews with members of the population in these regions, these estimates of VMT based on ridership etc., provide the best estimate available of the effects of TOD on VMT. Clearly, there is a direct effect of the presence of TOD on VMT.

Fuel Use and Oil Imports

Table 25. Effects of TOD on Fuel Consumption and Oil Imports.

Location	Reduction in Trips	Reduction in VMT
Beijing, China	4,383,751	230,723
Xinbeitou, Chinese Taipei	736,872	38,783
Shanghai, China	625,459	32,918
Beacon Hill Station, WA	255,054	13,424
South Lake Station, WA	137,971	7,262
Louisiana Station, Denver	29,543	1,555
Alameda Station, CO	27,966	1,472
New Lynn Station, NZ	22,366	1,177
Panmure Station, NZ	12,620	664
Average	43,272,208.50	**29%**

Recommendations

The lessons learned from these analyses clearly indicate that greater degrees of efficiency from the use of TOD on overall GHG emissions can be seen following the greater encouragement of the use of public transportation walking and bicycling. Accordingly, the following recommendations would seem to be in order:

1. Transit oriented development in and of itself appears to have a substantial impact on the reduction of GHG.
2. TOD that encourages the use of walking or bicycling as a means of transportation and or commuting to jobs or employment is likely the most sustainable and efficient and policies that encourage the use of walking or bicycling should be encouraged.
3. Policies that significantly encourage the use of public transportation around TOD also should be strongly encouraged. For example, while it goes without saying that TOD is available, companion policies that encourage the use of public transportation also need to be encouraged. Looking at the analyses and the census data shows that while public transportation is utilized, there is still considerable room in most locations for greater utilization of public transportation and non-motorized transport. These can include incentives to persons living in the immediate area, increasing paring costs in the employment related areas, etc.
4. Policies that encourage the use of more efficient transit are also needed. Simply creating transit and development around a station is not sufficient to reduce the use of private automobiles. The transportation system must be well-integrated and connected in order to ensure that development around stations provides the needed connectivity to ensure high utilization. Otherwise, people will continue to use individualized modes of transport. Transportation needs to be planned so that they provide easy access to the destinations of interest. Transit that doesn’t connect to the key or important areas is less likely to be used.
5. Policies that encourage bicycle use and pedestrian activity around the developed area are needed. The sites that encourage the use of bicycle routes (like in Seoul) and bike sharing programs are more likely to see greater use of non-motorized transportation. Nevertheless, additional incentives should be added, and definitely any barriers will need to be removed.
6. TOD benefits are more likely if motorcycle use is also decreased. The analyses conducted in this report are made primarily by comparing the use of public transportation to the use of automobiles. However, in many APEC regions the populace uses motorcycles as opposed to automobiles. Consequently, in addition to decreasing automobile use incentives and policies should also be put in place which decrease motorcycle use as well.
7. Encouraging dense development as well as the option of multiple modes intersecting in the transit hub seems to encourage high use of public and non-motorized transport.
8. Policies that emphasize pedestrian, cycling, and transit infrastructure over auto-mobility.
9. Stations located in TOD that are intermodal, and offer multiple choices, as well as highly integrated services are more likely to have a higher utilization factor.
10. Zoning laws and regulations around TOD areas that encourage greater density as well as opportunities for employment will likely have more utilization of environmentally sustainable transport.

11. Increasing employment opportunities in close proximity to residential dwellings. Proximity of employment to TOD also encourages and reduces trip frequency and use of private automobiles.
12. There is a need for a global TOD database to permit additional analyses and comparisons to better evaluate the various policies and projects designed to improve sustainable transportation, energy management, and to reduce congestion and GHG.

Translating the recommendations into the ASI framework results in the following:

Table 26. Recommended policies that promoted sustainable TOD.

Avoid	Shift	Improve
"travel with carbon footprint"	"to sustainable low carbon alternatives"	"efficiency of transport with technology & choice"
- zoning that promotes low density development	- TOD	- Use of public transport
- Free parking, drive-through establishments	- Employment opportunities to TOD areas	- non-motorized transport, pedestrian & bicycle friendly
- Single use structures	- Multiuse structures with both commercial and business uses	- Transit interconnectedness
- Warehouse and freight distribution facilities	- Transit choices	- Infrastructure that supports Non-motorized vehicles

Conclusion

The results of the ten case studies show that on the average transit oriented development reduces CO_2 emissions a little over 11% annually. CO_2 emission reductions vary according to population size and density. In addition, policies that encourage the use of non-motorized transport and public transportation are likely to contribute to the reduction in CO_2 emissions associated with transit oriented development. Land use policies would also be very important to encourage more appropriate transit oriented development.

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