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TRANSIT STATION ENERGY IMPACTS

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16. Abstract

Transit trips—when compared with automobile travel—not only relieve congestion, but also offer considerable energy savings per person. Transit trips also affect land use and development patterns that surround a transit station. This report addresses the energy effects of development in transit station areas; that is, development that occurs within a certain radius of a transit station (approximately a quarter-mile) is considered "transit-sensitive" development. This "transit-sensitive" development would, by design and density, encourage trip ends to and from land uses in the transit beltway. Since infrastructure serving high-density development is more efficient than infrastructure serving low-density, typically suburban, land uses, the potential exists to conserve energy that is used in everyday trips (home, work, shopping, etc.). In this report, a methodology will be developed to estimate the energy savings associated with land use changes in the station areas. Since changes in land use and development in a station area are partially dependent on the type of service offered (rail versus bus rapid, for example), a classification system will be developed for different types of transit stations, a system based on the land use and development changes that occur within the station's zone of influence.

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EXECUTIVE SUMMARY

This report addresses the energy impacts of development in transit station areas. Specifically, a model is developed to examine net energy savings for transit stations by mode (rail and bus rapid), station location (central business district, central city, and suburban), type of development (office, commercial, and residential), and number of trips. The model consists of a pre-simulation stage which converts development into fixed input; a simulation stage which estimates net energy savings based on average weekday vehicle trip ends; and a post-simulation stage for importing and aggregating model output. Seven metropolitan areas (6 in the U.S. and 1 in Canada) and 17 station ares are selected for analysis.

The model results indicate that the mode is not a key determinant in energy savings. Mode split, auto versus transit, and the transit load factor are more important. The location of the station is also not significant; high activity nodes occurred in all the areas. Development type also is not significant. The quantity of transit-sensitive development is a more important variable that is unrelated to the type of development. As expected, the volume, or number of trips, is significant. The stations with the largest number of trip ends experienced the highest level of energy savings per passenger.

ABSTRACT

Transit trips—when compared with automobile travel—not only relieve traffic congestion, but also offer considerable energy savings per person. Transit trips also affect land use and development patterns that surround a transit station. This report addresses the energy effects of development in transit station areas; that is, development that occurs within a certain radius of a transit station (approximately a quarter-mile) is considered "transit-sensitive" development. This "transit-sensitive" development would, by design and density, encourage trips ends to and from land uses in the transit beltway. Since infrastructure serving high-density development is more efficient than infrastructure serving low-density, typically suburban, land uses; the potential exists to conserve energy that is used in everyday trips (home, work, shopping, etc.). In this report, a methodology will be developed to estimate the energy savings associated with land use changes in the station areas. Since changes in land use and development in a station area are partially dependent on the type of service offered (rail vs. bus rapid, for example), a classification system will be developed for different types of transit stations, a system based on the land use and development changes that occur within the station's zone of influence.

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CHAPTER 1. INTRODUCTION

BACKGROUND AND OVERVIEW

The growth and decline of transit ridership in the United States is easily traced; it can be mapped by a simple, connect-the-dot review of U.S. history during the twentieth century. From 1900 to 1929, a healthy economy and the development of the street railway or trolley induced rapid growth in the transit industry, until the Great Depression ended the prosperity of the 1920's. The severe economic dislocation and hardship of the Depression caused a sharp decline in ridership, as people made fewer work and pleasure trips. Then as a consequence of December 7, 1941—the attack on Pearl Harbor—the United States entered the Second World War. At the beginning of the war, very ambitious armament production quotas were set by President Roosevelt. There were good wages available in places like Detroit, Chicago, and Houston, and many Americans left their small farms to begin working in the war production factories and shipyards of the cities. Because of gasoline rationing and the migration from farms to cities, more people than ever before used the transit system. In the 1950's, inexpensive gasoline and government policies that encouraged low density suburbs sent the pendulum of transit ridership swinging the other way; that is, ridership decreased rapidly. Since reaching a low point in 1973, the number of citizens using transit has grown modestly [Ref 1].

People who use transit belong to one of two groups: captive riders and choice riders. Captive riders use transit because they have no other option; choice riders, on the other hand, have access to an automobile, but they choose to ride transit because they find it cost effective and time saving. Since the time spent reaching the bus stop or park-and-ride is considered part of transit travel, transit usually cannot compete with the automobile when trips are short. A transit system *can* compete with the automobile when trips are longer (to work, for example); that is, if the service has limited stops (e.g. an express bus). An express bus becomes more competitive when the street or freeway is congested, and the bus has its own guideway (e.g., the transitways in Houston). Commuters are attracted to this service because it is faster, easier, and less expensive than driving their own car. A system with infrequent service and numerous stops would likely claim only a small percentage of the travel in that corridor, since using transit would be slower and costlier than driving. However, a system with frequent service and limited stops (coupled with a congested road network) would garner a greater percentage of the traveling public, since riding the transit system would be quicker and less expensive than driving.

Accessibility is one of many significant factors that contribute to land development: any plot of land designated for an economic purpose must be accessible to both labor and materials in order to develop and to market a product. Given the principle of accessibility, it is not surprising that the central business district (CBD) has emerged as a center of commercial activity or that there is a trend to build dense commercial and retail developments at freeway interchanges, that is, at very accessible suburban locations. Today, public transportation is called on to provide both the CBD and these suburban locations with high quality transit service that will attract automobile users [Ref 2].

This task is certainly not an easy one. Most major transit improvements, by themselves, do not lead to intensified land use in the CBD and in the suburbs; other factors have to act favorably. Regionally, no net economic or urban population growth has occurred as a consequence of these transit improvements; land development impacts, such as economic or urban population growth, are primarily dependent on economic conditions. Moreover, any land development policy changes will have a bearing on transit's influence of land development; conversely, improving a transit system also leads to land development policy changes [Ref 3]. Figure 1.1 shows how transit improvements, policy decisions, and economic conditions influence land development.

There are three major reasons for evaluating land development impacts. (1) Cities that are interested in building transit systems want a return from their transit investment in the form of urban development benefits. Therefore, urban development has to be measured in order to determine its relationship to the proposed transit system. (2) Transit improvements can often be partially supported or partially financed under joint development or value capture techniques. (3) For cities interested in building a quality transit system, land development studies can provide insight into the concerns of community groups that question the long-term effects of transit on their neighborhoods [Ref 2].

This report addresses the energy effects of development in transit station areas. The theory is that development that occurs within a certain radius of the transit station (approximately a quarter mile) would be "transit-sensitive." This "transit-sensitive" development would, by design and density, encourage trip ends to and from land uses in the transit station areas. Because infrastructure serving high-density development is more efficient than infrastructure serving low-density (typically suburban) land uses, the potential exists to conserve energy during everyday trips (home, work, shopping, etc.). In this report, a methodology is developed to estimate the energy savings associated with choice riders switching to transit because of land use changes. Since changes in land use and development in the station area are partially dependent on the type of service offered (rail vs. bus rapid); a classification system, based on the land use and development changes that occur within the station's zone of influence, will be developed to study different types of transit stations.

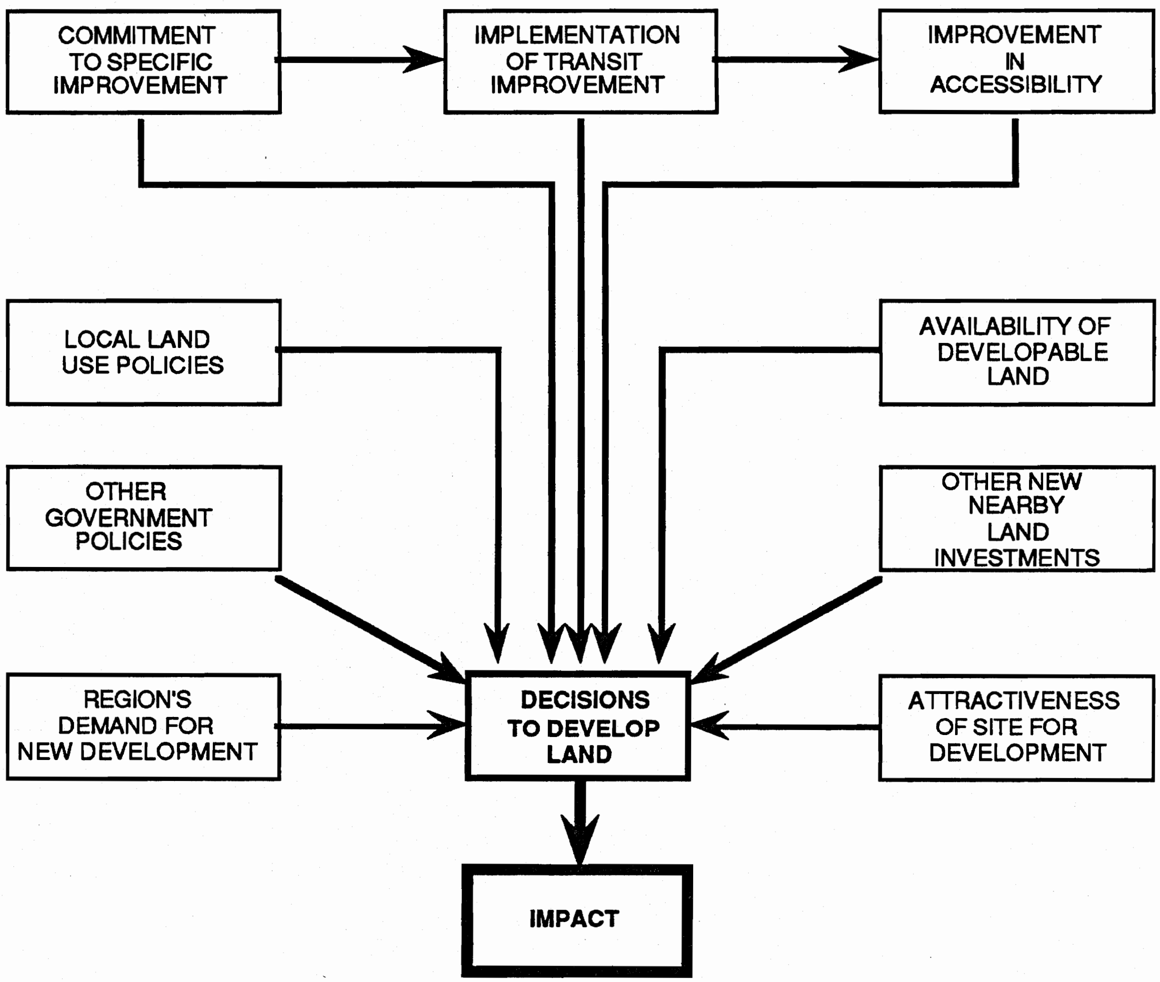

Figure 1.1 A Model for Land Use and Development Impacts

Source: Knight and Trygg, p. 7.

This report is divided into five chapters. The remainder of this chapter contains a literature review of transit, land use, transportation energy, and urban development studies. Chapter 2 includes the study methodology, relevant variables in the model, and a case study selection. Chapters 3 and 4 present case studies of rail and bus transit stations, respectively. Chapter 5 draws comparisons between transit station case studies, presents observations, and gives possible applications and suggestions for further research.

LITERATURE REVIEW

An in-depth literature review was conducted, to identify research pertaining to energy savings resulting from land development in the vicinity of transit stations and related topics. These studies are classified into four broad categories: (1) land use effects of existing transit systems, (2) strategies for assessing and improving land development effects of transit, (3) transportation energy and urban development patterns, and (4) transportation energy effects of existing land uses. The studies in the first two categories examine the relationship between land use and transit, and because of the great number of publications regarding transportation and land use, only transit's relationship to land use is reviewed. The studies in the last two categories explore the relationship between land use and transportation energy. The third group of studies predicts the relationship between transportation energy consumption, intensity of consumption, and urban development patterns. The fourth category contains research that empirically relates transportation energy requirements (consumption and intensity) to development patterns in existing metropolitan areas.

Land Use Impacts of Existing Transit Systems

Several studies examine the relationship between transit systems and land use development around transit stations. Three early (pre-1970's) works are included in this report—transit systems in New York, Boston, and Chicago. Land use impact studies of more recent (post-1970) transit systems are reviewed based on system type, availability, and the thoroughness of the data and methodology. The systems, with one exception, are relatively new (less than twenty years old). Bus rapid, rapid rail, and light rail system studies are examined. The systems are located in cities of different size, history, and geographic location. Two comprehensive studies of several systems are also reviewed.

Spengler [Ref 4] studied the relationship between land values and transit in New York City. Land values were shifted or transferred with the building of the subway system, and high-value, high-density "centers of concentration" began to form around transit facilities. Spengler discovered that obsolete transit lines like "elevated spurs" actually keep land values down. A transit investment can facilitate the "emergence of land values" (i.e., development), but the development is controlled largely by other factors. Finally, the "effects of rapid transit construction cannot be assumed to be uniform, and, therefore, no policy of special assessments can be equitably applied." In other words, value capture techniques are difficult to implement because transit does not influence development uniformly.

Warner [Ref 6] investigated the relationship of the street railway and growth in Boston from 1870 to 1900. He found that streetcar line construction and suburban development were linked; development patterns followed the streetcar lines and increased dramatically when reliable service became available.

Fellman [Ref 6] studied land values and rail transportation in Chicago. Commuter rail (initially intercity) lines influenced subdivision of land, but not sales. Mass transit in Chicago "followed rather than led" land subdivision, although mass transit caused rapid development because of the new level of accessibility.

The Metropolitan Transportation Commission [Ref 7] conducted the Bay Area Rapid Transit (BART) Impact Program. An "after" land use inventory was established by examining aerial and street level photographs of the station areas, land use maps from various local planning offices, and building permits. Three surveys were conducted: a household location survey, a downtown workers' survey, and a retail shoppers' survey. Data collection categories were as follows: 1965 was used as the "before" year, 1975 as the "interim" year, and 1977 as the "after" year. The surveys, covering about a three year period, were conducted in the mid-1970's. During the study period, BART had little influence on land use and development. Only 10 percent of new office development, mostly on San Francisco's Market Street, can be attributed to BART. Access to BART is not a key factor when employers decide on a business location, but it does influence, somewhat, workers' job decisions. BART also had little affect on retailers' location decisions. While BART did not generate much high-density residential development in station areas, it did effectively extend commuting distances. BART's influence on developer decisions is inconsistent, having no permanent influence on property values or rents.

BART is one of many interacting forces that shape land use/land development decisions in the Bay Area. At the study publication date, BART's strongest effect was at the local, or station area, level. BART has influenced redevelopment projects, zoning modifications, and some residential and commercial location decisions. BART has generally not induced development in blighted areas, but may have stabilized decentralization by improving access to the city's center. Land uses were only moderately influenced by BART where demand, community support, and public policy were favorable. Overall, changes in land use occur over the long term, and it will be several years (from 1979) before BART's effect on land use and development can be determined [Ref 8].

The Metropolitan Washington Council of Governments (MWCOG) [Ref 9] has gathered data from 1972 to 1976 on housing activity in station areas, employment trends, retail sales, and regional trends in attempting to assess the market potential for Metrorail. Land use and zoning issues are discussed in detail for eighteen METRO stations, as well as joint development cases. Changes in land use around the studied METRO stations resulted in mixed-use developments, with office space as the primary focus. High-density residential units have not been as common. In fact, suburban communities prefer to develop these office projects, since they are more profitable (in tax terms). Unfortunately, most of the workers that use these offices live outside the station area and prefer to drive to work. Therefore, "such development would be unlikely to generate many additional transit users." This is in contrast to office developments in the CBD, where there is a high level of transit usage by commuters from suburban areas.

Dueker, Pendelton, and Luder [Ref 10] studied a wide variety of effects relating to the Portland Mall, a downtown bus transit mall (not to be confused with the later Banfield light rail transit system). The effects that were examined include the following: traffic, transit ridership, development, land use, and environmental. An economic analysis indicates that the mall's benefits outweigh its costs. The mall specifically influenced land use and development by symbolizing public commitment to downtown Portland, so that the mall became a downtown focal point, creating a "center of gravity," which concentrated new office development in the CBD.

The Atlanta Regional Commission's (ARC) Transit Impact Monitoring Program, an annual effort from 1978 to 1983, was discontinued in 1984 [Ref 11]. Annual data collection focused on residential and commercial activity. Residential data include sales data, rental rates, and building and demolition permits. Commercial activity is measured through land sales, office supply, leasing data, building and demolition permits, and proposals for rezoning [Ref 12]. The methodology revolves around documenting annual changes and includes a land use case study for the Brookhaven station. High density development, both public and private, occurred at or near the CBD and center city station areas. Most of the major development is multi-story and has occurred within 1 to 2 blocks of a station. There are several joint development projects with direct access to stations. Public and private developments completed since 1975 are documented for 14 stations on all 4 lines. An example is Georgia's Twin Towers and the air rights over the Georgia State station. Thus, certain station areas in the CBD and city center experienced, and are continuing to experience, high-density public and private developments. There is some evidence of stabilization and improvement in neighborhoods along the East Line, which extends from the Five Points terminal to the Perimeter Highway (Interstate 285).

The Central Transportation Planning Staff of the Metropolitan Area Planning Council [Ref 13] studied the Red Line extension to Alewife in metropolitan Boston. The study outlined basic land use categories, such as industrial, retail and service, office, residential, and parking/open space. These categories varied slightly by station. The methodology, relatively straightforward, inventories land use changes within the transit station areas before (1978) and after (1986) the extension. The Alewife station area experienced major land use changes and significant increases in land prices. The Davis Square and Porter Square Stations also saw favorable changes, but not to the extent of Alewife. In sum, 1.4 million square feet of commercial space was added, and another 2.5 million (1987) was planned, although, interestingly, there was no discernible effect on housing prices. The Red Line extension was a contributing factor to the land use changes near the three new stations. Long-term demographic effects of the Red Line extension will not be completely known until 1990 census data are available, at which time another study is recommended.

The San Diego Association of Governments (SANDAG) [Ref 14] evaluated the land use effects of the first line of the San Diego Trolley. The methodology is relatively straightforward. Basic land use categories and acreage are used to measure changes in these categories by cataloguing building permits and zoning modifications. Business surveys and windshield surveys provided some insight into the influence the Trolley had on new construction. Overall, the Trolley has had a small effect on new development. The Trolley definitely provides a location advantage, but it is not the sole determinant for new construction; market forces are significantly more influential than the Trolley in producing development. At the time of the study, local governments paid little attention to station area development [Ref 15].

The Planning Department of the Regional Municipality of Ottawa-Carleton (OC) [Ref 16] measured land use and development effects for the OC Transpo busway system. The methodology in the report focuses on an inventory of land use changes within an 800-meter development envelope of the transit station, which is considered an accessible walking distance to each transit station. The report identifies four basic land use categories are identified: major institutional, commercial/office, residential, and industrial. Participating municipalities receive a "data collection package," which is used to inventory development within the envelope. Information on each of the land use categories is collected annually to determine the magnitude of development from the previous year. The Central City was excluded from the analysis because it was determined that the area was fully developed. The monitoring program is intended to be ongoing; this type of monitoring is geared toward reporting recent "snapshots" of development. Pre-transitway data has been included for comparison. On the whole, there are an additional 260,000 square meters of institutional and commercial/office development and 1,305 square meters of residential space with an estimated value of $270 million (Canadian). Overall, many positive indicators suggest that the transitway stations are influencing development within the "envelopes."

The Texas Transportation Institute [Ref 17] reviewed land use and development effects derived from the transitway system in Houston. Land use is categorized into three basic categories: commercial, residential, and public/quasi-public. The report studies four transit centers: North Shepard Park-and-Ride, Aldine-Bender, Kuykendahl, and Spring. Data collection—conducted by the Texas State Department of Highways and Public Transportation (now the Texas Department of Transportation)—involved station specific itemization of changes and five-year aerial photography. The monitoring is a semi-annual program. Basically, transitway development had little affect on land use changes; however, it is recommended that definite conclusions about land use effects be postponed for a number of years until the system has "matured."

Knight and Trygg [Ref 3] reviewed post- World War II transit investments in North America and Europe to determine when land use effects occur and the extent of their influence. Several mixed obervations are drawn with the authors stressing that their observations are not absolute and may change over time. The most important observations are as follows. When combined with other favorable influences, major improvements to rapid transit and commuter rail can induce intensified development near transit stations. The ability of busway and light rail systems to encourage development is more questionable, however. Rapid transit improvements tend to shift economic activity within a metropolitan area, but they prompt little net economic or population growth. General economic conditions govern the timing of a land use effect, and the "rule of thumb" for the occurence of a land use effect seems to be five years. A favorable local change in land development policy tends to facilitate transit's influence on land development, while it is also true that a transit improvement can induce changes in local land use policies.

Pushkarev and Zupan [Ref 18] investigated the relationship between the density of urban development and the use of public transit in the United States, and found that residential developments of seven units per acre were the "threshold" value of support for public transportation. Transit will claim more than half of all trips at densities of 60 units per unit or more (e.g., Manhattan). For nonresidential development, clustering in downtowns or other high-density centers is the most effective transit-sensitive land use policy. Thus, attempts to implement high-quality service in low-density (and thus, low-demand) areas will exceed the economic and energy costs of the automobile.

The land use effect studies indicate that the transit system is one factor, but not the only factor, that encourages land use changes in the system's service area. Market forces and land use policies are also very strong influences. With one exception (Ottawa), rapid rail systems seem to be more successful than light rail and busway systems in inducing the most intense land use changes.

Strategies for Assessing and Optimizing Land Use Impacts of Transit

The second group of studies includes suggested strategies for measuring the land use effects of a transit system. Reports that investigate favorable land uses for transit systems (i.e., "transit-sensitive development") are also included. A market analysis approach is incorporated in the majority of these works.

Lee [Ref 19] developed a framework for measuring the land use effects of a transit station. This framework differs from previous models in that public policy alternatives and outcomes are included as factors that influence different results. The Vienna, Virginia station of the Washington, D.C., METRO system is presented as a case study: strict policy measures were required to reach full land use potential, and the author stresses that the framework is incomplete and in need of further research .

In a later study, Lee [Ref 20] presents a number of arguments for using indirect development and economic effects to evaluate transit alternatives. Suggested approaches are outlined to determine whether or not the argument is "valid" in each case. These arguments are to be qualitatively difficult to perceive and quantitatively "imprecise." Market analysis and "consistency with regional forecasts" are seen as more useful than mathematical models. Only under the most ideal conditions will urban revitalization and efficient land use occur as a result of a transit investment. Favorable government action at all levels is more effective than trying to mathematically predict results.

Page, Demetsky, and Hoel [Ref 21] developed a methodology for assessing the effect of a transit terminal on its surroundings. Critical effects are identified using an interactive matrix procedure linked to a catalog of transit station studies [Ref 22]. The effect the transit station has on surrounding land use is identified by means of a cross-interactive matrix, and transit station design elements are identified using a self-interactive matrix. These predicted effects and design elements can then be used at the station location and in the design process to minimize potential problems and to improve potential benefits for surrounding land use.

Watterson [Ref 23] studied the economic and development effects of transit alternatives for the Seattle metropolitan area using conventional regional urban activity and econometric models. Alternatives included no build, light rail transit, and the "advanced technology bus/tunnel (now built)." The build alternatives show positive employment and residential effects in the Seattle CBD and city center. It was concluded that transit alternative analyses, as well as economic and development effect analyses, should not be considered separately and that urban activity and econometric models, with cautious assumptions, can complement alternative analyses.

Kadesh, et al. [Ref 24] examined land development and transportation management techniques that were created to enhance public transportation usage. Public transportation's changing role is outlined. Criteria for "planning a development which is compatible with public transportation" are presented. Various parking management strategies and zoning tools that promote public transportation are also reviewed.

Beimborn, Rabinowitz, Lindquist, and Opper [Ref 25] present guidelines for transit station design from a market-based point of view. For private and public development, they created design principles and policy alternatives. The transit market (i.e., the customers) should be the primary consideration when "planning, locating, and designing public transit facilities;" the authors also maintain that a mutually beneficial relationship can be cultivated between the private development community and public transit.

In a later work, Beimborn, Rabinowitz, Gugliotta, Mrotek, and Yan [Ref 26] developed guidelines for "Transit Corridor Districts (TCD's)." TCD's segregate transit and auto-oriented land uses. Thus, land uses would be mixed, with higher densities closer to the transit route. Another priority is "a high quality access system for pedestrians and bicyclists to permit easy connections between buildings and transit vehicles." Guidelines for planning, design, and administration are developed, and a hypothetical TCD is presented as an example.

Neuwirth [Ref 27] reviewed existing rapid transit effect reports in the United States and Canada. Opinions of planners, policy-makers, developers, and other business people from case study cities were gathered to evaluate the extent to which transit investments met planned objectives. Four cities, representing cities with different transit histories, are studied: "established rail cities (Boston), newer rail cities (Atlanta), cities proposing rail transit (Dallas), and small bus transit cities (Hartford, CT)." Goals and objectives, characteristics, and development effects are discussed in each of the case studies. Study results indicate that transit plays an important role (but not the only role) in the creation of new development, giving transit captives, for example, access to the CBD and thus to more economic opportunity.

Emerson [Ref 2] presents the Urban Mass Transportation Administration's (UMTA, now the Federal Transit Administration) latest approach for predicting land use and development effects of fixed guideway transit projects. This framework is intended to help local agencies conduct alternative analyses and transit planning studies. For the regional, corridor, and station area levels, land use effect identification methodology is outlined, policies for transit-sensitive development.

In conclusion, this group of studies contain strategies for assessing land use effects that vary from interactive matrices to econometric and urban activity models. Presumably, the effectiveness of these assessments depends on the level of quantitative detail and available funding. A common theme in all the studies is that policies should bolster transit-sensitive development. High-density development is shown to encourage transit ridership; thus, rational policies are needed that support high-density development and a market analysis, especially in new suburban areas.

Transportation Energy and Urban Development Patterns

This section includes a brief review of those studies that predict the relationship between transportation energy consumption, consumption intensity, and urban development patterns. Some of the studies examined very generalized development patterns (i.e., linear, radial, polynucleated, etc.), while others investigated various development scenarios of specific metropolitan areas.

Hemmens [Ref 28] experimented with changes in urban form and the resulting effects on urban structure. Urban form is defined as "the physical arrangement of residences, work places, etc.," and urban structure is "the pattern formed by the connection of these elements in the daily activities of the area's residents." The study provided the initial effort in developing better analytic methods to evaluate the performance of various urban forms, and, in addition, the study used a linear programming based allocation rule. Travel was minimized between residence origins and work and shopping destinations. The experiments suggest that transportation systems (i.e., alternative systems) have less influence on urban spatial structure than initially anticipated. Hemmens stresses that his approach is only one of many alternatives and that further work is needed.

Roberts [Ref 29] discussed the energy implications of various development scenarios for the metropolitan Washington, D.C. area. The five scenarios were as follows: dense center, transit-oriented, wedges and corridors, beltway-oriented, and sprawl. Inherent characteristics of energy-efficient land use are as follows: clustered high-density development that is contiguous without "leapfrogging," and transit-oriented. The dense center and transit-oriented scenarios are the most energy efficient. Energy conservation itself is seen as one factor that justified changes in urban form; other factors include rising housing costs, more accessible and improved public transit, practical commuting times, and better-designed dense development.

Edwards and Schofer [Ref 30] investigated the relationship between variations of three basic urban forms (linear, concentric ring, and polynucleated) and transportation energy consumption. Land use allocations from a Lowry model ware used in a travel demand model utilizing conventional trip generation and traffic assignment techniques. Instead of using a modal choice model, the authors give each urban form studied a range of transit shares. Energy requirements for vehicles are determined by using existing fuel consumption curves as a function of speed [Ref 31]. Experiments show that concentrating development into high-density polynucleated cities reduces transportation energy needs. Later, Peskin and Schofer [Ref 32] added a capacity restrained traffic assignment model and a modal choice (binary logit) model to Edwards and Schofer's model. Generally, it found that polynucleated cities use much less energy for transportation than the concentric ring form.

Kim and Schneider [Ref 33] identified relationships between urban form and transportation energy use by means of six different employment alternatives for dispersed, concentrated, and polynucleated city forms. Results of the study indicate that a high-density urban center with good access can reduce transportation energy requirements and that the polynucleated form is less energy efficient. If the centralized city has downtown congestion, however, the polynucleated city may be more energy efficient. This study utilized Peskin and Schofer's model and Schneider's urban statistics model, MOD3.

Wilson and Smith [Ref 34] evaluated transportation fuel needs for three residential and two commercial urban development alternatives inthe Madison, Wisconsin, metropolitan area for the year 2000. The effects of transit, ridesharing, and fuel economy improvements on fuel requirements are examined using available auto occupancy trip distribution and mode choice models. The study results demonstrate that locating most major commercial development in the central Madison area will decrease fuel consumption through higher transit usage. While the most energy efficient development scenario reduces fuel consumption by 7 to 15 percent, improvements in fuel economy are expected to decrease fuel consumption by 38 percent.

These studies generally report that *ceteris parabis*, a city with a dense urban core (i.e., a downtown), produces the most energy-efficient transportation system because of higher transit ridership and more efficient infrastructure. It is interesting to note that in scenarios with bus transit and traffic congestion in the traditional CBD, a polynucleated city is more efficient than a centralized one. This is a matter of interpretation, since the various nucleii in the metropolitan area can be considered "satellite downtowns."

Transportation Energy Impacts of Existing Land Uses

This final group includes works which empirically relate transportation energy requirements (consumption and intensity) to development patterns in existing metropolitan areas. Two studies specifically address transit energy requirements, while the others address all modes.

Levinson and Wynn [Ref 35] investigated some basic relationships between urban population density and transportation requirements. Historical, trip generation, car ownership, mode of travel, transit ridership, and freeway operations effects of population density are analyzed. Density is seen as an essential consideration in the analysis of transportation systems. For example, in large cities, the population density of a center city is greater than that in small cities; and older, densely developed cities are highly dependent on public transportation. Urban transportation systems serve three basic markets: (1) low-density to low-density areas, (2) high-density to low-density areas (and viceversa), and (3) high-density to high-density areas. The automobile dominates the first market; transit has great potential for the other two markets. Rapid transit's role in the last two markets will undoubtedly increase because of rapid transit's ability to minimize travel times in high-density areas and to "orient" development.

Curry et al. [Ref 36] analyzed air pollution and energy consumption effects for eight transit starts or improvements, including systemwide improvements, new bus rapid service, and new rail service. Probabilistic models were devised that took system and travel demand factors into account. The model results indicate that lower than anticipated patronage, extensive auto access (i.e., park-and-ride, kiss-and-ride) to corridor express services, and diversion from previous transit service cut energy reductions. New ridership resulting from system-wide bus service improvements may actually cause net energy use to increase owing to lower system load factors.

Stuntz and Hirst [Ref 37] investigated the energy intensity of new transit projects. They found that energy effects of new projects were small since transit carries few people nationally, and more ridership on any one system only marginally reduces automobile traffic. Thus, for the short term, energy savings from increased automobile efficiency are greater than energy savings from transit. The long-term rewards from public transit, however, may be great.

Soot and Sen [Ref 38] studied energy consumption patterns for journeys-to-work in the Chicago area and their relationship to urban form. Data were aggregated from square mile zones. For each mode, average work-trip distances were calculated and the number of trips recorded. For each area, existing data on energy consumption for each mode of travel were used to determine per capita and total modal energy consumption. Energy use was interpreted graphically. Based on socioeconomic and geographic variables that are related to energy use *a priori*, regression and correlation analyses are then performed. Results of the study indicate that there is a definite correlation between per capita work-trip energy consumption and commuting distance to the CBD. With increasing proximity to the CBD, average trip lengths are shorter and transit use higher, resulting in less energy consumption.

Janson, et al., [Ref 39] developed a procedure to calculate transportation energy consumption per person by mode at the zonal level, using highway link speeds and distances generated from existing transportation planning databases in Chicago. Transit energy consumption is determined from average loads per vehicle mile. The model outputs are "zone to zone energy flows for public (transit) and private (auto) modes." Results show that travel congestion caused an increase in direct energy consumption in zones near the Chicago CBD. On the other hand, energy consumption for transit decreased with increasing proximity to the CBD because of higher load factors and less automobile usage.

Cheslow and Neels [Ref 40] studied energy use and travel patterns derived from "various descriptors" of urban form. A statistical analysis of travel data from eight metropolitan areas was conducted. Cheslow and Neels found that transportation energy use is lower in some development forms than others and that high employment and residential densities are systematically related to fewer auto trips and higher transit usage. Controlling for household and other characteristics, the authors performed regression analyses, and these regression analyses showed that "high-density, centrally located development" is 40 percent more energy efficient than low-density development on the urban fringe for the same metropolitan area. The study recommended placing origins and destinations in close proximity (i.e., a jobs-housing balance). High density development should be encouraged within "walking radii" of transit stations.

Levinson and Strate [Ref 41] investigated the implications of energy consumption vis-a-vis land use in the Toronto metropolitan area. Both transportation energy and other energy intensities of different land uses are identified. The effects of population density on energy intensity are also measured along with suggested techniques to improve transportation energy intensity. Desirable actions that could be carried out over the long term in growing urban areas include the following: "compact urban form," higher residential densities, a jobs-housing balance, and higher transit ridership. In the short term, the greatest energy conservation potential arises from improved building operating efficiency and transportation energy efficiency.

The Dane County Regional Planning Commission (Madison, Wisconsin) [Ref 42] studied the transportation energy effects of single versus multi-family residential development. Existing data are used to calculate the annual number of vehicle trips per dwelling unit and the average trip length by dwelling unit for urban zones and rural areas in and around Madison. Annual vehicle miles of travel (VMT) for a dwelling unit are obtained by multiplying average trip length and average vehicle trips. Annual fuel consumption per dwelling unit is found by dividing VMT by average fuel efficiency ratings. Central Madison with its higher density residential development and higher transit usage had the lowest energy consumption per dwelling unit, while the rural areas had the highest.

Several observations can be drawn from this group of studies. In the short term, energy savings from increased automobile efficiency are greater than energy savings from incremental increases in transit ridership. The long-term rewards from public transit, however, may be great because of its ability to minimize travel times in high density areas and to "orient" development. In general, placing origins and destinations in close proximity (i.e., a jobs-housing balance) is recommended. High-density development should be encouraged within "walking radii" of transit stations. Desirable actions for the long term in growing urban areas include the following: compact urban form, higher residential densities, a jobs-housing balance, and higher transit ridership. These observations more or less confirm the coventional wisdom regarding what can be done to make trips more energy efficient.

CHAPTER 2. METHODOLOGY

BACKGROUND

This study utilizes a model that simulates the net energy savings that accrue when a transit trip supersedes an auto trip within an area of development surrounding a station area. Theoretically, development that occurs within a certain radius of the transit station would be "transit-sensitive." This "transit-sensitive" development would, by design and density, encourage trips to and from land uses within the transit station radius. It is also important to recognize that the infrastructure serving this high-density development is more efficient than the infrastructure serving low-density, typically suburban, land uses.

Figure 2.1 shows the theoretical study area. A quarter-mile is considered the farthest distance that a passenger would walk to or from a transit station in North America, although the quarter-mile distance varies slightly with local conditions. Thus, land development within a "quarter-mile" radius would be influenced to some degree by transit trips. By the same token, the effect of transit on development outside this radius decreases dramatically [Ref 18]. Since transit trips that remain within this quarter-mile radius would, typically, be reached by walking, the entire station area can be considered a single node. The arrows in Figure 2.1 represent trip ends to and from the node.

Whether or not transit serving this high-density development is more energy efficient—given existing operating characteristics—*per person-mile* than the automobile is a question that needs to be answered. Relatively "new" transit systems (less than 20 years old) are examined in this study, because these systems represent the greatest opportunity for influencing changes in land use, that is, from low- to high-density. An older system, such as the one in New York City, already has the high-density development needed for energy efficient trips.

This study uses a before-and-after scenario to measure development that occurs within station areas, although the before-and-after scenario measures changes in development only. Trip end comparisons are made using the "after" scenario; in addition, the "after" scenario is used to analyze any energy consumption savings that result from development after the transit improvement.

This study relies heavily on secondary data sources. For instance, existing land use effect studies yielded the development data of the transit systems under review; operational data are obtained from these land use effect studies, if possible. If operational data can not be obtained from these studies, other references such as the APTA Handbook, UMTA Section 15 reports, and UMTA's *Characteristics of Urban Transportation Systems* (CUTS) are used. The comparison figures for the automobile comes from CUTS.

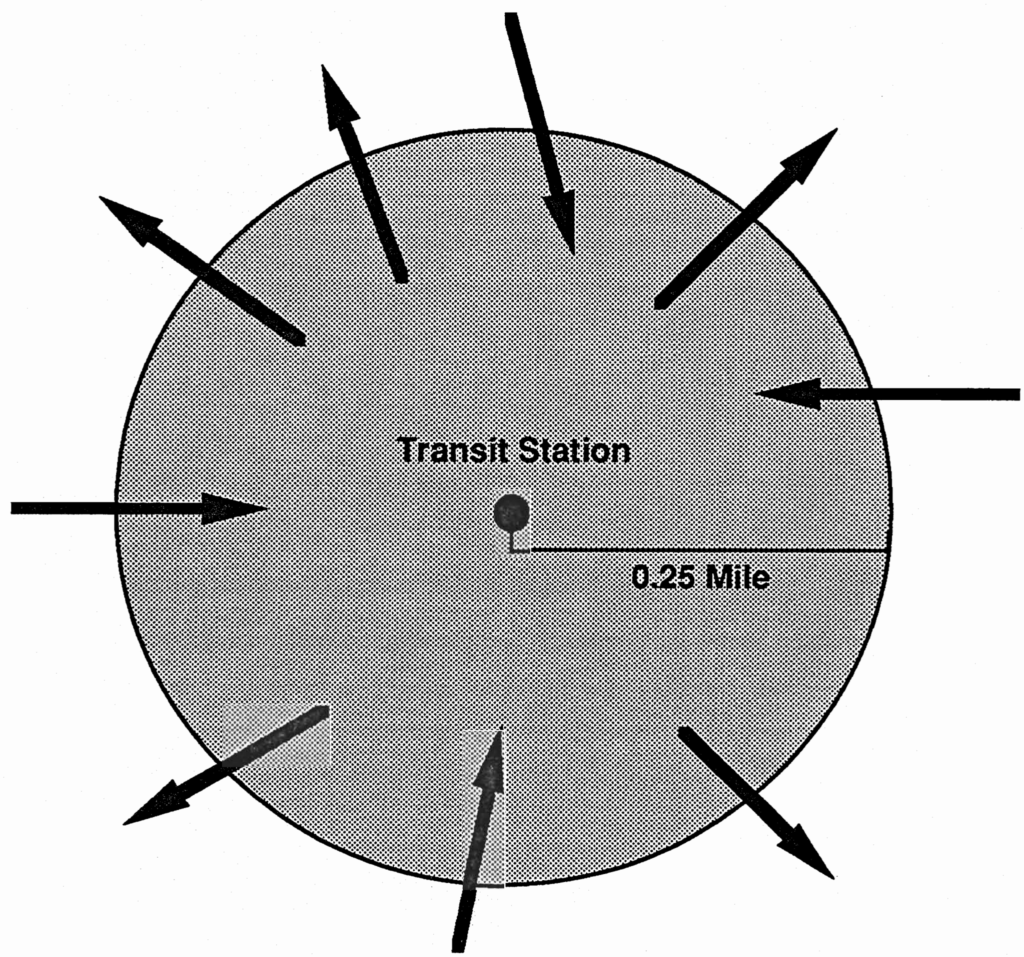

Figure 2.1 Theoretical study area

The results of each simulation are utilized in a case study of a station area. Since the analysis focuses on the station area, only trips that begin and end in the station area are being considered. Trip length is not considered. Input units are in average weekday trip ends, and outputs are in units of energy per passenger mile on a weekday.

This chapter addresses the methodology employed to determine the development-based net energy savings of trips to and from a station area. Characteristics of various types of transit service are reviewed in selecting transit systems for study. Factors that influence the energy efficiency of a transit system are discussed, also. Finally, the model used to describe net energy savings is outlined, along with a discussion of methods for classifying different station areas.

CASE STUDY SELECTION

System Characteristics

Transit service can be classified in many ways. A common method is by the type of vehicle or mode. Table 2.1 lists transit system characteristics by mode. Each mode is described by right-of-way (ROW), power, and capacity characteristics. ROW for local bus service is typically shared with other vehicles, whereas rapid rail has its own grade-separated ROW. Most buses are powered by diesel internal combustion engines (ICE); furthermore, buses have less vehicle capacity, since their size must conform to roadway geometrics. Most rail vehicles use electric traction technology, and the size of a rail vehicle can vary according to the track geometrics. Each mode's transit line capacity reflects its vehicle capacity.

Systems Selected

Because secondary data sources are used extensively, transit systems are selected for study based on the quality of their corresponding land use impact study. Land use impact studies are selected for review based on system type, availability, and thoroughness of the data and methodology. The seven transit systems selected for study are, with one exception, are relatively new (less than twenty years old). Table 2.2 shows that three bus and four rapid rail system studies are examined. The literature review indicated that no light rail land use impact study had adequate data for this analysis. The systems are located in cities of different size and history (see Figure 2.2). Studies from smaller, newer systems (Denver, Portland, Ottawa) are given the same consideration as the studies from the larger systems (Washington, D.C., San Francisco Bay Area, Atlanta, and Boston).

TABLE 2.1 TRANSIT SYSTEM CHARACTERISTICS

			Typical Capacity	
Mode	ROW	Motive Power	Vehicle (pass/veh)	Line (pass/hr)
Local Bus	Shared	Diesel ICE	50-70	Variable
Bus Rapid	Partially Reserved	Diesel ICE	40-50	5,000-7,000
Light Rail	40-90% Separated	Electric Traction	up to 250	18,000
Rapid Rail	100% Separated	Electric Traction	120-250	30,000
Commuter Rail	Existing Railroad	Electric Traction or Diesel ICE	120-175	10,000

Source: Machemehl, Class Notes, January 23, 1991

TABLE 2.2 TRANSIT SYSTEMS SELECTED FOR STUDY

System		Case Study	
Location	Mode	Time Frame	# Stations Selected
Atlanta	Rail	1979-1984	3
Boston	Rail	1980-1986	3
Denver	Bus	1982-1986	1
Ottawa	Bus	1987-1990	4
Portland	Bus	1975-1980	1
San Francisco Bay Area	Rail	1974-1977	3
Washington, D.C.	Rail	1980-1986	2

Figure 2.2 System Locations

FACTORS AFFECTING TRANSIT ENERGY EFFICIENCY

Several factors affect transit energy efficiency in this analysis. For instance, land use affects trip-making behavior which, in turn, indirectly affects consumer patronage of transit and transit energy efficiency. The number of trips made by transit influences the efficiency of the vehicle on a per passenger basis. Finally, the energy consumption of the transit vehicle itself and of a competing automobile directly influences the energy efficiency of the transit system.

Land Use

The way in which land is utilized affects the energy efficiency of the transit system that serves that development. High-density development promotes public transit usage, and this relationship between development and transit is valid for several reasons. For instance, auto ownership declines within increasing densities as a result of increasing parking costs and the ease of walking to destinations. For similar reasons, the density of the nonresidential destination is also a factor, since a dense central business district will draw more transit trips than a suburban office park [Ref 18].

On the residential side, seven dwelling units per acre is apparently the minimum threshold that will support a local bus service. Once this minimum threshold is crossed, transit ridership increases dramatically. Half of all trips made by transit are for a residential density of 60 dwelling units per acre [Ref 18]. For nonresidential destinations, 10 million square feet of office and/or commercial space is seemingly the smallest "downtown" that can support local bus service. Table 2.3 shows the minimum densities required to support various types of transit service. A "downtown" can be considered any "contiguous" nonresidential cluster of development [Ref 18].

The density requirements that are needed to support various types of transit service give a good *a priori* indication of development impacts. The largest development effects resulted from the installation or improvement of rapid rail systems. Lesser impacts were related to light rail, busway, and commuter rail systems. Obviously, these changes in land use cannot be attributed solely to the transit system itself. Transit is one of many factors that influence land use. Other important factors include economic conditions, community attitudes, and land use policies [Ref 43].

Studies have shown that a city with a dense urban core (i.e., a downtown) produces the most energy-efficient transportation system because of higher transit ridership and more efficient infrastructure [Ref 44]. It is interesting to note that in scenarios with bus transit and traffic congestion in the traditional CBD, a polynucleated city is more efficient than a centralized one. This is a matter of interpretation, since the various nucleii in the metropolitan area can be considered satellite downtowns. Thus, a higher-density, more energy-efficient development means that more commuters will choose to ride the transit system. It also means that auto ownership declines in the higher-density, more energy efficient development and that trip origins and destinations become accessible by transit. Finally, more riders taking shorter trips increase the energy efficiency of a transit system.

System Patronage

The number of people that ride on a particular transit vehicle or a competing automobile also affects the energy efficiency of the transit system. For example, an automobile carrying six persons is more efficient than a bus carrying the same number of persons. However, a bus carrying twenty persons is more efficient than twenty cars each carrying a single person (a more typical situation). The number of passengers in a vehicle is the vehicle load factor. Both the transit and auto load factors determine the relative efficiency of the transit system. Mode split gives the percentage of a given number of total trips that will use a specific mode. For example, a 10 percent transit mode split suggests that 10 percent of the trips between an origin and destination will use transit, while 90 percent will use other means (typically the automobile). This study will use the conventional two mode approach (transit and automobile).

TABLE 2.3 LAND USE REQUIREMENTS FOR TRANSIT SYSTEMS

System Characteristics		Typical Requirements	
Mode	Service	Residential Density (dwelling units/acre)	"Downtown" Size (million square feet)
Local Bus	40 buses/day	7	10
	120 buses/day	15	10
Express Bus (walk access)	5 buses/2-hour peak	15	50
Express Bus (auto access)	5 or more buses/2-hour peak	3	50
Light Rail	5-minute headways	9	50
Rapid Rail	5-minute headways	12	75
Commuter Rail	20 trains/day	1-2	100

Source: Pushkarev and Zupan, pp. 190-191

Table 2.4 lists aggregated work trip mode splits for public transportation and auto occupancy (load factors) for various regions of the U.S. Since these data are collected from a number of metropolitan areas, large variations (especially in mode split) are possible. For this reason, system-level data are used when available.

TABLE 2.4 REGIONAL MODE SPLIT AND AUTO OCCUPANCY

Region	Percent Transit Trips	Auto Load Factor
Northeast	14.2	1.16
North Central	4.9	1.14
South	3.2	1.17
West	4.9	1.14

Source: American Public Transit Association, *Transit Fact Book*, 1989 Edition, p. 53.

Table 2.5 shows selected peak hour transit volumes for various North American transit systems. The maximum load factor for transit buses falls within the 40 to 50 passengers/bus range, regardless of facility type. The selected rapid transit systems have peak load factors of about 200 passengers/train car. These peak load factors are in metropolitan areas with relatively high transit patronage. The load factors for other systems may vary greatly. The off-peak load factors for the systems listed below will vary as well. System level data are used when available.

TABLE 2.5 SELECTED PEAK HOUR TRANSIT VOLUMES

	Peak Hour Volume		
Facility	# Vehicles	Passengers	Load Factor
Busway/HOV			
Lincoln Tunnel, NYC	735	32,560	44.30
San Francisco-Oakland Bay Bridge	350	13,000	37.14
Local Bus on Arterial Street			
Madison Avenue, NYC	220	10,000	45.45
Peachtree Street, Atlanta	67	2,807	41.89
Rapid Rail			
BART, San Francisco	60	12,720	212.0
MBTA Red Line, Boston	60	14,340	239.0

Source: Reno and Bixby, p. 50, 130.
Vuchic, p. 572.

Vehicle Energy Consumption

The energy consumption of the vehicle itself is an obvious factor in transit system energy efficiency. The energy requirement of a particular transportation alternative has five components: vehicle propulsion, stations, maintenance, guideway construction, and vehicle manufacture [Ref 45].

These categories can be generalized into propulsion and nonpropulsion energy. Comparing nonpropulsion energy consumption with propulsion energy consumption can be useful when analyzing transportation system alternatives. However, this study examines the consequences of land development on systems, both auto and transit, that are already built. For this reason, nonpropulsion energy consumption is not considered in this analysis. The propulsion energy consumption of transit vehicles (bus and rail) and private vehicles (automobiles and light trucks) are reviewed.

The energy consumption of a rail transit vehicle can vary widely depending on the age of the vehicle, the type of vehicle, the condition of the guideway, and other local conditions. Table 2.6 shows values commonly used in sketch planning. These values are incorporated in this analysis.

TABLE 2.6 RAIL TRANSIT ENERGY CONSUMPTION

	Energy Consumption (BTU/veh-mi)		
Type of Service	High	Middle	Low
Rapid Rail (old)	93,000	61,000	50,000
Rapid Rail (new)	90,000	75,000	55,000
Commuter Rail	130,000	105,000	70,000
Light Rail	90,000	75,000	55,000

Source: Cohen, Stowers, and Petersilia, p. III-50.

Extensive research has been conducted on the fuel consumption of motor vehicles. A large store of information—representing various operating conditions—is available for automobile, truck, and bus fuel consumption [Ref 45]. As stated above, sketch planning values are sufficient for this analysis. Table 2.7 shows a range of bus fuel consumption rates for a variety of operating cycles. These values were obtained by simulation. Actual bus fuel consumption values will vary with equipment type and local conditions [Ref 46].

TABLE 2.7 DIESEL TRANSIT BUS ENERGY CONSUMPTION

	Fuel Consumption (miles/gallon)	
Operating Cycle	Average	Range
Central Business District	3.68	2.74-4.00
Local Service, Urban Arterial	4.07	3.21-4.30
Express Service	5.43	4.47-5.87
Weighted Average	4.14	3.24-4.41

Source: Reno and Bixby, p. 62.

Table 2.8 shows the fuel consumption rates for selected vehicles at various speeds. Fifteen vehicles, models from the early 1980's, were tested to examine the relationship between fuel efficiency and speed [Ref 47]. For this analysis, the vehicles, speeds, and fuel efficiency can be considered "typical" for the automobile trips in the case study areas during the time in which the land use impact studies examined changes in development.

Conclusion

This study investigates many of the factors affecting transit energy efficiency—development-induced transit trips and land uses; the number of people that use transit; the auto load factor; the transit load factor; the mode split to quantify system patronage; and finally, the energy consumption of the vehicles themselves, both automobile and transit.

TABLE 2.8 FUEL ECONOMY FOR SELECTED VEHICLES AT VARIOUS SPEEDS (MILES/GALLON)

Vehicle	Engine (cylinders)	Speed (miles/hour) 15	25	35	45	55	65	75
1981 Buick Century	6	23.5	29.4	30.2	31.3	29.2	27.6	20.7
1981 Chevrolet Caprice (Diesel)	8	21.2	31.3	33.7	36.5	33.0	27.7	-
1982 Chevrolet Caprice (Wagon)	8	17.5	20.1	24.6	30.6	23.3	21.4	16.1
1982 Chevrolet Chevette (Diesel)	4	57.3	70.7	49.0	47.2	39.7	27.6	-
1982 Chevrolet Citation	4	15.1	25.2	32.6	36.4	33.7	23.6	19.5
1983 Chevrolet Monte Carlo	6	20.9	28.6	31.4	31.9	29.5	26.1	21.4
1983 Chevrolet Pickup (Diesel)	8	18.2	24.7	24.7	23.8	22.9	18.9	16.2
1984 Chevrolet S-10 Pickup	4	22.0	28.4	33.6	34.1	26.5	21.8	17.2
1982 Datsun 210	4	44.0	55.5	54.7	43.0	37.7	33.5	-
1983 Ford Escort	4	28.9	45.1	45.7	39.0	36.3	29.6	24.0
1982 Ford Fairmont	4	21.4	30.9	32.2	32.2	27.6	23.0	20.1
1982 Ford Futura	6	24.6	33.5	33.6	31.8	28.0	23.6	18.6
1983 Pontiac Firebird	6	21.3	29.2	38.0	34.2	33.6	30.6	26.5
1983 Plymouth Reliant	4	21.6	32.4	32.5	29.9	28.1	23.8	19.7
1982 Toyota Corolla	4	37.0	35.0	36.3	32.8	30.3	27.4	22.7
Sales-Weighted Average	-	21.1	30.0	33.6	33.5	30.3	24.9	20.0

Source: Davis, Shonka, Andersen-Batiste, and Hu. p. 3-61.

MODEL DESCRIPTION

The model can be considered in three stages: pre-simulation, simulation, and post-simulation. The pre-simulation stage inventories development in a station area and determines the number of daily trips to and from that development. The simulation stage determines the net energy savings of the transit trip ends for a number of cases, given the factors discussed earlier. The post-simulation stage uses descriptive statistics to report the net energy savings the transit system offers over the automobile mode based on trips to and from the development in the station area. A classification system has been developed to characterize each station area and to compare net energy savings. Figure 2.3 outlines the model.

The Pre-simulation Stage

The presimulation stage converts development to a fixed input for the simulation. The first step is to conduct an inventory of new development in the station area (the "quarter mile" radius). Since secondary data sources are employed, this step has already occurred when the system effect study is conducted.

Given the land uses in the station area, development must be related to transportation. The connection between land use and the number of trips taken involves the number of trips a specific land use generates. The *ITE Trip Generation Report* can be used to estimate trips that a specific land use causes or "generates" [Ref 48]. Since the 1960's throughout the U.S. and Canada, trip generation data for specific land uses have been collected. The trip generation rates are given as weighted averages.

Caution must be exercised when using the *ITE Trip Generation Report*. Trip generation characteristics for a specific land use vary; for this reason, the regression coefficient (R^2) and the sample size are reported for each land use type in this analysis. Most of the trip generation studies were conducted at suburban locales that had little transit service [Ref 48]. This is corrected in the simulation stage. Overall, the accuracy of the ITE report is sufficient for the scope and the level of detail of the model.

The quantity of development (typically square footage of specific land uses) is converted into Average WeekDay Vehicle Trip Ends (AWDVTE). AWDVTE is defined as "the average 24-hour total of all vehicle trips counted to and from a study site from Monday through Friday" [Ref 48]. This is accomplished by interpreting the cross-classification graphs in the *ITE Trip Generation Report*. Once the AWDVTE is determined for the station area, the simulation can begin.

The Simulation Stage

The simulation stage of the model converts the AWDVTE for a station area into the net energy savings transit offers a station as a result of development. A FORTRAN program was developed to accomplish this task. The computer code is presented in Appendix A. The simulation can be divided into an input routine, a random variable routine, a calculation routine, and an output routine.

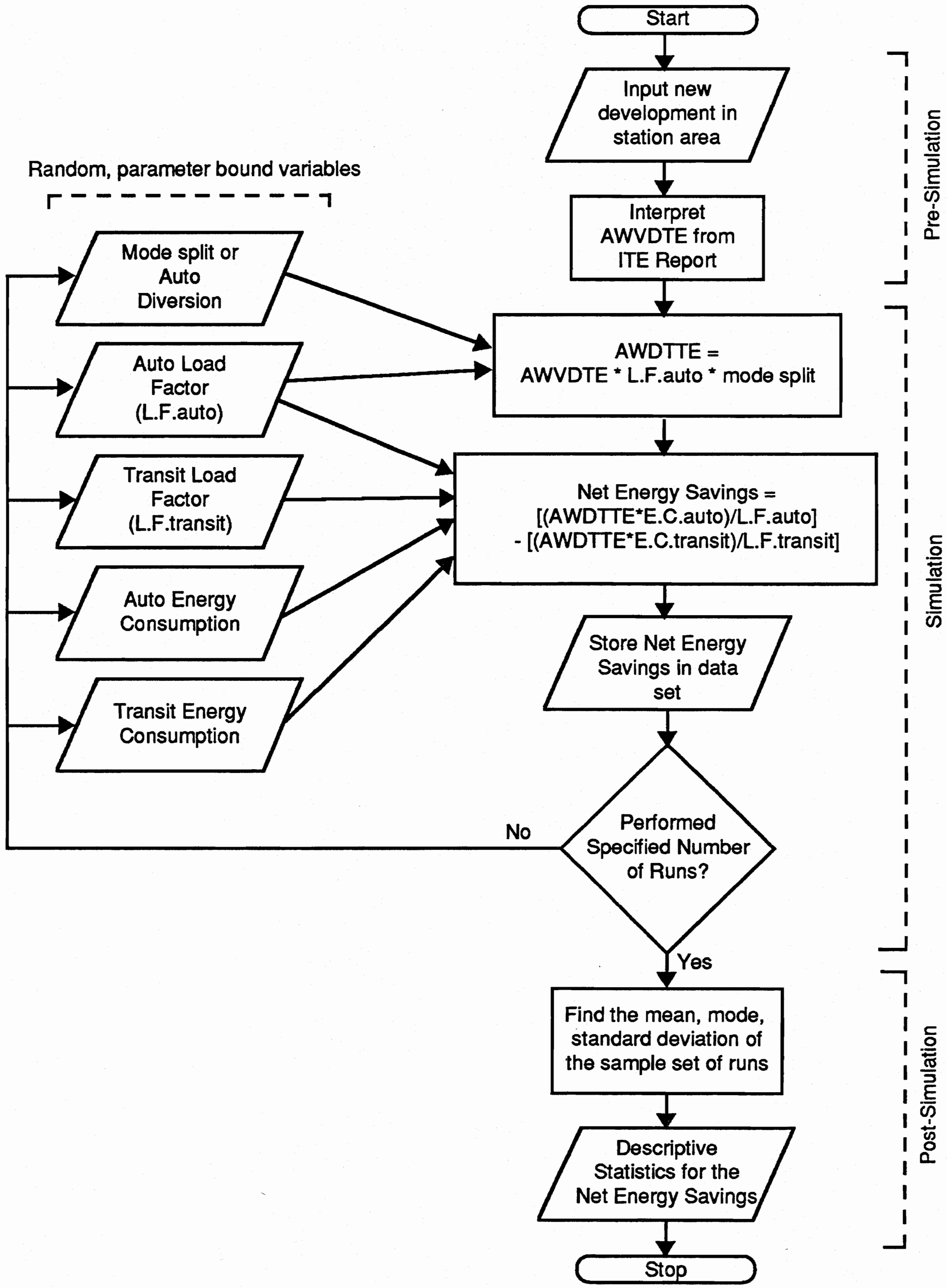

Figure 2.3 Model Flowchart

The input routine creates a data file for a station area. The AWDVTE, determined earlier, is entered in the file. This quantity is considered fixed input since a single quantity is used. A range of values for the auto load factor, transit load factor, auto energy consumption, transit energy consumption, and mode split are then entered in the file. All of these quantities vary by time of day, trip length, and a myriad of other intangible human factors. Thus, they are considered random or variable input.

Once the data are entered, values for the random input can be selected. The random variable routine uses a random number generator with an additional "shuffling" procedure to minimize sequential correlation for each run [Ref 49]. Five random numbers between 1 and 10 are selected. These random numbers are used to "pick" a value for each of the five random input quantities by addressing a number in the array.

Once the random variables are selected, two calculations are performed. The first calculation converts AWDVTE to Average Weekday Transit Trip Ends (AWDTTE) by multiplying AWDVTE by the mode split and auto load factor. This corrects for the ITE study bias toward suburban, transit-poor locations [Ref 48]. The second calculation determines the net energy consumption savings by subtracting the energy consumed by the AWDVTE if those trips had been made by auto from the energy consumed by the AWDVTE made by transit. In other words, only trips that have been diverted to transit are considered as energy savings. A comparison of the total auto trips and total transit trips is not being made. The auto trips in the simulation are not actually occurring. Instead, they represent energy units created for comparison if the trips made by transit did not occur.

A dimensional analysis is presented for the calculations:

(1) AWDTTE = AWDVTE * (1/auto load factor) * mode split

[transit trips/weekday] = [veh trips/weekday] [persons/veh] [transit trips/total trips]

(2) Net Energy Consumption Savings =

(AWDTTE * (1/auto load factor) * auto energy consumption)

- (AWDTTE * (1/transit load factor) * transit energy consumption)

[BTU/pass-mi/weekday] = [transit trips/weekday] [veh /person] [BTU/veh-mile]

- [transit trips/weekday] [veh/person] [BTU/veh-mile]

The output routine stores the resulting energy consumption savings in a data file. The simulation is then repeated to obtain a reasonable sample size (500 repetitions or cases).

The Post-simulation Stage

The post-simulation stage involves importing the data file into a statistical package and computing descriptive statistics for the sample set. These statistics represent the range of values for the net energy savings of a specific station area. Since the model input is a range of values that represents varying daily local conditions, the net energy savings should be expressed as a range of values that reflect those conditions.

Comparison of Station Areas

The range of net energy savings values for each station area are compared with that for other station areas in the system, as well as with the net energy savings values in other systems studied. This comparison is necessary in order to learn what energy savings will occur, where they will occur, and why. In a sense, these stations areas can be considered "analogies" for land development in station areas for future systems.

In order for these case studies to be considered analogies, a classification system must be imposed on the station areas. Generalization will occur in any system of classification, resulting in some loss of descriptive power, and since the model output is a range of values representing net energy savings, a level of generalization has already been assumed. However, since this report is attempting to make a broad statement about development and transit energy consumption, the levels of generalization imposed by the output and by a classification system do not hinder the study's purpose.

The Atlanta Regional Commission (ARC) developed a classification system for MARTA station areas in its Transit Impact Monitoring Program (TIMP). The system placed station areas into five categories, depending on the development desired at that station [Ref 50]. The categories and development policies are presented in Table 2.9.

While the ARC's classification system may have helped to plan and channel anticipated development, it is cumbersome to use in reverse—that is, to classify a station area based on the development that occurred there (this report), instead of the development that will occur in the station area (the MARTA case). Also, this classification system was developed for a transit system in one metropolitan area—Atlanta. A system comparing station areas from across the continent would need to be more general.

TABLE 2.9 MARTA STATION AREA CLASSIFICATION

Category	Development Policy
High-Intensity Urban Node	Large-scale, high-density projects
Mixed Use Regional Node	Regional shopping, office
Commuter	Little development potential
Community Center	Preservation and redevelopment
Neighorhood	Commercial development prohibited

Source: Davis, Brown,and Holmes, p. 35.

For these reasons, a new classification system is developed (see Table 2.10). Station areas are classified by the mode of the transit system, the location of the station in the metropolitan area, and the type of new development occurring there. The transit mode and station location might affect the willingness of those in charge to include transit in the developer's decision-making process. As discussed earlier, the type of development affects the number of transit trips. This system will allow each station area to describe itself based on the system mode, where it is located, and the development that occurred.

TABLE 2.10 STATION AREA CLASSIFICATION

Classification	Category
Mode	Rapid Rail Bus Rapid
Station Location	CBD Center City Suburban
Development Type	Office Commercial Residential Institutional

SUMMARY

This chapter outlines the methodology for this study. An introductory discussion of the relationship between development in station areas and the resulting net energy savings is presented. An overview of the different transit modes led to the selection of systems for study. Based on the transit, development, and energy consumption relationships presented in this chapter, the factors that affect transit energy efficiency are explored, and the model used to describe the net energy savings is outlined. Finally, a classification system is created to compare different station areas.

CHAPTER 3. RAIL TRANSIT STATIONS

INTRODUCTION

This chapter presents case studies of rapid rail station areas (from the transit systems mentioned in Chapter 2). Each system operates in a different geographical area and has different development markets and transit histories. Within each system, the station areas themselves represent further geographic and socioeconomic diversity. These differences, which are based on available data, will be represented by system level input distributions. Once the system-level inputs are established, two to three station areas in each system are examined in detail. New development is inventoried in these station areas, and their corresponding trip generation characteristics are estimated. A computer simulation is used to estimate a range of net energy savings for five hundred cases. The collective results of these cases are presented using descriptive statistics.

ATLANTA

Atlanta's rapid rail system, operated by the Metropolitan Atlanta Rapid Transit Authority (MARTA), has 32.1 miles of line with 29 stations. The system is expected to be completed by fiscal year 1996. High-density development, both public and private, has occurred at or near the CBD and center city station areas. Most of the major development is multistory and has occurred within 1 to 2 blocks of a station. There are several joint development projects with direct access to stations; for example, the State of Georgia's Twin Towers has the air rights over the Georgia State station. There is some evidence of stabilization and improvement in neighborhoods along the East Line, which extends from the Five Points terminal to the Perimeter Highway (Interstate 285). This report examines the Five Points terminal area as well as the Peachtree Center and Lenox station areas on the North Line.

Model Inputs

The model inputs for the MARTA stations involve values at the study, system, and station level. The study values are the auto and transit energy consumption values discussed in Chapter 2. The system values include transit load factors, auto load factors, and the mode split. Finally, for each station, the Average Weekday Vehicle Trip Ends (AWDVTE) are estimated. The system level values are discussed below, while the AWDVTE are calculated in each case study.

At the system level, as a rule of thumb, 30 percent of daily travel occurs during the peak hour [Ref 18] . Nearly half of the average weekday transit trips occur in the peak hour and in the two hours before and after the peak (known as "shoulder" hours). This peaking affects the input distribution of both the mode split and the transit load factor. The mode split for the MARTA station areas is estimated by obtaining a peak journey to work value (representing the peak service) and an aggregate metropolitan area value (representing off-peak service). The transit load factor distribution is obtained in a similar fashion. Since the majority of park-and-ride and kiss-and-ride trips occur in the morning, the auto load factor distribution is also affected by peaking. Table 3.1 lists the model input for the MARTA stations. The mode and the range of values for the frequency distributions are listed.

TABLE 3.1 MODEL INPUT, MARTA STATIONS

Variable	Mode	Range	Ref.
AWDVTE	Single Value, Station Specific	Single Value, Station Specific	F
Auto Load Factor	1.2 persons/veh	1-1.2 persons/veh	C
Transit Load Factor	200 persons/veh	25-200 persons/veh	D,E
Percent Transit Trips	20%	5-20 %	C,G
Auto Energy Consumption	4,100 BTU/veh-mi	3,500-6,900 BTU/veh-mi	B
Transit Energy Consumption	90,000 BTU/veh-mi	50,000-93,000 BTU/veh-mi	A

Sources: [A] *Evaluation Urban Transportation System Alternatives,* p. III-10.
[B] *Transportation Energy Data Book, Edition 10,* pp. 3-61.
[C] *Transit Fact Book,* 1989 Edition, pp. 51, 53.
[D] *Characteristics of Urban Transportation Systems,* p. 130.
[E] *National Urban Mass Transportation Statistics, 1985 Sec. 15 Report,* p. 3-279.
[F] *ITE Trip Generation Report,* 5th Edition.
[G] *Public Transportation and Land Use Policy*, p. 27.

Five Points

Opened in 1979, the Five Points station is the hub of the MARTA rail system, serving as the transfer point between the North-South and East-West Lines. Located near the intersection of Alabama and Peachtree Streets, Five Points is located in the heart of Atlanta's CBD. The area north of the station is predominantly office space with retail establishments, such as Rich's Department Store, to the south. Significant new development in the station area includes new office space and the Heart of Atlanta project; Heart of Atlanta is an effort to revitalize Underground Atlanta, an entertainment and retail district.

Table 3.2 summarizes this new development and its trip generation characteristics. Trip generation data for a museum are not available, so data on libraries are used as a substitute. The sample size of the theater trip generation data consisted of a single study, and, for lack of more substantial data, this study is used to characterize the theater in the Five Points station area. Large hotel trip generation data had an insufficient sample size and correlation coefficient, so motel data are substituted. The Five Points station area is located in downtown Atlanta, and no new residential development was reported in that area during the study period. Thus, the Five Points station area is classified as a CBD location containing office and commercial development.

TABLE 3.2 FIVE POINTS TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Retail	145,000 sf	820	0.78	267	8,914
Theater	10,000 sf	443	*	1	777
Museum	22,500 sf	590	0.71	4	1,375
Retail	37,700 sf	820	0.78	267	3,841
Office	135,900 sf	710	0.82	66	1,769
Office	340,000 sf	710	0.82	66	3,539
Office	680,000 sf	710	0.82	66	5,977
Office/Retail	312,000 sf	710	0.82	66	3,316
Hotel	325 rooms	320	0.77	20	121
Office	1,200,000 sf	710	0.82	66	9,182
Total					38,811

Sources: Land Use Data: *Transit-Linked Development*, p. 39.
Transit Impact Monitoring Program, Annual Report, 1982, pp.61-63.
ITE Data: *Trip Generation Report*, 5th Edition.

Peachtree Center

Peachtree Center—built by John Portman in the 1960's—is a major downtown office and retail location. The Peachtree Center station, which opened in 1983, is located at Ellis and Harris Streets [Ref 50] . It is the first station above Five Points on the North Line. During the study period, office and hotel development occurred in the station area. Table 3.3 shows this development and its trip generation characteristics. Given the importance of Peachtree Center as a downtown business center, the station area is classified as a CBD location. The hotels, which are probably constructed for business travelers, are grouped under the broad "office" category. Thus, the station area contains primarily office development.

TABLE 3.3 PEACHTREE CENTER TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Hotel	1674 rooms	320	0.77	20	608
Hotel	500 rooms	320	0.77	20	184
Hotel	1077 rooms	320	0.77	20	393
Office	307,000 sf	710	0.82	66	3276
Office	1,900,000 sf	710	0.82	66	12,997
Hotel	358 rooms	320	0.77	20	133
Hotel	267 rooms	320	0.77	20	100
Hotel	472 rooms	320	0.77	20	174
Hotel	1250 rooms	320	0.77	20	455
Total					18,320

Sources: Land Use Data: *Transit-Linked Development*, pp. 41-43.
Transit Impact Monitoring Program, Annual Report, 1982, pp.63, 65.
ITE Data: *Trip Generation Report*, 5th Edition.

Lenox

Since the opening of the Lenox Square Shopping Center over 25 years ago, the Lenox area has experienced a development boom. The opening of the MARTA station in late 1984 is seen as an answer to the area's traffic congestion problems, since Lenox is second only to downtown as a traffic generator. Moreover, MARTA is being cited by local real estate agents as stimulating development [Ref 50]. Retail outlets, offices, hotels, and condominiums compose most new station area development. Table 3.4 lists the new development and its trip generation characteristics. When the Lenox Square Shopping Center opened over 25 years ago, the development surrounding it was typically suburban. A generation later, with higher-intensity land uses and chronic traffic congestion, the Lenox area is still suburban in character. For this reason, the Lenox station area is classified as a suburban location. Office, commercial, and residential developments are all present.

TABLE 3.4 LENOX TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Hotel	583 rooms	320	0.77	20	214
Office	1,600,000 sf	710	0.82	66	11,413
Hotel	600 rooms	320	0.77	20	220
Condominiums	2,040 d.u.	230	0.82	185	8,455
Office	169,000 sf	710	0.82	66	2,086
Retail	34,000 sf	320	0.77	20	3,601
Retail	90,000 sf	320	0.77	20	6,616
Office	195,000 sf	710	0.77	20	2,324
Condominiums	850 d.u.	230	0.82	185	4,017
Total					38,946

Sources: Land Use Data: *Transit-Linked Development*, pp. 66-76
Transit Impact Monitoring Program, Annual Report, 1982, pp. 70-71.
ITE Data: *Trip Generation Report*, 5th Edition.

Simulation Results

The simulation results for the three Atlanta case studies indicate that energy savings can vary greatly not only within each station area, but also between station areas. This finding was expected, given the number of local factors that influence both transit ridership and development decisions. Figures B.1 through B.3 in Appendix B show the simultion results in frequency distributions. Table 3.5 summarizes the station area classification and net energy savings for the MARTA stations. The Lenox station had the greatest median and range of energy savings, which can be attributed to the amount of development at that suburban location. The two downtown stations, Five Points and Peachtree Center, also had significant development. However, the land uses in these station areas (especially office space) have more peaked trip generation characteristics. Of course, the large number of hotel rooms at Peachtree Center may be deceiving, since hotel guests are less likely to use transit than Atlanta residents. In fact, the large condominium and retail projects at Lenox are more likely to contribute to MARTA's ridership than the hotel rooms at Peachtree Center.

TABLE 3.5 MARTA STATION AREA NET ENERGY SAVINGS

	Station Areas		
	Five Points	Peachtree Center	Lenox
Classification			
Location	CBD	CBD	Suburban
Development	Office Commercial	Office	Office Commercial Residential
Net Energy Savings (million BTU/passenger-mile)			
Low	- 4.4	- 2.3	- 4.8
10th Percentile	3.5	1.6	3.2
Median	14.5	6.3	14.3
90th Percentile	31.0	13.9	31.9
High	52.7	25.1	52.9
Positive Cases (Percent)	97.6	96.8	96.0

It is important to remember, however, that these energy savings are derived from development-based transit trip end estimates, not ridership figures. Nevertheless, these station areas appear to be generating a significant net energy savings as a result of development in that area. The simulation produced very few cases with negative net energy savings (4 percent or less). These cases probably had low mode splits and transit load factors. Since these negative values occurred in only a small percentage of the total number of cases, it is likely that the transit trips to and from development in the MARTA station areas on a given weekday are more efficient than automobile trips.

BOSTON

Boston has an extensive multimodal (RRT, LRT, and bus) transit system, operated by the Massachusetts Bay Transportation Authority (MBTA). The study of interest concerns an extension of the Red Line (RRT) from Harvard Square-to-Alewife, rather than the entire system. This extension, completed in March 1985, is 3.2 miles long and has three stations: Porter Square, Davis Square, and Alewife. While the rebuilding of the Harvard Square station is also part of the improvement project, it is not reviewed in this report. The Red Line Extension cuts through areas that were undergoing major redevelopment at the time of the extension—from industrial to "gentrified" commercial and residential use. For this reason, the Red Line Extension is included in this analysis.

Model Inputs

The model inputs for the Boston Red Line stations involve values at the study, system, and station level. The study values are the auto and transit energy consumption values discussed in Chapter 2. The system values include transit load factors, auto load factors, and the mode split. For each station, the Average Weekday Vehicle Trip Ends (AWDVTE) are estimated. The system level values are discussed below, while the AWDVTE are calculated in each case study.

At the system level, the three stations on the Red Line extension had 49 percent of their total boardings during a three hour morning peak period (6:30 to 9:30 am) [Ref 51]. Thus, nearly half of the average weekday transit trips are made in the morning; this peaking affects the input distribution of both the mode split and the transit load factor. The auto load factors for park-and-rides, kiss-and-rides, and drive-only trips are also reported. Since the majority of park-and-ride and kiss-and-ride trips occur in the morning, the auto load factor distribution is also affected by the peaking. Table 3.6 lists the model input for the Boston Red Line stations. The mode and the range of values for the frequency distributions are listed.

TABLE 3.6 MODEL INPUT, BOSTON RED LINE

Variable	Mode	Range	Ref
AWDVTE	Single Value, Station Specific	Single Value, Station Specific	F
Auto Load Factor	1.2 persons/veh	1-1.2 persons/veh	E
Transit Load Factor	240 persons/veh	25-240 persons/veh	D
Percent Transit Trips	50%	12.5-50 %	C
Auto Energy Consumption	4,100 BTU/veh-mi	3,500-6,900 BTU/veh-mi	B
Transit Energy Consumption	90,000 BTU/veh-mi	50,000-93,000 BTU/veh-mi	A

Sources: [A] *Evaluation Urban Transportation System Alternatives,* p. III-10.
[B] *Transportation Energy Data Book, Edition 10,* p. 3-61.
[C] *Transit Fact Book,* 1989 Edition, p. 51.
[D] *Characteristics of Urban Transportation Systems,* p. 130.
[E] *Red Line Extension to Alewife: Before/After Study,* p. 59.
[F] *ITE Trip Generation Report,* 5th Edition.

Alewife

The traditional industries in the Alewife area, part of the city of Cambridge, were moving and storage, and steel fabrication. The late 1970's saw a change in the economic base in Alewife and in the Boston area as a whole. Traditional industries closed or moved elsewhere, leaving large parcels of land available for other uses. In the 1980's, a substantial amount of new or renovated office development (over a million square feet) has emerged.

Despite the trouble in the economy of the Boston area, the Red Line Extension was still an important factor in new or renovated office development. In anticipation of the day when the Red Line would be operational, Cambridge officials began to channel development in a favorable "transit-sensitive" way. The Red Line put the Alewife area on an equal footing, when competing for new development, with other locations that enjoyed rapid rail service [Ref 13].

The major development that has occurred in the station area since the Red Line Extension opened is shown in Table 3.7. The Alewife station area is located in a relatively urban area in Cambridge that has substantial new office and commercial development. No new residential development was reported during the study period. Thus, the Alewife station area is classified as a center city location containing office and commercial development.

TABLE 3.7 ALEWIFE TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size (sq. ft.)	Land Use Code	R^2	# Studies	AWDVTE
Office	185,000	710	0.82	66	2,250
Office	250,000	710	0.82	66	2,750
Office	80,000	710	0.82	66	130
Office/R&D	125,000	760	0.7	27	1,250
Office/retail	130,900	710	0.82	66	1,500
Office/R&D	100,000	760	0.7	27	1,000
Office	136,000	710	0.82	66	1,500
Total	1,006,900				10,380

Source: Land Use Data: *Red Line Extension to Alewife: Appendix A: Red Line Extension Land Use Study.,* p.22.
ITE Data: *Trip Generation Report,* 5th Edition.

Porter Square

The Porter Square area of Cambridge has traditionally served as a commercial and retail center. With the establishment of the Red Line, the commercial role of the land use continued, but with some gentrification. An old Sears and Roebuck store and a closed auto dealership were converted to upscale office and retail space, in addition to some new residential development. Whereas the Alewife station area had vacant (formerly industrial) land waiting for redevelopment, concerns about neighborhood preservation were strong in the Porter Square area resulting in policies favoreing existing land uses over more intense uses [Ref 13]. Table 3.8 outlines new development in the station area. Like Alewife, the Porter Square station area is located in Cambridge in a relatively urban area that has new office and commercial development. The intensity of new development is about one-fifth that of the Alewife station area; this is, in part, owing to neighborhood preservation efforts in the Porter Square station area. New residential development was reported in the Porter Square station area, unlike the Alewife area, during the study period. Thus, the Porter Square station area is classified as a center city location containing office, commercial, and residential development.

TABLE 3.8 PORTER SQUARE TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Office	150,00 sf	710	0.82	66	200
Office/retail	100,000 sf	710	0.82	66	1,500
Residential	51 d.u.	220	0.92	33	310
Residential	8 d.u.	220	0.92	33	40
Residential	11 d.u.	220	0.92	33	60
Total					2,110

Source: Land Use Data: *Red Line Extension to Alewife: Appendix A: Red Line Extension Land Use Study.,* p.31.
ITE Data: *Trip Generation Report,* 5th Edition.

Davis Square

The Davis Square Station area is located in the city of Somerville, adjacent to Cambridge. Like the Porter Square station, the Davis Square station area has experienced a decline in its traditional role as a commercial center. While there has been new development at Davis Square, it is not representative of the gentrification trends of the other two Red Line stations [Ref 13]. Somerville, anticipating the Red Line extension, undertook renewal efforts in the Davis Square station area. These renewal efforts included sidewalk widening, the placement of street furniture, and the construction of new building facades. The result has been modest new development that complements, rather than forcing out, existing development. Table 3.9 shows new development in the Davis Square station area. Like Porter Square, the Davis Square station area experienced new office, commercial, and residential development. The intensity of new development was half that of Porter Square. On the other hand, existing land uses were not forced to change because of gentrification. The Davis Square station area is classified as a center city location containing office, commercial, and residential development.

TABLE 3.9 DAVIS SQUARE TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Office/retail	50,000 sf	710	0.82	66	750
Residential	53 d.u.	220	0.92	33	320
Total					1070

Source: Land Use Data: *Red Line Extension to Alewife: Appendix A: Red Line Extension Land Use Study.*, p.41-42.
ITE Data: *Trip Generation Report*, 5th Edition.

Simulation Results

The simulation results for the three Boston case studies indicate that energy savings can vary greatly not only within each station area, but also between station areas. Figures B.4 through B.6 in Appendix B are histograms of the frequency distributions for the net energy savings of each station area. Table 3.10 summarizes the station area classification and net energy savings for the Boston stations. The Alewife station had the greatest median and range of energy savings, which is a function of the amount of development and redevelopment occurring there. Porter Square and Davis Square had significantly less energy savings, obviously because of less development at these locations. Nevertheless, all three stations had median energy savings that were similar in size. The three station areas had very few or no cases with negative net energy savings from the simulation results, indicating that while the development activity was small in scale, energy-efficient transit trips were generated.

TABLE 3.10 RED LINE STATION AREA NET ENERGY SAVINGS

	Station Areas		
	Alewife	Porter Square	Davis Square
Classification			
Location	Center City	Center City	Center City
Development	Office Commercial	Office Commercial Residential	Office Commercial Residential
Net Energy Savings (million BTU/passenger-mile)			
Low	- 0.1	0.0	- 0.3
10th Percentile	5.1	1.0	0.5
Median	13.2	2.7	1.4
90th Percentile	23.8	4.8	2.5
High	35.7	7.1	3.7
Positive Cases (Percent)	99.9	100	98.2

SAN FRANCISCO BAY AREA

The Bay Area Rapid Transit system (BART) is a 71 mile rail rapid transit system with 20 miles of subway, 24 miles of elevated track, and 27 miles of track at ground level. The 34 stations are located in San Francisco, Oakland, Berkeley, and other parts of the Bay Area. The system began service in five phases from September 1972 to September 1974.

During the study period (1965 to 1977), BART was one of many interacting forces that shaped land use/land development decisions in the Bay Area. At the study publication date, BART had its strongest effect at the local, or station area, level. BART has influenced redevelopment projects, zoning modifications, and some residential and commercial location decisions. BART has generally not induced development in blighted areas, but it may have stabilized decentralization by improving access to center cities. Land uses were only moderately influenced by BART where demand, community support, and public policy were favorable.

Overall, changes in land use occur over a long period, and it will be years(dating from 1979) before BART's effect on land use and development can be determined [Ref 52].

This study examines station areas in the West Bay Area. Downtown Oakland, Fremont, and Walnut Creek are examined. The intent is to examine development in station areas that were previously without rail transit. Thus, locations in San Francisco are not examined.

Model Inputs

The model inputs for the BART stations involve values at the study, system, and station level. The study values are the auto and transit energy consumption values that were discussed in Chapter 2. The system values include transit load factors, auto load factors, and the mode split. For each station, the Average Weekday Vehicle Trip Ends (AWDVTE) are estimated. The system level values are discussed below, while the AWDVTE are calculated in each case study.

At the system level, two-thirds of all boardings on the BART system occurred in the morning (7 a.m. to 9 a.m.) and afternoon (4 p.m. to 7 p.m.) peaks [Ref 53]. This peaking affects the input distribution of both the mode split and the transit load factor. Since the majority of park-and-ride and kiss-and-ride trips occur in the morning and in the evening, the auto load factor distribution is also affected by the peaking. Table 3.11 shows the model input for the BART stations, as well as the mode and the range of values for each variable in the frequency distributions.

TABLE 3.11 MODEL INPUT, BAY AREA RAPID TRANSIT

Variable	Mode	Range	Ref
AWDVTE	Single Value, Station Specific	Single Value, Station Specific	F
Auto Load Factor	1.2 persons/veh	1-1.2 persons/veh	E
Transit Load Factor	240 persons/veh	25-240 persons/veh	D
Percent Transit Trips	32%	7-32 %	C
Auto Energy Consumption	4,100 BTU/veh-mi	3,500-6,900 BTU/veh-mi	B
Transit Energy Consumption	90,000 BTU/veh-mi	50,000-93,000 BTU/veh-mi	A

Sources: [A] *Evaluation Urban Transportation System Alternatives,* p. III-10.
[B] *Transportation Energy Data Book, Edition 10,* p. 3-61.
[C] *BART's First Five Years: Transportation and Travel Impacts,* p. 94,120.
[D] *Characteristics of Urban Transportation Systems,* p. 130.
[E] *Transit Fact Book,* 1989 Edition, p. 51, 53.
[F] *ITE Trip Generation Report,* 5th Edition.

Downtown Oakland

The Oakland Central Business District was in decline during the planning stages for BART in the late 1950's and early 1960's. BART was considered, along with other redevelopment projects, a key catalyst for Oakland's revitalization. Zoning around two downtown stations, 12th Street and 19th Street, provides for mixed use and no parking requirements. The two stations are 1,800 feet apart. Since their quarter mile radii overlap, the stations are considered a single node for trip ends in this analysis. During the study period, 1.2 million square feet of new office space was developed in the vicinity of these two stations [Ref 7]. An estimated total of 9,182 Average Weekday Vehicle Trip Ends (AWDVTE) were generated from these offices. No other new development was reported during the study period. Since the station areas are located in downtown Oakland, both the 12th Street and the 19th Street station areas are classified as a CBD location containing office development.

Fremont

Fremont is located approximately 25 miles southeast of San Francisco on the East Bay. The station is the southern terminus of the Fremont line. Fremont was incorporated in 1956 and since then has been transformed from farmland to a residential and industrial area [Ref 7]. The major development in the Fremont station area is indicative of a commuter oriented station area. Table 3.12 shows the trip generation characteristics of that development. Since the Fremont station is a terminal point in an area that was, until recently, farmland, the station area can be considered a suburban location. Residential and commercial development are the predominant land uses in the station area.

TABLE 3.12 FREMONT TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Condominiums	300 d.u.	230	0.82	185	1,657
Retail	250,000 sf	320	0.78	267	12,530
Condominiums	712 d.u.	230	0.82	185	3,455
Total					17,642

Source: Land Use Data: *Land Use and Urban Development Impacts of BART,* p. 76,136
ITE Data: *Trip Generation Report,* 5th Edition.

Walnut Creek

Walnut Creek is located at the junction of Interstate 680 and Route 24, approximately 25 miles east of San Francisco. Development on a large scale did not occur at Walnut Creek until the 1950's, even though the city was incorporated in 1914 [Ref 7]. Development in this station area is residential, with some office development as well. Table 3.13 shows the trip generation characteristics of new development in the station area. Since Walnut Creek did not grow rapidly until the 1950's, a period of extensive suburbanization, the station area can be considered a suburban location. As stated earlier, the predominant land uses are residential and office.

TABLE 3.13 WALNUT CREEK TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Office	135,000 sf	710	0.82	66	1,760
Apartments	339 d.u.	210	0.86	109	2,155
Apartments	788 d.u.	210	0.86	109	5,113
Condominiums	400 d.u.	230	0.82	185	2,116
Total					11,144

Source: Land Use Data: *Land Use and Urban Development Impacts of BART,* p. 76,133
ITE Data: *Trip Generation Report,* 5th Edition.

Simulation Results

The simulation results for the three Bay Area case studies indicate that energy savings can vary greatly not only within each station area but also between station areas, which was expected, given the number of local factors that influence both transit ridership and development decisions. The frequency distributions of the results—Figures B.7 through B.9—are in Appendix B. Table 3.14 summarizes the station area classification and net energy savings for the BART stations. The Fremont station had the greatest median and range of energy savings, owing to the amount of retail development at that location. The two downtown Oakland stations, 12th and 19th Streets, also had significant development; however, the office space in these station areas has more peaked trip generation characteristics. The large condominium and retail projects are more likely to contribute to BART's ridership at other times during the day. Again, it is important to remember that these energy savings are derived from development-based transit trip end estimates, not ridership figures. Nevertheless, the Fremont station area appears to be generating a significant net energy savings as a result of development in that area. The high percentage of cases with postive net energy savings indicate that the transit trips to and from development in the studied BART station areas are more efficient than automobile trips on a given weekday.

TABLE 3.14 BART STATION AREA NET ENERGY SAVINGS

	Station Areas		
	12th/19th Street	Fremont	Walnut Creek
Classification			
Location	CBD	Suburban	Suburban
Development	Office	Commercial Residential	Office Residential
Net Energy Savings (million BTU/passenger-mile)			
Low	- 1.2	-3.2	- 1.9
10th Percentile	0.9	2.1	1.0
Median	4.3	10.3	4.7
90th Percentile	8.4	23.7	20.2
High	16.1	38.1	39.8
Positive Cases (Percent)	96.2	97.0	96.2

WASHINGTON, D.C.

Washington, D.C.'s rapid rail system, known as METRO or Metrorail, is operated by the Washington Metropolitan Area Transit Authority (WMATA). METRO initiated rail service in 1976; 103 miles of line and 87 stations are planned. To date (1991), 77 stations and 89 miles have been completed. Changes in land use around the studied METRO stations resulted in mixed-use developments with office space as the primary focus. High-density residential units have not been as common. In fact, suburban communities prefer to develop office projects, since they are more profitable. Unfortunately, most of the labor force for these offices live outside the station areas and drive to work. Therefore, "such development would be unlikely to generate many additional transit users" [Ref 9]. This is in contrast to office developments in the District of Columbia, where there is high transit usage by commuters from the suburban areas.

This study examines station areas in nearby northern Virginia, such as the Crystal City and Rosslyn station areas. Downtown Washington, D.C. is not examined, since development density and transit ridership are high, and, therefore, there is already an energy savings that transit ridership, in competition with the automobile, is providing.

Model Inputs

The model inputs for the WMATA stations involve values at the study, system, and station level. The study values for auto and transit energy consumption were noted in Chapter 2. The system values include transit load factors, auto load factors, and the mode split. For each station, the Average Weekday Vehicle Trip Ends (AWDVTE) are estimated. The system level values are discussed below, while the AWDVTE are calculated in each case study.

At the system level, two-thirds of all trips on METRO occurred in the morning (7 a.m. to 9 a.m.) and afternoon (4 p.m. to 7 p.m.) peaks [Ref 54]. This peaking affects the input distribution of both the mode split and the transit load factor. Since the majority of carpooling and ridesharing trips occur in the morning and in the evening, the auto load factor distribution is also affected by the peaking. Note that the auto occupancy rates for Washington, D.C. are higher than the occupancy rates of other systems studied. Table 3.15 lists the model input for the WMATA stations. The mode and the range of values for the frequency distributions are also listed.

Crystal City

The Crystal City station, located off the Jefferson Davis Highway in Arlington County, Virginia, opened in 1977. It is currently served by the Blue and Yellow Lines. Near both the Pentagon and National Airport, the station area has office, retail, and residential uses [Ref 55]. Table 3.16 shows the trip generation characteristics of new development during the study period.

TABLE 3.15 MODEL INPUT, WASHINGTON, D.C.

Variable	Mode	Range	Ref
AWDVTE	Single Value, Station Specific	Single Value, Station Specific	F
Auto Load Factor	1.55 persons/veh	1-1.64 persons/veh	E
Transit Load Factor	240 persons/veh	25-240 persons/veh	D
Percent Transit Trips	50%	11-62 %	C
Auto Energy Consumption	4100 BTU/veh-mi	3500-6900 BTU/veh-mi	B
Transit Energy Consumption	90,000 BTU/veh-mi	50,000-93,000 BTU/veh-mi	A

Sources: [A] *Evaluation Urban Transportation System Alternatives,* p. III-10.
[B] *Transportation Energy Data Book, Edition 10,* p. 3-61.
[C] *Development Related Ridership Survey.*, p. 20,33,38,49,59.
[D] *Characteristics of Urban Transportation Systems,* p. 130.
[E] *The First Four Years of Metrorail: Travel Changes,* p. 70,72.
[F] *ITE Trip Generation Report,* 5th Edition.

TABLE 3.16 CRYSTAL CITY TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Hotel	452 rooms	320	0.77	20	167
Office	490,000 sf	710	0.82	66	4,665
Hotel	685 rooms	320	0.77	20	251
Retail	150,000 sf	320	0.77	20	9,105
Retail	150,000 sf	320	0.77	20	9,105
Condominiums	540 d.u.	230	0.82	185	2,732
Total					26,025

Source: Land Use Data: *Development-Related Ridership Survey,* p. 13,34,46,54.
ITE Data: *Trip Generation Report,* 5th Edition.

The Crystal City station area is located across the Potomac River from Washington, D.C. in a relatively urban area in northern Virginia. New office, residential, and commercial development has occurred there. Thus, the Crystal City station area is classified as a center city location containing office, residential, and commercial development.

Rosslyn

The Rosslyn station, like Crystal City, opened in 1977. It is the first station located in Virginia on the Blue and Orange Lines. Since Rosslyn lies close to Washington, intense "spillover" development had been occurring there even before the METRO station opened. This development trend has continued since the opening of the station. Table 3.17 shows the new development in the Rosslyn station area and the related trip generation characteristics.

TABLE 3.17 ROSSLYN TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Hotel	558 rooms	320	0.77	20	205
Office	430,000 sf	710	0.82	66	4,226
Retail	52,000 sf	320	0.78	267	4,696
Condominiums	432 d.u.	230	0.82	185	2,260
Total					11,387

Source: Land Use Data: *Development-Related Ridership Survey,* p. 13,34,46,54.
ITE Data: *Trip Generation Report*, 5th Edition.

The Rosslyn station area is also located across the Potomac River from Washington, D.C. in an urban area in northern Virginia. Even though high-density development occurred in the Rosslyn station before the coming of METRO, significant new office, residential, and commercial development has been constructed since the opening of the station. Thus, the Rosslyn station area is classified as a center city location containing office, residential, and commercial development.

Simulation Results

The simulation results for the Crystal City and Alewife case studies indicate that energy savings can vary greatly not only within each station area, but also between station areas, which was expected, given the number of local factors that influence both transit ridership and development decisions. Histograms of the frequency distributions for the two station areas—Figures B.10 and B.11—are in Appendix B. Table 3.18 summarizes the station area classification and net energy savings for the WMATA stations. The Crystal City station had the greatest median and range of energy savings, which is the result of the amount of development occurring at Crystal City since the station opened. The Rosslyn station area had significantly less energy savings, owing to a decline in new development after rail service was initiated. This reduction in energy savings for Rosslyn does not imply that the land uses in the Rosslyn station area produce fewer transit trips than the land uses in the Crystal City station area; it does indicate that more new development occurred at Crystal City during the study period.

TABLE 3.18 WMATA STATION AREA NET ENERGY SAVINGS

	Station Areas	
	Crystal City	Rosslyn
Classification		
Location	Center City	Center City
Development	Office Commercial Residential	Office Commercial Residential
Net Energy Savings (million BTU/passenger-mile)		
Low	-14.5	- 0.6
10th Percentile	2.2	0.6
Median	18.4	7.1
90th Percentile	53.3	18.4
High	112.4	42.3
Positive Cases (Percent)	93.4	92.6

The two station areas had slightly lower percentages of positive energy savings from the simulation than the station areas examined on the other systems likely due to the relatively high auto load factor in the Washington, D.C. area. Nevertheless, since these negative values occurred in less than 8 percent of the total number of cases in either station area, it is likely that the transit trips to and from development in the WMATA station areas on a given weekday are more efficient than automobile trips.

SUMMARY

This chapter examined—from systems across the United States—eleven case studies of rapid rail stations. These systems varied in age and in geographical area served. Within each system, the station areas represented further geographic diversity. Once the model inputs from each system are outlined, two or three station areas are studied in detail. For each station area, new development is inventoried and trips ends for an average weekday are estimated. The simulation results are statistical interpretations of 500 cases, representing the variability of the model inputs. The statistics described the most likely energy savings for each station area. Table 3.19 summarizes the station areas and the simulation results in tabular form. The station areas are categorized by their location (CBD, Center City, or Suburban) and the type(s) of development present. Chapter 5 will present a comparison of the station areas as well as the study's conclusions.

TABLE 3.19 SUMMARY, RAIL STATION AREAS

Station Area	Development Type†	AWDVTE	Net Energy Savings (million BTU/passenger-mile) Low	Median	High
CBD Stations					
Five Points	OC	38,810	-4.4	14.5	52.8
Peachtree Center	O	18,320	-2.3	6.3	25.1
12th/19th Streets	O	9180	-1.2	4.3	16.1
Center City Stations					
Alewife	OC	10,380	-0.4	13.3	35.7
Porter Square	OCR	2110	0	2.7	7.1
Davis Square	OCR	1070	-0.3	1.4	3.7
Crystal City	OCR	26,025	-14.5	18.4	112.4
Rosslyn	OCR	11,390	-0.6	7.1	42.3
Suburban Stations					
Lenox	OCR	38,950	-4.8	14.3	31.9
Fremont	CR	17,640	-3.2	10.3	38.1
Walnut Creek	OR	11,140	-1.9	4.7	39.8

†O=Office, C=Commercial, R=Residential

CHAPTER 4. BUS TRANSIT STATIONS

INTRODUCTION

Given the expense of constructing rapid rail systems, many cities have attempted to upgrade their bus systems by operational improvements such as preferential lanes and priority signalization. These improvements—some of which have produced high quality bus systems that resemble rapid transit in their operational characteristics—are often included under the umbrella of "Transportation Systems Management" or TSM. This study examines "bus rapid" facilities in relation to rapid rail systems in terms of development in station areas and ability to generate energy-efficient transit trips.

In this chapter, case studies of bus transit station areas (from the systems described in Chapter 2) are presented. Each system is from a different geographical area and has different development markets and transit histories. These differences, which are based on available data, are represented by system level input distributions. Once the system level inputs are established, the selected station areas in each system are examined in detail. New development will be inventoried in these station areas, and their corresponding trip generation characteristics will be estimated. The computer simulation then estimates a range of net energy savings for 500 cases. The collective results of these cases are presented using descriptive statistics.

OTTAWA

The Regional Municipality of Ottawa-Carleton has a Bus Rapid (BRT) system operated by the Ottawa-Carleton Regional Transit Commission (OC Transpo). Service, initiated in December 1983, currently consists of three lines totaling 12.4 miles (19.3 miles planned) with 14 stations (23 by 1994). This system consists of two-directional bus-only roadway with high-quality stations. Some buses stop at every station, while others use the system as a High Occupancy Vehicle (HOV) lane, providing feeder and then express service to the Ottawa CBD. Overall, there are an additional 2.8 million square feet of institutional and commercial/office development and 1,305 dwelling units that are worth an estimated $270 million (Canadian); many positive indicators suggest that the transitway stations are influencing development within the station areas [Ref 56].

In this analysis, four stations—Baseline, Blair, St. Laurent, and Tunney's Pasture—are reviewed. These stations are in the suburbs and will be classified as such (suburban) in this analysis. The initial study of Ottawa did not investigate the CBD transit mall or the center city, since it was felt that the development was "mature" [Ref 56].

Model Inputs

The model inputs for the Ottawa bus rapid stations involve values at the study, system, and station level. The study values are the auto and transit energy consumption values discussed in Chapter 2. The system values include transit load factors, auto load factors, and the mode split. Finally, for each station, the Average Weekday Vehicle Trip Ends (AWDVTE) are estimated. The system level values are discussed below, while the AWDVTE are calculated in each case study.

At the system level, as a rule of thumb, 30 percent of daily travel occurs during the peak hour [Ref 18]. When the peak hour is combined with the two "shoulder" hours before and after the peak, nearly half of the average weekday transit trips can be placed in the peak hour, shoulder hours time frame. Since no specific peaking data are available for Ottawa-Carleton, the rule of thumb given for the system level is used. This peaking affects the input distribution of both the mode split and the transit load factor. Articulated buses are not considered in estimating transit load factors. The mode split for the OC Transpo station areas is estimated by assuming equal transit and auto travel times. The mode split was then obtained using OC Transpo's calibrated transit usage curves [Ref 19]. Since the greatest concentration of work trips occurs in the morning, the auto load factor distribution is also affected by the peaking. Table 4.1 lists the model input for the OC Transpo stations.

Baseline

Opened in December 1983, the southwestern terminus of the transitway is at the Baseline station. Before the opening of the station, development was primarily low to medium residential and strip commercial. Table 4.2 shows development in the station area since the opening. The corresponding trip generation characteristics are also listed, and new development is valued at approximately $30 million (1987 Canadian) [Ref 56].

Blair

The Blair station, which opened in 1989, is one of the newer facilities on the transitway. Before the station opening, existing development consisted of a community shopping center, "strip center" retail, and low to medium density residential units. Since the station opening, extensive office development and some residential development has occurred. Table 4.3 categorizes this new development, valued at $89.9 million (1987 Canadian) [Ref 56], and its corresponding trip generation characteristics.

TABLE 4.1 MODEL INPUT, OC TRANSPO STATIONS

Variable	Mode	Range	Ref
AWDVTE	Single Value, Station Specific	Single Value, Station Specific	E
Auto Load Factor	1.2 persons/veh	1-1.2 persons/veh	B
Transit Load Factor	45 persons/veh	25-50 persons/veh	C,D
Percent Transit Trips	50%	35-75 %	F
Auto Energy Consumption	4,100 BTU/veh-mi	3,500-6,900 BTU/veh-mi	A
Transit Energy Consumption	30,000 BTU/veh-mi	23,000-48,000 BTU/veh-mi	C

Sources: [A] *Transportation Energy Data Book, Edition 10,* p. 3-61.
[B] *Transit Fact Book,* 1989 Edition, p. 51, 53.
[C] *Characteristics of Urban Transportation Systems,* p. 62,130.
[D] *Nati Urban Mass Transportation Statistics, 1985 Sec. 15 Report,* p. 3-279.
[E] *ITE Trip Generation Report,* 5th Edition.
[F] *A Review of Canadian Urban Passenger Mode Choice Models*, p. 28.

TABLE 4.2 BASELINE TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Apartments	1,584 d.u.	210	0.86	109	10,451
Office/Retail	480,070 sf	710	0.82	66	4,593
Office	786,841 sf	710	0.82	66	6,674
Total					21,718

Sources: Land Use Data: *Development in the Vicinity of Transitway Stations*, p. 3.
ITE Data: *Trip Generation Report,* 5th Edition.

TABLE 4.3 BLAIR TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Apartments	325 d.u.	210	0.86	109	2,064
Office/Retail	1,583,371 sf	710	0.82	66	11,324
Total					13,388

Sources: Land Use Data: *Development in the Vicinity of Transitway Stations* , p. 6.
ITE Data: *Trip Generation Report*, 5th Edition.

St. Laurent

Opened in 1987, the St. Laurent station is considered one of the busiest stations on OC Transpo's system [Ref 56]. Pre-existing development in the station area included a regional shopping center, as well as industrial and low to medium residential land uses. Table 4.4 shows new development in the station area and the resulting trip generation characteristics.

TABLE 4.4 ST. LAURENT TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Apartments	337 d.u.	210	0.86	109	2,142
Office/Retail	1,332,572 sf	710	0.82	66	9,939
Manufacturing	229,271 sf	140	0.88	60	877
Total					12,958

Sources: Land Use Data: *Development in the Vicinity of Transitway Stations* , p. 5.
ITE Data: *Trip Generation Report*, 5th Edition.

Tunney's Pasture

The Tunney's Pasture Station commenced operations in 1984. Prior to the opening of the station, development in the station area consisted of Canadian government offices as well as strip commercial and low to medium density residential land uses. One of the major projects that has been completed since the opening of the station is a $33.5 million (1987 Canadian) mixed use development [Ref 56]. Table 4.5 shows this mixed use development and other development along with their trip generation characteristics.

TABLE 4.5 TUNNEY'S PASTURE TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Apartments	4188 d.u.	210	0.86	109	28,286
Office/Retail	3,349,728 sf	710	0.82	66	19,953
Hospital	115,173 sf	610	0.75	14	3,011
Manufacturing	72,118 sf	140	0.88	60	266
Total					51,516

Sources: Land Use Data: *Development in the Vicinity of Transitway Stations*, p. 4.
ITE Data: *Trip Generation Report*, 5th Edition.

Simulation Results

The simulation results for the four Ottawa case studies indicate that energy savings can vary greatly not only within each station area, but also between station area; as expected. Table 4.6 summarizes the station area classification and net energy savings for the OC Transpo stations.

Histograms showing the frequency distribution of the net energy savings are in Appendix B—Figures B.12 through B.15. The Tunney's Pasture station had the greatest median and range of energy savings, because of the extensive amount of residential and office development at that suburban location. Two stations, Blair and St. Laurent, also had very similar energy savings. None of these station areas produced cases with negative net energy savings. Two reasons account for this: (1) a bus is, incrementally, more efficient than a train, since it is more efficient to add one more bus than another train to the system, and (2) Ottawa has a good "transit history," that is, Canadian transit consistently commands a higher share of transit trips than do American systems, regardless of whether such transit is bus or rail. Moreover, Canadian planning policy is very well-coordinated and favors "transit-sensitive" development. The Canadian planning policy for Ottawa is especially well-designed, since Ottawa is the federal capital. It is important to remember, however, that these energy savings are derived from development-based transit trip end estimates, not ridership figures. Nevertheless, the stations on OC Transpo's unique system appear to be generating a significant net energy savings as a result of development in their station areas.

TABLE 4.6 OC TRANSPO STATION AREA NET ENERGY SAVINGS

	Station Areas			
	Baseline	Blair	St. Laurent	Tunney's Pasture
Classification				
Location	Suburban	Suburban	Suburban	Suburban
Development	Office	Office	Office	Office
	Commercial	Commercial	Commercial	Commercial
	Residential	Residential	Residential	Residential
Net Energy Savings (million BTU/passenger-mile)				
Low	6.6	5.0	4.0	22.4
10th Percentile	15.8	10.7	10.3	39.7
Median	30.3	19.2	19.0	76.8
90th Percentile	55.6	37.3	36.4	137.0
High	103.0	61.5	62.6	231.7
Positive Cases (Percent)	100.0	100.0	100.0	100.0

BUS TRANSIT MALLS

Bus transit malls have the twofold purpose of transit improvement and downtown revitalization. Bus transit malls, which have become an important focus of the regional transit system, combine pedestrian malls and preferential bus treatment, that is, auto restricted zones (ARZ's) are created while maintaining bus lanes. From a development perspective, a transit mall can be considered a "compromise." Pedestrian and transit rider volumes considered separately probably do not warrant the implementation of an ARZ, but considered in tandem they might. Transit and pedestrian uses can "complement" each other, stimulating development and downtown revitalization while improving transit service and increasing ridership [Ref 10].

This study examines two bus transit malls in Portland and Denver. Again, the intention is to see whether high-quality bus facilities can compete with the rapid rail systems discussed in Chapter 3 in generating transit-sensitive development that will produce energy-efficient transit trips. Since one purpose of a transit mall is downtown revitalization, both transit mall station areas are classified as CBD locations.

The Portland Mall

The Portland Mall (not be be confused with the cross-mall Banfield Light Rail Transit alignment) encompasses 11 blocks in downtown Portland. Fifth Avenue handles southbound buses, while northbound buses use Sixth Avenue. The purpose of the mall is to "eliminate the private auto from a major segment of a Central Business District (CBD) street system and to dedicate those streets to transit usage" [Ref 10]. The Mall was completed in 1978 and is operated by the Tri-County Metropolitan Transportation District of Oregon (Tri-Met); each street consists of two bus lanes with an intermittent auto access every three blocks.

Bus travel within the mall is free. Since the blocks are 200 feet long, approximately six blocks are a quarter-mile. The mall would fit into the theoretical station area, if a station were located exactly in the mall's center. Given the mall's size and the free bus travel, the entire mall is considered a single station area in this analysis. Trips to and from the mall, but not within the mall, is considered.

The model inputs for the Portland Mall involve values at the study, system, and station level. Values for the auto and transit energy consumption values ARE FROM Chapter 2, and the system values include transit load factors, auto load factors, and mode split. Finally, at the station level, the AWDVTE are estimated.

The 30 percent rle of thumb for daily travel during the peak hour is used [Ref 18], and when combined with the "shoulder" hours before and after the peak, nearly half of the average weekday transit trips take place in that time frame. This peaking affects the input distribution of both the mode split and the transit load factor; articulated buses are not considered in estimating transit load factors; reported mode splits are available for the Portland Mall [Ref 10]. Since the greatest concentration of work trips occur in the morning, the auto load factor distribution is also affected by the peaking. Table 4.7 lists the model input for the Portland Mall, and the mode and the range of values for the frequency distributions.

TABLE 4.7 MODEL INPUT, THE PORTLAND MALL

Variable	Mode	Range	Ref
AWDVTE	Single Value	Single Value	E
Auto Load Factor	1.2 persons/veh	1-1.2 persons/veh	B
Transit Load Factor	45 persons/veh	25-50 persons/veh	C,D
Percent Transit Trips	27.6%	5-53%	F
Auto Energy Consumption	4100 BTU/veh-mi	3500-6900 BTU/veh-mi	A
Transit Energy Consumption	30,000 BTU/veh-mi	23,000-48,000 BTU/veh-mi	C

Sources: [A] *Transportation Energy Data Book, Edition 10,* p. 3-61.
[B] *Transit Fact Book,* 1989 Edition, p. 51, 53.
[C] *Characteristics of Urban Transportation Systems,* p. 62,130.
[D] *National Urban Mass Trans.Statistics, 1985 Sec. 15 Report,* p. 3-279.
[E] *ITE Trip Generation Report,* 5th Edition.
[F] *The Portland Mall Impact Study,* , p. 75-76.

Table 4.8 shows new development in the Portland Mall "station area" and its corresponding trip generation. Most of the new development has been office and retail; no residential development has been reported. A strong office market and the transit mall were cited as reasons for new development locating in the Portland Mall "station area" [Ref 10].

TABLE 4.8 PORTLAND MALL TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Retail	377,000 sf	320	0.78	267	16,198
Office	1,629,000 sf	710	0.82	66	11,569
Total					27,767

Sources: Land Use Data: *The Portland Mall Impact Study*, p. 103-107.
ITE Data: *Trip Generation Report*, 5th Edition.

The 16th Street Mall (Denver)

Located in Denver's downtown shopping district, parallel to the financial district, the 16th Street Mall consists of a 13 block two directional bus circulator that links two regional bus transfer stations. These transfer stations handle about 600 regional and express buses daily from outlying areas. The mall opened in October 1982. Since that time, approximately 45,000 riders per day use the shuttle system, which in 1982 had a projected daily ridership of 10,000 patrons [Ref 57].

Travel within the mall is free on the shuttle system. As stated earlier, this shuttle system connects two high-quality transfer facilities that form the hub of the Regional Transportation District's (RTD) downtown regional service and express service. Given the nonexistent travel cost within the mall and the number of buses carrying passengers to and from various locations in metropolitan Denver, the mall is considered a single station area in this analysis. Trips to and from the mall, but not within the mall, is examined.

The model inputs for the 16th Street Mall involve values at the study, system, and station level. As for the other cases, for auto and transit energy consumption values are from Chapter 2. The system values include transit load factors, auto load factors, and the mode split. At the mall or station level, the AWDVTE are estimated. At the system level, the30 percent rule of thumb for daily travel during the peak hour is used [Ref 18]. When combined with the "shoulder" hours, nearly half of the average weekday transit trips are included in that time frame. This peaking affects the input distribution of both the mode split and the transit load factor. Articulated buses are not considered in estimating transit load factors. The 16th Street Mall, while viewed favorably in Denver, has not significantly decreased auto trips [Ref 57]. Thus, the percentage of transit trips to downtown Denver is lower than that in Portland, although closer, perhaps, to the typical mode split for large southwestern cities. A conservative estimate for mode split is made. Since the greatest concentration of work trips occurs in the morning, the auto load factor distribution is also affected by the peaking. Table 4.9 lists the model input for the 16th Street Mall, as well as the mode and the range of values for the frequency distributions.

TABLE 4.9 MODEL INPUT, 16TH STREET MALL

Variable	Mode	Range	Ref
AWDVTE	Single Value	Single Value	E
Auto Load Factor	1.2 persons/veh	1-1.2 persons/veh	B
Transit Load Factor	45 persons/veh	25-50 persons/veh	C,D
Percent Transit Trips	20%	5-20%	B
Auto Energy Consumption	4,100 BTU/veh-mi	3,500-6,900 BTU/veh-mi	A
Transit Energy Consumption	30,000 BTU/veh-mi	23,000-48,000 BTU/veh-mi	C

Sources: [A] *Transportation Energy Data Book, Edition 10,* p. 3-61.
[B] *Transit Fact Book,* 1989 Edition, p. 51, 53.
[C] *Characteristics of Urban Transportation Systems,* p. 62,130.
[D] *National Urban Mass Trans. Statistics, 1985 Sec. 15 Report,* p. 3-279.
[E] *ITE Trip Generation Report,* 5th Edition.

Table 4.10 shows new development in the 16th Street Mall "station area" and its corresponding trip generation. Most of the new development has been office and retail; no residential development has been reported.

TABLE 4.10 16TH STREET MALL TRIP GENERATION

Land Use Data		ITE Report Data			
Type	Size	Land Use Code	R^2	# Studies	AWDVTE
Retail	120,000 sf	320	0.78	267	7,920
Retail	76,000 sf	320	0.78	267	5,953
Retail	50,000 sf	320	0.78	267	4,582
Retail	50,000 sf	320	0.78	267	4,582
Office	2,500,000 sf	710	0.82	66	15,994
Total					39,031

Sources: Land Use Data: "Denver's 16th Street Mall," p. 133.
ITE Data: *Trip Generation Report*, 5th Edition.

Simulation Results

The simulation results for the bus transit mall case studies indicate that energy savings can vary within each transit mall. Table 4.11 summarizes the station area classification and net energy savings (frequency distributions can be found in Appendix B). Given the number of local factors that influence both transit ridership and development decisions, the median and range of the net energy savings for the two malls are similar. The Portland Mall had the greatest median and range of energy savings, which had nothing to do with the amount of development occurring in the area; the data shows that it was the relatively high transit trip percentage in the Portland area that effected the energy savings. The 16th Street Mall in Denver had more development (and thus more trips generated), but a lower transit mode split. Neither of the station areas produced cases with negative net energy savings—a possible explanation for this being the capacity argument discussed in the Ottawa summary. It is important to remember, however, that these energy savings are derived from development-based transit trip end estimates, not ridership figures. It has not been proved that the Portland and Denver malls, while successful in revitalizing downtown and increasing CBD-oriented transit ridership, have affected regional land use or development patterns or increased aggregate transit share [Ref 10, 57]. Nevertheless, these transit malls appear to be generating a significant net energy savings as a result of development in their station areas.

TABLE 4.11 BUS TRANSIT MALL NET ENERGY SAVINGS

	Station Areas	
	The Portland Mall	16th Street Mall
Classification		
Location	CBD	CBD
Development	Office Commercial	Office Commercial
Net Energy Savings (million BTU/passenger-mile)		
Low	1.8	1.9
10th Percentile	3.7	7.0
Median	21.7	15.1
90th Percentile	50.0	32.3
High	94.2	149.9
Positive Cases (Percent)	100.0	100.0

SUMMARY

This chapter examined six case studies of bus transit stations across the United States and Canada. The intent is to study bus rapid systems, using the same criteria as that of the rapid rail stations in the previous chapter. The three bus systems are different in size, type, and geographical area served. Once the model inputs from each system are outlined, specific station areas are studied in detail. For each station area, new development is inventoried and trip ends for an average weekday are estimated. The simulation results for each station area are statistical interpretations of 500 cases representing the variability of the model inputs. The statistics described the most likely energy savings. The station areas, categorized by their location (CBD or Suburban), and the type(s) of development present, are summarized in Table 4.12. A comparison of the station areas (both bus and rail) are presented in the next chapter, as well as the study's conclusions.

TABLE 4.12 SUMMARY, BUS STATION AREAS

Station Area	Development Type†	AWDVTE	Net Energy Savings (million BTU/passenger-mile) Low	Median	High
CBD Stations					
Portland Mall	OC	27,770	1.8	50.0	94.2
16th Street Mall	OC	39,030	1.9	32.3	149.9
Suburban Stations					
Baseline	OCR	21,720	6.6	30.3	103.0
Blair	OCR	13,390	5.0	19.2	61.5
St. Laurent	OCR	12,958	4.0	19.0	62.6
Tunney's Pasture	OCR	51,520	22.4	76.8	231.7

†O=Office, C=Commercial, R=Residential

CHAPTER 5. GENERAL FINDINGS

INTRODUCTION

The purpose of this chapter is twofold. First, the characteristics of the 17 station areas are compared in order to determine the factors that contribute to a station area's ability to generate energy-efficient trip ends through new development. The second part of the chapter presents a summary of the report, possible applications, conclusions, and recommendations for further research.

COMPARING STATION AREAS

All the station areas examined in Chapters 3 and 4 show positive net energy savings for a majority of the 500 model applications performed for each station area. Of course, these energy savings vary greatly by station area. Thus, comparisons between station areas are needed to determine why some station areas are more efficient than others. Station areas are compared by system mode, station location, type of development, and quantity of trip ends generated.

These comparisons are formulated by examining the relationship between the trip ends for station area development and the median net energy savings for each station area. It should be made clear that the median value is a means of comparison only and does not represent the most likely value. Still, the median net energy savings defines a minimum level of energy efficiency for trips to and from development in the station area for half of the observations. A plot—named a "trip end-energy savings" plot—can be made of Average Weekday Vehicle Trip Ends (AWDVTE) versus the median net energy savings (in BTU/passenger-mile) for a station area. A very efficient station area relative to the number of trip ends is located in the lower right area of the graph, while the least efficient is located in the upper left area of the graph. For each comparison, a trip end-energy savings plot is used to investigate which station areas have similar characteristics and which generate the most energy-efficient trip ends.

System Mode

Figure 5.1 is a trip end-energy savings plot that compares rail and bus facilities. The three stations with the greatest median net energy savings are Tunney's Pasture, Baseline, and the Portland Mall. All three stations serve bus systems. There are two possible reasons for the bus stations' efficiency. One reason is incremental increases in system capacity, since it is more efficient to add another bus to the system than to add another train. The second reason, however, probably accounts for most of the energy savings. All three station areas have remarkably high mode splits. Buses traveling to and from the Portland Mall claim over 50 percent of trips during the morning and evening peaks [Ref 10]. Tunney's Pasture and Baseline, stations on OC Transpo's transitway, have slightly higher mode splits [Ref 19]. The rail station with the greatest net energy savings is Crystal City. The percentage of trips taken on transit during the peak hours to and from Crystal City also falls in the 50 percent range [Ref 55]. Stations like Five Points, Lenox, and the 16th Street Mall generate numerous trip ends, but they have a lower percentage of trips on transit. It appears that system mode type does not influence whether or not trips to and from station area development are efficient; this determination is based on the assumption that the transit system commands a large share of trip ends in and out of its station areas.

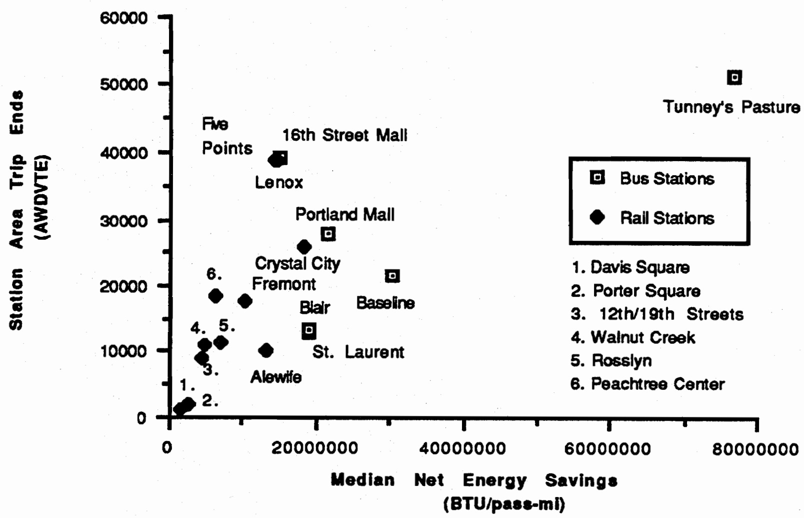

Figure 5.1 Station Areas by System Mode

Station Location

Figure 5.2 is a trip end-energy savings plot that differentiates between CBD, Center City, and Suburban station areas. The stations with the greatest median net energy savings—Tunney's Pasture, Baseline, and the Portland Mall—are located in different areas of their respective cities. The first two are suburban stations, whereas the Portland Mall is very much a CBD station. The model relates the net energy savings of a station area to the number of trips the new development in the station area generates; the model clearly shows that substantial "transit-sensitive" development in a suburban station area can generate just as many trip ends as similar development in a CBD or center city. Thus, station areas in cities with favorable zoning for station area development are realizing more development, generating more trip ends, and realizing a greater net energy savings. The Ottawa stations and the Lenox station in Atlanta are examples of suburban station areas with such "transit-sensitive" land use policies [Ref 58,59]. The two bus transit malls in downtown Denver and Portland, by their design, also have "transit-sensitive" policies. Stations in areas with restrictive development policies (Davis Square [Ref 13]) or in areas nearing saturation or "buildout" (Alewife [Ref 13], Rosslyn [Ref 55]) have less new development and realize less net energy savings. Therefore, local land use policy and the amount of available land are two factors that influence the net energy savings of a station area. Depending on the locality, these factors may be present in the CBD, Center City, or Suburban areas. Thus, a station's location alone does not guarantee a specific net energy savings range.

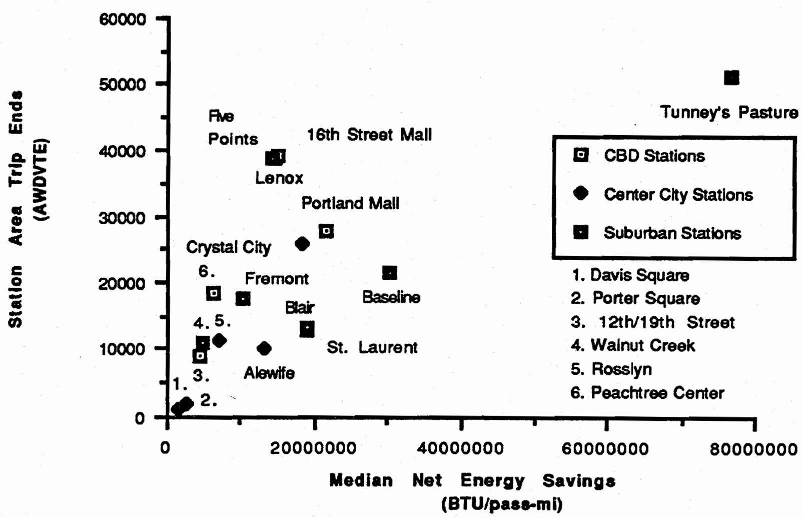

Figure 5.2 Station Areas by Location

Development Type

Station areas classified by development type are shown on a trip end-energy savings plot in Figure 5.3. The boldface letters indicate the type of new development in the station areas (**O**-office, **C**-commercial or retail, and **R**-residential). Two of the three station areas with the greatest median net energy savings, Tunney's Pasture and Baseline, contained all three development categories. The majority of station areas with a high median net energy savings also contained the three categories. New development in CBD stations like Five Points and the Portland Mall mainly consisted of office and commercial development; the predominant presence of office development may result in mainly peak hour trips [Ref 18]. Commercial and residential development, depending on size and density, may generate considerable off-peak transit trips. [Ref 18]. Nevertheless, it cannot be concluded that any specific combination of development (e.g., office, commercial, and residential) produces an optimal net energy savings. It is the quantity of development that produces the necessary trip ends and thus the energy savings.

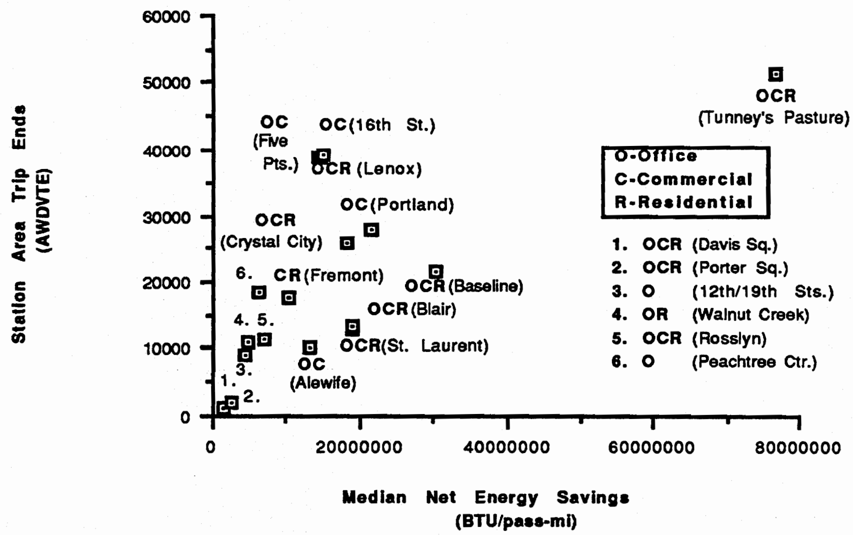

Figure 5.3 Station Areas by Development Type

Station Area Trip Ends

The station areas can be classified into groups by the number of station area trip ends which that area's development generates. Group I station areas are those with Average Weekday VehicleTrip Ends (AWDVTE) of less than 10,000. Group II stations are those with an AWDVTE of 10,000 to 20,000. Station areas with an AWDVTE over 20,000 are assigned to Group III. Figure 5.4 is a trip end-energy savings plot with the station areas assigned to these three groups. Generalizations can be made about the station areas in each group. Table 5.1 lists the station areas by group.

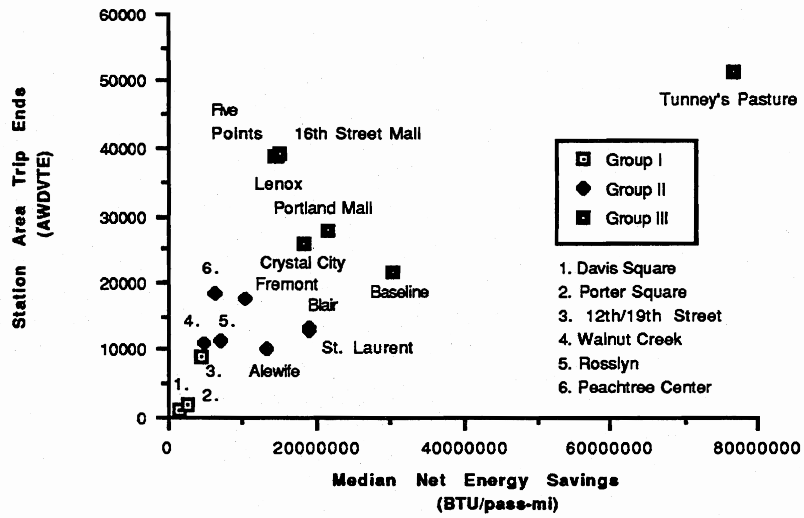

Figure 5.4 Station Areas by Trip Ends

The stations in Group I have the lowest number of trip ends of any of the stations observed. Thus, according to the model, they have the smallest quantity of new station area development. This level of development may result from lack of available land, local land use policy, or an undesirable location. The two Boston stations in the group, Porter Square and Davis Square, have little available land, and local policy favors the preservation of existing land uses (i.e., neighborhoods) [Ref 13]. The 12th/19th Street stations in the Oakland CBD represent a depressed area, which, during the study period, did not attract the same quantity of development as, for instance, the San Francisco CBD [Ref 7]. The reasons, cited above, for lack of development in each station area contributed to a constrained development environment, which is reflected in the lower net energy savings.

TABLE 5.1 STATION AREAS CLASSIFIED BY TRIP ENDS

Group I	Group II	Group III
Porter Square	Peachtree Center	Five Points
Davis Square	Alewife	Lenox
12th/19th Streets	Fremont	Crystal City
	Walnut Creek	Baseline
	Rosslyn	Tunney's Pasture
	Blair	Portland Mall
	St. Laurent	16th Street

The second group represents station areas with Average Weekday Vehicle Trip Ends in the 10,000 to 20,000 range. In general, these stations are in "transition" from one development pattern to another. Some station areas are increasing in population density as transit-sensitive development occurs and as the stations lose some of their pretransit suburban sprawl (Fremont [Ref 7] Walnut Creek [Ref 7], Blair [Ref 56], and St. Laurent [Ref 56]). Other station areas are reaching "buildout" (Peachtree Center [Ref 50], Alewife [Ref 13], and Rosslyn [Ref 55]), and development opportunities are decreasing. For the first subgroup, new development will continue to generate more trip ends and thus greater net energy savings beyond the study period. Development in these station areas is characterized by a mix of high- and low-density land uses. Since the second subgroup of stations is approaching buildout, these areas will realize less new development (short of renovation or demolition) and new trip ends. Development in this subgroup of station areas is characterized by incremental additions of high-density land uses. Outside the context of this analysis, the station areas in the buildout category are, of course, quite energy-efficient, owing to transit trips generated from existing development.

The third group of station areas, those with more than 20,000 average daily trip ends, all have high-intensity development. Three station areas serve as focal points to downtowns (Five

Points [Ref 50], Portland Mall [Ref 10], and the 16th Street Mall [Ref 57]), while four station areas are high-intensity nodes outside the CBD (Lenox [Ref 59], Crystal City [Ref 55], Baseline [Ref 56], and Tunney's Pasture [Ref 56]). While each station area has its differences, certain observations can be made as follows. Each station area already had substantial "anchor" development to attract further projects. The regional shopping center at Lenox and the government offices at Tunney's Pasture are good examples. Substantial commercial or retail development occurred in all the station areas. Such large-scale commercial development as Underground Atlanta (Five Points) can generate off-peak transit trips and thus can increase the station's net energy savings.

While system mode, station location, and development type by themselves cannot be used to classify station areas that produce optimal energy savings, the number of trip ends a station area generates can be used to categorize station areas. General statements can be made about the station areas in each of these groups: Group I station areas represent a constrained development environment; station areas in Group II are in transition, either becoming more "transit-sensitive" or nearing "buildout"; finally, Group III includes stations with significant high-intensity development.

CLOSURE

Summary and Conclusions

Chapter 1 has three main components. The introduction presents background information relating transportation to land use. A literature review follows, with studies grouped into four broad categories: (1) selected land use effect studies of transit systems, (2) strategies to improve land use impact of transit systems, (3) relationships between transportation energy consumption and urban development patterns, and (4) transportation energy requirements (consumption and intensity) of existing metropolitan areas. Finally, the structure and the purpose of this report are outlined.

The methodology of this study is presented in Chapter 2. Generalized relationships between station area development and energy savings per trip are established; basic differences in transit modes are discussed. Systems for study ware selected, and factors that could affect transit energy efficiency are explored. Given these factors and the generalized relationships, a model is developed to describe the net energy savings. Finally, a classification system was created so that different station areas can be compared more easily.

The case studies of the station areas are presented in Chapters 3 and 4. Chapter 3 explores rail transit stations, and Chapter 4 examines bus transit stations. The systems and station areas represent geographic and socioeconomic diversity. This diversity is reflected in the model input. Model input is discussed at the system level. Once this input is established, one to three station areas are examined. In each station area, new development is inventoried, and trip generation characteristics are estimated. The computer simulation then produces 500 random cases. The collective results of these cases are presented using descriptive statistics.

The first part of this chapter draws comparisons between station areas. The basis for these comparisons is the relationship between the Average Weekday Vehicle Trip Ends and the median net energy savings for each station area. This relationship is presented graphically in a trip end-energy savings plot. The effects of system mode, station location, development type, and trip ends are investigated. Several conclusions are drawn from these comparisons. The factors in the first three comparisons (system mode, station location, and development type) are characteristics of the classification system developed in Chapter 2.

System mode (bus or rail) is shown not to be a factor if the system mode split and vehicle load factors are favorable. In other words, if a bus rapid system has high ridership and is run efficiently (i.e., high transit load factors), then it can attract development in its station area in the same way as a rapid rail system. The OC Transpo transitway (particularly the Tunney's Pasture station) is a clear example of a successful bus rapid system attracting key development in its station areas.

Station location alone does not ensure a particular quantity or type of development. It is important to remember that most urban areas in North America today are polynucleated [Ref 59], and, therefore, high-density development of any type (office, commercial, or residential) can occur in a variety of locations. It would be incorrect to say that CBD locations did not experience station area development; CBD station areas (Five Points, Portland Mall, 16th Street Mall) did attract transit-sensitive development and energy saving transit trips. However, some suburban station areas (Lenox and the Ottawa stations) experienced as much, or more, development than did the other locations. Transit-sensitive land use policies and the success of the system (i.e., high mode split and transit load factor) are better indicators of a station area's ability to attract development than the geographic location alone. The type of development in the station areas is not likely to influence the overall net energy savings as much as the quantity of development and whether or not it is "transit-sensitive." The majority of the stations areas with the highest median net energy savings do contain all three types of development (office, commercial, and residential). The presence of extensive high-density commercial and residential development may generate considerable off-peak transit trips and thus increase the median net energy savings.

Since the three attributes of the classification system outlined in Chapter 2 did not clearly define differences in the station areas, the station areas were placed in three groups based on their Average Weekday Vehicle Trip Ends (AWDVTE): Group I (AWDVTE < 10,000), Group II (10,000 < AWDVTE < 20,000) and Group III (AWDVTE > 20,000). The station areas in Group I had a constrained development environment, which contributed to their low (but positive) median net energy savings. Group II station areas were in transition, either to a more transit-sensitive development pattern or to a constrained "buildout" pattern. The last group of stations, all regional nodes or focal points, already had substantial development "anchoring" the station area, which provided an impetus for more development. Significant commercial development occurred at all Group III station areas, providing off-peak trips and contributing to their high median net energy savings. Table 5.2 summarizes the study findings in tabular form.

Applications and Recommendations for Further Research

The model in its current state has limited applications, and it is important to recall that this model is not predictive. The intent of the model is to provide a broad sketch of the range of net energy savings, given the development in the station area. Thus, the model is transferable for about ten years (approximately five years before and after system start-up). Data would have to be intensively collected during this time, which would not be a problem if a land use impact study was being conducted simultaneously and operational data (mode split, load factors, etc.) were available.

Further research is needed to formulate a more accurate and predictive model. The first step would be to collect actual data for the station areas reviewed. The development data are, of course, primary data. However, the mode split, load factor, energy consumption, and travel peaking data are all system- and industry-based and are all from secondary sources. Once primary data are collected, the model can be calibrated. The second step is to conduct more case studies. Seventeen station areas is too small a number for reliable econometric modeling. About three times as many station areas would have to be examined to give the model any predictive power.

TABLE 5.2 SUMMARY OF FINDINGS

	Relationship to Station Area Net Energy Savings	
Classification Criteria	Revelant?	Comments
System Mode	No	Mode Split and transit load factor are more revelant factors
Station Location	No	High activity nodes can occur anywhere (CBD or suburbs)
Development Type	No	Quantity of transit-sensitive development more relevant
Quantity of Trip Ends	Yes	Number of trip ends depends on amount and type of development; can be generalized into groups

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APPENDIX A
FORTRAN CODE FOR THE MODEL

```
C*************************************************
C
C-------STATION AREA SIMULATION-----------------
C
C      THIS PROGRAM SIMULATES THE NET ENERGY
C      SAVINGS OF A TRANSIT SYSTEM OVER THE
C      AUTOMOBILE MODE DUE TO DEVELOPMENT
C      IN THE STATION AREA
C
C*************************************************
C-------EXTERNAL FUNCTIONS----------------------
C
C-------RANDOM NUMBER GENERATOR-----------------
C      (NUMERICAL RECIPIES, P.195)
C
C-------RANDOMIZER-----------------------------
C
      FUNCTION RANF(ID1)
      REAL*4 RANF
      PARAMETER (IM=714025,IA=1366,IC=150889)
      JRAN=MOD(JRAN*IA+IC,IM)
      RANF=FLOAT(JRAN)/FLOAT(IM)
      RETURN
      END
C
C-------SHUFFLING PROCEDURE---------------------
C
      FUNCTION RAND(ID2)
      DIMENSION V(100)
      DATA IFF /0/
      IF(ID2.LT.0.OR.IFF.EQ.0)THEN
            IFF=1
            ISEED=ABS(ID2)
            ID2=1
            DO 11 J=1,100
                  DUM=RANF(ISEED)
11          CONTINUE
            DO 12 J=1,100
                  V(J)=RANF(ISEED)
12          CONTINUE
            Y=RANF(ISEED)
      ENDIF
      J=1+INT(100*Y)
      IF(J.GT.100)THEN
            J=100
      ENDIF
      IF(J.LT.1)THEN
            J=1
      ENDIF
      Y=V(J)
      RAND=Y
      V(J)=RANF(ISEED)
      RETURN
      END
C
```

```
C-------RANDOM OUTPUT----------------------------
C
      FUNCTION RANI(ID3)
      INTEGER RANI
      YEAH=ABS(RAND(-1))
      RANI=INT(10*YEAH)+1
      RETURN
      END
C
C************************************************
C-------MAIN PROGRAM----------------------------
C
C-------INPUT ROUTINE----------------------------
C
      REAL*4 AWDVTE,LFAUTO(10),AUTOLF,LFTRAN(10),
     *                  TRANLF,DIVER(10),MODE,AUTOEC(10),
     *            ECAUTO,TRANEC(10),ECTRAN,AWDTTE
     *            ECSAVE
C
      OPEN (UNIT=5,FILE='STATION.IN',STATUS='OLD')
      OPEN (UNIT=10,FILE='STATION.OUT',STATUS='NEW')
C
      READ (5,*) AWDVTE
      WRITE (*,*) AWDVTE
      DO 15 N=1,10
            READ(5,*) LFAUTO(N),LFTRAN(N),DIVER(N),
     *                  AUTOEC(N),TRANEC(N)
            WRITE(*,14)LFAUTO(N),LFTRAN(N),DIVER(N),
     *                  AUTOEC(N),TRANEC(N)
14          FORMAT(F4.2,2X,F6.2,2X,F4.2,2X,F10.2,2X,F8.2)
15    CONTINUE
C
C-------RANDOM VARIABLE ROUTINE------------------
      DO 25 K=1,500
            AUTOLF=LFAUTO(RANI(-1))
            TRANLF=LFTRAN(RANI(-1))
            MODE=DIVER(RANI(-1))
            ECAUTO=AUTOEC(RANI(-1))
            ECTRAN=TRANEC(RANI(-1))
C
C-------CALCULATION ROUTINE----------------------
C
            AWDTTE=AWDVTE*(1/AUTOLF)*MODE
            ESAVE=((AWDTTE*ECAUTO)/AUTOLF)
     *                  -((AWDTTE*ECTRAN)/TRANLF)
C
C-------OUTPUT ROUTINE---------------------------
C
            WRITE(10,19)AUTOLF,TRANLF,MODE,ECAUTO,ECTRAN,ESAVE
19          FORMAT(F4.2,',',F6.2,',',F4.2,',',F8.2,',',F8.2,
     *                  ',',F12.2)
            WRITE(*,20)AUTOLF,TRANLF,MODE,ECAUTO,ECTRAN,ESAVE
20          FORMAT(F4.2,2X,F6.2,2X,F4.2,2X,F8.2,2X,F8.2,2X,F12.2)
25    CONTINUE
      END
```

APPENDIX B

FREQUENCY DISTRIBUTIONS OF SIMULATION RESULTS

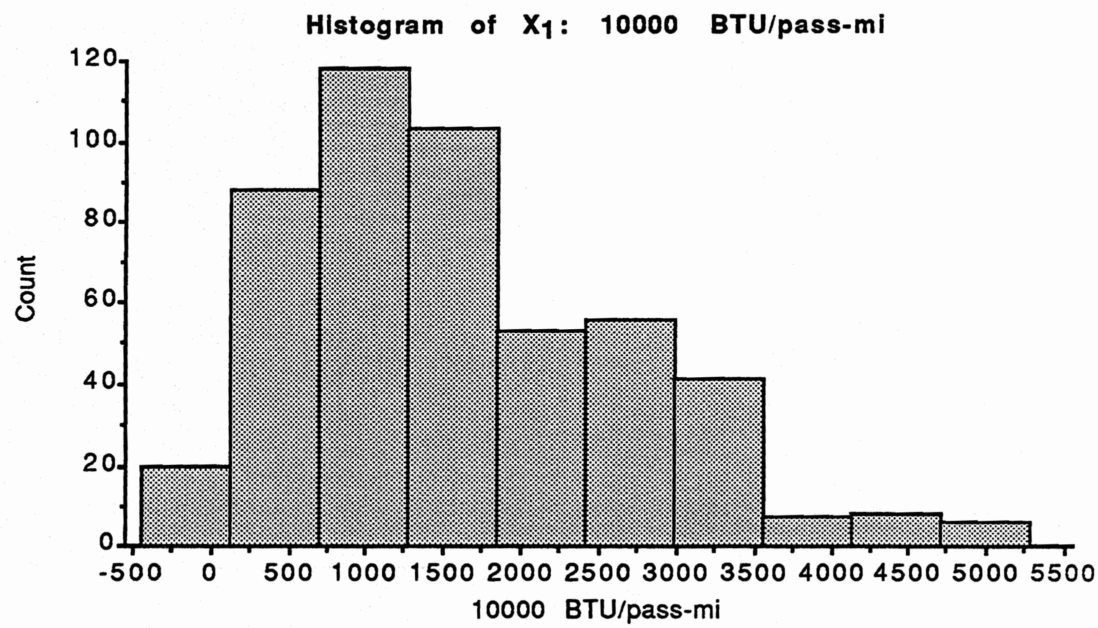

Figure B.1 Five Points Station Area

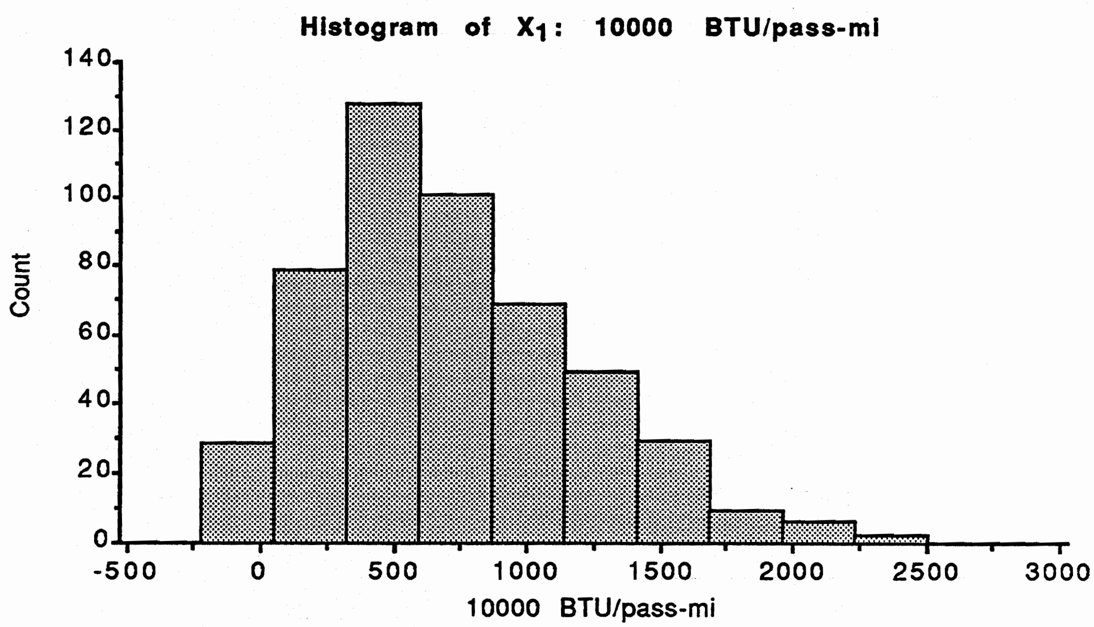

Figure B.2 Peachtree Center Station Area

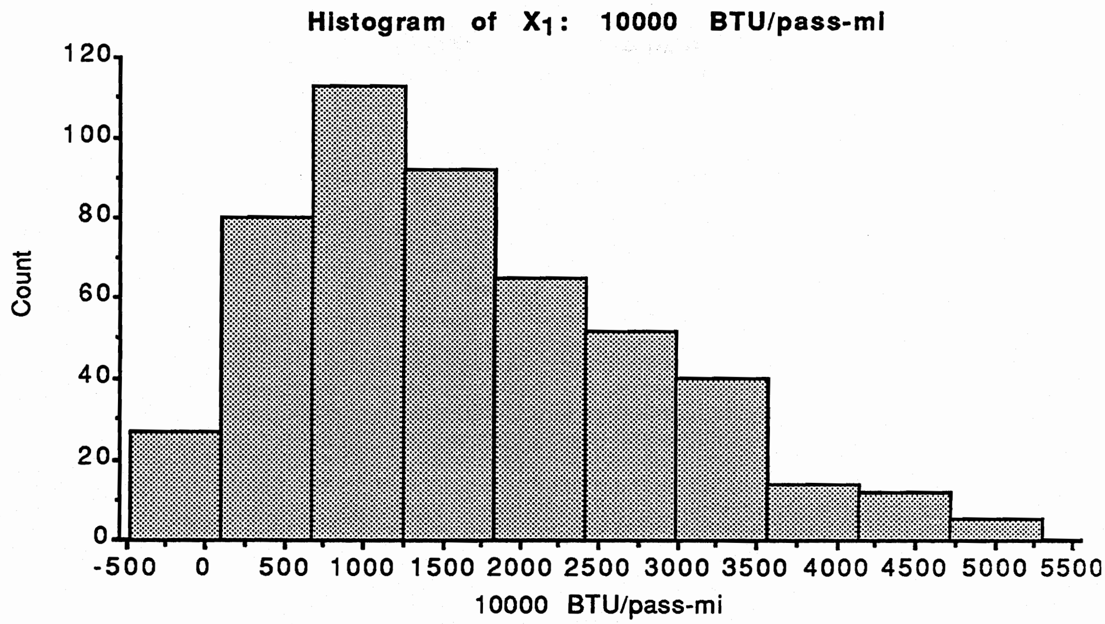

Figure B.3 Lenox Station Area

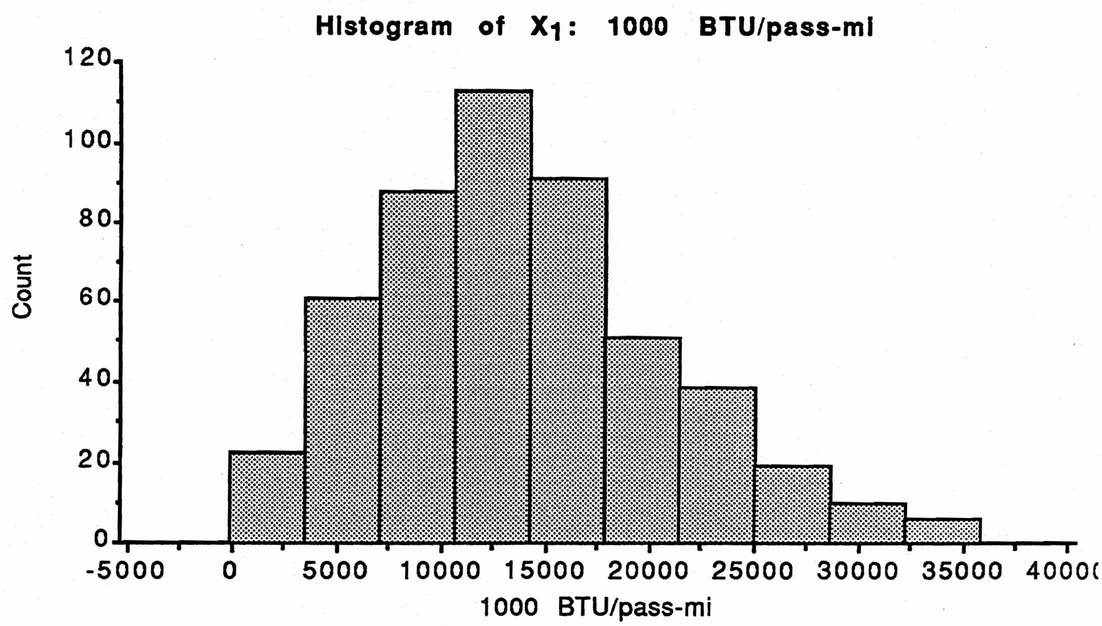

Figure B.4 Alewife Station Area

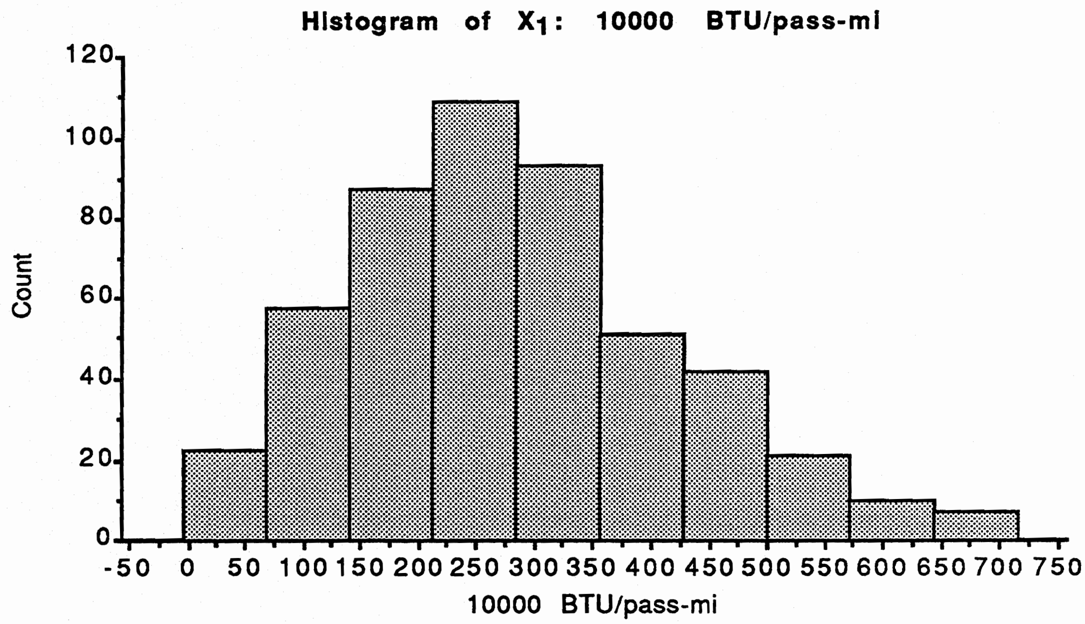

Figure B.5 Porter Square Station Area

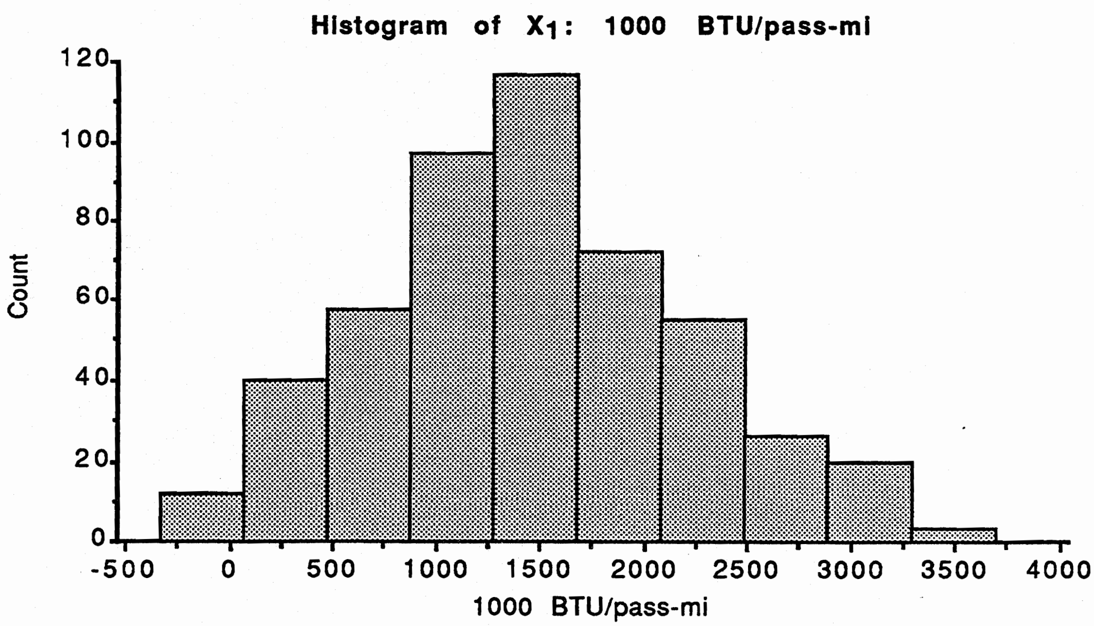

Figure B.6 Davis Square Station Area

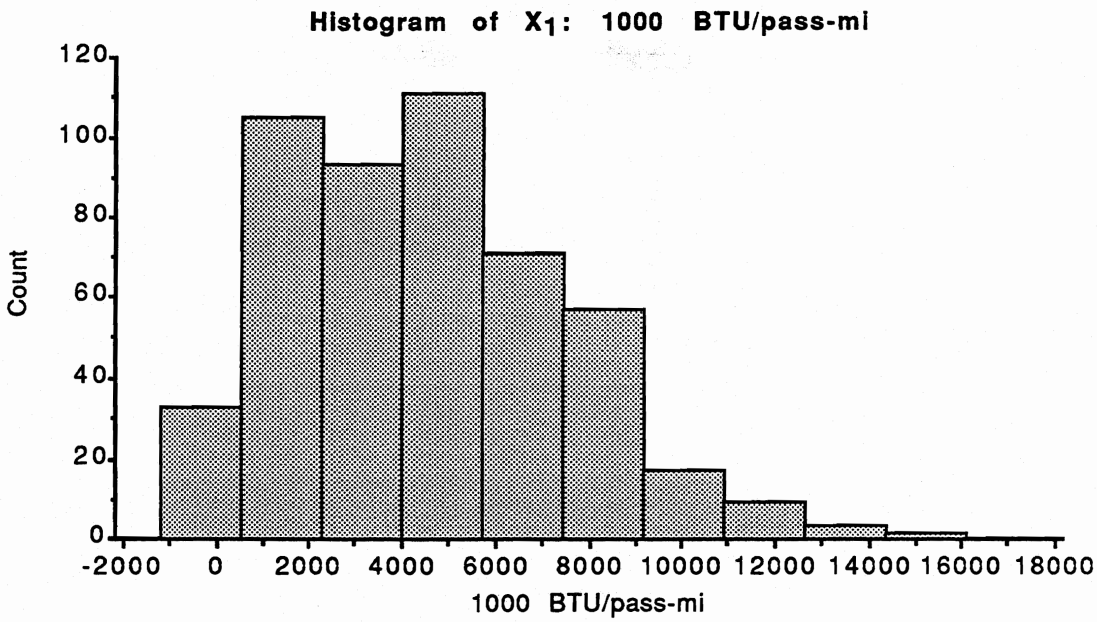

Figure B.7 Oakland Station Areas

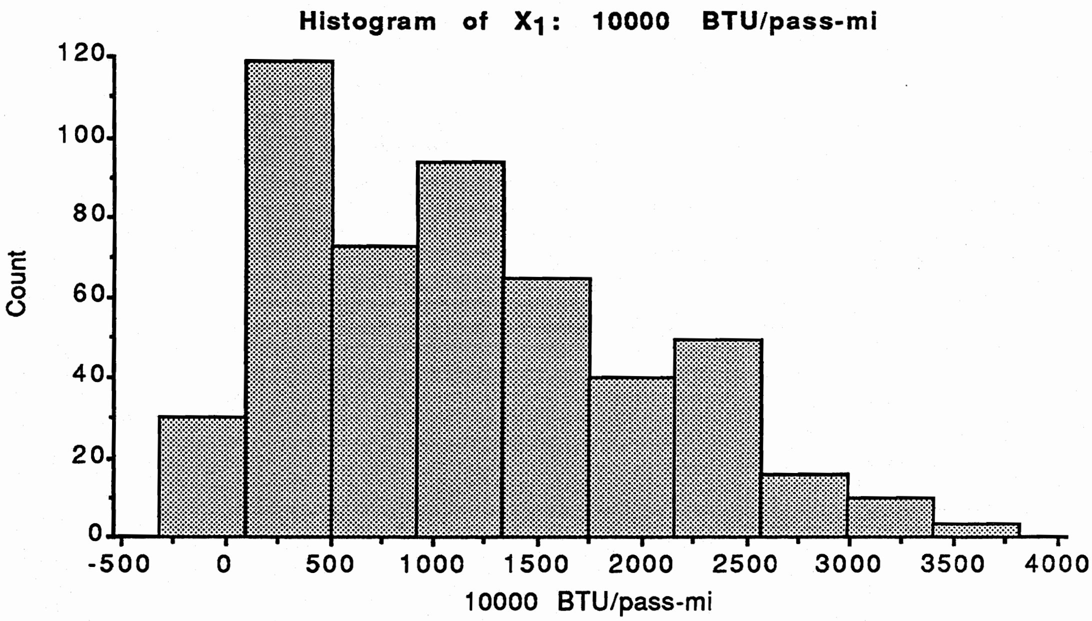

Figure B.8 Fremont Station Area

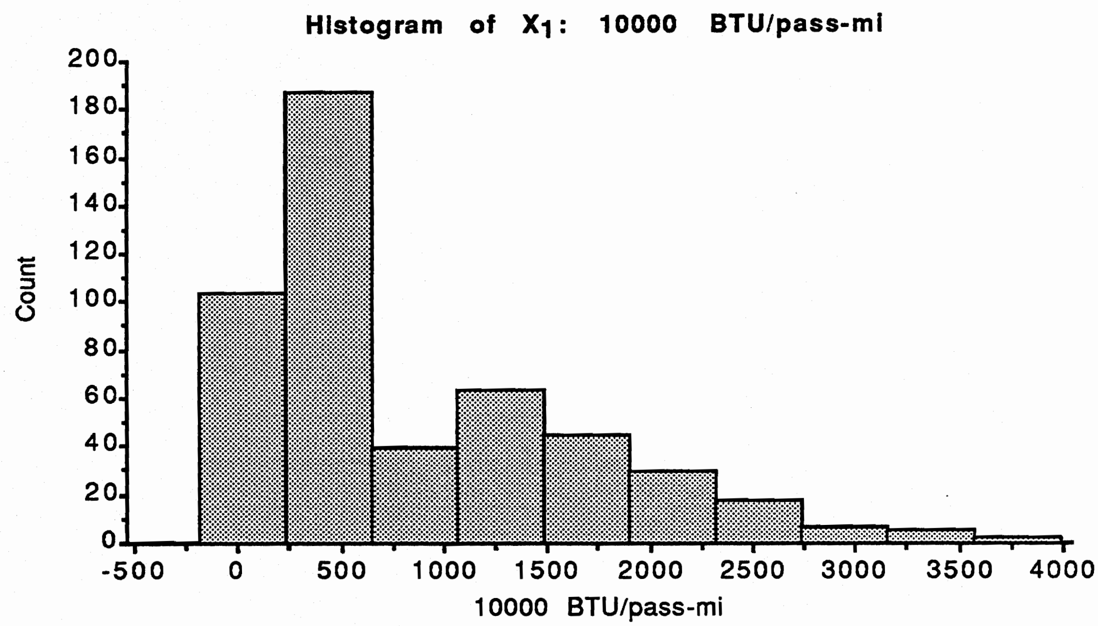

Figure B.9 Walnut Creek Station Area

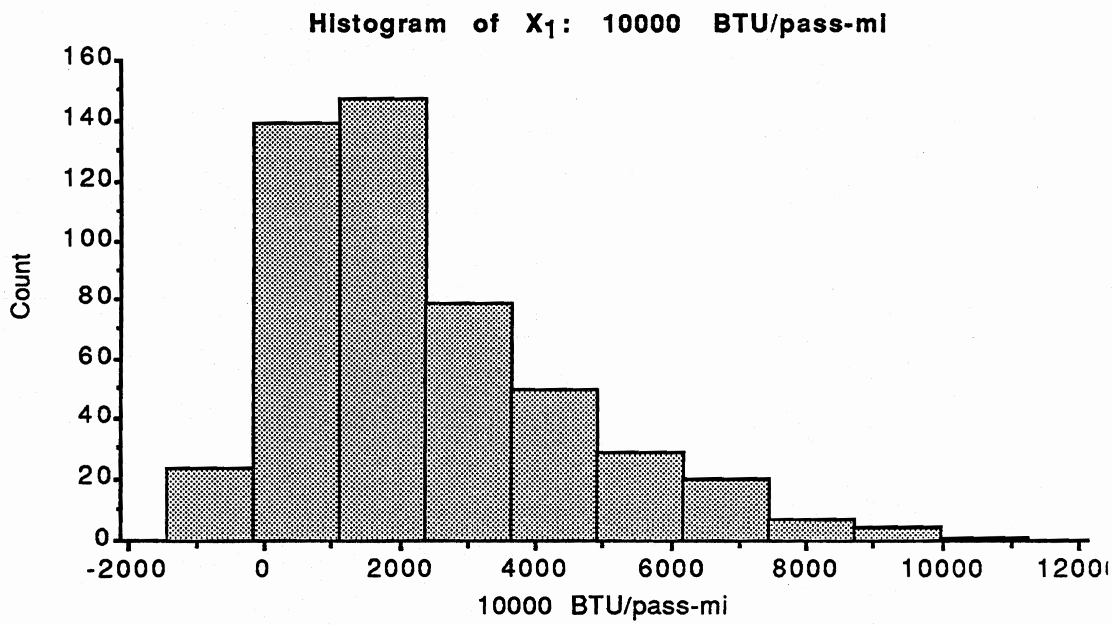

Figure B.10 Crystal City Station Area

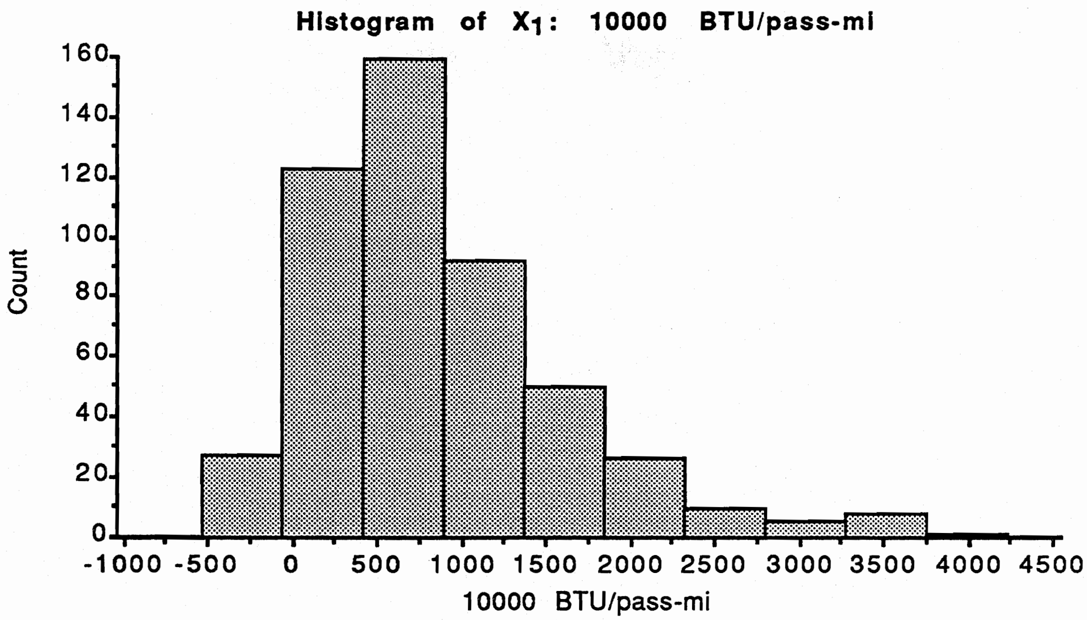

Figure B.11 Rosslyn Station Area

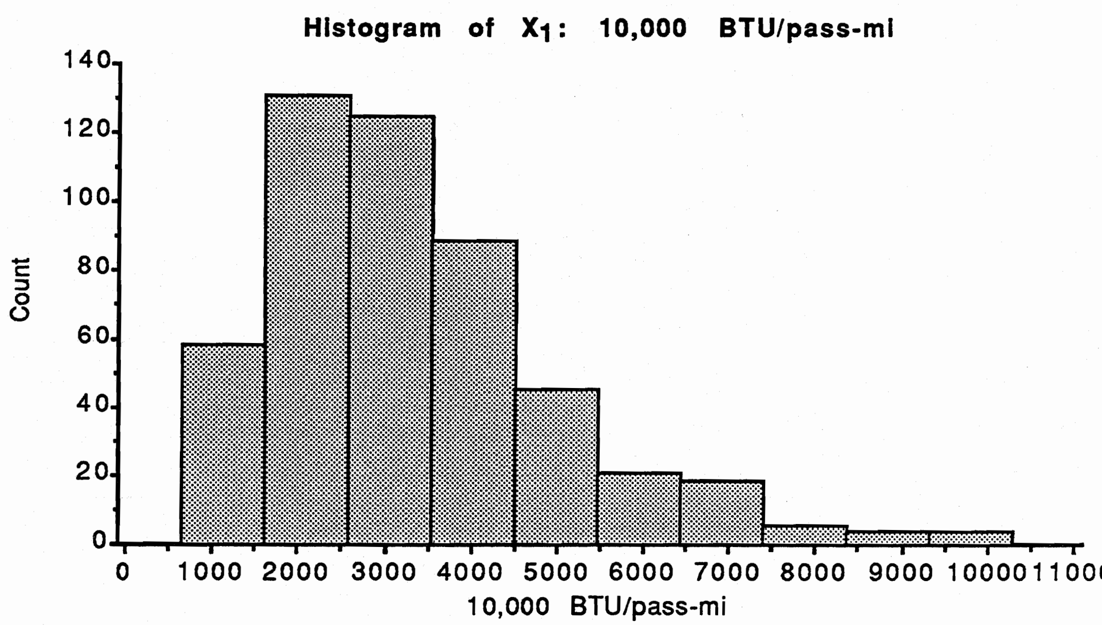

Figure B.12 Baseline Station Area

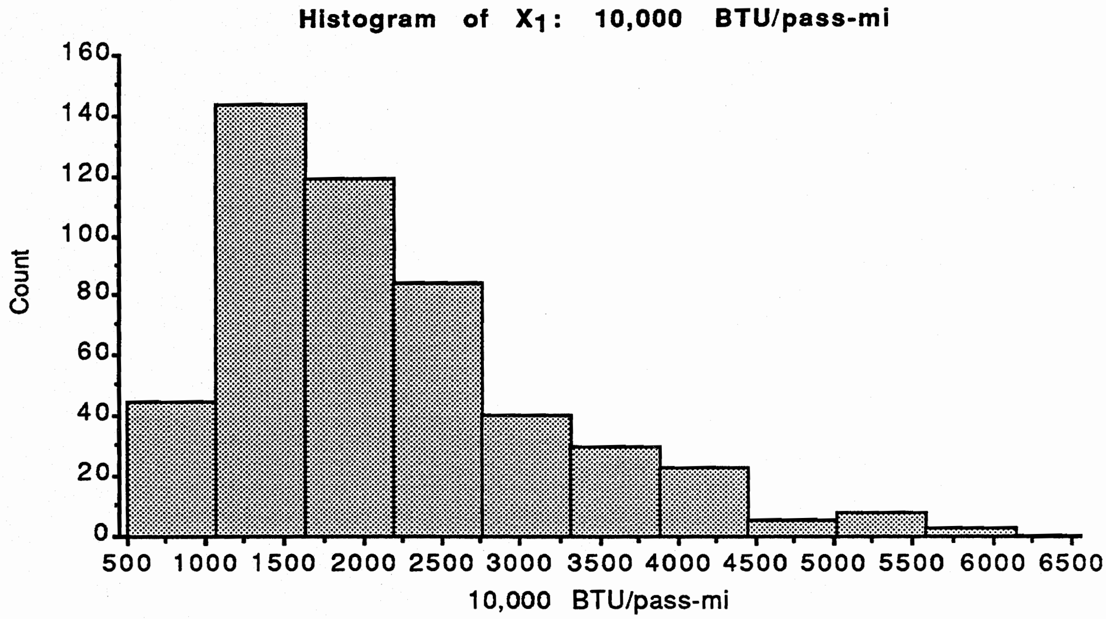

Figure B.13 Blair Station Area

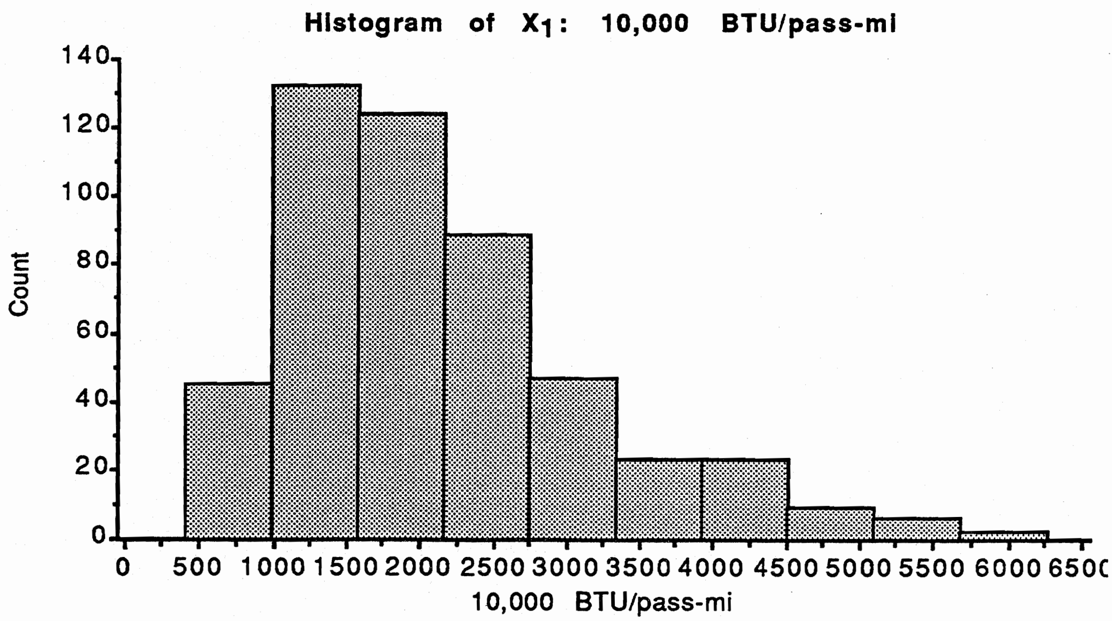

Figure B.14 St. Laurent Station Area

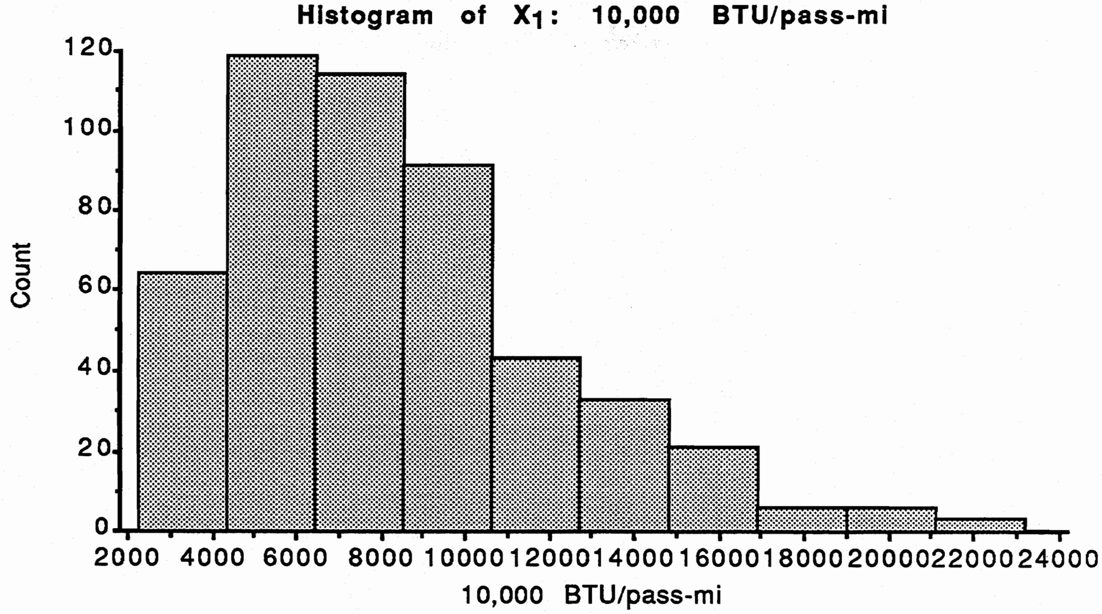

Figure B.15 Tunney's Pasture Station Area

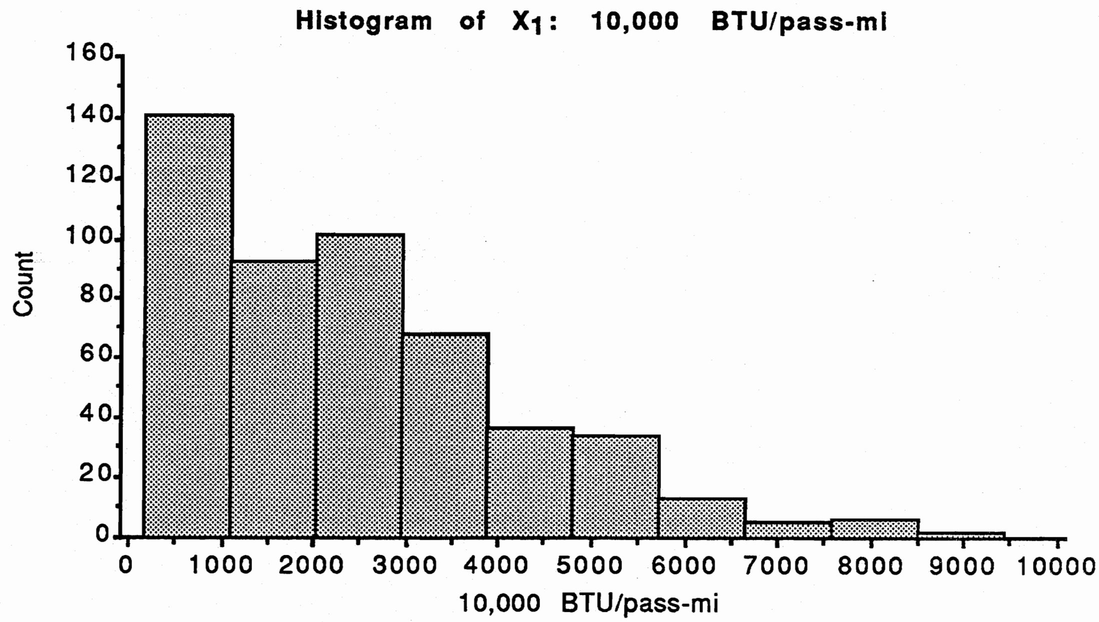

Figure B.16 The Portland Mall

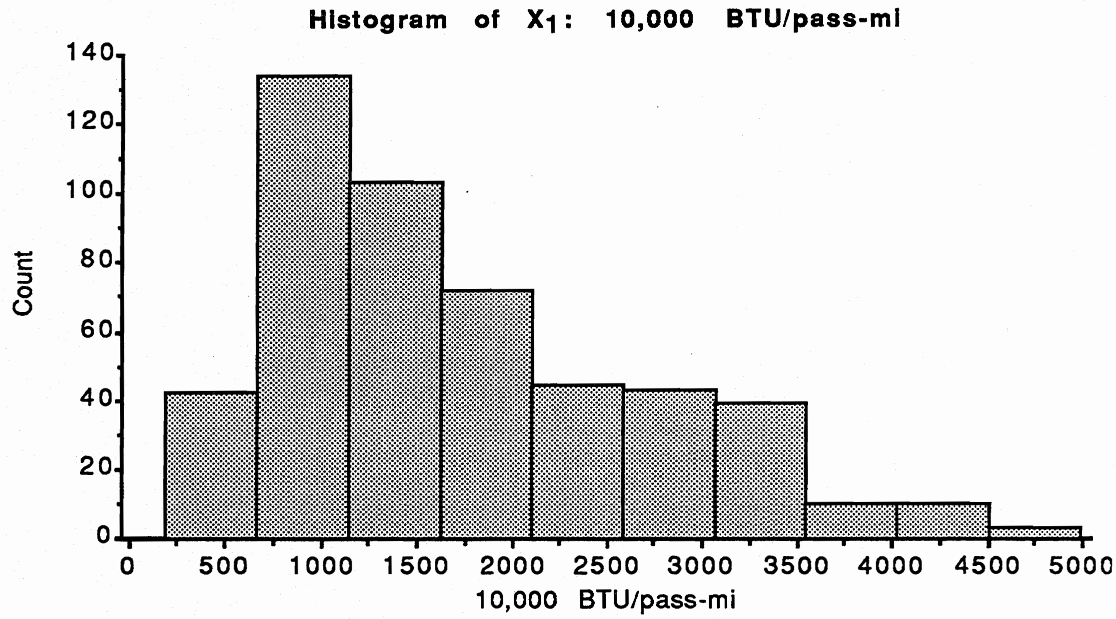

Figure B.17 The 16th Street Mall