



Trip Attraction Rates of Shopping Centers in Northern New Castle County, Delaware

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July 2004

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This work was sponsored by the Delaware Center for Transportation and was prepared in cooperation with the Delaware Department of Transportation. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Delaware Center for Transportation or the Delaware Department of Transportation at the time of publication. This report does not constitute a standard, specification, or regulation.

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July 2004

EXECUTIVE SUMMARY

This report presents the trip attraction rates of the shopping centers in Northern New Castle County in Delaware. The study aims to provide an alternative to ITE Trip Generation Manual (1997) for computing the trip attraction of shopping centers in Delaware. As part of this study, a total of eighteen shopping centers were surveyed, for which the number of vehicles entering and leaving the shopping center in every fifteen minutes interval and the number of people visiting each store in the shopping center along with their movement patterns were measured.

Based on the surveyed data and the aerial photographs, two approaches, microscopic and macroscopic, are developed to compute the trip attraction rate. The microscopic approach deals with the relationship between the trip attraction rates of individual stores and the shopping center as a whole. The macroscopic approach relates the trip attraction of the shopping center as a function of the physical features of the shopping center, e.g. total parking spaces, total floor area, and the number of stores in the shopping center.

The study shows that microscopic approach gives a better estimate of trip attraction compared with the macroscopic approach. The proposed models incorporate the factors that have been neglected in ITE Trip Generation Manual. These models should be useful for estimating the traffic volume to/from a new shopping center which, is being planned and to assess the traffic impact of the shopping center on the geometric design of roadways in the surrounding area.

The report consists of the description of the analytical approach, survey methods, the data collected from the survey and the analysis of the data using the models proposed.

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1. INTRODUCTION

Travel demand forecasting is essential for the design of transportation facilities and services, and also for planning, investment, and policy development. Trip generation is the first step of the traditional four-step travel demand forecasting process. It is critical that this step produces an accurate value as these values form the basis for the subsequent steps and the errors in this step can propagate in the entire estimation process.

The trip generation step consists of the processes to estimate trip production and trip attraction (TA) of a traffic analysis zone (TAZ). TA identifies the number of trips attracted by the various activity centers in the TAZ and trip production identifies the number of trips produced by the households in the TAZ. In general, an estimate of TA is less accurate than trip production as it is difficult to generalize and model the factors that influence one's decision to travel to a particular place. The main contributing factor for TA is work trips. Trips for shopping are the next main category of TA. This study deals with the trip attraction rate (TAR) of the shopping centers (SC), the number of people coming to the shopping center per unit time.

The purpose of this study is to collect data about the number of people coming to SCs in northern New Castle County in Delaware, and develop models for estimating the TAR of the SCs. The models will be used for planning and design of SCs for the geometric design and traffic control schemes on the roadways near the SCs. A series of surveys was conducted to obtain data about the TA at many SCs. Using this data two models are developed. They are called Microscopic and Macroscopic. The terms microscopic and macroscopic refer to the perspective on which the factors affecting the TAR are considered. These models can serve as an alternative to the ITE Trip Generation Manual (1997).

Chapter 1 introduces importance of TA of SCs in travel demand forecasting process and presents the purpose of the study. Chapter 2 defines the problem and the approach method undertaken. Chapter 3 presents a brief history and the trends in evolution of shopping centers. It also introduces how the ITE Trip Generation manual is used in dealing with the problem. Chapter 4 discusses in detail the analytical approach for the microscopic and macroscopic models. Chapter 5 gives a description of the stores that were visited as part of the survey and the classification of these stores. Chapter 6 gives description about the data that is needed for the analysis and the data collection process. Chapter 7 and Chapter 8 present the analysis and results of the microscopic and the macroscopic models respectively. Chapter 9 presents the application of the proposed models and lists the recommendations for using these models. Chapter 10 presents some topics of discussion that aroused during the formulation of the models and the analysis process. Chapter 11 summarizes the findings of the study.

This study consists of the following major components:

- Survey at eighteen shopping centers during fall 2002, and spring/summer 2003 in Northern New Castle County, Delaware.
- Developing the models of trip attraction.
- Analysis and validation of the models.

2. PROBLEM AND APPROACH

2.1 Trip Production and Trip Attraction

A trip is a movement of a person from one place (origin) to another (destination). Trip production represents a trip starting or ending in a residential area, since a trip is considered “produced” at a person’s residence. Trip attraction (TA) represents a trip starting or ending in a non-residential area. Figure 2.1 shows how a person traveling from residence to an activity center generates two trip productions and two trip attractions.

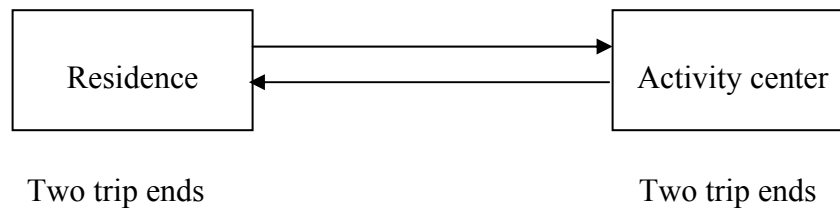


Figure2.1 Trip productions and trip attractions

A trip-end is the point at which a given trip starts or terminates; one trip has two trip ends. The TA or the trip production “rate” is defined as the number of trip ends per unit time per unit of independent variables (per employee, per square feet of floor area, etc.). Most typically, however, it refers to the number of trips per day per activity center.

2.2 The Problem: Trip Attraction Rate of Shopping Center

The trip attractions rate (TAR) of a shopping center (SC) is influenced by a number of factors, including time of the day, day of the week, seasonality, weather, configuration and composition of the SC. Peaking is caused by business and social characteristics. The most typical time for shopping during the weekday is after work, in particular, 4 to 6 PM

on Fridays attracts the most number of customers on a weekday. In addition Saturdays and Sundays are very busy periods for SCs having a supermarket and discount stores.

In general, there is a large variation in the number of people arriving at the SC even during the same time period over different fifteen-minute intervals. This variation is more clearly shown in Table 7.2 of Chapter 7 where in the TA of a SC for two different days during the same time period are shown. As a result, the sample size becomes very important particularly when significant fluctuations exist in the number of trips to the SC. The need for a large sample space and the highly inconsistent nature of the TA makes the estimation of TAR of the SC a very complex process.

The ITE handbook has been the main reference material in the transportation planning community when estimating TA of an activity center. Although the ITE Trip Generation Manual (1997) is a concise and easy to use reference, the models for SC do not consider some of the features of SC, such as the number of stores, the number of the parking spaces, and the location of the SC that can have significant influence on the TAR of the SCs. As a result, the TAR estimated cannot be made specific to a SC. On the other hands, The ITE Trip Generation Manual (1997) offers the TAR for many different types of establishment or stores, when the establishment is freestanding. In other words, there is no differentiation between the stores independently located or located in a SC along with other stores. The phenomenon of trip chaining, in which a customer visits more than one store during one trip to a SC, has to be taken into account for the estimation of the TA in a SC.

It is difficult to consider all the factors influencing the TAR of SC especially factors like land use characteristics of the surrounding area. However other factors like the physical features of the SC that are easy to measure and analyze should be incorporated in the

estimation of the TAR. In addition to this the general procedures for estimating TAR of the SC do not consider the effect of the type and features of the constituent stores of a SC. The TA of the constituent stores in a SC affects the level of trip chaining in the SC. It is very vital to involve the trip-chaining phenomenon in the estimation of TAR of the SC. The above-mentioned points form the basis for undertaking this study.

2.3 The Approach

There are two approaches that have been developed in this study. The first approach is to examine the TAR of the individual stores and aggregate the TARs of all the stores in the SC to get the overall TAR of the SC. This idea is based on the understanding that the system being considered as consisting of small parts explains its properties better than the system being considered as a whole unit. The second approach is to examine the SC as a system and develop a relationship between the number of people (or vehicles) attracted to the SC and the features of the whole SC, disregarding the characteristics of the individual stores in the shopping center. This idea is based on the understanding that the considering the characteristics of the system on the whole define its behavior better than considering the combination of the characteristics of the individual components. Incidentally, this is the approach taken in ITS Trip Generation Manual.

The microscopic approach consists of two parts. The first part deals with obtaining parameters called as weights for each store in the SC, which reflect the trip-chaining phenomenon seen in the SC. The second part deals with the trip attraction of individual stores, which can be obtained either from ITE manual or by inspection of similar stores in different SCs. These two parts are combined to obtain the TAR of the SC, in other words, this approach consider weights in the trip attraction rate of individual store.

The macroscopic model computes the trip attraction rate of the SC using the regression model, where following explanatory variables are used:

- The total floor area of the SC (cumulative floor area of all stores in the SC)
- The total number of parking spaces in the SC
- The total number of stores in the SC

The steps involved in the two approaches and the application of the models is presented in the flowchart shown in Figure 2.3. Both the approaches are explained in a more detailed manner in Chapter 4.

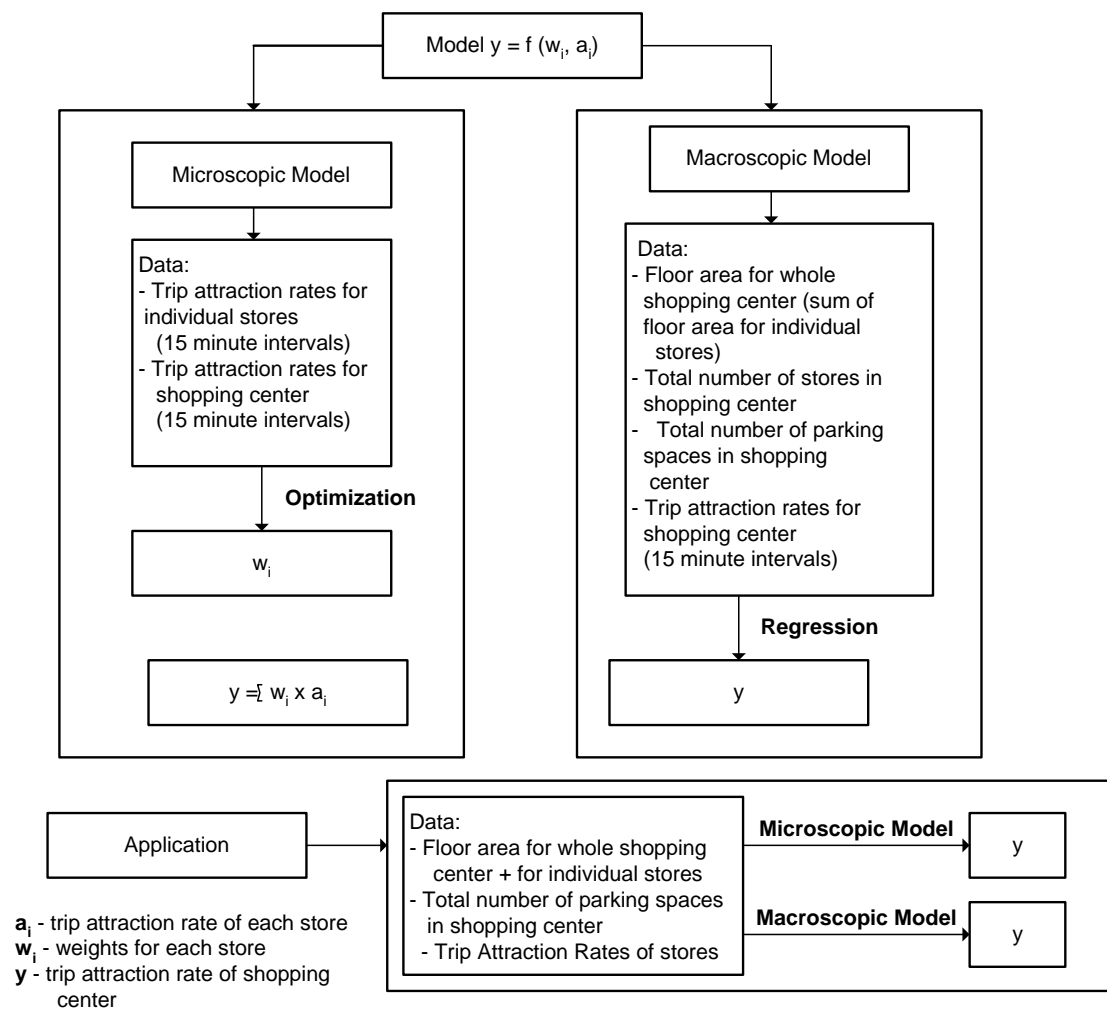


Figure 2.2 Microscopic Model and Macroscopic Model

3. BACKGROUND: SHOPPING CENTERS AND EMERGING TRAVEL PATTERNS

The suburban malls and shopping centers (SCs) are inseparable part of our daily activities and American image of consumer culture. The first major suburban SC in the US was Country Club Plaza in Kansas, which opened in 1923 (Sternlieb and Hughes, 1981). The timing coincided with the beginning of motorization and suburbanization. (Ibrahim and McGoldrick, 2003). The decentralization of retailing facilities and the movements of population from cities to suburbs was caused by the increasing level of car ownership and personal income. Other factors for the suburban expansion include cheaper land and liberal planning policies (Jonassen, 1953). The liberal planning policy is characterized by area, where the land use is not strictly controlled and the exploitation of rural land is not very restricted. (ESPON, 2003).

Suburban development and population growth after World War II created the rapid growth in demand for more SCs. The number of SCs exceeded 7,600 in 1964 (International Council of shopping centers, 2004), and it continued to increase except for during the oil crisis in the 1970s (National Research Bureau, 2004). Between 1989 and 1993, the development of new SCs dropped from 1,510 construction starts in 1989 to 451 starts in 1993 (International Council of Shopping Centers, 2004).

On-line shopping became popular in the 1990's with the advent of Internet. The July of 1998 issue of Time had an article, "Kiss your mall goodbye: Online shopping is cheaper, quicker and better" (Krantz, 1998). However the Internet and other new technologies so far have not proven to be the negative impact, rather posed a positive (synergy) effect in

the growth of SC. There are 46,336 SCs in the United States today, and 201 million people visit them each month in 2002 (International Council of Shopping Centers, 2004). The International Council of Shopping Centers (ICSC) defines SCs into categories as shown in Table 3.1.

The SCs contain stores and parking spaces. The number of parking spaces is based upon accessibility characteristics, e.g., pedestrian orientation and transit availability. The minimum standard for parking space for the SC is 5 spaces per 1,000 square feet retail area (Calthorpe, 1993; Steiner, 1998). A rule of thumb parking requirement is two hundred square feet per vehicle. The scale of the SC, the distance between establishments (stores), the vast parking lots to cross, and lack of direct pedestrian connections discourage the visitor to travel from store to store on foot (Campoli, Humstone and McLean, 2002). Based on our observation, in all the SC's surveyed there are plenty of parking spaces. Figure 3.1 shows the typical parking occupancy condition at College Square, People's Plaza and Governor's Square.



College square

People's Plaza

Governor's Square

Figure 3.1 Aerial views of three shopping centers.

Source: CD-Deldot

There are three trip types defined in the ITE report (Trip Generation Manual, 1997):

1. Primary – trips made for the specific purpose of visiting generator (SC)
2. Pass-by – trips made as intermediate stops on the way from an origin to a primary destination.
3. Diverted linked – trips attracted from other roadways within the vicinity of the generator but in which a diversion from that roadway to another roadway is required to gain access to the site.

The hedonic motivation of shopping is described by Arnold and Reynolds (2003). They defined six categories of hedonic shopping motivations: Adventure shopping, value shopping, role shopping, idea shopping, social shopping and relaxation shopping. The six categories as defined by Arnold and Reynolds (2003) are as follows. Adventure shopping refers to shopping for stimulation, adventure, and the feeling of being in another world. Social shopping refers to the enjoyment of shopping with friends and family, socializing while shopping, and bonding with others while shopping. Gratification shopping involves shopping for stress relief, shopping to alleviate a negative mood, and shopping as a special treat to oneself. Idea shopping refers to shopping to keep up with trends and new fashions, and to see new products and innovations. Role shopping reflects the enjoyment that shoppers derive from shopping for others. Value shopping refers to shopping for sales, looking for discounts, and hunting for bargains.

The ITE Trip Generation Manual refers to trip attraction rates of the SC for different time periods (peak-on, off-peak, weekend, etc.). The ITE model uses the gross leasable area (in thousand square feet) as independent variable, and the average number of vehicle trips ends per one day to the SC as dependent variable. The gross leasable area (GLA) is the total floor area designed for tenant occupancy and exclusive use, including any basements, mezzanines, or upper floors, expressed in square feet. For the purpose of trip

generation calculation, the floor area of any parking garages within the building should not be included within the GLA of the entire building (ITE Trip Generation Manual, 1997). The ITE Manual provides different models for weekdays (peak hours, off peak hours), Saturday, Sunday and Christmas Season. The ITE manual does not consider the difference in the type and the size of the SC. The models in the ITE Trip Generation Manual use just one independent variable to predict the trip attraction. No attempt has been made to use any other factor.

4. MODELS: MICROSCOPIC AND MACROSCOPIC

4.1 Microscopic Model:

The microscopic model expresses the trip attraction (TR) of the shopping center (SC) in terms of the trip attraction (TA) of the individual stores. The trip attraction rate (TAR) of the whole SC cannot be expressed in terms of the individual stores' TARs by taking just the sum of the TARs. The main objective of the model formulation is to obtain the weights for the TARs of each store in the SC for estimating the weighted sum of the TARs that gives the TAR of the SC.

4.1.1 Microscopic Model: The Concept

The sum of the TARs of individual stores is greater than the TAR of the SC because of the trip-chaining phenomenon as shown in the Figure 4.1. Instead of the normal sum, a weighted sum of the TARs of the individual stores needs to be adopted. The model is based on the following equation where TAR of SC is expressed in terms of the weighted sum of the TARs of individual stores in the SC.

$$TAR_{SC} = TAR_A * W_A + TAR_B * W_B + TAR_C * W_C + TAR_D * W_D - d_1^+ + d_1^- \quad (4.1)$$

where, TAR_A is the TAR of store A in the SC and A, B, C and D are the stores in the SC.

Each store's TAR has to be converted into a value, which gives an indication of not just the number of people coming to that store alone, but also the level to which the store is involved in trip chaining. The sum of these values for each of the stores should give the TAR of the whole SC.

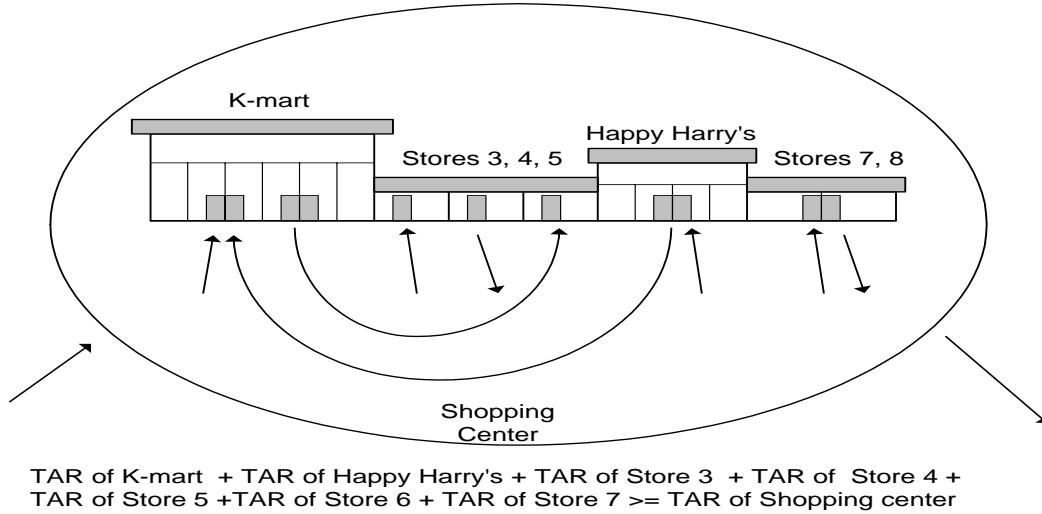


Figure 4.1 Trip Chaining inside the Shopping center

4.1.2 Estimation of the weights (W_i)

Weighted sum is the sum of the product of individual store's TAR and its weight. The weights for the TARs have to be assigned such that this weighted sum is equal to the TAR of the SC on the whole. For a given time interval the data about the TARs of the stores and the TAR of the whole SC is collected. Based on this data, there exists an equation (4.1) for every time interval. In this study a 15 minutes time interval has been considered. The equations thus generated are solved by linear programming to obtain the weights.

The objective of the optimization process is to minimize the error between the observed TAR of the SC and the calculated TAR of the SC, which is calculated based on the weighted sum of the TARs of the stores.

$$\text{Minimize } d = \sum_{j=1}^k d_j^+ + d_j^- \quad (4.2)$$

where, d_i^+ is the surplus and d_i^- is the shortage between the computed and observed TAR of the SC for the i^{th} 15 minute interval;

weights in this case would be equal to the total number of stores considered (N). This situation indicates no trip chaining in the SC. This situation is illustrated in figure 4.2.

The sum of the weights gives an indication of the amount of trip chaining in the SC. This value varies between 1 and N. If the sum of the weights is close to 1, it means that there is more overlapping among the people visiting the stores and the percentage of customers visiting more than one store is high. On the other hand, if the sum of weights is close to the N, it indicates less overlapping among the people visiting the stores. Figures 4.2 and 4.3 illustrate the concept of weights and the calculation of the TAR of the SC based on these weights.

The notation in the figures 4.2 and 4.3 mean the following.

T – TAR of the SC, T_A – TAR of Store A, W_A – Weight assigned to T_A of store A .

If there is no overlapping among the people visiting the different stores, then the total TAR of the SC is equal to the sum of the individual store's TARs.

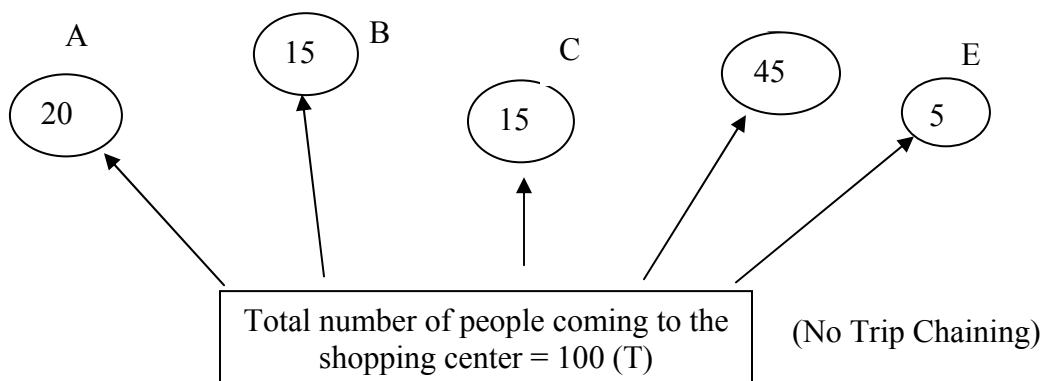


Figure 4.2 Trip Attraction Rate of the shopping center when there is no trip chaining

$$T = T_A * (W_A) + T_B * (W_B) + T_C * (W_C) + T_D * (W_D) + T_E * (W_E)$$

$$T = 20 * (1) + 15 * (1) + 15 * (1) + 45 * (1) + 5 * (1) = 100$$

Sum of weights = 5

In the case of trip chaining in the SC, the contribution of each store's TAR to the total TAR of the SC would be a fraction of the store's TAR. This fraction is indicated by the weight of the store multiplied by the TAR of the store.

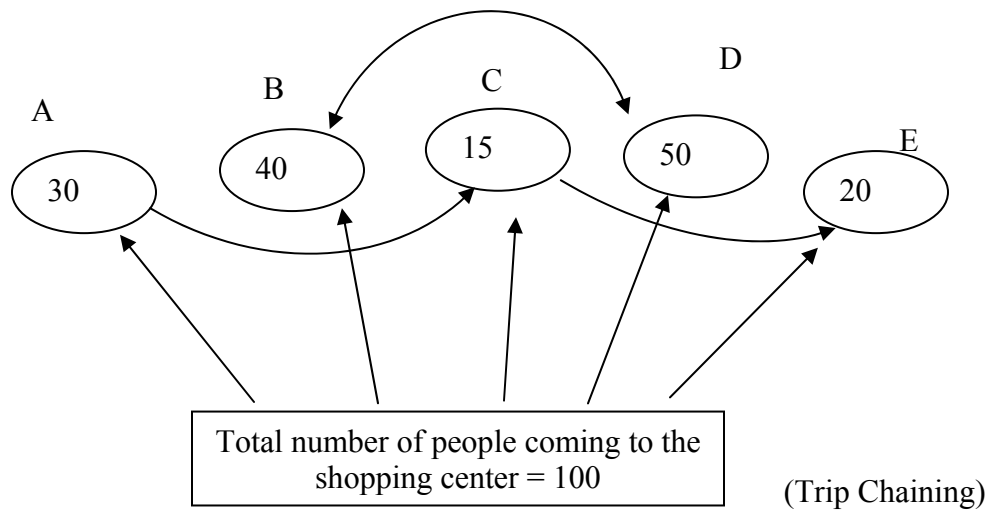


Figure 4.3 Trip Attraction Rate of the shopping center with trip chaining.

$$T = T_A * (W_A) + T_B * (W_B) + T_C * (W_C) + T_D * (W_D) + T_E * (W_E)$$

$$T = 30 * (0.8) + 40 * (0.5) + 15 * (1) + 50 * (0.6) + 20 * (0.6) = 100$$

$$\text{Sum of the weights} = 0.8 + 0.5 + 1 + 0.6 + 0.6 = 3.5$$

4.1.4 Trip Attraction Rate of Individual Stores (a_i)

The TARs of the individual stores for different 15-minute intervals are obtained from survey. These are required for the purpose of obtaining the weights of the stores through optimization. The ITE Trip Generation Manual (1997) also provides TARs of certain type of stores but these values cannot be used in the calculation of the weights, as the calculation of weights requires a set of observed TARs for each store instead of one single value.

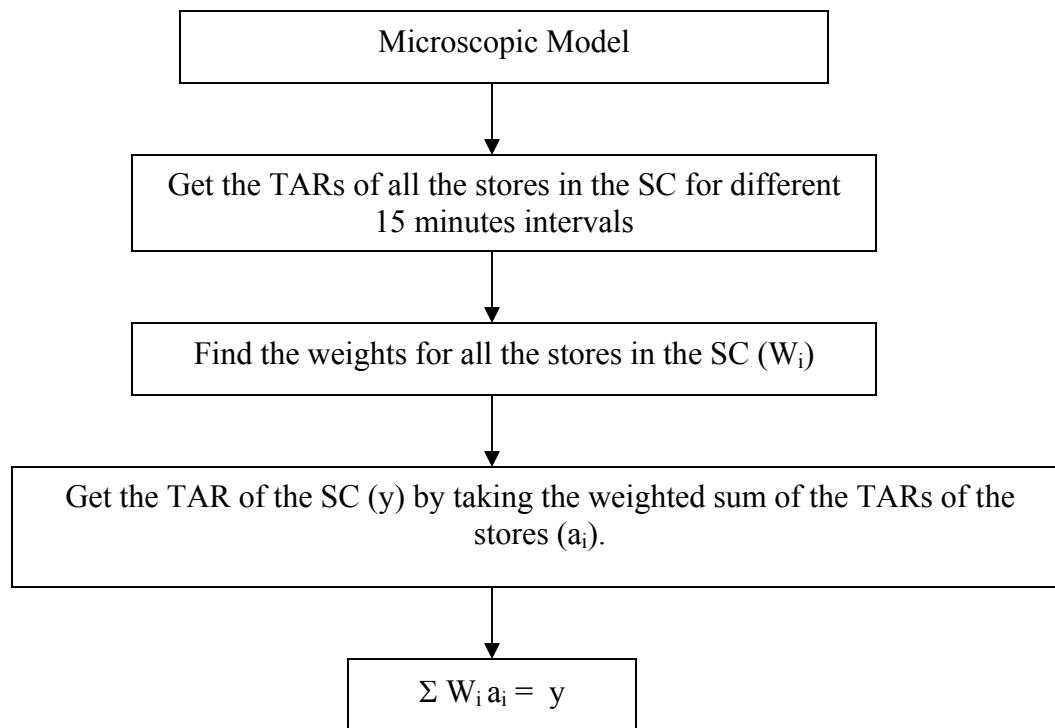


Figure 4.4 Approach of the microscopic model

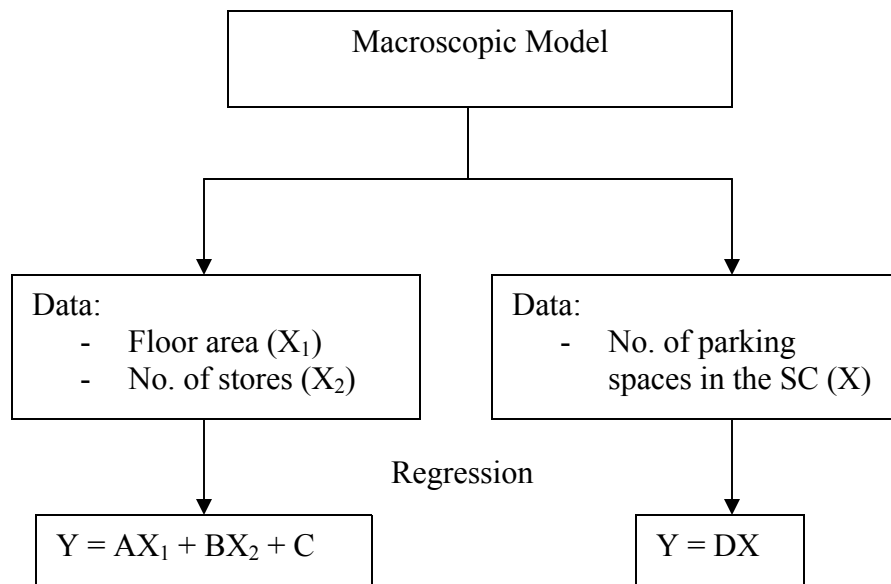
4.2 Macroscopic Model Formulation

The macroscopic model computes the TAR of the SC, by considering the SC on the whole as one “store” or the unit of analysis. The ITE Trip Generation Manual (1997) expresses the relationship between the Gross Leasable Area (GLA) and TAR of the SC in the form of a regression model. This is similar to the macroscopic models proposed here except for the variables that are considered. These factors are total floor area of the SC, total number of parking spaces and total number of stores. The factors are selected based on the literature review and the survey results.

The total floor area influences the number of customers visiting the SC and the total number of attractions for various individual stores. The TA to a SC also depends on the total number of parking spaces, which, in turn depends on the total floor area, and the

concentration of the customer at a particular time. The number of parking spaces is controlled by the minimum parking standards for the SC based on its floor area. Another factor that the number of people coming to the SC depends on is the number of stores in the SC. Also the extent of trip chaining depends on the number of stores available in the SC. The relationship between these factors and the TAR of the SC is obtained by regression analysis.

In this approach there are two regression models that establish the relationship between the TAR of the SC and the factors of the SC. The first regression model considers the floor area of the SC and the number of stores in the SC. The second regression model considers the number of parking spaces in the SC. The process of the macroscopic approach is shown in Figure 4.5.



Y = Trip Attraction Rate of the Shopping Center
A, B, C are coefficients of the regression model

Figure 4.5 Approach of the macroscopic model.

4.3 Regression Analysis

Regression analysis gives the functional relationship between two or more variables based on the available data as follows.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \quad (4.4)$$

Where \hat{y} is the dependent variable, x_1, x_2, \dots, x_n are the independent variables, ε is the random error component, and β_k determines the contribution of the independent variable x_k . In our study, the TAR of the SC is the dependent variable and the attributes of the SC are independent variables. The values of the coefficients, β 's are derived by the least squares method. The least squares method minimizes the sum of squares of the difference between the observed values and the computed values, mathematically:

$$SSR = \sum (y_i - \hat{y}_i)^2 \quad (4.5)$$

where SSR is the sum of squared residuals (errors), y_i is the observed value of the TAR of the SC, and \hat{y}_i is the computed value of the TAR of the SC.

5. SHOPPING CENTERS STUDIED

The survey was conducted for eighteen Shopping Centers (SCs) in northern New Castle County, Delaware. This section describes how the SCs are categorized into different groups for the purpose of analysis and the characteristics of the SCs belonging to these groups. The location of the SCs surveyed is shown in Figure 5.1.

5.1 Classification of the Shopping Centers (SCs)

The SCs are classified into 4 groups based on the composition of the stores in the SC.

Type 1: This is a large SC with a large supermarket, a large discount retail store, one or two restaurants, a bank, and many small stores are located. The SC in this category are College Square, Pike Creek SC, Governor's Square, Eden Square and People's Plaza.

Type 2: This is a medium size SC where a medium sized supermarket, a medium sized discount retail store and many smaller stores are located. The SCs in this category are Lantana Square, Suburban Plaza, Four Season's SC and Shop Rite.

Type 3: This is a small SC where one supermarket and several small stores are located. The SCs in this category are Polly Drummond SC and Fairfield SC.

Type 4: This is a collection of specialty stores, but does not include a supermarket or discount retail store. The SCs in this category are Limestone Hill, Omega SC, Welsh Tract, Astro SC, Glendale SC, Harmony Plaza and Shops of Linden.

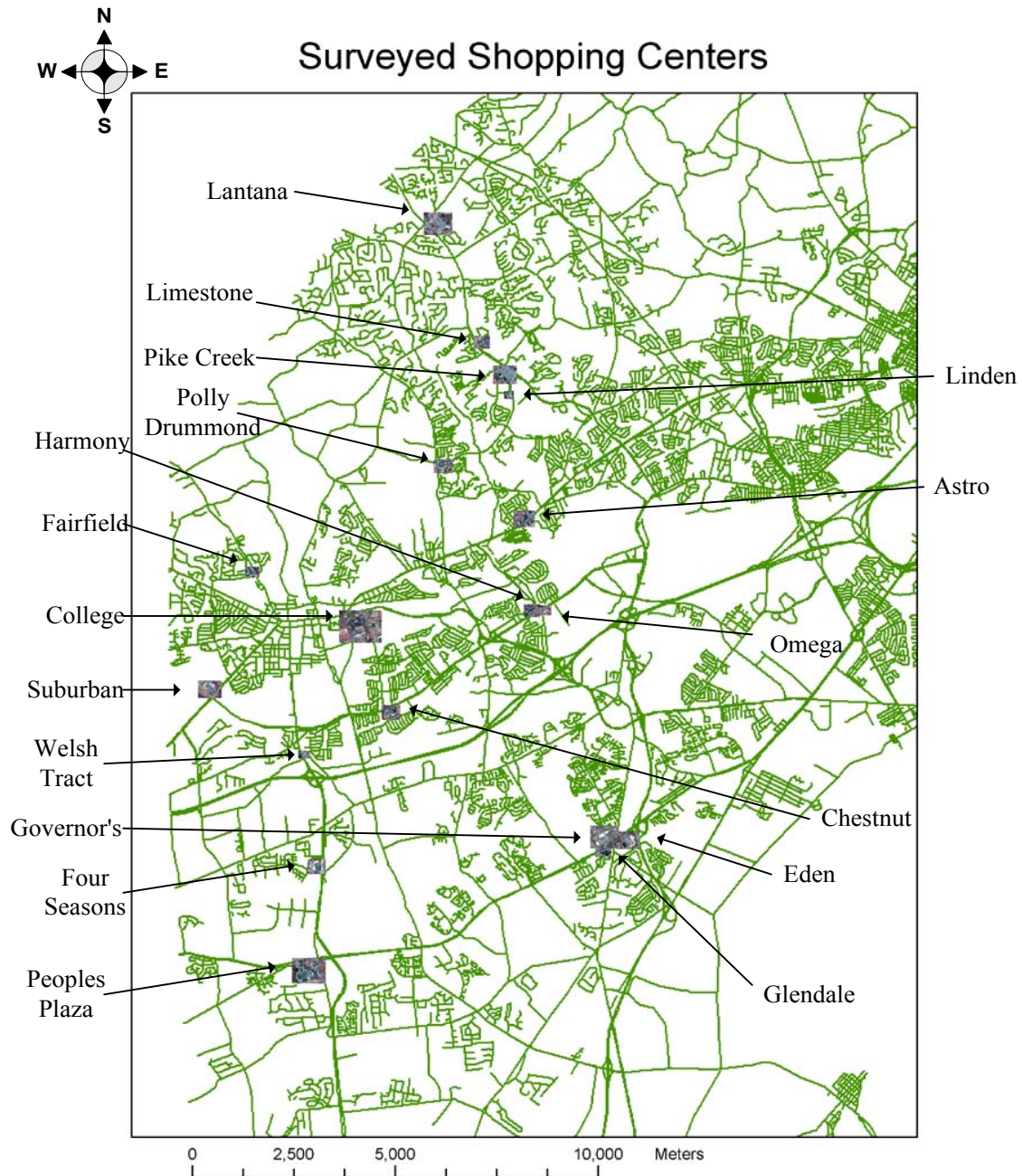


Figure 5.1: Surveyed shopping centers in northern New Castle County (Delaware)

The images of the SCs obtained from satellite pictures provided by the DelDOT are presented in Appendix E. The space occupied by the different stores in the SC and the

space occupied by parking lots is clearly demarcated in these pictures for all the SCs. The layout of the stores present in the SCs surveyed is also provided in Appendix D. As a sample, the satellite picture of Welsh Tract with the parking space and the store space clearly depicted on the image is shown in figure 5.2. The placement of different stores in the SC is shown in the layout of the SC is given in figure 5.3.

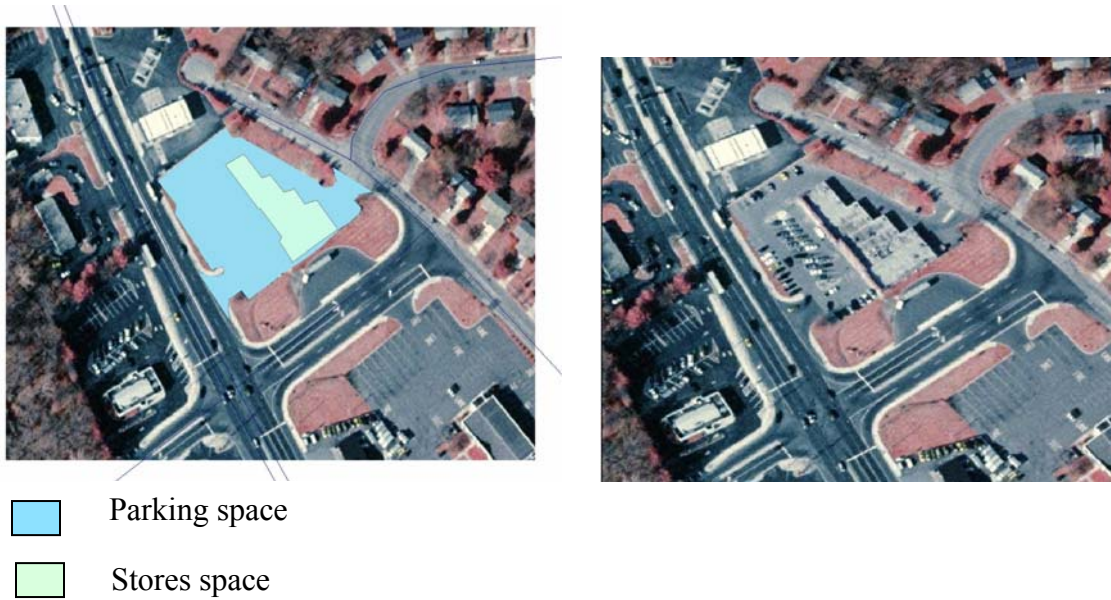


Fig 5.2 Parking space and the Store space super imposed on the Satellite picture of Welsh Tract Shopping center.

Source: DelDOT

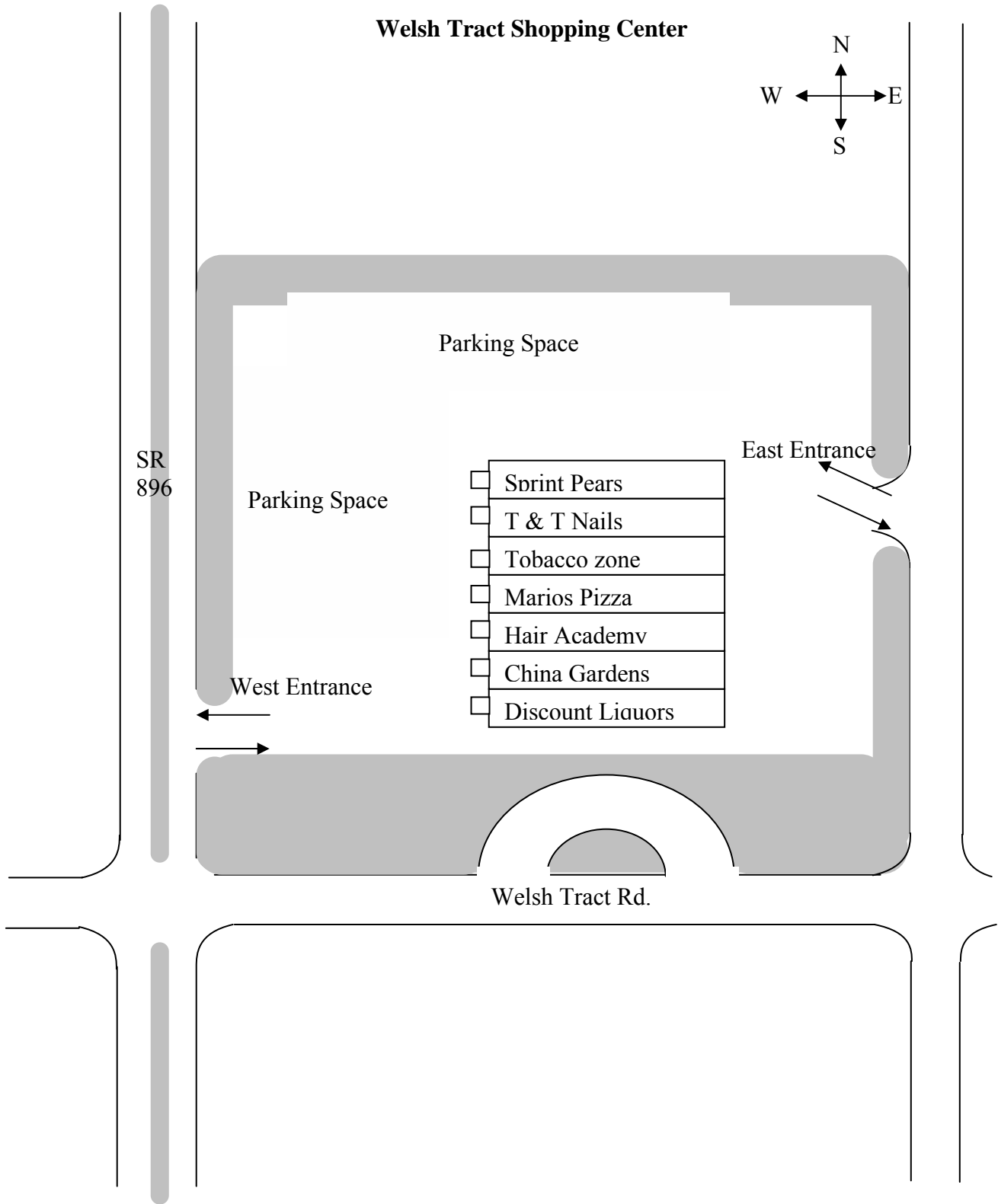


Figure 5.3 Layout of the stores in Welsh Tract Shopping Center.

5.2 Characteristics of Shopping Centers Surveyed.

The characteristics of the SCs grouped with respect to the type of the SC are presented in Table 5.1. The average value of the physical features of the SCs belonging to each type is also provided in the Table.

Table 5.1 Characteristics of the Shopping Centers of different types.

| Type | Name of the Shopping Center | Floor Area (Sq. ft) | No. of stores | Parking Space | Supermarket (yes=1,no= 0) | Discount store (Yes=1, no=0) |
|--------|-----------------------------|---------------------|---------------|----------------|---------------------------|------------------------------|
| Type 1 | College Square | 375,308.8 | 45 | 2,097 | 1 | 1 |
| | Pike Creek | 233,533.1 | 31 | 1,522 | 1 | 1 |
| | Governor's Square | 326,793.8 | 38 | 2,261 | 1 | 1 |
| | Eden Square | 271,991.3 | 23 | 1,376 | 1 | 1 |
| | People's Plaza | 565,467 | 44 | 3,231 | 1 | 1 |
| | Average | 354,618.8 | 36.2 | 2,097.4 | | |
| Type 2 | Lantana Square | 221,777.6 | 42 | 1,460 | 1 | 1 |
| | Suburban Plaza | 159,282.2 | 31 | 1,045 | 1 | 1 |
| | Four Season's | 134,116.2 | 17 | 689 | 1 | 1 |
| | Chestnut Hill | 204,095.7 | 19 | 726 | 1 | 1 |
| | Average | 179,817.9 | 27.2 | 980 | | |
| Type 3 | Polly Drummond | 87,445.1 | 16 | 527 | 1 | 1 |
| | Fairfield | 63,169 | 12 | 281 | 1 | 0 |
| | Average | 75,307 | 14 | 404 | | |
| Type 4 | Limestone | 36,803.8 | 13 | 213 | 0 | 0 |
| | Omega | 47,269.3 | 15 | 221 | 0 | 1 |
| | Welsh Tract | 11,460 | 7 | 60 | 0 | 0 |
| | Astro | 57,240.6 | 18 | 310 | 0 | 1 |
| | Glendale Plaza | 85,884 | 15 | 396 | 0 | 0 |
| | Shops of Linden | 37,673 | 11 | 195 | 0 | 1 |
| | Harmony Plaza | 89,874.4 | 21 | 443 | 0 | 1 |
| | Average | 52,315 | 14.3 | 262.6 | | |

It is interesting to see the commonality of the composition of stores in the various SCs that were analyzed in this study. Figure 5.4 indicates the pattern of distribution of different establishments in the 18 SCs that were surveyed, through a bar chart. It is seen that almost every SC has a cleaner and at least one restaurant. It is also interesting that

many SCs have a hair and nails shop. This representation of the store identifies the most commonly found store types in the SCs.

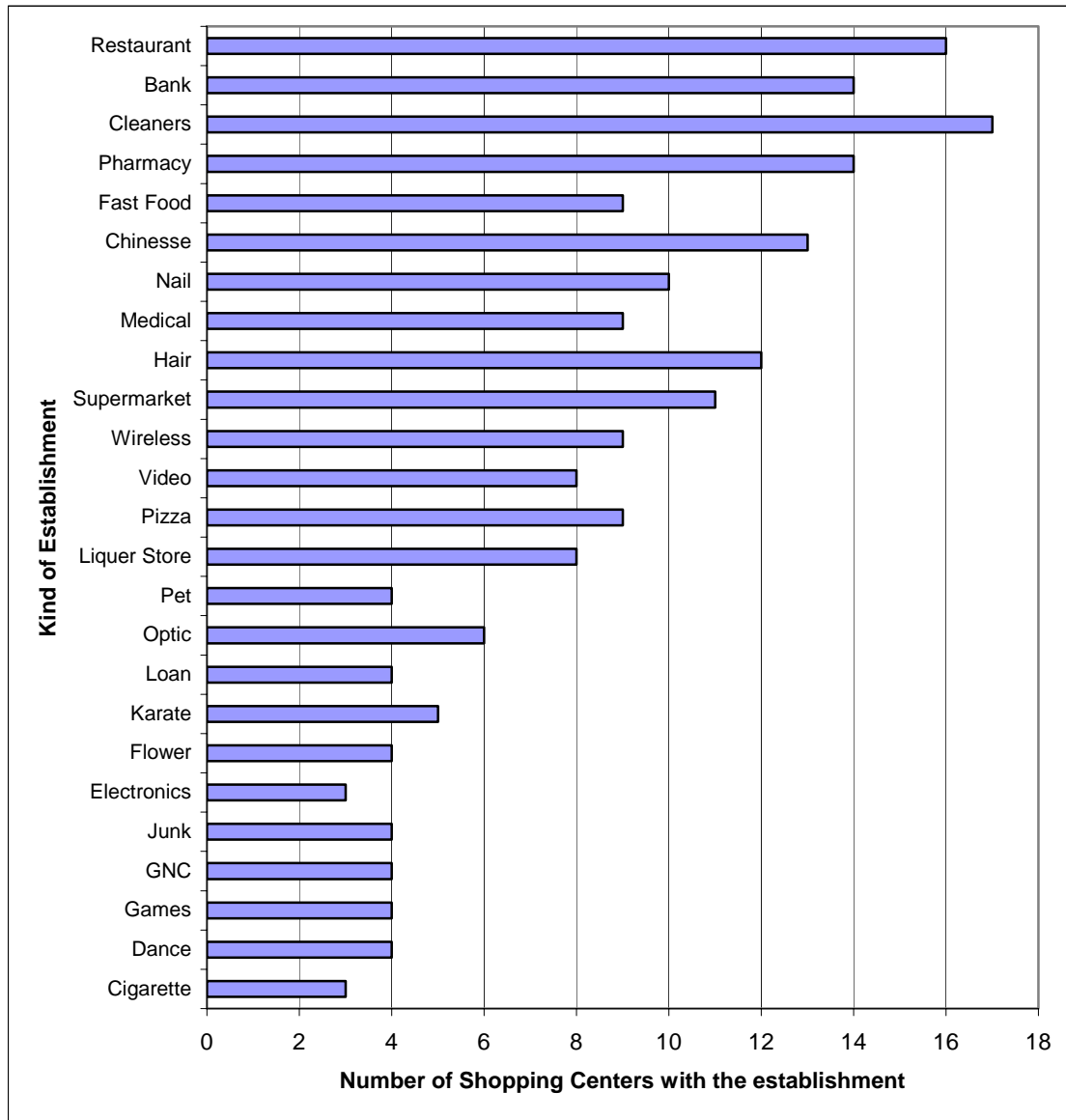


Figure 5.4 Presence of various establishments in the 18 Shopping Centers.

6. SURVEY AND DATA COLLECTED

Data collection is one of the main efforts of this project. The project team surveyed 18 shopping centers at different time and dates to collect trip pattern to the individual stores as well as the shopping center (SC) as a whole. This section presents the SCs that were surveyed and their characteristics. The types and the amount of data collected was determined by the requirement to set up the models (microscopic and macroscopic models)

6.1 Data required for the analysis

Based on the models proposed in Chapter 4, the data required for the analysis is divided into three general categories:

- The trip attraction rate (TAR) of the whole Shopping Center (SC) in terms of the number of vehicles entering the SC in 15-minute intervals.
- TAR of individual stores in a SC in 15-minute intervals.
- The physical features of the SC, e.g., floor space of individual store, number of parking spaces, and total site area.

6.2 Survey: Time and Place.

The data was collected on different days of the week and different times of the day for a period of 12 months (Fall of 2002 to fall of 2003.) All the data was collected for every 15 minutes time interval. This interval is chosen because Highway Capacity Manual uses this interval as the base unit for capacity calculation, and also it is rather practical from the standpoint of the person collecting the data. The typical duration of a survey was three hours. The smaller SCs were observed between 1 p.m. and 4 p.m., usually during the weekdays. The larger SCs were observed during the peak hour traffic on Fridays (4

p.m. – 7 p.m.), Saturdays (10 a.m. – 1 p.m.) and Sundays (11 a.m. – 2 p.m.). The dates and time of the survey for each SC are shown in Table 6.1.

Table 6.1 The Dates of the Survey for Each Shopping Center

| Name of shopping center | Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Time |
|--|--------|--------|---------|-----------|----------|--------|----------|------|
| College Square | X | | | | | | X | AM |
| | | | | | | X | | Mid |
| | | | | | | X | | PM,E |
| Pike Creek Shopping Center | | X | | | | X | X | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Governor's Square | X | | | | | | X | AM |
| | | | | | | X | | Mid |
| | | | | | | | | PM,E |
| Eden Square | | | | | | | X | AM |
| | | | | | | | | Mid |
| | | | | X | | | | PM,E |
| People's Plaza | X | | | | | | X | AM |
| | | | | | | X | | Mid |
| | | | | | | | | PM,E |
| Lantana Square | X | | | | | | X | AM |
| | | | | | | | | Mid |
| | | | | | | X | | PM,E |
| Suburban Plaza | | X | | X | | | X | AM |
| | | | | | | X | | Mid |
| | | | | | | | | PM,E |
| Four Season's Shopping Center | | X | | X | | | X | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Shop-Rite at Marrow's Rd/Rt4 (Chesnut Hill Plaza) | | | | | | | | AM |
| | | 2 x X | | | | | | Mid |
| | | | | | | 2 x X | | PM,E |
| Polly Drummond Shopping Center | X | | | | | | | AM |
| | | X | | X | | | | Mid |
| | | | | | | X | | PM,E |
| Fairfield Shopping Center | | X | | X | | | X | AM |
| | | | | | | X | | Mid |
| | | | | | | | | PM,E |
| Shops at Limestone Hills | | | | X | | X | | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Omega Shopping Center | | X | X | | X | | | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Rt896/Welsh Tract | | X | | X | X | | | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Astro Shopping Center | | X | | | | X | | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Glendale Plaza | | X | | | | X | | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Shops of Linden | | X | X | X | | | | AM |
| | | | | | | | | Mid |
| | | | | | | | | PM,E |
| Harmony Plaza | | | X | 2 x X | | | | AM |
| | | | | | | | | Mid |
| | | | | | | X | | PM,E |

AM: 10:00 – 14:00 Mid: 13:00 – 16:00 PM, E: 16:00 – 19:00

6.3 Data Collected

The TAR of the SC is obtained from the number of vehicles entering and leaving the SC in every 15 minutes interval. This number is converted to the number of persons, using the observed vehicle occupancy rate of 1.1 persons per vehicle. The detailed observations regarding the number of people visiting each store in the SC were performed for 15 SCs. For larger SCs, such as Governor's square, Lantana and People's Plaza, only the number of people entering major stores like supermarkets and major discount retail stores was counted. The data collected is shown in Appendix A. As a sample the data for the Astro SC is provided in Table 6.2. The incoming number of people to various establishments in the SC for different fifteen minutes intervals is shown. The last row in the table (Entrances) provides the number of incoming vehicles to the SC.

The statistical data about the number of people coming to the SC like the average, median, mode and standard deviation are shown in Appendix A. The total value in the table gives the total number of people coming to the SC at all times of the survey. Average gives the average number of people visiting the store per 15 minutes. Median is the middle number of a group of numbers that have been arranged in order by value. Mode is the most frequent value. Standard deviation is an indication of how widely the data are spread. The statistics of the data collected for Astro SC is provided in Table 6.3

There is a large variation in the number of people coming to the SC depending on the number of the time of the day, day of the week and the season. The fluctuations in the TAR of the stores and the SC on the whole show the complexity involved in studying the trip attraction of SCs. Figure 6.1 shows the number of vehicles entering and leaving the Astro SC during a three-hour survey period for two different days. The graphs showing similar values for other 17 SCs included in the survey are presented in Appendix F.

Table 6.2 Number of incoming persons to different stores and incoming vehicles to the Astro shopping center in fifteen minutes intervals.

| Store | Time interval | | | | | | | | | | | | | | | | | | | | | |
|-------------------|---------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| Happy Harrys | 13 | 32 | 21 | 19 | 14 | 19 | 16 | 9 | 20 | 13 | 23 | 14 | 21 | 23 | 17 | 10 | 23 | 15 | 12 | 12 | 9 | 15 |
| Peper.Farm | 2 | 9 | 1 | 7 | 3 | 6 | 5 | 12 | 5 | 6 | 6 | 8 | 2 | 10 | 0 | 2 | 5 | 3 | 8 | 6 | 12 | 2 |
| Tuxedo | 3 | 3 | 0 | 6 | 1 | 1 | 5 | 1 | 0 | 5 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 4 | 0 | 2 |
| Sun Chasers | 2 | 2 | 5 | 3 | 2 | 2 | 4 | 1 | 3 | 3 | 4 | 1 | 2 | 2 | 1 | 4 | 4 | 3 | 3 | 3 | 4 | 2 |
| Karate for Kids | 0 | 0 | 2 | 3 | 0 | 1 | 0 | 0 | 2 | 5 | 1 | 0 | 0 | 2 | 1 | 4 | 0 | 2 | 0 | 3 | 7 | 3 |
| Wells Fargo | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 3 | 2 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 3 |
| Hair Sensation | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 4 | 1 | 2 | 2 | 1 | 3 | 0 | 1 | 1 |
| RedWing Shoes | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| ScarpBooks | 5 | 3 | 5 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 3 | 0 | 1 |
| Taco Shop | 2 | 0 | 0 | 0 | 3 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 1 |
| Jenny Craig | 0 | 1 | 2 | 0 | 0 | 2 | 0 | 2 | 0 | 1 | 1 | 3 | 1 | 2 | 3 | 1 | 2 | 1 | 0 | 0 | 0 | 0 |
| Top Cleaners | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 3 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| Sir Speedy | 3 | 1 | 1 | 3 | 3 | 0 | 0 | 0 | 1 | 3 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 2 |
| Taj Mahal | 6 | 4 | 5 | 0 | 0 | 3 | 1 | 1 | 8 | 6 | 5 | 2 | 5 | 3 | 5 | 8 | 1 | 3 | 3 | 6 | 2 | 1 |
| Hibachi | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 3 | 0 | 0 | 4 | 1 | 3 | 0 | 0 | 0 | 1 | 0 | 1 | 5 |
| Wells Fargo | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 2 | 2 | 6 | 3 | 0 | 0 | 0 | 2 | 0 | 1 | 1 | 0 |
| Chinatown Kitchen | 1 | 1 | 1 | 0 | 2 | 1 | 2 | 1 | 0 | 0 | 8 | 4 | 1 | 2 | 2 | 1 | 0 | 1 | 1 | 2 | 0 | 0 |
| Bakery | 11 | 8 | 3 | 6 | 7 | 7 | 5 | 3 | 9 | 7 | 9 | 5 | 7 | 5 | 11 | 7 | 6 | 8 | 10 | 5 | 7 | 8 |
| Entrances | 34 | 35 | 33 | 37 | 28 | 29 | 33 | 27 | 34 | 37 | 40 | 38 | 43 | 36 | 38 | 32 | 41 | 35 | 37 | 36 | 27 | 38 |

Table 6.3 Statistical data for Astro Shopping Center per 15 minutes.

| Astro Shopping Center | | | | | | | |
|-----------------------|---------|---------|--------------------|---------|---------|-------|--------|
| | Total | Average | Standard Deviation | Maximum | Minimum | Mode | Median |
| Happy Harrys | 391.00 | 16.29 | 5.69 | 32.00 | 9.00 | 12.00 | 15.00 |
| Peper.Farm | 129.00 | 5.38 | 3.28 | 12.00 | 0.00 | 2.00 | 5.00 |
| Tuxedo | 41.00 | 1.71 | 1.88 | 6.00 | 0.00 | 0.00 | 1.00 |
| Sun Chasers | 67.00 | 2.79 | 1.18 | 5.00 | 1.00 | 2.00 | 3.00 |
| Karate for Kids | 39.00 | 1.63 | 1.88 | 7.00 | 0.00 | 0.00 | 1.00 |
| Wells Fargo | 21.00 | 0.88 | 0.90 | 3.00 | 0.00 | 1.00 | 1.00 |
| Hair Sensation | 20.00 | 0.83 | 1.05 | 4.00 | 0.00 | 0.00 | 1.00 |
| RedWing Shoes | 15.00 | 0.63 | 0.65 | 2.00 | 0.00 | 0.00 | 1.00 |
| ScarpBooks | 27.00 | 1.13 | 1.51 | 5.00 | 0.00 | 0.00 | 1.00 |
| Taco Shop | 20.00 | 0.83 | 1.31 | 5.00 | 0.00 | 0.00 | 0.00 |
| Jenny Craig | 22.00 | 0.92 | 1.02 | 3.00 | 0.00 | 0.00 | 1.00 |
| Top Cleaners | 13.00 | 0.54 | 0.72 | 3.00 | 0.00 | 0.00 | 0.00 |
| Sir Speedy | 32.00 | 1.33 | 1.09 | 3.00 | 0.00 | 1.00 | 1.00 |
| Taj Mahal | 87.00 | 3.63 | 2.37 | 8.00 | 0.00 | 3.00 | 3.00 |
| Hibachi | 25.00 | 1.04 | 1.65 | 5.00 | 0.00 | 0.00 | 0.00 |
| Wells Fargo | 23.00 | 0.96 | 1.46 | 6.00 | 0.00 | 0.00 | 0.00 |
| Chinatown Kitchen | 32.00 | 1.33 | 1.71 | 8.00 | 0.00 | 1.00 | 1.00 |
| Bakery | 161.00 | 7.00 | 2.15 | 11.00 | 3.00 | 7.00 | 7.00 |
| Total | 1165.00 | 48.54 | 9.45 | 70.00 | 32.00 | 51.00 | 47.50 |

Astro Shopping Center

10/14/2002 (Monday) 13.00 - 16.00, 10/18/2002 (Friday) 13.00 - 16.00

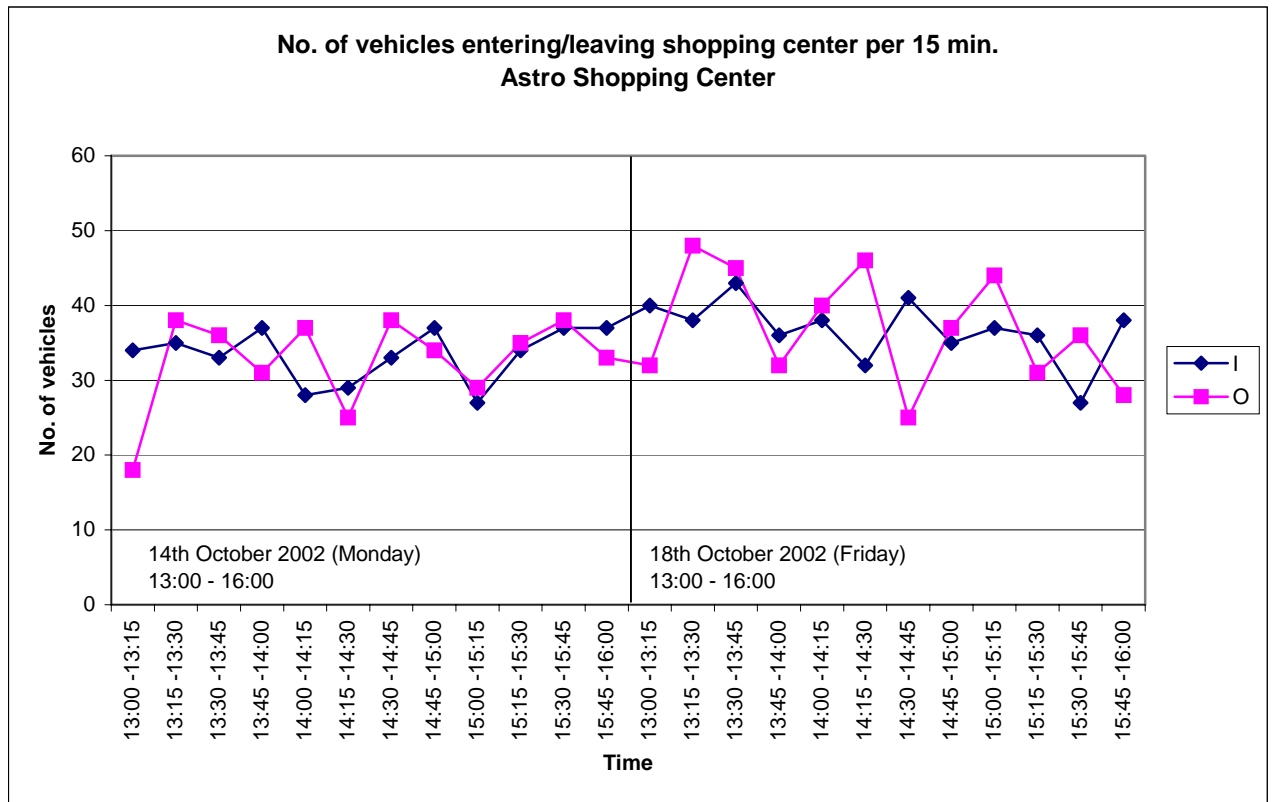


Figure 6.1 Number of vehicles entering and leaving Astro Shopping Center.

7. ANALYSIS AND RESULTS: MICROSCOPIC MODEL

The purpose of this chapter is to examine the validity of the microscopic model, introduced in Chapter 4, for its utility using the data collected in Chapter 6. The microscopic model expresses the shopping center's (SC) trip attraction rate (TAR) as a function of the sum of the products of the TAR of individual store and the weight for the store. First we develop a method of classify each store in the SC into a major store or minor store based on its share of TAR, and all the minor stores are grouped together for the purpose of developing the microscopic model. Second, the weights for the TAR of the SC are derived for each of the major stores and also for the combined total of the minor stores. The model parameters are calibrated and a discussion follows.

7.1 Classification of major and minor stores.

The TAR of some of the stores in a SC is very small. The influence of the TAR of such stores on the total TAR of the SC may be insignificant. Because of this reason and also in order to ease the computation effort for obtaining the weights for all the stores, stores with small values of TAR are combined to form a group, called the minor stores. The cumulative TAR of all the stores in the minor stores is considered in developing the model.

The criterion for deciding whether a store is major or minor is based on the ratio of the store's TAR with respect to the sum of the TARs of all the stores in the SC. The TAR of a major store should be at least equal to the average TAR. This rule is based on the assumption that any store with the TAR less than this value is too small to affect the SC's TAR. The criterion is expressed as follows:

$$\frac{a_i}{\sum_{i=1}^n a_i} \geq \frac{1}{n} \quad (7.1)$$

In Equation 7.1, a_i is the TAR of a store and n is the total number of stores in the SC. The stores that do not satisfy this criterion are considered as minor stores, and the sum of the TAR of these minor stores is taken. For each SC, thus, there are a certain number of major stores and one set of minor stores for the analysis purpose.

Table 7.1 shows the ratio between the TAR of each store and the sum of TARs of all stores in the SC in percentages. This ratio represents the share of store's TAR relative to all other stores. In this case, the number of stores is 18; hence the threshold TAR for being a major store is $100/18 = 5.55\%$.

Table 7.1 Share of the store's trip attraction rate relative to all other stores' trip attraction rates in percentage for Astro Shopping Center

| Name | Share | Name | Share | Name | Share |
|----------------------|--------------|----------------|--------------|-------------------|--------------|
| Happy Harry's | 33.76% | Hair Sensation | 1.82% | Sir Speedy | 2.83% |
| Peper.Farm | 10.95% | RedWing Shoes | 1.19% | Taj Mahal | 7.12% |
| Tuxedo | 3.38% | ScarpBooks | 2.37% | Hibachi | 2.10% |
| Sun Chasers | 5.47% | Taco Shop | 1.82% | Wells Fargo | 2.01% |
| Karate for Kids | 3.28% | Jenny Craig | 2.01% | Chinatown Kitchen | 2.83% |
| Wells Fargo | 1.92% | Top Cleaners | 1.09% | Bakery | 14.05% |

There are four major stores (the stores with the value of the ratio greater than 5.55%) and the remaining 14 stores form the minor stores.. The major stores are Happy Harry's, Pepper Farms, Taj Mahal and Bakery, as marked in bold in Table 7.1.

7.2 Calculation of weights.

After classifying the stores into the major and the minor stores, the weights for the individual stores are derived. Based on the formulation in Equation 4.3 of Chapter 4, the weights are obtained by solving the following equations for W_i in optimization problem

$$\begin{aligned}
 & \text{Minimize } d = \sum_{j=1}^k d_j^+ + d_j^- \\
 & \sum_{i=1}^c a_{i1} w_i + a_{o1} w_o - d_1^+ + d_1^- = y_1 \\
 & \sum_{i=1}^c a_{i2} w_i + a_{o2} w_o - d_2^+ + d_2^- = y_2 \\
 & \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \\
 & \sum_{i=1}^c a_{ik} w_i + a_{ok} w_o - d_k^+ + d_k^- = y_k \tag{7.2} \\
 & 0 \leq w_i \leq 1, \quad \text{for } i = 1, 2, \dots, c \\
 & 0 \leq w_o \leq 1 \\
 & d_j^+ + d_j^- \geq 0 \quad \quad \quad \text{for } j = 1, 2, \dots, k
 \end{aligned}$$

where,

c is the number of stores that satisfy equation 7.1;

a_{ok} is the TAR of the group of minor stores for the k^{th} 15-minute interval;

w_o is the cumulative weight for the group of minor stores;

and the remaining variables are same as defined in Equation 4.3.

Using the data collected for different 15-minute intervals, the weights are calculated. Each equation corresponds to the data for each 15-minute interval. A sample TAR data used in the calculation for Astro SC is shown in Table 7.2. The vehicle trips measured in the survey were converted into person trips using a car occupancy rate of 1.1 persons per car. This value is used as the observed TAR of SC. A sample equation obtained from the data for 13.00-13.15 hrs on day one is as follows:

$$13 \times W_1 + 11 \times W_2 + 2 \times W_3 + 6 \times W_4 + 19 \times W_o - d_1^+ + d_1^- = 37.4 \tag{7.3}$$

where W_i is the weight of store 'i' and W_0 is the weight of the group of minor stores.

Table 7.2 Trip attraction rate per 15 minutes for major and minor stores in Astro Shopping Center for two days.

Day one

| Time | Major Stores | | | | Group of Minor Stores | Observed TAR of SC |
|--------------|--------------|--------|-------------|-----------|-----------------------|--------------------|
| | Happy Harrys | Bakery | Peper. Farm | Taj Mahal | Others | |
| 13:00 -13:15 | 13 | 11 | 2 | 6 | 19 | 37.4 |
| 13:15 -13:30 | 32 | 8 | 9 | 4 | 13 | 38.5 |
| 13:30 -13:45 | 21 | 3 | 1 | 5 | 22 | 36.3 |
| 13:45 -14:00 | 19 | 6 | 7 | 0 | 17 | 40.7 |
| 14:00 -14:15 | 14 | 7 | 3 | 0 | 13 | 30.8 |
| 14:15 -14:30 | 19 | 7 | 6 | 3 | 10 | 31.9 |
| 14:30 -14:45 | 16 | 5 | 5 | 1 | 24 | 36.3 |
| 15:00 -15:15 | 9 | 3 | 12 | 1 | 7 | 29.7 |
| 15:15 -15:30 | 20 | 9 | 5 | 8 | 11 | 37.4 |
| 15:45 -16:00 | 13 | 7 | 6 | 6 | 22 | 40.7 |

Day two

| Time | Major Stores | | | | Group of Minor Stores | Observed TAR of SC |
|--------------|--------------|--------|-------------|-----------|-----------------------|--------------------|
| | Happy Harrys | Bakery | Peper. Farm | Taj Mahal | Others | |
| 13:00 -13:15 | 23 | 9 | 6 | 5 | 27 | 44 |
| 13:15 -13:30 | 14 | 5 | 8 | 2 | 21 | 41.8 |
| 13:30 -13:45 | 21 | 7 | 2 | 5 | 22 | 47.3 |
| 13:45 -14:00 | 23 | 5 | 10 | 3 | 23 | 39.6 |
| 14:00 -14:15 | 17 | 11 | 0 | 5 | 15 | 41.8 |
| 14:15 -14:30 | 10 | 7 | 2 | 8 | 16 | 35.2 |
| 14:30 -14:45 | 23 | 6 | 5 | 1 | 11 | 45.1 |
| 14:45 -15:00 | 15 | 8 | 3 | 3 | 15 | 38.5 |
| 15:00 -15:15 | 12 | 10 | 8 | 3 | 13 | 40.7 |
| 15:15 -15:30 | 12 | 5 | 6 | 6 | 18 | 39.6 |
| 15:30 -15:45 | 9 | 7 | 12 | 2 | 14 | |
| 15:45 -16:00 | 15 | 8 | 2 | 1 | 21 | 41.8 |
| Total | 370 | 154 | 120 | 78 | 374 | 485 |
| Share | 33.76% | 14.05% | 10.95% | 7.12% | 34.12% | |

For data corresponding to each time interval a similar equation is developed based on the values of the row in Table 7.2. The equations are then solved to obtain the optimum values of the weights minimizing the objective function

7.3 Meaning of the weights.

The weights can be an indicator of how people “shop around” within the SC; a shopper may come just to one store and leave or may stop by many stores in one visit. The pattern of how a shopper visits one or many stores can be identified by using the value of TAR. If the TAR of a store is very high, then we hypothesize that more number of shoppers come just for that store. If the TAR of a store is very small then we hypothesize that less number of shoppers come just for that store.

Let us define the following. A shopper, who comes to a store P alone, is called exclusive shopper to the store and a shopper who comes to a store P and also visits another store is called an overlapping shopper for the purpose of this analysis. If the number of exclusive shoppers to a store is large, then the contribution of the store to the total TAR of SC, i.e. the weight of the store, is large. In other words if all the shoppers to a store P are exclusive shoppers then the weight of that store, W_P is one. Combining the propositions presented above, it can be stated that stores with higher TAR must have higher weights. This means if $TAR_1 > TAR_2$, then $W_1 > W_2$. Considering this proposition, the following constraint is added in the computation of weights in Equation 7. 2.

$$0 \leq w_1 \leq w_2 \leq \dots \leq w_{c+1} \leq 1 \quad (7.3)$$

where, w_1 is the weight for the store with the smallest share of TAR, w_2 is the weight for the store with the second smallest share of TAR, and w_{c+1} is the weight for the store with the highest share of TAR. This constraint increases the correlation between the two variables - TAR of the store and the weight assigned to TAR of the store. Figure 7.1 and

Figure 7.2 show the correlation between these two variables before and after adding the constraint 7.3 respectively.

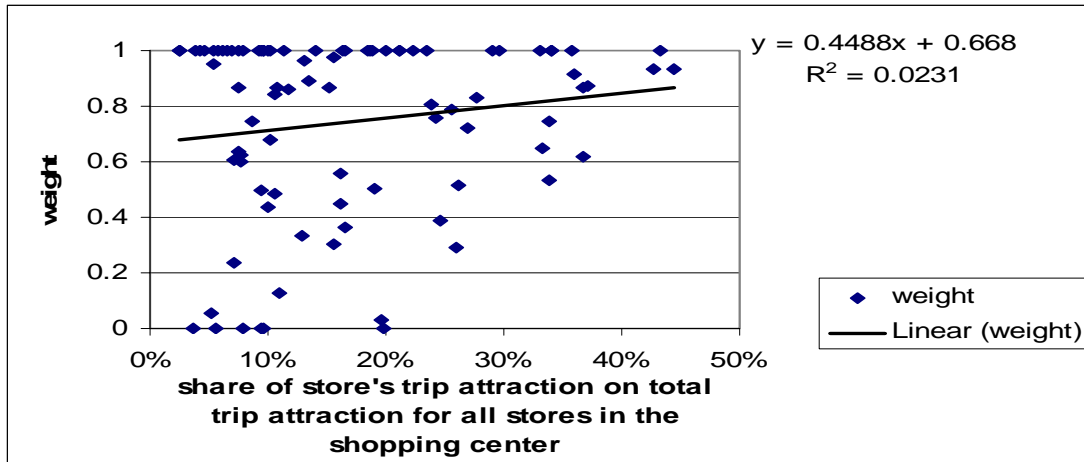


Figure 7.1: Relationship between the store's trip attraction and the weight of the store without the constraint

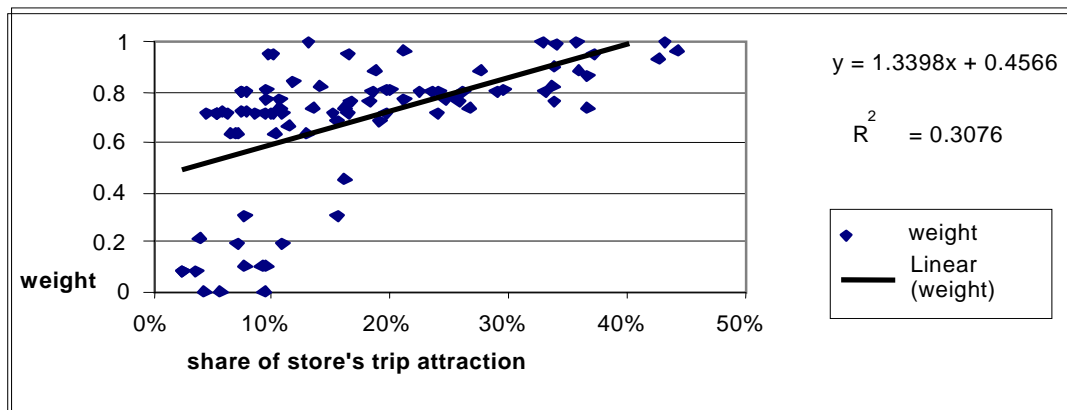


Figure 7.2: Relationship between the store's trip attraction and the weight of the store with constraint.

The correlation between the TAR and the weight of the store in figure 7.2 is much higher than that of figure 7.1. That is by adding the constraint the weights have become more sensitive to the TAR. The sensitivity of the weights to the TAR is needed for studying the trip chaining in the SC based on the values of the weights obtained in the model.

7.4 Computation

The constraint 7.3 applied to the case of Astro SC, would be of the following form

$$0 \leq w_{\text{Taj Mahal}} \leq w_{\text{Peper.Farm}} \leq w_{\text{Bakery}} \leq w_{\text{Happy Harry's}} \leq w_{\text{others}} \leq 1 \quad (7.4)$$

where w_{others} is the weight of the group of minor stores and w indicates the weight for the respective store's TAR. The microscopic model was solved for the Astro shopping center with this added constraint. The results are shown in Table 7.3.

Table 7.3 Computed Weights for Major Stores and the Group of Minor Stores in Astro Shopping Center.

| | Major Stores | | | | Group of Minor Stores |
|--------|---------------|--------|------------|-----------|-----------------------|
| | Happy Harry's | Bakery | Peper.Farm | Taj Mahal | Others |
| weight | 0.82 | 0.82 | 0.20 | 0.20 | 0.99 |

The table shows that the weight of Happy Harry's is larger than that of Taj Mahal and Peper Farm. And so is the TAR. The TAR of Bakery is larger than the other two stores though all the three stores are of same size because, the people coming to Taj Mahal and Peper Farm usually shop in other stores also but the people-visiting Bakery in general visit Bakery alone. The high weight of "others" indicates that the people coming to the group of small stores visit just these small stores and rarely visit any of the remaining 4 major stores. This is a reasonable deduction from the analysis because for a SC like Astro having just a discount store and no supermarket it can be expected that very few people coming to the small stores actually go to the major stores like Happy Harry's. For SCs that have a supermarket, the weight of group of minor stores is lesser, which means that the people coming to the group of minor stores go to other major stores (especially the supermarket) also.

The data for all the SCs is analyzed by using optimization. The objective function and the constraints for the Astro SC case is provided in Appendix B. The values of the weights obtained from the optimization are provided for all the SCs in Appendix C. Appendix C gives the values of the weights obtained from the microscopic model for all the major stores and the group of minor stores for each SC.

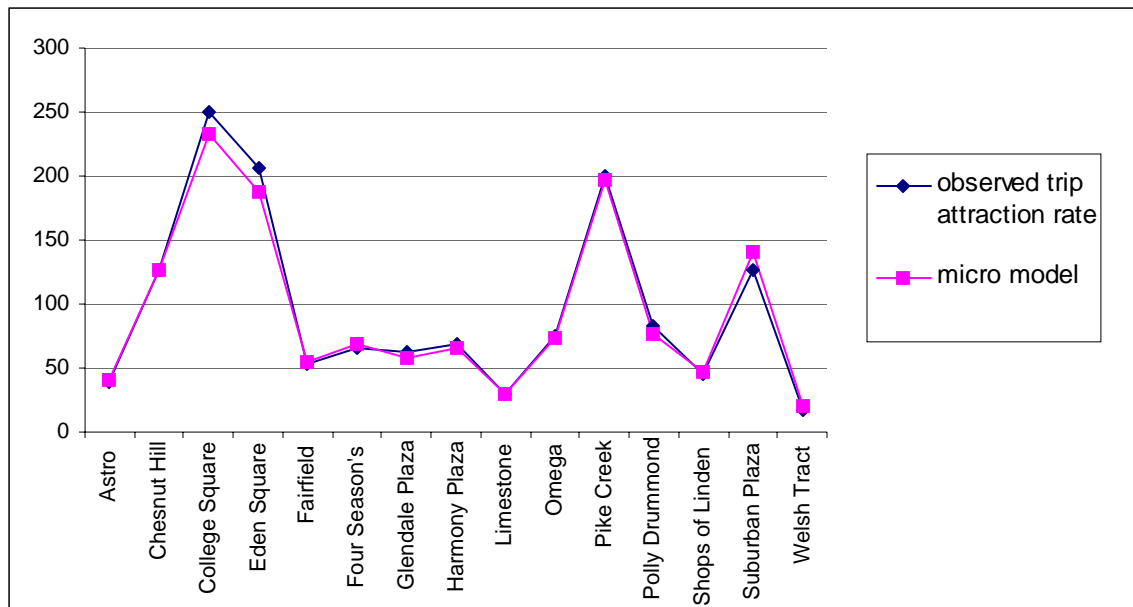


Figure 7.3: Observed and computed trip attraction rate of shopping centers.

The values estimated from the microscopic model are very close to the observed values. This is because the model takes into consideration the observed values of the TAR of each store. The goodness of the model depends on the variation of the TAR of the SC in the sample that is considered for analysis. If the data is collected for different time periods spread across different days of the week and has a lot of variation in the observed values, then the estimated values can be expected to deviate from the observed values by higher proportions than the case presented in figure 7.3.

The steps involved in the approach of the microscopic model are shown in figure 7.3.

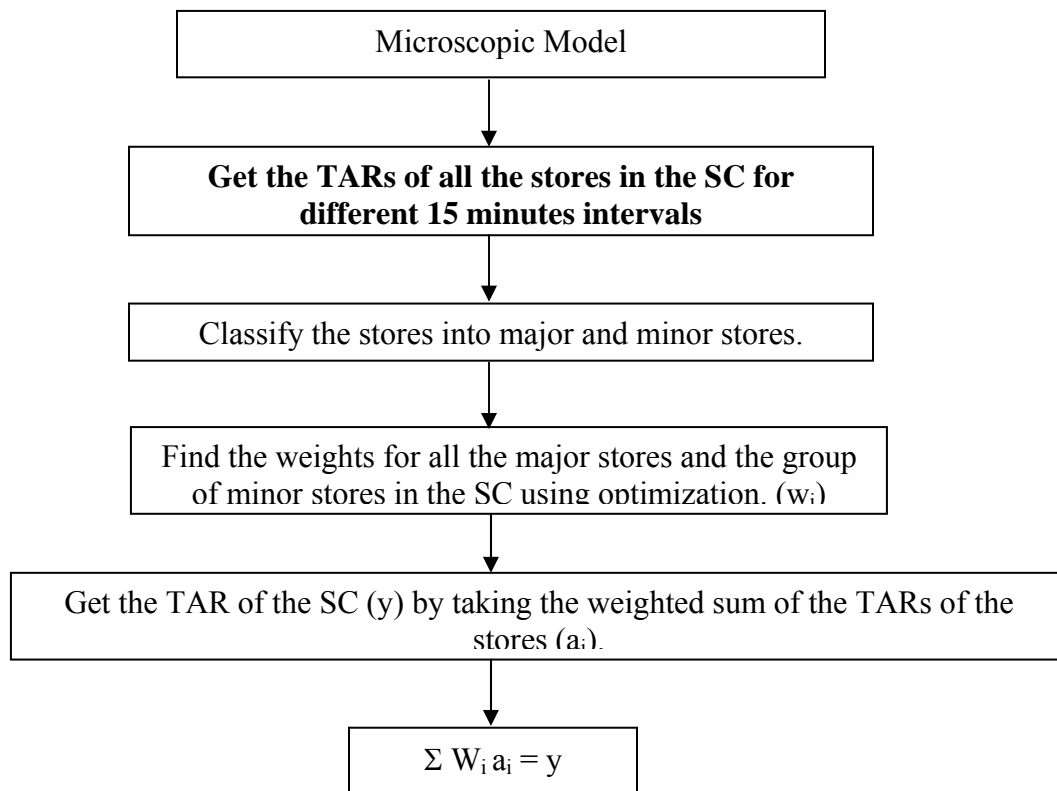


Figure 7.4 Approach of the microscopic model

7.5 Limitations

A major drawback of the microscopic model is the large volume of data that is required for calculation of the TAR of individual stores and the weights. The number of people entering individual stores needs to be collected for different time periods. This data is used to calculate the average TAR of individual stores and also to group them between the major and the minor stores. The weights of the stores are computed based on the regression analysis; for this purpose, a large set of datum is required to make a meaningful values of the weights. Basically, the model is valid for the time period in which the trip chaining behavior is relatively uniform. Therefore ideally, the microscopic model should be developed for different time period (time of the day, day of the week, and maybe for seasons) separately.

8. ANALYSIS AND RESULTS: MACROSCOPIC MODEL

The macroscopic model estimates the trip attraction rate (TAR) of the Shopping Center (SC) based on the physical features of the whole SC unlike microscopic model, as described in Chapter 4. This chapter discusses the calibration of the parameters of the model, and the performance and implications of the model.

8.1 Parameters considered for the evaluation.

As discussed in Chapter 4, the independent variables in the model are the number of stores, floor space area of the SC, and the number of parking spaces in the SC. The dependent variable in the model is the 15-minute TAR for the SC. Table 8.1 shows the values of the variables considered in the regression analysis for the 18 SCs that are surveyed. TAR in the first column of Table 8.1 is the average value of all the 15-minute observations of the TAR of the SC. The floor area is estimated from the aerial photographs using the Arc GIS. The aerial photographs are also used to estimate the number of parking spaces. The number of stores was observed by site visit.

The general equation of the model is as follows:

$$\text{TAR} = AX_1 + BX_2 + C X_3 + \beta \quad (8.1)$$

Where X_1 , X_2 and X_3 represent the physical features of the SC β is a constant.

Table 8.1 Parameters Describing the Shopping Centers

| Name | Trip attraction rate (15 min.) | Floor area (feet square) | No. of stores | No. of parking spaces | Supermarket (1=yes, 0=no) | Discount Shop (1=yes, 0=no) |
|-------------------|---------------------------------------|---------------------------------|----------------------|------------------------------|----------------------------------|------------------------------------|
| Astro | 38.4 | 57240.6 | 18 | 310 | 0 | 1 |
| Chesnut Hill | 126.3 | 204095.7 | 19 | 726 | 1 | 1 |
| College Square | 250.0 | 375308.8 | 45 | 2097 | 1 | 1 |
| Eden Square | 206.1 | 271991.3 | 23 | 1376 | 1 | 1 |
| Fairfield | 52.4 | 63169.0 | 12 | 281 | 1 | 0 |
| Four Season's | 64.9 | 134116.2 | 17 | 689 | 1 | 1 |
| Glendale Plaza | 63.0 | 85884.0 | 15 | 396 | 0 | 0 |
| Governor's Square | 305.4 | 326793.8 | 38 | 2261 | 1 | 1 |
| Harmony Plaza | 68.2 | 89874.4 | 21 | 443 | 0 | 1 |
| Lantana Square | 199.6 | 221777.6 | 42 | 1460 | 1 | 1 |
| Limestone | 29.7 | 36803.8 | 13 | 213 | 0 | 0 |
| Omega | 74.3 | 47269.3 | 15 | 221 | 0 | 1 |
| People's Plaza | 312.4 | 565467.0 | 44 | 3231 | 1 | 1 |
| Pike Creek | 200.2 | 233533.1 | 31 | 1522 | 1 | 1 |
| Polly Drummond | 83.2 | 87445.1 | 16 | 527 | 1 | 1 |
| Shops of Linden | 45.7 | 37673.0 | 11 | 195 | 0 | 1 |
| Suburban Plaza | 126.2 | 159282.2 | 31 | 1045 | 1 | 1 |
| Welsh Tract | 17.3 | 11460.0 | 7 | 60 | 0 | 0 |

8.2 Calibration of the parameters of macroscopic model

Two forms of the macroscopic model are considered in this study. In the first form, TAR of the SC is estimated as a function of floor space and the number of stores. In the second from, TAR of the SC is estimated by the number of parking spaces. The reason for having two separate forms is to avoid multi-collinearity. The number of parking spaces is related to both the number of stores and also the floor area of the store. Multi-collinearity is a situation where in two independent variables are highly correlated and they both convey essentially the same information

Using the data given in Table 8.1, the parameters of the two forms of macroscopic model are calibrated separately. In the first form, the equation obtained is the following.

$$y = 0.44x_1 + 2.30x_2 \quad R^2 = 0.9199 \quad R = 0.9591 \quad (8.2)$$

Where x_1 and x_2 are the floor area of SC in thousand square feet and the number of stores, respectively; and y is the average TAR of a SC in terms of number of persons per 15 minutes. Coefficients of x_1 and x_2 are positive. This means that. The values of R^2 and R represent the coefficient of determination and coefficient of correlation respectively. $R^2 = 0.92$ means 92.0% of the variation of the TAR is explained by the variation of x_1 and x_2 . $R = 0.95$ indicates a very strong positive correlation; and as the floor area and the number of stores increase, the TAR of the SC increases.

In the second form, the result of the regression analysis is the following:

$$y = 0.12x \quad R^2 = 0.9014 \quad R = 0.9494 \quad (8.3)$$

where x is the number of parking spaces and y is the average TAR of the SC in number of persons per 15 minutes. The expression indicates that with an increasing number of parking spaces, the TAR of the SC increases. $R^2 = 0.90$ indicates that 90.1% of the variation of the TAR is explained by the variation in the number of parking spaces. $R = 0.95$ means very strong positive correlation between x and y . The details of the regression analysis for equations 8.2 and 8.3 are provided in Appendix D.

8.3 Validation of the model.

The TAR of the SC that is computed by the model is compared with the actual values obtained through the survey. The comparison is shown in Figure 8.1.

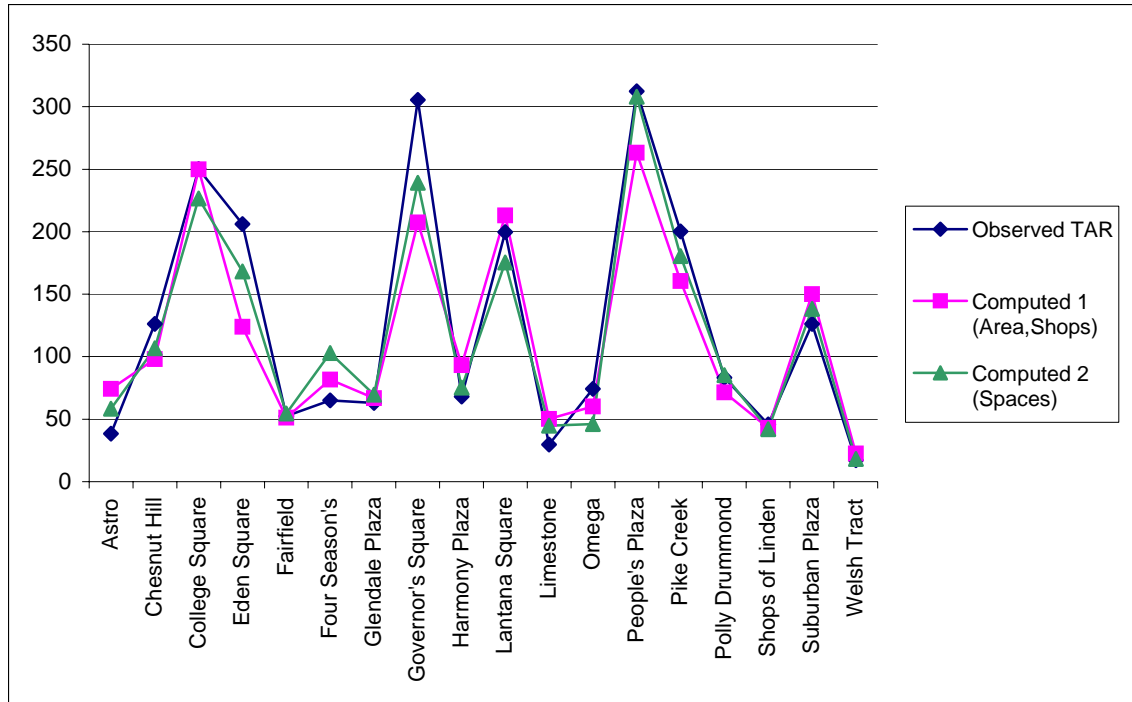


Figure 8.1: Observed and computed trip attraction rate of shopping centers for 15 minutes intervals

It is seen that the estimated values from both forms of the model are very close to the observed values. The maximum difference between the estimated values from the observed value was 90, which was seen at Governor's Square. In general a better match between the estimated and observed is seen at SCs with small value of TAR.

The ITE Trip Generation Manual (1997) provides regression models for estimating the TAR of SC for different time periods. The two forms of the model are compared with the results from the ITE Trip Generation Manual. The models in the ITE Trip Generation Manual consider TAR of SC as a function of the gross leasable area (GLA) only. For this comparison we assumed that GLA is equivalent to total floor space.

In figure 8.2 we show TARs computed using the models in ITE Manual. The ITE Manual provides different values of the coefficients for different time periods, e.g., peak hour 4-6 P.M. on weekdays, non peak hours on weekdays and peak hours on Saturday. Therefore three values are presented for each SC in figure 8.2.

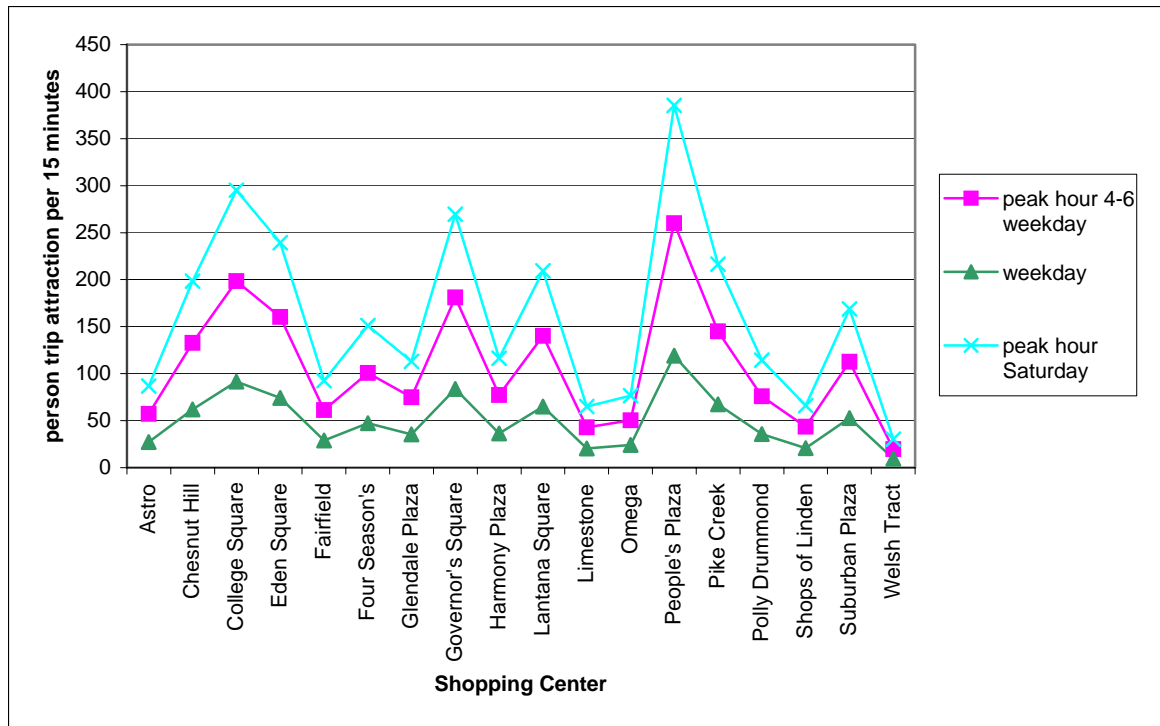


Figure 8.2: Trip attraction rates for 15 minutes intervals estimated using the models in ITE Trip Generation Manual.

Figure 8.3 compares observed TAR, the models in ITE Trip Generation Manual and the two forms of the proposed model. It is seen that all the estimated values and observed are very close indicating that all three models are equally valid in estimating TARs of SCs in New Castle County. Note that the observed value in figure 8.3 is the average value of the TAR of all the time intervals.

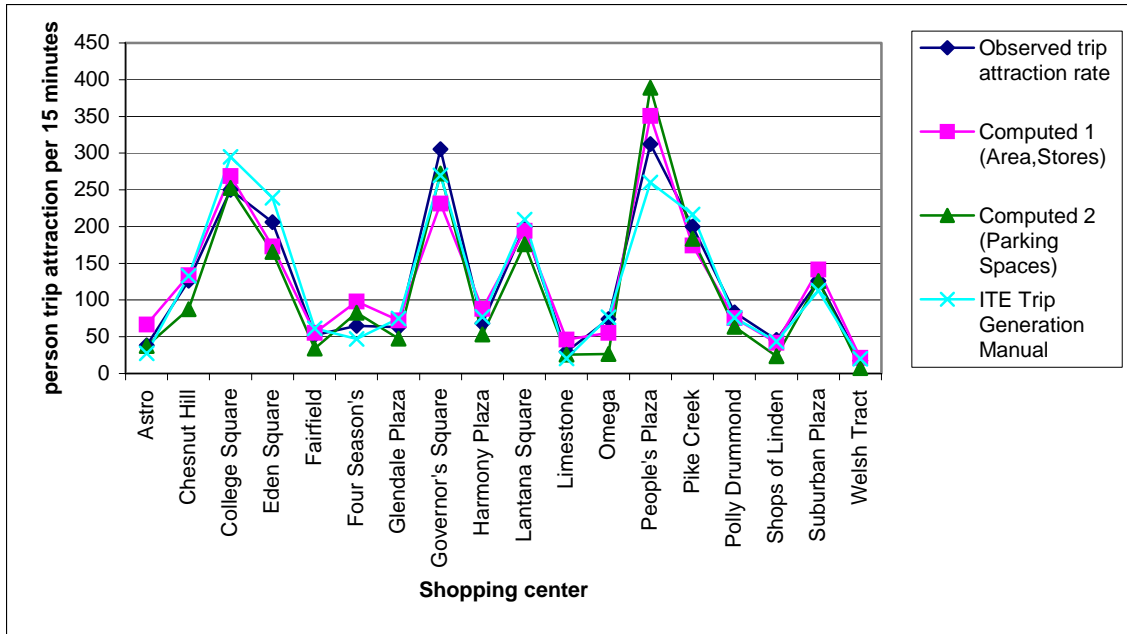


Figure 8.3: Comparison of values obtained from Macroscopic Model and the ITE Trip Generation Manual.

8.4 Relationship between the floor area and the TAR of individual stores.

The ITE Trip Generation Manual (1997) provides models for estimating the TAR for selected store types. Some of the store types that we surveyed in this study were not included in the ITE manual. In order to obtain TAR for the store types that were not included in the ITE Manual we developed a regression model, which expresses the TAR in terms of the floor space. As stores like Nails are found to exist at almost every SC yet they are not included in the ITE Manual, we have developed a model for TAR of these store types. The equation for Nails is

$$y = 0.0005x + 1.2436 \quad R^2 = 0.1799 \quad (8.4)$$

Where x is the floor area and y is the fifteen minute based TAR.

The details of the regression analysis are provided in Appendix D.

Because supermarket is the main attractor to all the SCs we have examined the TAR of the supermarket for the 18 SCs. Using regression analysis the relationship between the floor space area and TAR of the supermarkets is developed.

$$a_i = 22.37 + 0.67x_i \quad R^2 = 0.3266 \quad R = 0.5715 \quad (8.4)$$

where x_i is the floor space area of the supermarket in thousand square feet.

The regression lines and data points are shown in figure 8.4.

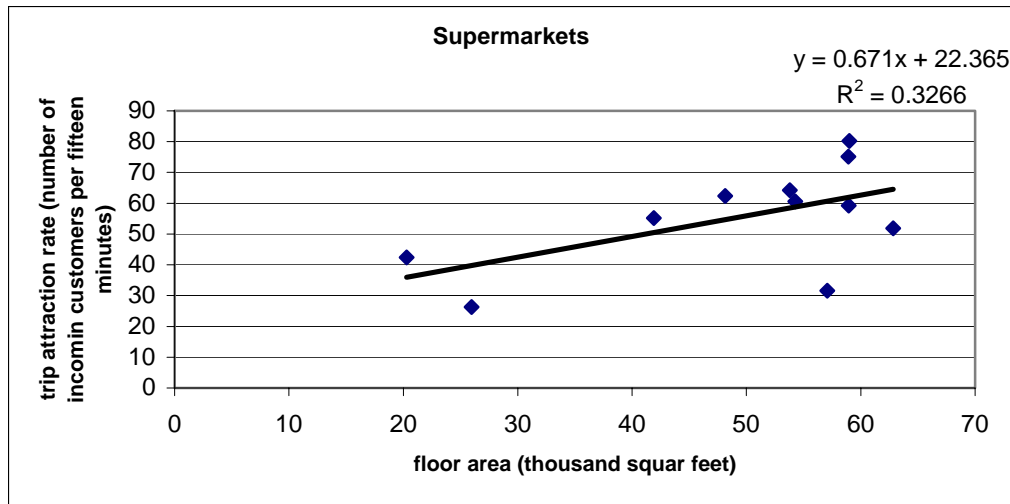


Figure 8.4: Relationship between the floor area and the trip attraction of a supermarket.

This figure shows that the TAR of a SC is fairly well related to the floor area. The point that falls very far away from the line is for Fairfield SC. The supermarket in Fairfield has a small floor space area compared to other supermarkets attracting the same number of people.

Figure 8.5 shows the comparison between the observed TAR, TAR estimated by the proposed model and TAR estimated by the ITE Trip Generation Model. The TARs of the supermarkets was estimated using the regression formula for weekday evenings provided in the ITE Trip Generation Manual.

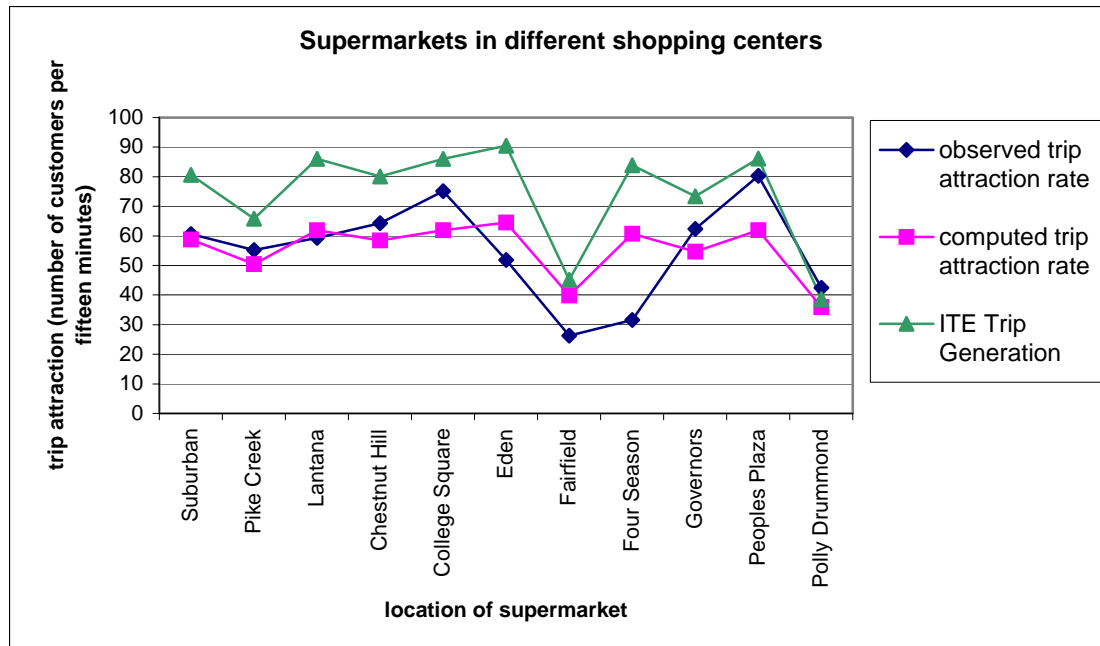


Figure 8.5: Observed and computed trip attraction of supermarkets

Generally the values estimated by the ITE Manual are greater than the observed values. The values estimated using the proposed regression model are close to the observed values for many of the SCs. Our proposed model follow the pattern of the observed TAR better than the ITE Manual model. The ITE model, in spite of being a weekday model consistently over estimates the observed TAR, which is the average value of different weekdays.

8.5 Limitations

The macroscopic model is a general model in which TAR of the SC is treated as a function of the physical features of the SC only, not the types of stores in the SC. This poses a problem if two SC's with different composition of stores but the same physical features, then the model yields the same TAR for the two SC's. The model is insensitive to the nature of stores that the SC is made up of which is a major shortcoming. The model is good at estimating the average value of the TAR but does not give any information

about the deviation that these values can have. Further, the model does not consider the effect of time period on the TAR of the SC. The model uses floor space area of the SC, which is not the correct indication of the space occupied by the stores. Gross leasable area (GLA) is a better parameter, but it is not easy to obtain GLA for every store in the SC.

9. APPLICATION OF THE MODELS

Both the microscopic and the macroscopic models aim at estimating the trip attraction rate (TAR) of the shopping center (SC). The main application of the microscopic model is to analyze the interactions between the TARs of individual stores and the TAR of the whole SC. The macroscopic model, on the other hand, is to estimate the TAR of the whole SC based on the physical features of the SC. This section discusses how these two models can be applied for planning and traffic engineering analysis.

9.1 Application of Microscopic Model

The microscopic model estimates the average TAR of the SC based on the number of customers to individual stores as presented in Chapter 7. An important feature of this model is the weighted sum of the TARs of the stores; this account for the importance of different stores in the SC. The idea behind the weighted sum is to consider all the constituent stores of the SC and assign a reasonable level of importance to each of these stores in the estimation of the total TAR of the SC. In the following we discuss the features of the microscopic model.

1. It is possible to get a good estimate of the average TAR of a SC based on the data collected over different time periods. Instead of the average observed value of the TAR of the SC, if the weighted sum of the TAR of the stores is considered, we believe that it would be a better representation of the real world situation.
2. The microscopic model helps in understanding the trip chaining in the SC. The model can be used to gauge the intensity of activity within the SC. In other words the model helps in understanding the degree of overlapping that exists among the

- shoppers coming to different stores. The sum of weights gives an indication of the intensity of trip chaining in the SC. If the sum of weight is close to one then it means maximum overlapping among the stores.
3. The weight of each store indicates the degree of overlapping of the store's TAR. Stores with higher weights indicate that they have more number of exclusive customers as discussed in Chapter 7.
 4. Based on how the TAR of a particular type of store influences the overall TAR of the SC, it is possible to analyze the impact of a new store coming up or a store being replaced by another store in the SC.
 5. The concept of using weights can be extended to other analysis of trip chaining character with multiple destinations to measure the tendency of trip chaining e.g. trips starting from home and visiting different places before coming back to home.

9.2 Application of Macroscopic Model.

Macroscopic model is more useful for predicting the TAR of a SC, particularly for a SC that is being planned. The calibrated model was found to match the observed TAR closely for all the SCs surveyed. The model produces very accurate estimate of the average values of the TAR of the SC. This model is useful for prediction rather than analyzing the existing SCs.

Possible scenario of application include,

1. When a new SC is planned and the traffic impacts on the surrounding roadways need to be estimated for the purpose of designing traffic control device and geometric design (e.g. channelization).
2. When a new SC is planned and the overall increase in the travel time delay in the region is to be estimated, using a Network Simulation Model

3. If for an existing SC an additional floor space area or more number of parking spaces are being planned then the estimate for the additional trips attracted can be estimated.

The model can be applied to the case of individual stores to estimate the TAR of the stores by capitalizing on the features common to these stores in various SCs. This is very useful in getting an accurate estimate of the TAR of a store type based on the regression analysis on the stores of same type in the SCs of a particular region. The ITE Trip Generation Manual does not provide models for estimating TARs of all kinds of stores. The proposed model is localized in its approach, which is better than the models in the ITE Manual based on nationwide data. The model can analyze the TAR of stores like Chinese restaurants and liquor stores that do find a mention in the ITE Manual.

10. CONCLUSION

The shopping trips constitute the second largest share of trips after the work trips in Delaware. In the suburbs, majority of shopping trips are the trips to/from shopping centers (SCs). The size of a shopping center is growing in Delaware; some of them actually began to show the feature of a downtown of a small city, including a post office, a library and a bank as well as many small and large stores/offices. Further, the size of a SC has become very large, e.g. People's Plaza, College Square, and Lantana Square; hence the travel pattern in the region is greatly affected by the size and activities of the SC. This project collects data on trip attraction rates (TAR) of SCs in Delaware, and develops models that express the trip attraction as a function of individual stores and also the features of the SCs and the composition of the stores. This report shows a large volume of trip attraction data obtained at 18 shopping centers in northern Delaware.

Our objective is to develop a formula that shows the number of trips attracted to the SC (not individual stores in it.) Two different approaches are considered. The microscopic approach deals with the relationship between individual stores' TAR and whole SC's TAR. The macroscopic approach deals with the relationship between physical features of the SC on the TAR. Both the approaches have provided a reasonably good estimate of the TAR of the SCs when compared to the observed values.

The microscopic model gives more accurate results of the TAR of the SC compared to the macroscopic approach. The microscopic model considered the TARs of individual stores and their weight in the SC for estimating the TAR of the SC. The concept of weights used in the model gives a good indication of the extent of trip chaining

phenomenon observed in the SC. The model has been successful in measuring the pattern of the shoppers' movement in the SC. This model can explain the intensity of trip chaining inside the SC, and the relative importance of the stores. Thus this model is not a forecasting model; rather it is a descriptive model of trip chaining phenomena.

The macroscopic model relates the TAR of the SC to the physical features of the SC. The model confirms that the floor area of stores, the number of stores and the number of parking spaces have relevant impact on the TAR of the SC and establishes the relationship. The macroscopic model can be used as an alternative to ITE Trip Generation Manual (1997). This model incorporates more factors than the ITE model.

A good estimate of TAR at SC is fundamental in planning of transportation facilities, be it the regional transportation network or the channelization of traffic control around a shopping center. The data and the model should be useful in assessing the traffic impacts surrounding a new shopping center, and also the region wide traffic volume impacts.

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