TRAVEL CHARACTERISTICS-BASED PARKING DEMAND MODELS FOR INSTITUTIONAL URBAN AREAS

by

Md Mahmudul Huque Chayan

B.Sc. in Civil and Environmental Engineering,

Shahjalal University of Science and Technology, 2012

Submitted to the Graduate Faculty of

Swanson School of Engineering in partial fulfillment

of the requirements for the degree of

Master of Science

University of Pittsburgh

2018

UNIVERSITY OF PITTSBURGH

SWANSON SCHOOL OF ENGINEERING

This thesis was presented

by

Md Mahmudul Huque Chayan

It was defended on

November 14, 2018

and approved by

Keith Johnson P.E., Senior Lecturer

Departmental of Civil & Environmental Engineering

Kevin Sheehy, Director

Auxiliary Finances and Parking, Transportation, and Services

Thesis Advisor: Mark J. Magalotti, Ph.D., P.E, Professor of Practice,

Departmental of Civil & Environmental Engineering

TRAVEL CHARACTERISTICS-BASED PARKING DEMAND MODELS FOR INSTITUTIONAL URBAN AREAS

Md Mahmudul Huque Chayan, MS

University of Pittsburgh, 2018

Parking demand estimation is a complex topic. Traditionally, land use patterns are used as independent variables for estimating parking demand, which is useful for predicting parking generation for specific land use types such as commercial, industrial and institutional areas where there is little or no non-auto travel opportunities. But for urban institutional areas travel characteristics could be more influenced by other independent variables, in addition to land use only, to estimate peak weekday parking demand. In addition, to maximize the utilization of parking resources, off peak parking demand estimates also are needed in an urban environment to management facilities.

The hypothesis of this research is, "As an alternative to using traditional parking demand models, travel characteristics-based data should give more accurate estimations of parking generation for a shared institutional urban area". Travel characteristics such as auto occupancy, mode split of institutional staffs, students and visitors, cost of parking and temporal/geographic distribution of demand should be used as independent variables in parking demand models. These types of non-traditional land use areas are difficult to predict with accuracy, parking demand, based on the land use type and building areas alone. This research determined if a more

accurate methodology and model can be developed to estimate parking demand and compare it to supply, based upon the relationship between the consumers' travel characteristics with measured parking utilization.

The Oakland institutional area of the City of Pittsburgh was used to test the methodology. This large institutional area has all the needed characteristics of a University and commercial district that requires a complex parking demand model for analysis along with significant transit accessibility. The model was used to test different scenarios of the parking supply and demand such as improved transit accessibility, growth of the institutions or changes in demand management policies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

I would like to acknowledge my wife Sumaiya for her continued support and inspiration throughout my academic career. Without her support it could not be possible to continue my academic career, chasing my dreams.

I would like to thank my advisor Dr. Mark Joseph Magalotti for his patience and detail guidelines not only for this research but also throughout my master's degree. It's a blessing to be a student of a mentor and a human being like Dr. Magalotti.

1.0 INTRODUCTION

On his *magnum opus* on parking studies "High cost of Free Parking", Donald Shoup said,

"*Ask anyone to define a livable city. Some will say clean air and safe streets. Others will mention good restaurants, affordable housing, pleasant parks, or less traffic congestion. But, chances are, they'll all agree on one thing – plenty of free parking."* [1]

Parking is one of the key elements of urban planning. Parking in urban areas is considered as challenging policy work for transportation planners. In another research study, Shoup mentioned that sixteen studies from 1927 to 2001 in different major cities of different continents have found an average of 30 percent of the traffic in central business districts areas is generated from cruising for curb parking [2]. Today, cars are becoming cheaper and available to move people than in the previous century. The number of cars on roads are increasing. So, it can be said that though this result of 30 percent is based on the studies starting from 1927, considering the recent number of cars on roads, this percentage might be higher than 30 percent for major urban areas of the United States.

Institutional parking demand has an impact on overall parking demand of the country. According to National Parking Association's (NPA) parking demand report 2018, college/university enrollment in the United States increased 30 percent from 2009-10 [3]. NPA identified increased college/university attendance as one of the eight factors for driving parking demand.

Parking demand estimation based on the traditional parking requirements, generally give more demand than required. It is evident from surveys that many of the parking facilities were not full even during peak hour [6]. Another comparison report of parking in San Francisco area shows that average 28 percent of total parking spaces remain unused, for which the construction cost is around $198,034,400 [7]. From a survey of a hundred parking structures it has been found that median construction cost was $19,700 per space in 2017 [8]. So, a method to estimate parking demand more accurately than conventional method could be economically beneficial.

Parking and land use development has been recognized as the important component for Transportation Demand Management (TDM) or Mobility Management strategies [4]. Parking demands varies from one location to another and these variations mirrors difference in density of developments, transit accessibility and parking prices [5]. Though different practices provide recommendation or base points for the demand calculation, demand calculation considering these variations should give a more accurate result.

1.1 BACKGROUND

Several professional publications provide base ratio or starting points to calculate the peak parking demand for different types of land uses. Mainly, recommendation for parking space requirements by land uses are given by from the analysis of the empirical data. The Institute of Transportation Engineers (ITE) publishes “Parking Generation” report 4th edition, which is an informational report rather than a manual or standard [9]. According to ITE, this report can provide a point of reference for planners for parking study and peak demand calculations. ITE provides these reference points from empirical studies in the different land uses in different area types like urban, sub-urban. Typical institutional areas are divided into different land uses based on type of the institutions such as elementary school, middle school, high school, junior/community college and university/college. For the university/college land use types which is land use code is 550 in the Parking Generation 4th edition, average demand is 0.22 vehicles per school population where the 85th percentile demand is 0.29 vehicles per school population. University/college is defined as a land use which includes four-year universities or colleges that may or may not offer graduate programs. These recommendations are for the institutional land uses in an urban area also. ITE provides these data from the linear regression analysis of peak hour data of five University/college study sites. The reference data of ITE for the urban institutional area is shown in the Figure 1

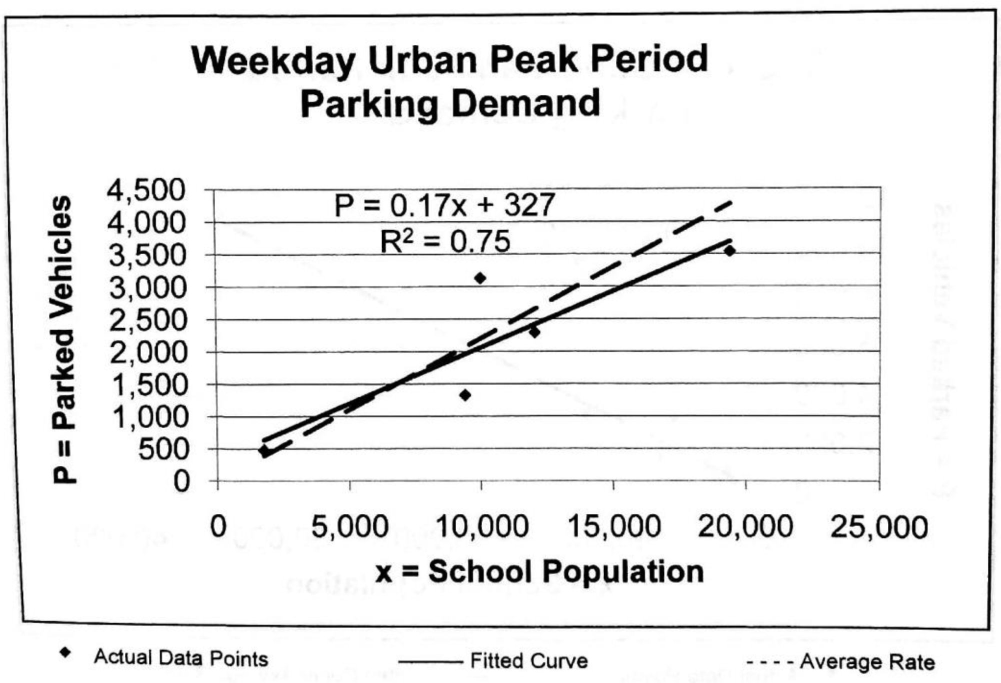

Figure 1: ITE requirements for parking study in institutional area

(Source: ITE Parking Generation 3rd edition)

From the empirical studies, the ITE parking generation publication provides the 85th percentile, average and 33rd percentile as ratios of spaces per unit of land but does not recommend any specific ratio to be used for any type of land use.

However, in the publication "The Dimensions of Parking" of the Urban Land Institute (ULI), primarily the average ratio data of the ITE publication is used as the recommended standard, which it states is not always correct [10]. It is cited in the publication that much of the data in the parking generation publications, including the ITE parking publication, are statistically unreliable.

The National Parking Association (NPA) also provides parking space recommended requirements for different land uses [5]. For the zoning ordinance administrators, NPA also provides guidelines for adjustment of parking requirements for areas with alternative mode accessibility. Along with other adjustment factors, it is recommended that zoning administrators reduce the parking requirement based on the number of on-street parking and off-street parking which are available to public. A reduction factor can also be applied in a specific area based on the alternative transportation services such as transit and carpooling/vanpooling. The Parking Consulting Council (PCC) of NPA does not recommend any specific base ratio for the college and university land uses in the section of institutional land uses. But they provide specific ratios for other institutional land uses such as elementary schools and secondary schools. For colleges, universities and hospitals PCC recommends a study on the specific area for the baseline demand ratio establishment.

Although the ULI have several publications for different types of parking scenarios such as shared parking, parking for downtowns, or other types of land uses, ULI recommends PCC's demand recommendation [10].

The American Planning Association (APA) also does not recommend any base ratio for demand calculation for a specific land use. It also does not provide any statistical regression data as ITE provides. The "Parking Standard" publication of APA listed several base ratios for demand calculation for different land uses [11]. These base ratios were collected from different areas of the United States.

1.2 HYPOTHESIS

The hypothesis of this research is-

"As an alternative to using traditional parking demand models, travel characteristics-based data should give more accurate estimations of parking generation for a shared institutional urban area".

Parking is considered as one of the most challenging problems for the urban transportation planner. Generally, demand is predefined for land development approval purposes and planning by the zoning ordinance of an area, and in most cases traditional Institute of Transportation Engineer's (ITE) or Urban Land Use (ULI) standards are used to calculate the parking demand of a specific area. In the ITE parking generation manual, standards and land use patterns are used as independent variables for estimating parking demand, which is useful for predicting parking generation for specific land type such as commercial, industrial and institutional areas in areas with little or no non-auto travel opportunities [9]. The urban institutional area travel characteristics could be more influenced by other independent variables in addition to land use only to estimate peak weekday parking demand. In additional to maximizing the utilization of parking resources, off peak parking demand estimates also are needed in an urban environment for parking management.

Travel characteristics such as auto occupancy, mode split of faculty, staff, students, shoppers and visitors, cost of parking and temporal/geographic distribution of demand should be used as independent variables in models. These types of non-traditional land use areas do not provide the accurate parking demand estimations based on the land use type and building areas alone. The hypothesis of this research is generated from this idea.

1.3 OBJECTIVES

The main objective of this research was to develop a model to test the hypothesis. Based on the hypothesis, it is a challenge to determine how the travel characteristics like auto occupancy, mode split can be adopted in the model. This research explored if a more accurate methodology can be developed to estimate parking demand and compare it to utilization of the supply, based upon the relationship between the consumers' travel characteristics with measured parking utilization. The model was validated by comparing estimated demand to usage of parking.

1.4 METHODOLOGY

A methodology was developed to meet the research objectives. Prior to starting the data collection, a literature review was done on published academic journal articles and professional practices to obtain background information for building the methodology and model.

The Oakland, area of the City of Pittsburgh, Pennsylvania. is an institutional shared urban area and was selected as the study and model area. To test the hypothesis, a new parking demand estimation model of the study areas was developed and compared with the existing utilization. Also, a traditional demand model, based on ITE standards and the Pittsburgh Zoning Ordinance, was developed and compared with the new demand model. Finally, calibration of the model was needed to be done before using the model for a scenario analysis by the newly developed demand prediction model. The methodology of the research is described in a flowchart shown in Figure 2.

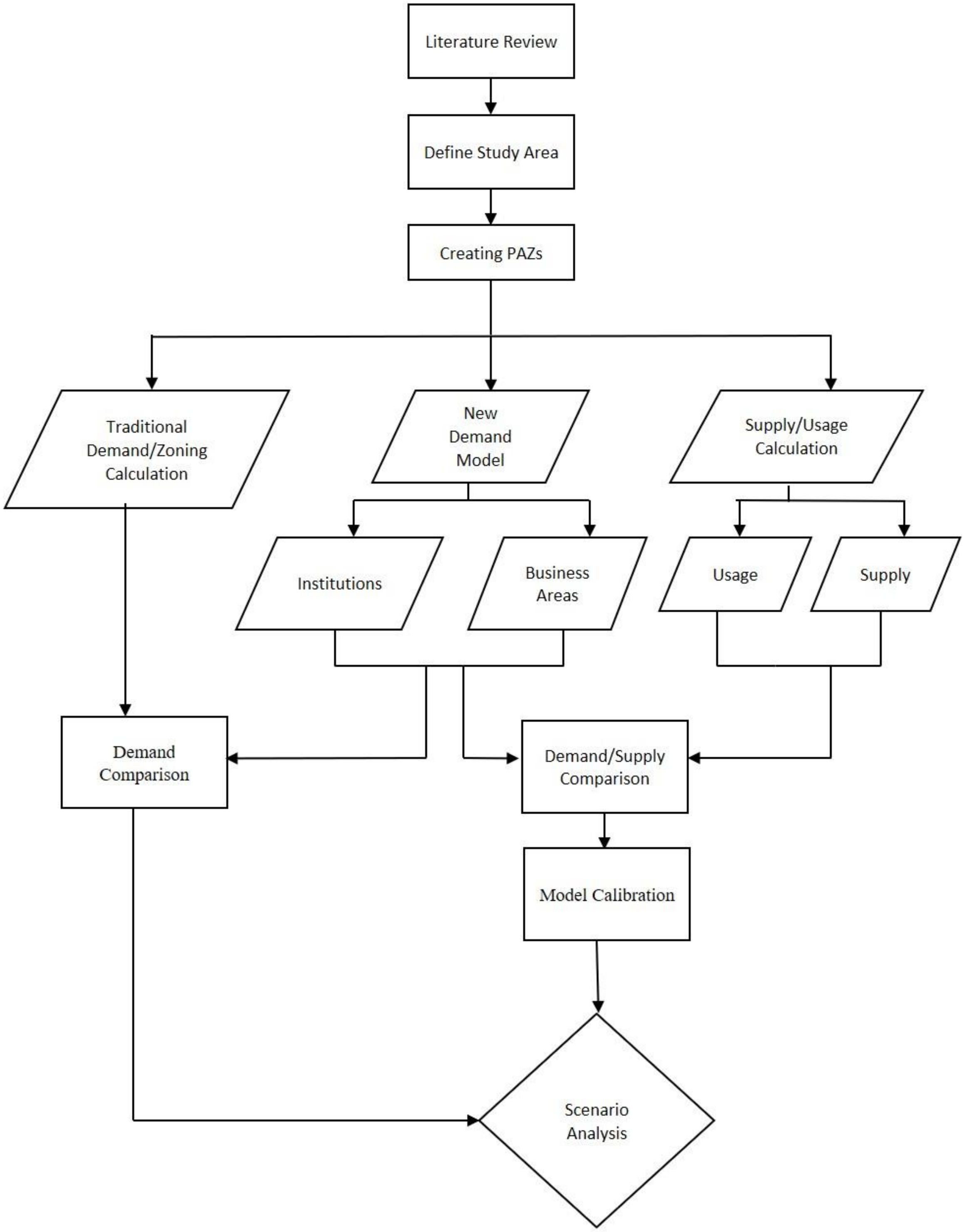

Figure 2. Methodology flowchart of the research

1.5 SUMMARY

The hypothesis of the research and the development of methodology for testing the hypothesis and a background study on how and which methods are currently being using for the peak parking demand estimation was described in this section. Background studies show that parking is a key element of TDM strategies. Based on the hypothesis a research methodology was developed. Results from the new model were compared with the traditional demand and existing supply to ensure the accuracy of model.

2.0 LITERATURE REVIEW

A literature review was conducted to identify the recent and current research on determining parking demand and supply. A review was also done to find the traditional methods for determining the parking demand of institutional and shared mixed land uses. Along with the recent research, this chapter also focused on describing professional practices and laws of different cities and states on parking demand and supply determination. The background section of this thesis previously described current professional practices, which were not included in the literature review. The review also focused on how traditional supply and demand analysis can be modified to consider travel characteristics such as mode and auto occupancy as well as comparing supply and demand in off-peak periods.

2.1 CURRENT RESEARCH BACKGROUND

As parking is a key policy element in urban transportation planning, new research approaches from different perspectives have been introduced day by day for overcoming the challenges in urban areas. This literature review explored both academic research and innovative methods being used in professional practice reflected through new parking demand regulations and ordinances used by governments.

2.1.1 Academic Research

This part of literature review was focused on the published academic research. Though there are several studies to determine the accurate parking demand for specific land uses, very limited studies have been found to determine parking demand for urban institutional areas based on travel characteristics. Due to this scarcity of published research on this specific topic, this part of the literature review was completed focusing on all general aspects of parking demand forecasting.

Silva and Mackiewicz estimated existing parking demand for an urban college in New York City, New York, based on the parking characteristics of the population of the college. They did a survey of the students, faculty, residents and staff for establishing the prominent parking characteristics and developed a demand equation adopted from "Parking for Institutions and Special Events" [12], based on different adjustment factors like auto commuter factors, hourly accumulation factors, auto usage factors and auto ownership factors. The authors also mentioned another methodology of analyzing course scheduling which could be a more accurate way for parking demand forecast based on the student group of parkers [13].

Though traditionally, parking choice is considered as an exogenous factor in the mode choice component of the travel demand model, Habib et al. investigated parking choice behavior in combination with activity-travel decisions. They used survey data in Montreal, Canada and considered a Generalized Extreme Value (GEV) model structure for the joint start-time, parking type choice and the log-normal regression model for the duration choice model. The authors found that the activity-travel scheduling processes of auto drivers are very much influenced by parking type choice. They concluded that for the auto drivers, parking availability and parking type choice along with destination activity, play a significant role in activity-travel schedule formation. Habib et al. also stated an interesting observation that people who drive to the study area for study-related activities are most likely to choose parking with a fee charging option and least are likely to make park & ride- or kiss & ride-type trips [14].

As part of a parking demand model study, Wong et al. developed a parking demand model for private cars and goods delivery vehicles in Hong Kong. They assumed six trip purposes from the traditional four step demand study and estimated the usage related parking activities for the purposes in a zone. They disaggregated these activities into on-street, off-street and illegal parking. Off-street parking also was disaggregated into land use patterns. Using linear regression analysis, they created unit-graphs per parking activity to find the parking accumulation for a specific time and they found that modeled data was very close to the observed data [15].

Weis et al. tried to find the influence of parking on location and mode choice by a stated choice survey. Estimating occurred using a multinomial logit model and mixed logit model in a willingness-to-pay space. They have found that parking characteristics like costs, search times and the parking type, have a significant influence on choices, they also mentioned these attributes as powerful policy tools for shifting modal shares and location choices [16].

Waraich and Axhausen proposed an agent-based parking model for parking choice in the City of Zurich. The authors defined parking choice as a decision process used to select parking spaces and they did not consider parking searches in the model. They found two thirds of the agents parked within 100m from the destination while 95 percent parked within 450m. From the MATSim (Multi Agent Transportation Simulation) model run for the study area they found traffic volumes reduced in the area of public parking in the evening peak hours. Waraich and

Axhausen concluded that their model can help to improve traffic models to consider parking occupancy, walking distance, and price preferences. [17].

2.1.2 Professional Practice and Innovative Regulations

A review was conducted to identify the professional practices and recent innovative regulations of different cities and towns for parking demand analysis of institutional areas, mixed land-use areas in urban settings. For this review several cities and towns have selected which have land use areas similar to the study area of this research.

In addition to minimum parking requirements, almost every city has introduced a limitation on the maximum number of parking spaces. These limitations on maximum parking spaces are added for encouraging people to use other modes of transportation rather than auto.

2.1.2.1 City of Pittsburgh, Pennsylvania

The city of Pittsburgh requirements was selected to be reviewed because it is the location of the model development. Parking requirements of new developments and expansions of existing developments are specified according to zoning areas. According to Article VI of Title nine of code of ordinance of City of Pittsburgh, Pennsylvania, minimum and maximum parking space for "educational institution not otherwise listed" areas are 1 space per 800 square feet and 1 space per 300 square feet of gross floor area respectively as minimum and maximum requirements. No specific standard of parking requirements is given for the land use type of universities. So, university land use might be considered as "educational institutional not otherwise listed" type land use. Also, the requirements state that parking needs might be determined by a parking demand analysis for elementary or secondary schools. For a parking demand analysis, it is suggested in Section 914.02.B, that off-street parking requirements may include recommendations of the Institute of Traffic Engineers (ITE) and data may be collected for the same type land use or a land use that is comparable to the proposed use.

In addition, to these requirements the City of Pittsburgh has introduced off-street parking exemption and reduction areas in Section 914.04 of Title nine. For the Oakland area, 50 percent of minimum parking shall be reduced for new or existing developments of any land use types [18] within a specified area. The areas of exemption in the City of Pittsburgh, including Oakland, are shown in Figure 3. But the method of selecting these reduction factors was not specified in the zoning ordinance.

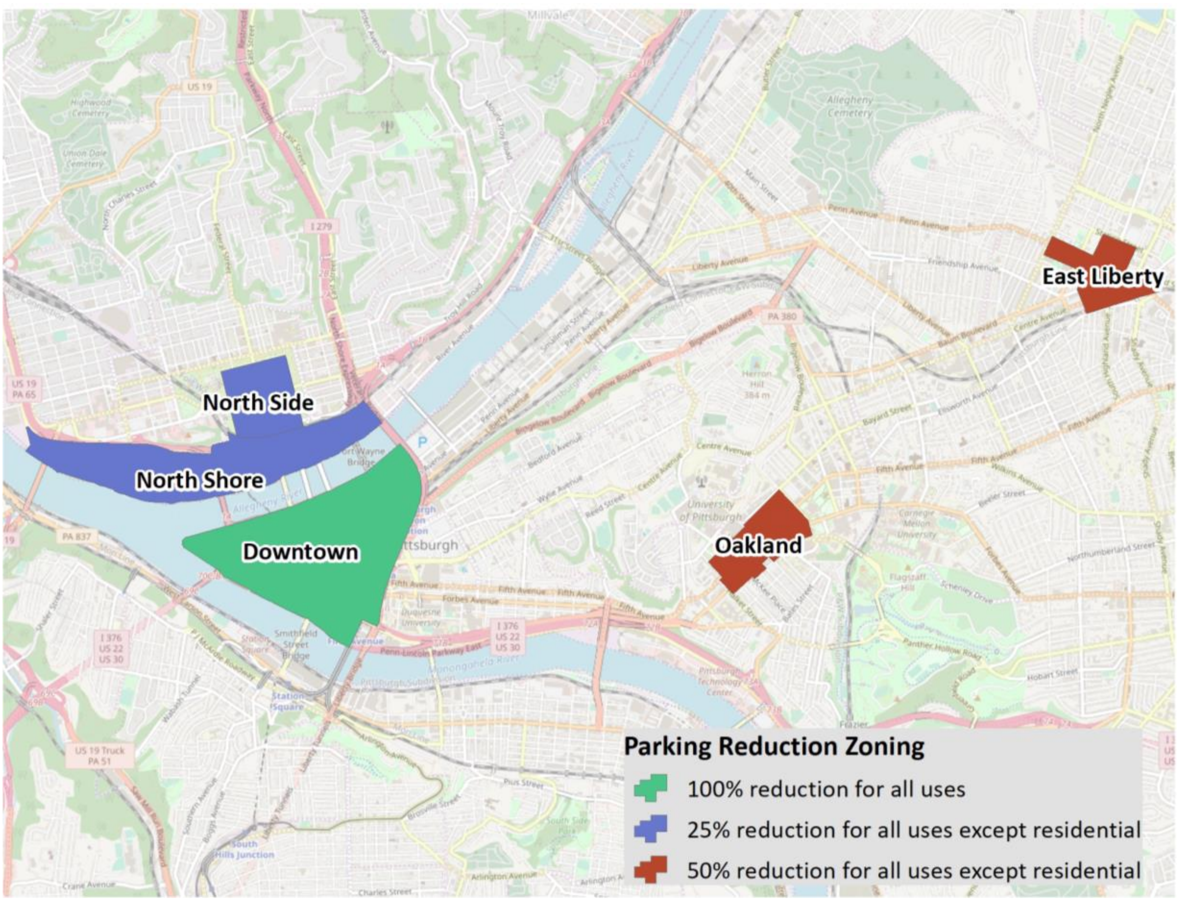

Figure 3. Pittsburgh parking reduction zoning map

2.1.2.2 City of Portland, Oregon

Off-street parking of developments is regulated by the zoning code of the City of Portland, Oregon. Minimum and maximum parking requirements are specified in Title 33.266 of Zoning code. In the zoning code, parking requirements of different institutions are described in institutional categories of table 266-2. For graduate schools minimum parking requirement is 1 space per classroom and the maximum permitted construction is 1.5 spaces per classroom.

Portland has introduced a reduction and exemption of minimum parking requirements for a development site based on travel characteristics, including transit proximity. Non-residential sites are exempt from off-street parking if the site is situated within 1,500 feet of a transit station or 500 feet of a street with 20-minute transit service during morning and evening commute hours [19].

2.1.2.3 Blacksburg, Virginia

Blacksburg is mainly a university-based town. Virginia Tech, the university in Blacksburg, plays an important role both in the economy and demographics of the town. Similar to the Oakland section of the City of Pittsburgh, Blacksburg also introduced 100 percent reduction in off-street parking for the downtown area. According to the Article V, Section 5220 of Blacksburg Zoning Ordinance, minimum requirement and maximum requirements for off-street parking are not specified in numbers like other cities mentioned in this section of literature review.

For the institutional areas or universities in Blacksburg, minimum parking requirements shall be determined by the Town Administrator based on several issues such as location of proposed use, number of employees on largest shift, expected demand and traffic generated by the institution, and appropriate traffic engineering and planning criteria and information. Blacksburg also introduced reduction percentages for off-street parking based on land-use proximity to public transit. If transit service is available within a one-quarter mile of the proposed development, measured as a pedestrian would walk to the transit stop, and the transit service provides thirty minutes peak hour service on a regular schedule, then a fifteen percent reduction in off-street parking would be permitted. Also, with proper data and analysis for justification of decreasing the parking, one can appeal for a reduction of off-street parking.

Maximum parking entitlement shall be determined based on the size of the parking area with the number of required minimum parking spaces. They specified the maximum numbers in the following Table 1 [20].

Table 1. Maximum allowed parking in the town of Blacksburg

Size of Parking Area	Maximum Parking Allowed
Less than or equal to 20 parking spaces	125 percent of Required Minimum
Greater than 20 parking spaces and less than or equal to 50 parking spaces	110 percent of Required Minimum
Greater than 50 parking spaces	105 percent of Required Minimum

[Source: Zoning ordinance, Town of Blacksburg]

2.2 SUMMARY

Several published academic research and professional practices have been reviewed to develop the methodology of the research as well as to gain some knowledge of current practices. From the academic perspective it is observed that very limited research has been published on this specific research topic. On the other hand, in terms of professional practices it can be said from above section that zoning ordinances sometimes referred to the ITE parking generation manual or APA standards for the demand calculation. Some cities or towns have introduced travel characteristics (mode split) for the urban setting to determine parking requirements.

3.0 DATA COLLECTION

In this chapter the study area selection and data collection process are presented. A shared parking institutional area in an urban setting has been selected as the study area. Based on the anticipated methodology, data was collected for developing a new parking demand model, comparing the usage to the traditional demand model and measuring the existing parking supply utilization. The following describes the study area selected to test the hypothesis, the parking demand data, parking supply data, land use information and travel characteristics data.

3.1 STUDY AREA

The Oakland section of Pittsburgh, Pennsylvania was selected as the study area for the model development. This area can be described as an urban institutional land use area that has the required characteristics for testing the hypothesis. Three different universities, a medical school, hospitals, a library, museums, residential hotels and business districts are land uses in this area. The institutions are University of Pittsburgh, Carnegie Mellon University, Carlow University, University of Pittsburgh Medical School, Carnegie Museums of Art and Natural History and the VA Pittsburgh Healthcare System. Because Oakland is a relatively large area of the City of Pittsburgh, a more specific area within Oakland was selected for this research that represents the expected parking influence area of the institutions and in particular the University of Pittsburgh.

More specifically, surrounding residential use areas were excluded as well as any smaller institutions that were considered self-contained in their parking supply and demand. The primary larger institutions have been included in the selected study area. These include the University of Pittsburgh and business areas are located in the study area. The selected study area is illustrated with the neighborhood names of the City of Pittsburgh is shown in Figure 4 of page 22.

3.1.1 Parking Analysis Zones

The study area was divided into several zones for data collection and analysis purposes. These zones were identified as parking analysis zones (PAZs). A Total 43 PAZs of the study area were identified as numerical numbers. PAZs were selected by blocks and the boundary of each zone is generally the center of a street. Based on the City of Pittsburgh zoning districts, different types of land uses are present in the study area [21] and each PAZ. In this research, all available zoning types were renamed as four zoning types to group and simply the descriptions. Zoning types and renamed zoning types are tabulate in following Table 2.

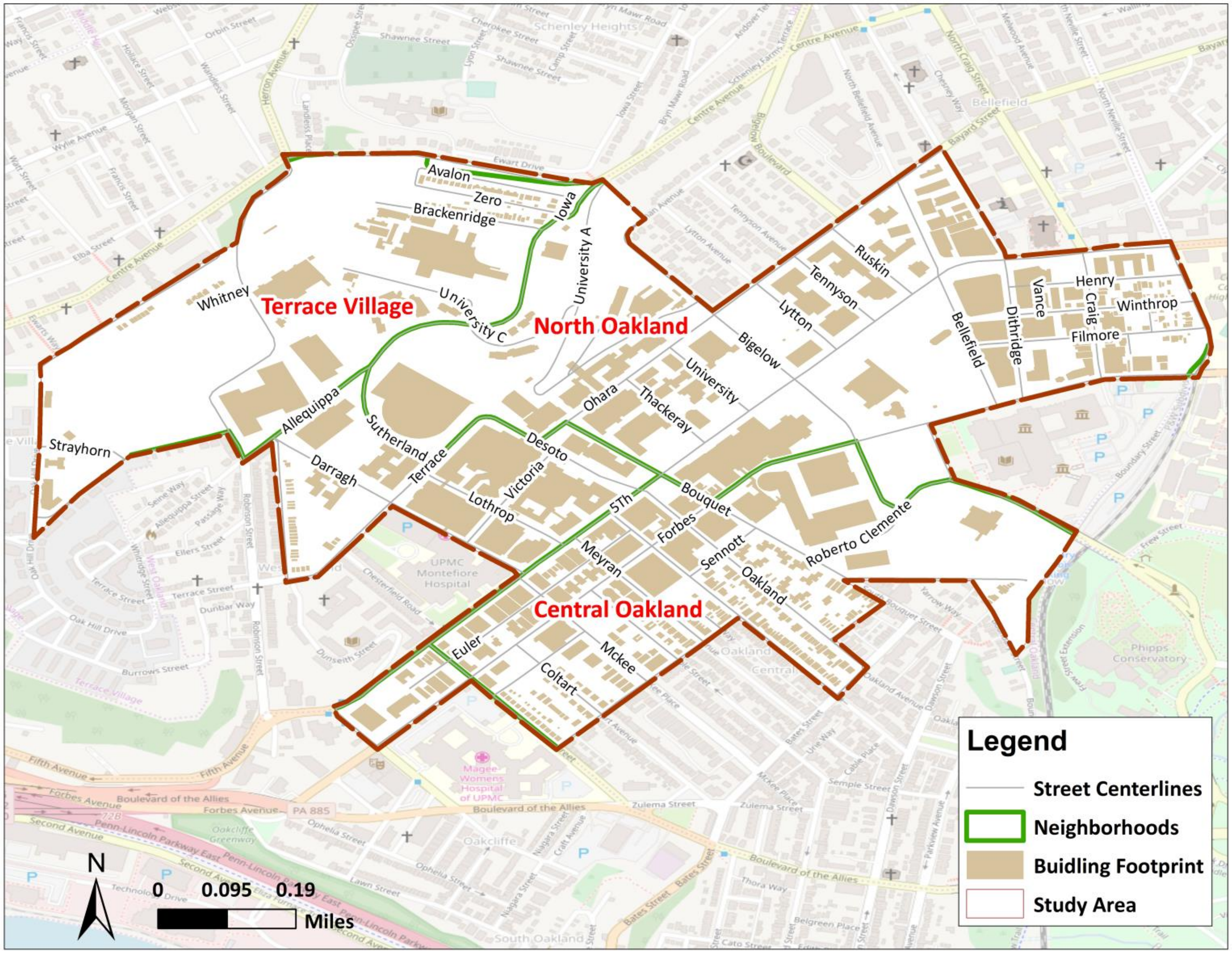

Figure 4. Study area map

Table 2. Zoning type in the study area

Available Zoning Type	Renamed Zoning Type
Educational/Medical Institution	Institutional
Multi-Unit Residential	Residential
Oakland Public Realm	Oakland Public Realm
Parks	Parks
Planned Unit Development	Residential
Single-Unit Attached Residential	Residential
Single-Unit Detached Residential	Residential

When comparing the zoning districts of City of Pittsburgh to the PAZs, some PAZs of the study area had mix land uses. The parking demand model needed to consider these mixed land use types. In this research, all residential areas were excluded for both demand estimation and supply data collection. These were excluded from the study area because they were considered to be self-contained in parking supply and demand. It is noted that the Oakland section of the city of Pittsburgh has designated on street parking zones for residents that require permits. Therefore, usage of on-street parking demand by institutional or commercial parkers is not likely and they cannot use the same parking areas as residents, therefore these residential zones were excluded. The PAZs are illustrated with the zoning type in the study area are shown in the Figure 5.

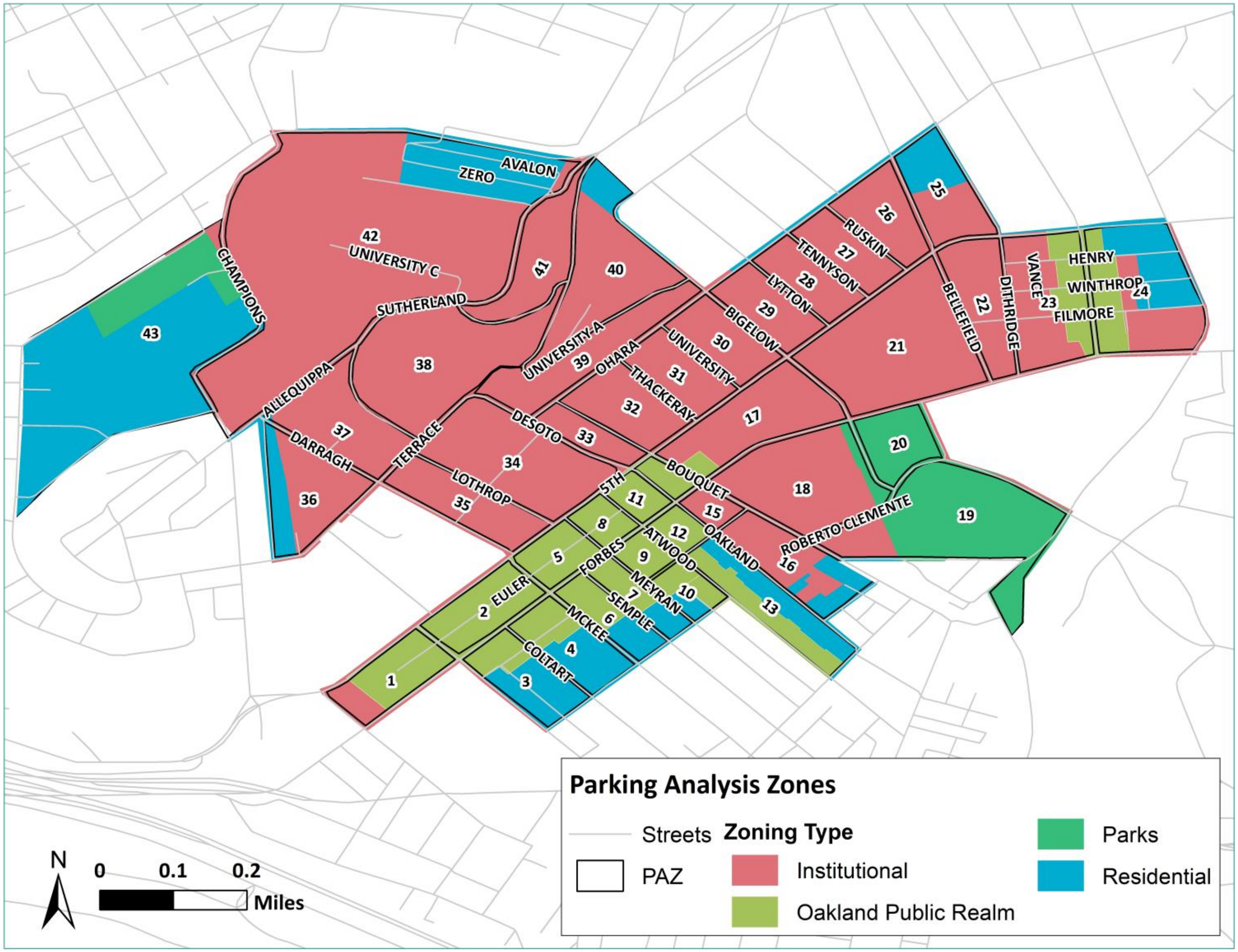

Figure 5. Parking analysis zones (PAZs) map

3.2 PARKING DATA COLLECTION

Based on the research approach, both parking demand and supply data was collected for developing the proposed demand model and calibration of the model. Data was collected from primary and secondary sources. Because the study area is primarily an urban institutional area, the data collection time period was selected based on the most active academic session of the universities.

3.2.1 Parking Demand Data

Required data were collected for the proposed demand estimation method as well as the traditional method of determining demand. The proposed method requires data on the number and type of travelers as well as their mode choices. The traditional method is based upon building sizes and uses. Also, building size data was collected for traditional demand analysis purposes based on the Pittsburgh Zoning Ordinance (PZO).

3.2.1.1 Building Area Data

To determine the traditional parking demand for the institutional and mixed-use land areas, total building gross floor area (GFA) data was collected or calculated. As discussed earlier all the buildings were not considered for the model. Buildings that were considered to be self-contained for supply and demand were excluded. Building locations included in the lists are illustrated in Figure 6.

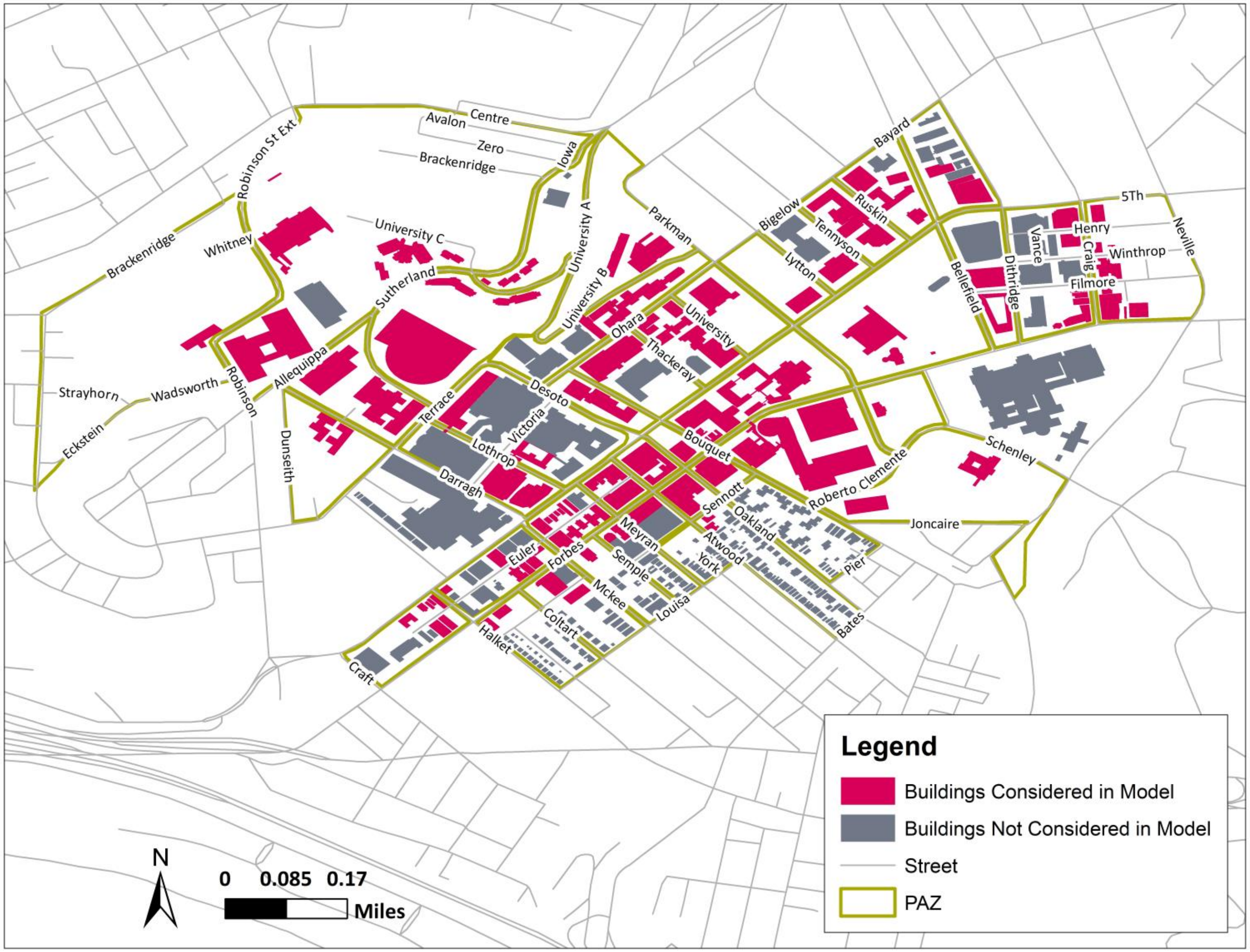

Figure 6. Buildings in the study area

University building GFA area data was collected from the Facilities Management office of the University of Pittsburgh. A sample of the collected data of the University of Pittsburgh is tabulated in Table 3 and all the data are listed in Appendix A. Business building data was calculated using the data from Western Pennsylvania Regional Data Center of the University of Pittsburgh (WPRDC). Open access data from Allegheny County Building Footprints 2018, was used from WPRDC website [22]. Only building footprint data of the buildings were available in the dataset and total gross area was calculated by multiplying the footprint area by number of levels of the buildings.

Table 3. Building GFA data of the University of Pittsburgh

Building Name	Gross Floor Area (square feet)
Thackeray Hall	102,179
Thaw Hall	51,379
Trees Hall	244,412
University Club	96,591
University Public Safety Building	29,339

3.2.1.2 Population Data

Based on the research methodology, population data of institutional and mixed land use areas was required for the proposed model estimation. It was very difficult to determine the population by buildings or PAZs for both institutional areas and business areas. However, class schedules for the academic term of Fall 2017 was collected from the Registrar office of the University of Pittsburgh [23]. In this dataset, class starting time and ending time data of every courses was available along with the total student enrollment and classroom number by academic buildings. The sample data is tabulated in Table 4.

Table 4. Class schedule data of academic term of Fall 2017 Allen Hall, University of Pittsburgh

Subject Code	Class Number	Start Time	End Time	Days	Facility ID	Enrollment Total
MATH	25695	09:00 AM	09:50 AM	Tu	ALLEN00103	25
MATH	25701	09:00 AM	09:50 AM	Th	ALLEN00103	15
MATH	25692	10:00 AM	10:50 AM	Tu Th	ALLEN00103	21
PHYS	30201	10:00 AM	10:50 AM	M W F	ALLEN00103	9
PHYS	30199	11:00 AM	12:15 PM	Tu Th	ALLEN00103	16

It was possible to determine the possible maximum presence of the students by hour in any of the academic buildings of the university which has been used as classrooms. But there was no available information of the students who were present in the buildings without attending any classes, were studying in the lounges or working as student employees in the buildings. Also, it was not possible to get the data to determine the faculty/staffs' number of persons by hour or by buildings. However, the student data was deemed to be useful for other purposes. From the Fact Book 2018 of the University of Pittsburgh, it was possible to find the total number of enrolled students and faculty/staffs in the academic term of Fall 2017 [24]. The numbers are tabulated in Table 5.

Table 5. Number of students, faculty/staffs of the University of Pittsburgh

Category	Total Number
Student	28,642
Faculty-Staff	12,942

It was not possible to get the total or hourly population data of the business areas. There was no available source of data to get the number of employees or shoppers by a specific business or by the PAZs of the study area.

3.2.1.3 Travel Characteristics Data

Based on the hypothesis of the research, travel characteristics are an important attribute for demand estimation. These data could be used to either estimate demand based on population or modify current zoning requirements. No direct data collection on travel characteristics was necessary for institutional uses because several transportation recent surveys were available and reviewed to select the travel characteristics data to be used for the model of the selected study area. Only two travel characteristics, mode split and auto occupancy, were needed as input for the model.

Mode Split: A transportation survey was carried out of the students, faculty and staff of the University of Pittsburgh in the Fall session of 2017 [25]. Based on this survey, 44 percent employee respondents drive for commuting to work. The mode split result of the survey is illustrated in Figure 7. For the student respondents, though mode usage questions like bike, walking and shuttle usage were available in this survey, separate mode split data for students was not available. Some other surveys were reviewed to obtain the students mode split data.

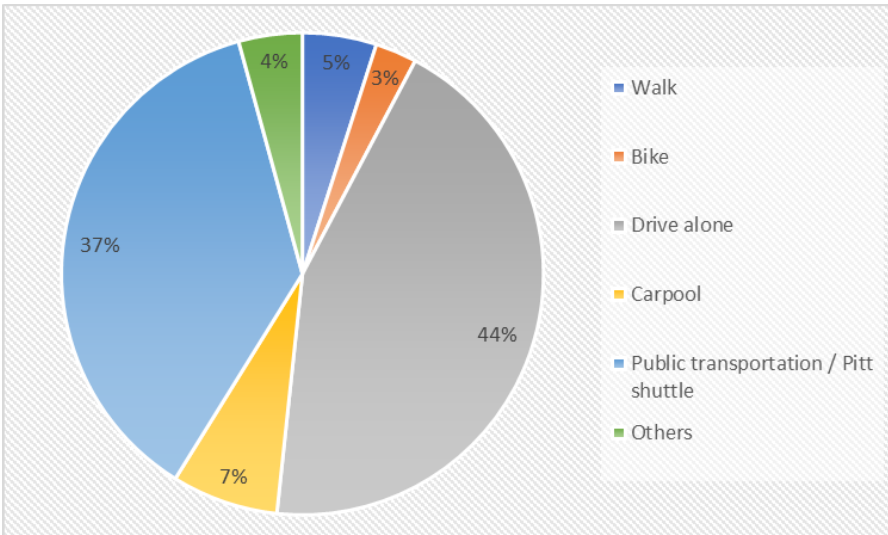

Figure 7. Mode split data from University of Pittsburgh transportation survey for employees

The Sustainability Tracking, Assessment & Rating System (STARS) program of The Association of Advancement of Sustainability in Higher Education (AASHE), published separate mode spilt data (2015) for the University of Pittsburgh's students and employees [26]. They collected the data from the "Make My Trip Count" survey, a regional transportation survey designed for Pittsburgh region [27]. Survey results of both students and employees are tabulated in Table 6 and Table 7 respectively. As this is a complete survey where both student's and employee's mode split data were available, this survey data was used for this research.

Table 6. Student's commute modal split data of the University of Pittsburgh

Mode of transportation	Percentage
Commute with only the driver in the vehicle (excluding motorcycles and scooters)	11
Walk, bicycle, or use other non-motorized means	36
Vanpool or carpool	3
Take a campus shuttle or public transportation	49
Use a motorcycle, scooter or moped	1

Table 7. Employee's commute modal split data of the University of Pittsburgh

Mode of transportation	Percentage
Commute with only the driver in the vehicle (excluding motorcycles and scooters)	37
Walk, bicycle, or use other non-motorized means	12
Vanpool or carpool	8
Take a campus shuttle or public transportation	41
Use a motorcycle, scooter or moped	2

In the "Make My Trip Count" survey, another regional transportation survey designed for the Pittsburgh region, collected mode spilt data and was categorized by two destination choices of Downtown and Oakland [27]. According to this survey, in 2015, about 47.3% of respondents used auto to get in the destination of Oakland, the study area of this research. This data was not used because it did not distinguish between students and other travelers. The mode split result of this survey is illustrated in Figure 8.

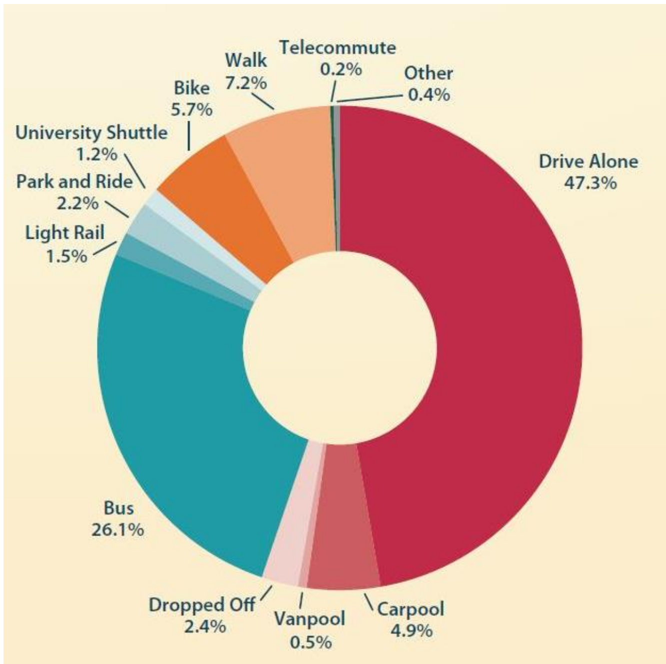

Figure 8. Mode split data for Oakland destination

For the business area is in Oakland, it was assumed that the above-mentioned mode split data of MMTC survey does not represent workers or shoppers in the business district. Because this business area's primary shoppers were the students and employees of the institutions of the study area and it was assumed that walking should be their primary mode to explore business areas from their work location so direct data collection was needed. No specific transportation survey was available for determining the mode split data of the business areas of Oakland. A short in-person interview survey was designed and performed for this research and conducted for the customers of the business areas. Six locations at Forbes Avenue, Fifth Avenue and Craig Street were selected for the survey. Locations are shown in Figure 9.

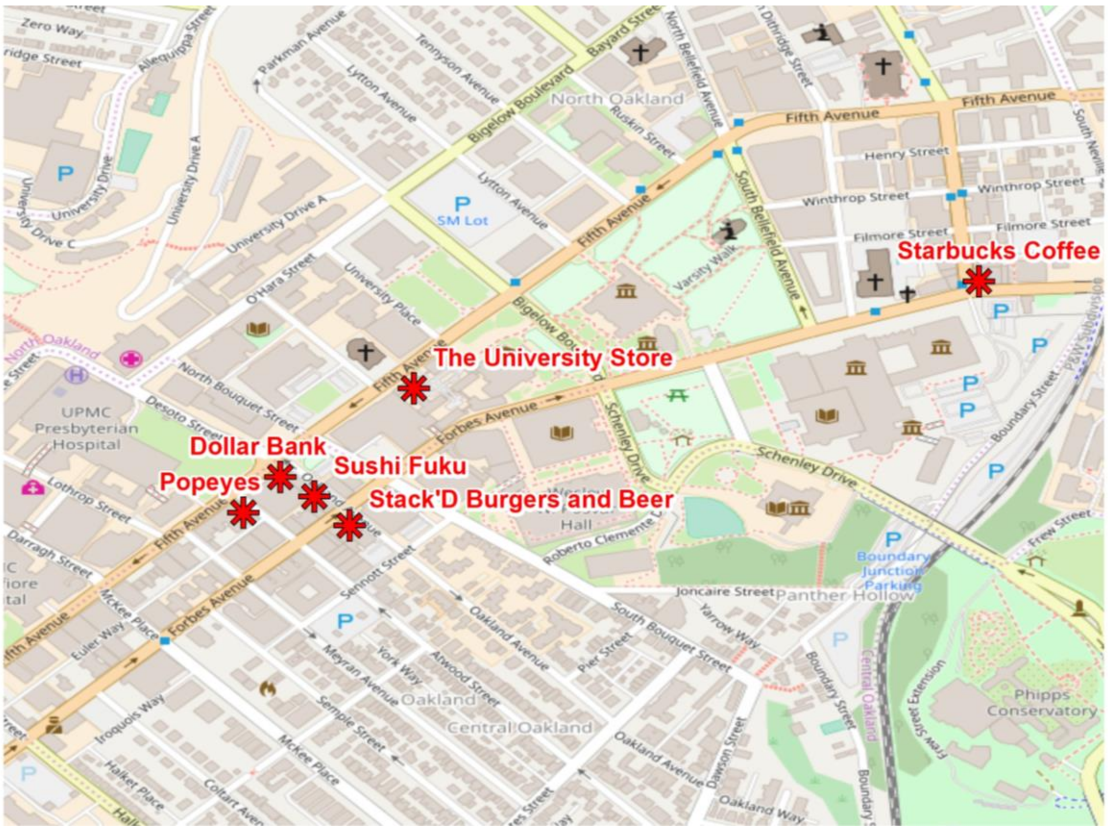

Figure 9. Shopper's survey locations in study area

In-person interviews were taken at two time periods, morning (7:30 am to 9:30 am) and noon (11:30 am to 1:30 pm). Interviews were taken on 5th, 6th and 20th of September 2018. A total 108 persons were interviewed for the survey. Respondent's numbers by location are shown in Table 8. Most of the respondents either worked or studied in the Oakland area and walking was their main mode of transportation for commuting to the business area. Survey questions are attached in Appendix B.

Table 8. Survey respondents by location

Survey Location	Number of Respondents
Sushi Fuku	10
Stack'D Burgers and Beer	12
Starbucks Coffee	27
Dollar Bank	3
Popeyes Louisiana Kitchen	8
The University Store on Fifth	48
Total	108

The mode split data from the survey is illustrated in Figure 10.

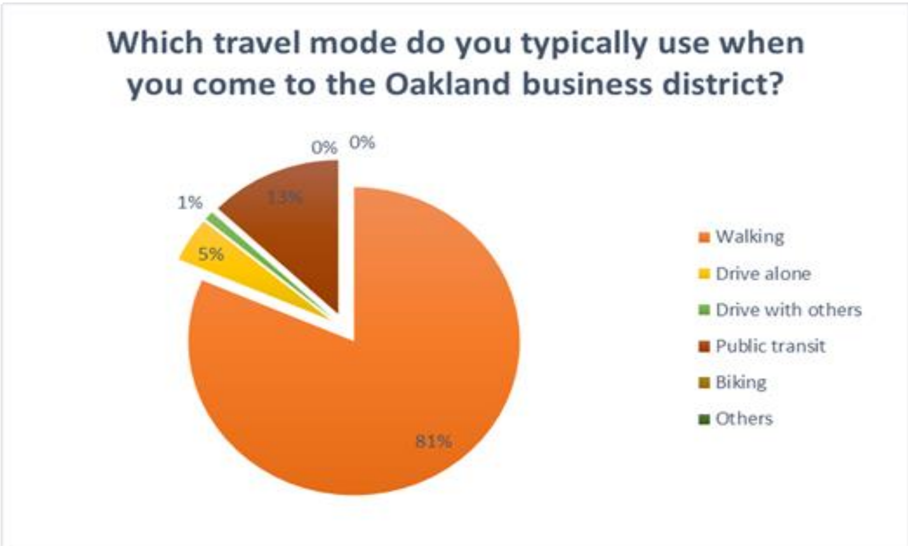

Figure 10. Mode split data for business area customers of Oakland

A question about where the customers generally park vehicles was also asked. As most of the customers of the business area commute by walking, this question was not applicable for them. Five percent of the respondents used public on-street metered parking and most importantly none of them used public garages for parking. Parking status result is illustrated in Figure 11.

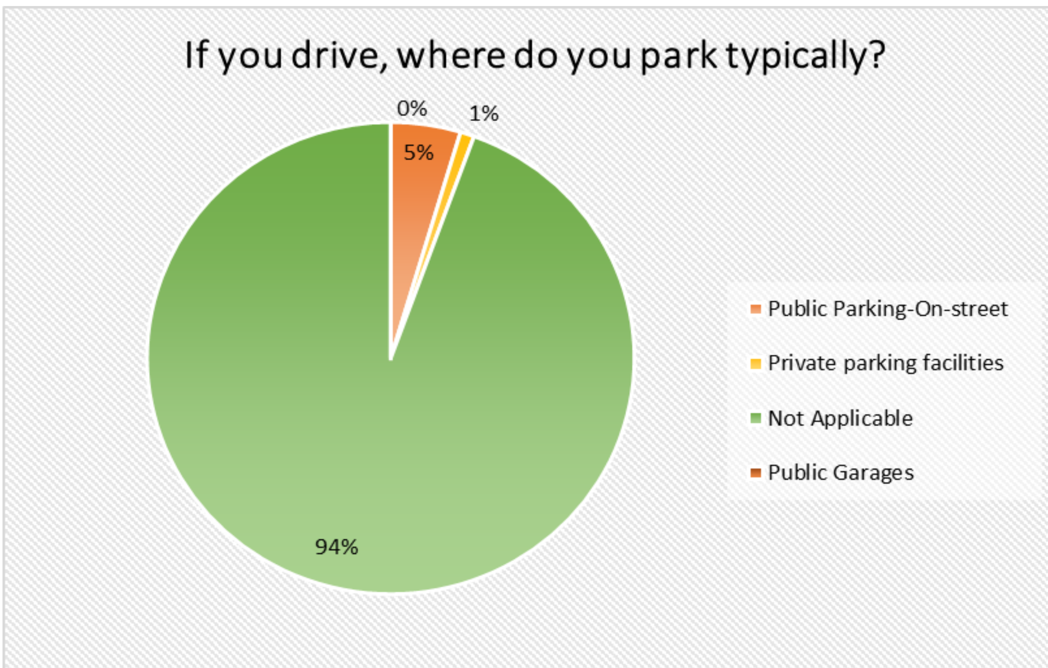

Figure 11. Customers parking places in business area

Auto Occupancy: Auto occupancy data was collected from the National Household Travel Survey, 2017 because local data was not available [28]. NHTS calculated the average vehicle occupancy rate for different trip purposes for the United States. According to the NHTS 2017 survey, average vehicle occupancy for work trips is 1.18 and overall (considering all trip purposes) average vehicle occupancy is 1.67. Extracted 2017 survey data is tabulated in Table 9.

Table 9. Average vehicle occupancy for selected trip purposes, NHTS 2017

Survey Year	Trip Purposes				
	To / From Work	Shopping	Other Family / Personal Errands	Social / Recreation	All Purposes
2017	1.18	1.82	1.82	2.1	1.67

3.2.2 Parking Supply Data

A parking inventory was created to measure existing parking supply in the study area. Both primary and secondary sources were used for parking supply data collection. Parking facilities in the study area were categorized as below:

1. On-street Parking
2. Off-street Parking
    a. Private Garage
    b. Private Lots
    c. Public Garage
    d. Public Lots

3.2.2.2 On-street Data

For on-street parking supply, an inventory was created based on primary source data which was direct field observations. There were some residential permits parking zones in the study area. On-street data was not collected from those areas as these parking mainly used for residential purpose. Some of the permit parking of the institutions and most of the on-street parking are public metered parking. Because public on-street parking spaces are not marked, the number of spaces could not be counted and had to be estimated. As mentioned in the "The Dimensions of Parking" published by ULI, currently recommended length of the parking space is 18 feet [10]. Quoted from Mary Smith, ULI mentioned this recommendation is based on the design vehicle of 17 feet 3 inches and 9 inches typical distance from bumper to the end of the parking stall [29]. Though this is recommendation is for off-street parking spaces, it could be used for on-street parking spaces also.

However, the length of on-street parking space dimensions per vehicle might vary from 18 feet to 20 feet depending on the vehicle's length and parker's efficiency. It was determined that there should be a better method of estimating capacity by block face. It was not possible to find the total capacity by street from the observation as all the streets because not all were fully occupied. For the homogenous data usage of the study area, a constant length was required to determine the total on-street parking capacity. For the public parking, Schenley Drive of PAZ 20 opposite of PAZ 19 was selected to determine the constant length of an on-street parking space in the study area. Total parking length of that street was 252 feet and the maximum number of parked cars, using the whole parking length during the data collection time period, was 14 vehicles. From this information, the average parking space length for a car was 252/14 = 18 feet. The selected street of Schenley drive is illustrated in the Figure 12. The University of Pittsburgh also has marked one on-street parking space as 18 feet length at North Bouquet street and Ruskin street which is illustrated in Figure 13. So, a length of 18 feet per vehicle was used as the parking space length to determine the overall on-street parking capacity.

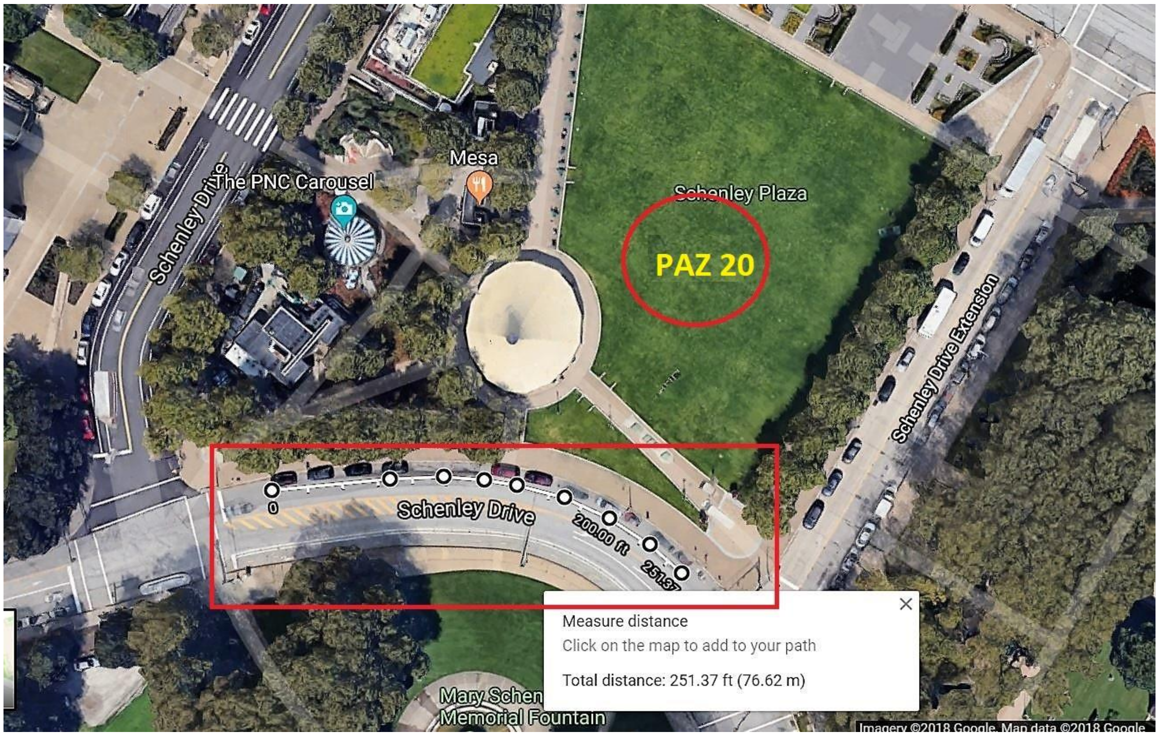

Figure 12. Location for Estimation of on-street parking space per vehicle

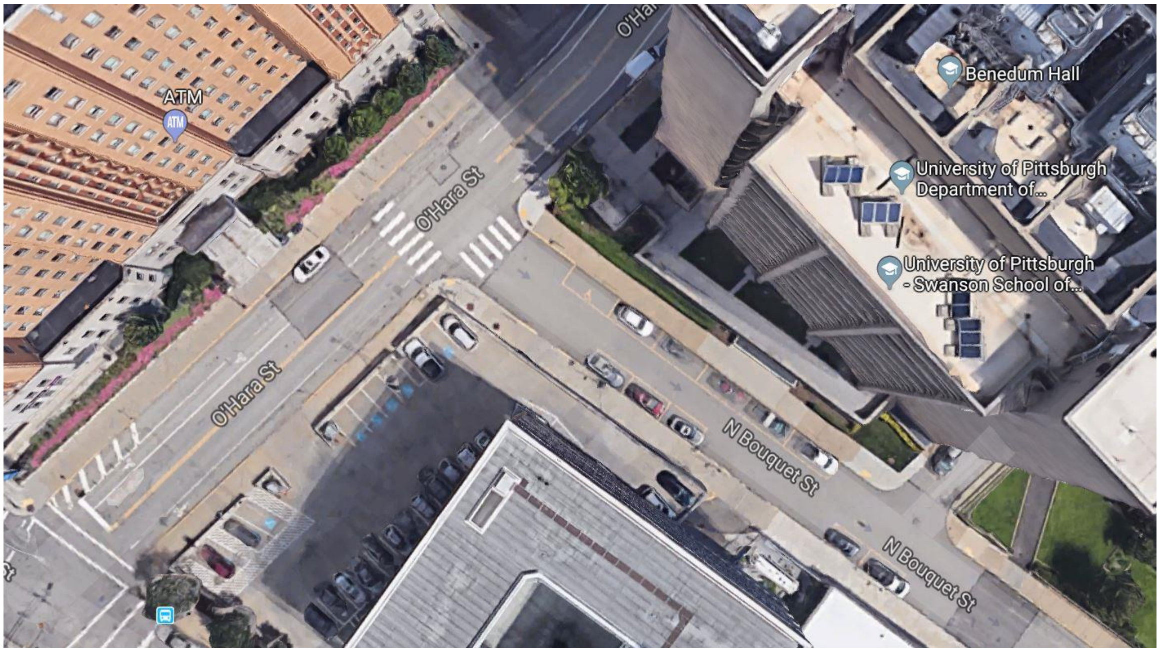

Figure 13. Location for Marked on-street parking spaces at N Bouquet Street

3.2.2.3 Off-street Data

For off-street parking data, both primary and secondary sources data were used in the inventory. Total parking capacity of some parking lots and garages were collected from secondary sources. Secondary sources are identified in the next section of parking usage data. Total parking capacity of the study area is tabulated by category of on-street and off-street facility in Table 10.

Table 10. Total parking capacity in the study area

Type of parking facility	Total capacity (number of stalls)
On-street Parking	1198
Off-street Parking	4948
Total	6146

3.2.3 Parking Usage Data

Parking usage data was collected to identify the supply used by time of the day. For on-street parking, hourly parking accumulation data for twelve hours (7:00 am to 8:00 pm) was conducted for the identified supply. On-street data was collected on Tuesdays thru Thursdays between April 3rd and April 19th, 2018. Only typical weekdays were considered. Weekends were not considered for data collection because weekdays do not represent the maximum usage for an institutional area. The month of April month was selected because that time represents a typical activity level in an active academic session.

Hourly data of the only publicly operated garage at Forbes Avenue and Semple Street was collected from the Pittsburgh Parking Authority, owners of the garage. Some of the off-street parking facilities data of the University of Pittsburgh was also collected from the transportation office of the university. Some of the off-street parking lot data was collected through primary sources such as observation from on-street locations. From the secondary sources, data was also obtained for a typical weekday of April.

It was not possible to collect hourly usage data from one private parking facility on Sennott Street in PAZ 12 of the business district area. For the model development these types of facilities were considered as full for all twelve hours. Private parking facilities of hotels in the study area were not considered in the estimation. Data were not collected from several private parking lots and garages which was designated only for specific institutions, which were not considered in the model. Although these hotels and institutions were situated in the study area, all of these hotels and institutions were considered to be self-constrained in terms of both parking demand and supply. The total hourly usage of both off-street and on-street parking spaces by hour of the day is illustrated in Figure 14 and Figure 15 respectively.

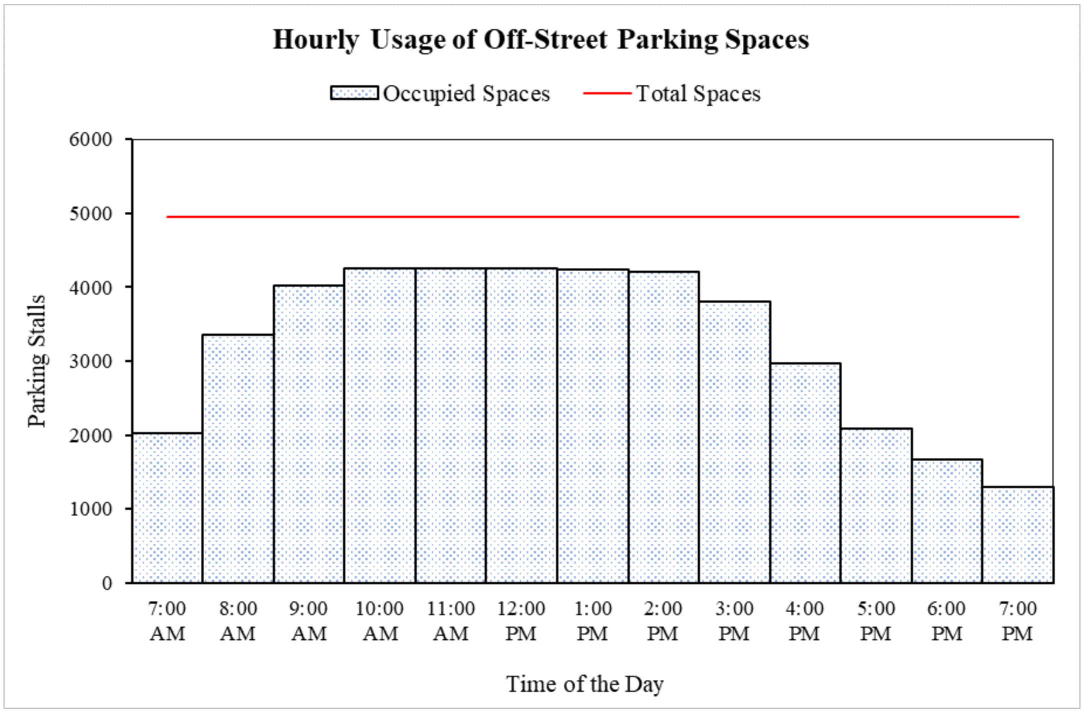

Figure 14. Hourly usage of off-street parking spaces

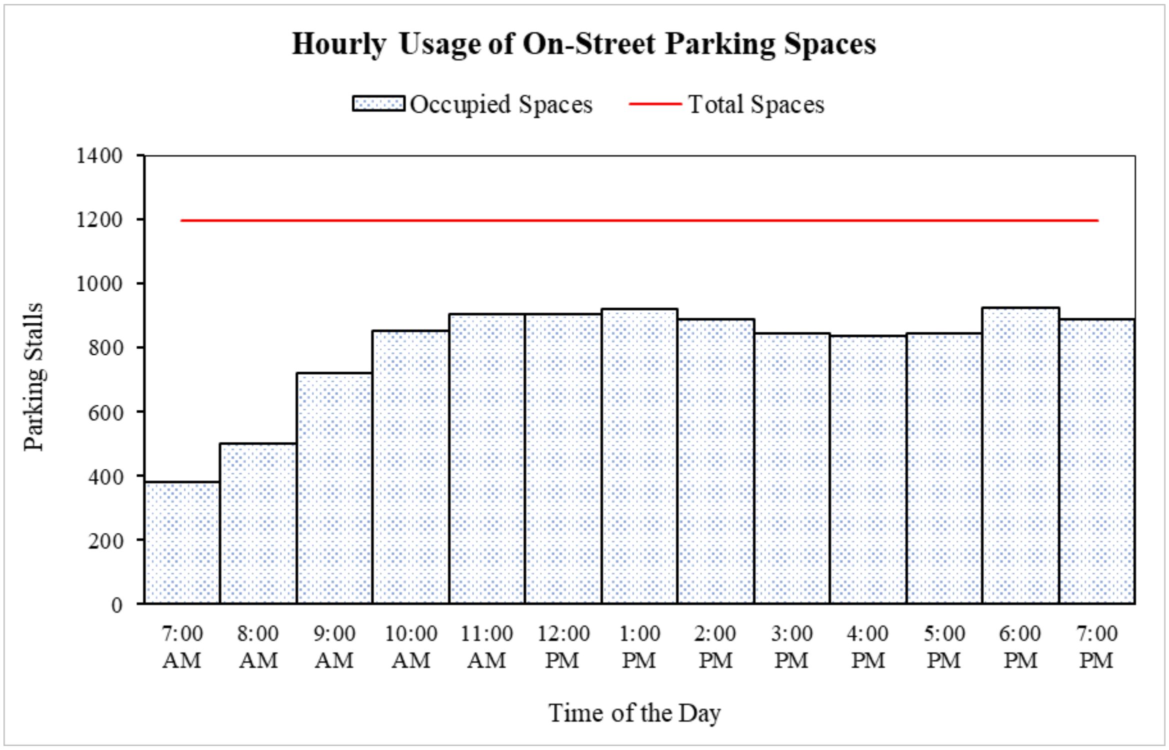

Figure 15. Hourly usage of on-street parking spaces

From the collected on-street and off-street parking usage data the peak occupancy rate was calculated. Maximum hourly usage was 5,166 spaces at 1 PM to 2 PM which was 84.1 percent of total supply. The occupancy rate is illustrated in Figure 16. From the graph, it was observed that highest occupancy rate of the total supply of the study area was 84.1 percent. This peak usage describes that parking efficiency varies from person to person and this can be used as the parking efficiency factor for this study area. Also, this percentage proves that is some PAZs full supply was not used even in peak hour. All collected supply data are tabulated in Appendix C.

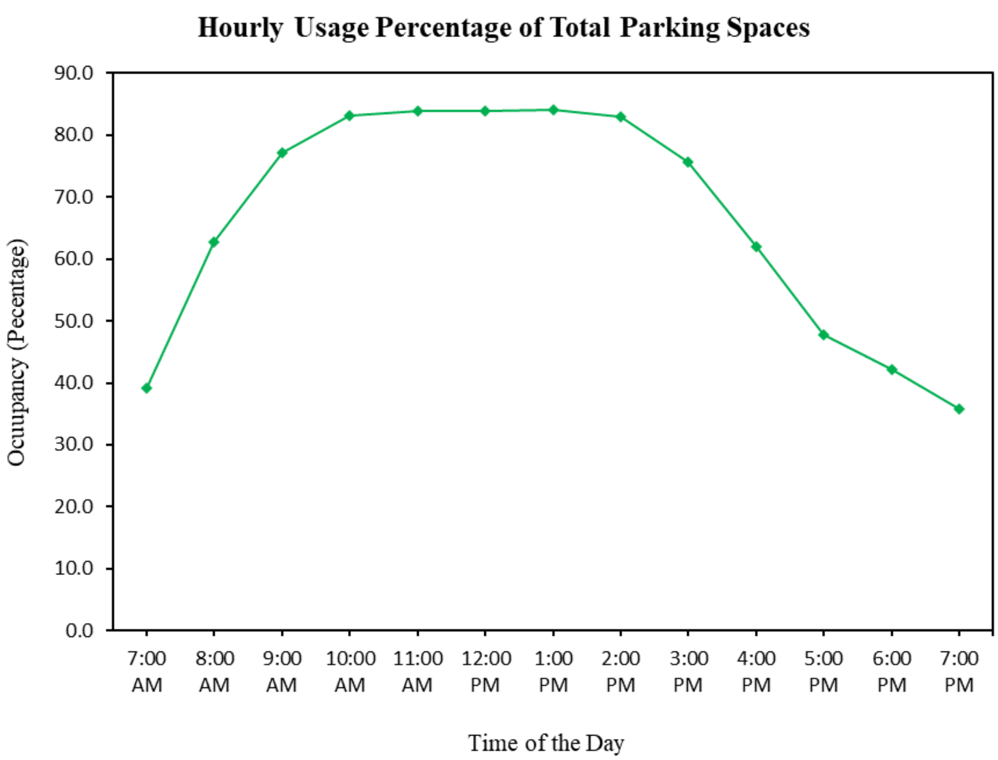

Figure 16. Hourly usage percentage of total parking spaces

3.3 SUMMARY

All of the collected data is described in this data collection section of the report. A comprehensive dataset was created for this research. Several data sources were reviewed for all required data to calculate the demand and measure the usage. Along with the available data, data from secondary sources was also obtained. An in-person survey was conducted to obtain travel characteristic data for the business area. This was because available data was not accurate enough to measure mode choice for this business area.

Based on the logical explanation and arguments, reasonable datasets from all available sources were selected or collected for this study. For the supply capacity and hourly usage data of the area, most of the data was directly counted data, except some university garage data. Data was collected during the month of April 2018. After a comprehensive effort, a dataset was ready for the demand estimation and calibration of the model

4.0 DEVELOPMENT OF A PREDICTIVE PARKING DEMAND MODEL

This section the thesis describes the development of the parking demand model and comparison of the results to the field data. The field data was used to calibrate the model. This describes the data analysis, finalization of the data and assumptions for the model and a description of the predictive model. Finally, this chapter concludes with the description of calibration of the model.

4.1 PARKING PREDICTIVE DEMAND MODEL

Based on the hypothesis of the research, it was assumed that development of the predictive model would be based on the population by buildings and PAZs, time of the day and travel characteristics. But based on the available and collected data, it was not possible to proceed with utilization of all these data and pre-assumptions. Data finalization and development of the demand model is discussed here.

4.1.1 Population Data

Initially it was planned to use the building peak period population data, for the institutional buildings, directly to calculate the peak demand of the institutional areas. This is because person trip generation is the basic starting point to determine vehicle trip generation and in turn parking demand. However, this is very difficult data to obtain. Population density within public and private buildings is difficult data to obtain, but critical in planning for parking.

The student level peak population data was available and collected from the registrar's office of the University of Pittsburgh, as mentioned in section 3.2.1.2 of this report, it was possible to determine the student population by the PAZs and buildings by hour and level of peak utilization. This data was based on the student numbers who are enrolled in the classes by classroom and building. Generally, apart from attending classes, students also pass time in the academic buildings for studying, lab work, working as student employees and so on. These data were not available in the afore mentioned dataset. Also, no data was available for buildings which were not used as classrooms or buildings that had a mix of classroom and offices or labs. In addition, it was not possible to collect the hourly presence data or total number of faculty/staffs by buildings.

Also, it was not possible to collect the hourly population by PAZs for the business areas because this involves numerous buildings and businesses and is not publicly available information. Based on the initial hypothesis of the research it would be a preferred method, if demand could be calculated directly from the peak population data. However, it was not possible to collect the population data for all categories (students, faculty/staffs, shoppers, employees). Due to this limitation of the population data, it was then determined to use the GFA of the buildings, translated to populations based upon the zoning ordinance requirements which are based upon anticipated building peak populations, as a starting point to calculate the demand and then modified the population estimates by travel characteristic data.

4.1.2 Building Area Data

Because population data was not available to calculate the number and density of persons by buildings or PAZs, building area data was used to calculate populations first without adjustment by mode choice. Though GFA is generally used for traditional parking demand calculations, it was not a deviation from the hypothesis of the research, which was to incorporate the travel characteristics as independent variables for demand calculations. Instead of actual population data, it was determined to incorporate the travel characteristics and apply them to the total demand based on the GFA using zoning ordinance requirements from the City of Pittsburgh. This approach was developed because zoning ordinance requirements from the City of Pittsburgh and other jurisdictions are based upon typical peak building population densities, that are then translated into parking demand, without any adjustment for mode of arrival. It is noted that the City of Pittsburgh does have a mode of arrival adjustment factor which was previously discussed but was not considered to be precise enough for the model.

As described in the section 3.2.1.1 in this report, it was possible to collect or estimate the GFA data of all buildings and resulting peak populations of the study area. Buildings were categorized based on the main usage type of the buildings such as institutional, laboratory, library, restaurant and others in order to calculate the populations and base demand per the usage type mentioned in the off-street parking schedule of Pittsburgh Zoning Ordinance.

4.1.3 Hourly Parking Demand

As hourly population data by PAZs was not available, except for students, it was also not possible to calculate the hourly parking demand by PAZs directly. So, an alternative method was needed to determine the hourly demand for comparison to the field data. The purpose of estimating hourly demand is to assist with improving management of current parking resources through a typical day. The class schedule and enrollment data of Fall 2017 term identified in section 3.2.1.2 was a good resource to model the general hourly parking demand of an institutional areas [24]. For this calculation a typical class schedule of Wednesday was selected, which is a peak day of student attendance.

Based on this class enrollment data, hourly students' presence was calculated for all buildings of the university. Calculated data is tabulated in Table 11. It was observed that the maximum number of 8,320 students were present in an hour which should coincide with the peak parking demand generating hour for students.

Table 11. Students' hourly presence by class enrollment in the university buildings

Start Time	End Time	Students enrolled in classes
7:00 AM	8:00 AM	0
8:00 AM	9:00 AM	1782
9:00 AM	10:00 AM	4966
10:00 AM	11:00 AM	7233
11:00 AM	12:00 PM	7869
12:00 PM	1:00 PM	7414
1:00 PM	2:00 PM	7354
2:00 PM	3:00 PM	7048
3:00 PM	4:00 PM	8045

Table 11 (continued)

Start Time	End Time	Students enrolled in classes
4:00 PM	5:00 PM	8320
5:00 PM	6:00 PM	4678
6:00 PM	7:00 PM	5788
7:00 PM	8:00 PM	1830

Because there are few classes at the time period of 7 AM to 9 AM, there is little parking demand generated by students. But this is not the actual scenario of total parking demand in institutional PAZs, which is evident when compared to the collected hourly usage data of the parking spaces in the study area. From the collected supply data, it can be determined that there is parking demand in that time period which is mainly from the faculty/staffs of the university. So, for a better predictive model, faculty/staffs' data were needed to be calculated and added to the student data, which was not available by PAZs or buildings in order to create an hourly parking demand model for institutional uses.

A parking occupancy rate of the university parking garages and lots, which are provided only for faculty/staffs, was also calculated for the peak and off-peak periods and used as a model of estimating this hourly variation of this type of demand. To get the hourly presence of faculty/staffs in the University buildings from 7 AM to 9 AM and 4 PM to 8 PM, these parking occupancy rates were used as a model. A model was developed based upon the parking occupancy data of the lease spaces of Soldiers and Sailor's garage of the university. This facility represents the single largest parking facility for faculty/staffs. It was observed that a maximum occupancy rate 80.77% of the lease parking occurred on 11th April 2018. The lease data for that day is tabulated in Table 12. This date was selected because it coincided with the general data collection period of the research.

Table 12. Parking data of Soldiers and Sailor's garage

Time	Occupied spaces	% Full
7:00 AM	204	31.38%
8:00 AM	409	62.92%
9:00 AM	494	76.00%
10:00 AM	513	78.92%
11:00 AM	518	79.69%
12:00 PM	525	80.77%
1:00 PM	524	80.62%
2:00 PM	515	79.23%
3:00 PM	449	69.08%
4:00 PM	284	43.69%
5:00 PM	136	20.92%
6:00 PM	62	9.54%
7:00 PM	33	5.08%
Total lease spaces	650	

From this data, an absentee rate of 19.23% was used for determining the typical attendance of faculty/staffs because this reflected the unused faculty/staffs parking leases during the peak demand hour. It was assumed that 80.77% faculty/staffs were present in the university throughout the time period of 9 AM to 4 PM. It was not considered that all the faculties were present throughout the whole day, because this might not reflect the actual scenario. It can be assumed that beyond the 19.23% absentee rate that on a typical day not all faculty/staffs are present due to travel, class schedules and other factors.

Finally, to develop the hourly demand variation model, reflecting students and faculty/staff and other parkers in the study area, hourly students class attendance of all buildings was calculated and added to the estimated faculty/staff's presence levels. Hourly presence data of students and faculty/staffs for all buildings of the university is illustrated graphically in Figure 17.

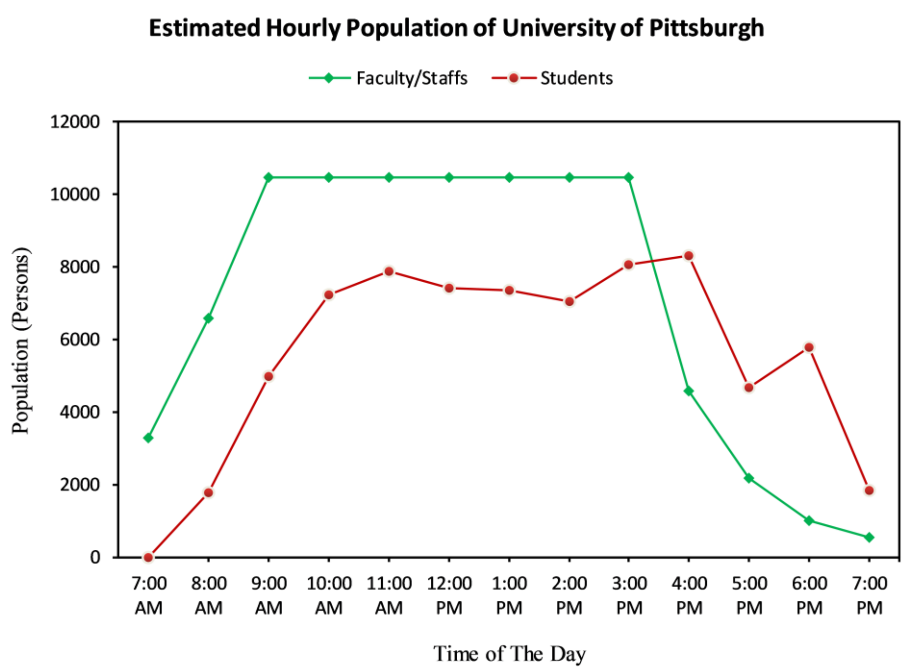

Figure 17. Estimated Hourly population of the University of Pittsburgh

After adding these students and faculty/staffs' data, a maximum 18,499 persons were estimated to be present at time period of 3 PM to 4 PM. Considering this number as peak, the hourly person occupancy percentage was calculated as used as the model to determine the hourly presence of faculty/staffs for all the buildings of the university. The estimated hourly person presence for students, faculty/staffs is illustrated in Figure 18. This variation in percentage was used as the hourly parking demand calculation.

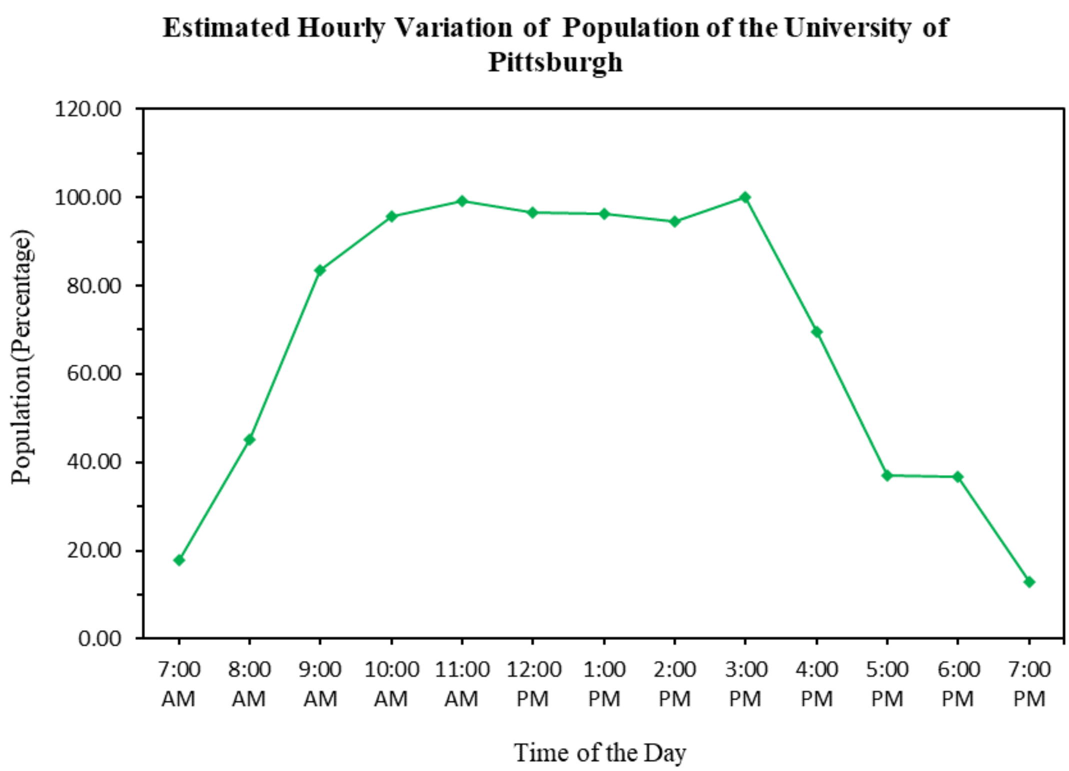

Figure 18. Estimated Hourly population variation in percentage, University of Pittsburgh

4.1.4 Travel Characteristics

Once the peak and hourly person presence was determined from both the zoning ordinance calculations and model of University persons present, the travel characteristic data was applied. For this research, travel characteristics of mode split and auto occupancy were considered as the independent variables for developing the proposed demand model to be applied to the person occupancy estimates. These travel characteristics varies depending on different criteria such as location of the demand, types of building usage and trip purposes. Generally, these characteristics also depend on the other factors such as public transportation accessibility and proximity in the targeted areas, usage of the area such as shopping areas or institutional areas. For an accurate model development, data was needed specifically for the Oakland area. Because all of the residential areas were excluded from the model area only the work, recreational and shopping trips characteristic data were considered for the proposed model. It is noted that student mode of travel was considered separately from work and shopping trips because it is not a standard trip purpose. The finalized data for the proposed model is describes here.

Mode Split: As described in the section 3.2.1.3 of this report, mode split data of the University of Pittsburgh population was collected from the AASHE and mode split data of business area population and was collected from MMTC survey data and in-person surveys [26][27]. Though different data on mode of arrival were collected for the students and faculty/staffs of the university, it was not possible to use the separate mode split data by University buildings or PAZs. This was because data was not available to determine total number of students and faculty/staffs specifically by buildings and therefore by PAZs. However, to ensure that accurate mode split data was applied for the University impacts, a composite percentage of mode split was used for the proposed model for all University buildings in the

PAZs. Because only travel by private vehicles was considered for the demand calculation, the auto composite percentage (ACP) was calculated for the auto travel mode. The use of the ACP provides an accurate presentation of travel via auto for all of the University buildings reflecting travel characteristics of students and faculty/staff as a total and was applied to each university building as an approximation. This approach provides an accurate overall demand estimate for the University but not necessarily by building or PAZ.

Total student enrollment and faculty/staffs of Fall 2017 was collected from the factbook of the University of Pittsburgh [24]. Using this total population number, the ACP was calculated for the ratio of students and faculty/staffs. The total population data and calculation of the ACP is tabulated in Table 13. The ACP is a composite auto arrival mode split based upon the survey model split results weighted by the relative student and faculty/staff ratio of the University as a whole and used separate mode split data for students and faculty/staffs based upon the survey results.

Table 13. ACP calculation for the population of the University of Pittsburgh

Population Category	Total Person Number	Mode Split-Auto (Percentage)	ACP
Students	28,642	11	19.09
Faculty/staffs	12,942	37	

For the shoppers of the business areas, mode split percentage of the auto was 5 percent, which was collected from the direct survey. From MMTC survey, auto mode split percentage for the offices was 19 percent for both institutional and business areas [27]. These travel characteristic data were applied to the model for the business or office land uses in the study area. The mode split data was applied for each building based upon the uses in each building characterized as either institutional, office and business area.

Auto Occupancy: Regional or Oakland area auto occupancy data for work trips and shopping trips were not available from current survey information. It was determined that the national level data of NHTS would be used for the proposed model to translate auto usage to the number of vehicles that parked for the demand. For the parking demand calculation of institutional and office buildings an auto occupancy data of 1.18 persons per vehicle was applied and for other buildings of business PAZ areas, an auto occupancy data of 1.82 was applied in the model.

4.1.5 Traditional and Person Demand Calculations

As the first step of demand calculation, based on the methodology of this research, the peak person occupancy was calculated for the buildings based on the standards and requirement of City of Pittsburgh PZO. Buildings in the study area were grouped based on their locations in each of the PAZs. For the demand calculation, these buildings were categorized based on the usage characteristics of the buildings. Definitions from the Pittsburgh Zoning Ordinance (PZO) were used for categorizing the buildings.

Primarily, person occupancy was calculated based on the GFA of the buildings and the zoning requirement. Minimum criteria guidelines of off-street parking requirement from PZO were followed to calculate the person occupancy or base demand, without any travel characteristics applied, based on the above-mentioned categories of the buildings. One of the basic premises of parking zoning requirements in ordinances is that the requirement is based upon the peak period number of persons present in a building. The minimum standards for off-street parking requirements of PZO is tabulated in Table 14.

Table 14. Minimum off-street parking schedule, Pittsburgh Zoning Ordinance

Use Type	Minimum Off-Street Space Requirement based on GFA of Building
Bank or Financial Institution	1 per 500 sf above first 2,400 sf
Educational Institution not otherwise listed	1 per 800 sf
Laboratory/Research Service	1 per 500 sf above first 2,400 sf
Library	1 per 600 sf
Medical Office	1 per 400 sf above first 2,400 sf
Office	1 per 500 sf above first 2,400 sf
Restaurant, Fast Food	1 per 75 sf of customer service/dining area or 1 per 200 sf if no customer service area, plus 6 queuing spaces per service window
Restaurant	1 per 125 sf above first 2,400 sf
Retail Sales and Services	1 per 500 sf above first 2,400 sf

There is a 50 percent reduction in off-street parking requirements that can be incorporated in the business area on Forbes avenue and some parts of the lower campus of the University of Pittsburgh. Areas where parking reduction factor can be used by PZO in the study area is illustrated in Figure 19. After calculating the demand or person presence based on GFA and the PZO calculations, these reductions were incorporated in the calculation of traditional or the PZO requirement for parking of the respective buildings. A sample calculation is tabulated in Table 15 for two different types of buildings.

Table 15. Traditional demand based on Pittsburgh Zoning Ordinance

PAZ No	32	4
Building Name	Benedum Hall	CVS Pharmacy
Category	Institutional	Retail
GFA (sf)	536,596	14,014
PZO Parking Requirement (GFA per space)	800	500
Traditional Parking space requirement (spaces)	671	28
Traditional Parking requirement with PZO reduction factor applied(spaces)	336	14

From the calculation of all the buildings within all PAZs of the study area, the total traditional demand or peak person presence was estimated to be 16,105 spaces and considering 50 percent reduction factor of the PZO total traditional demand is 8,047 spaces. Demand by PAZs are tabulated in Table 16.

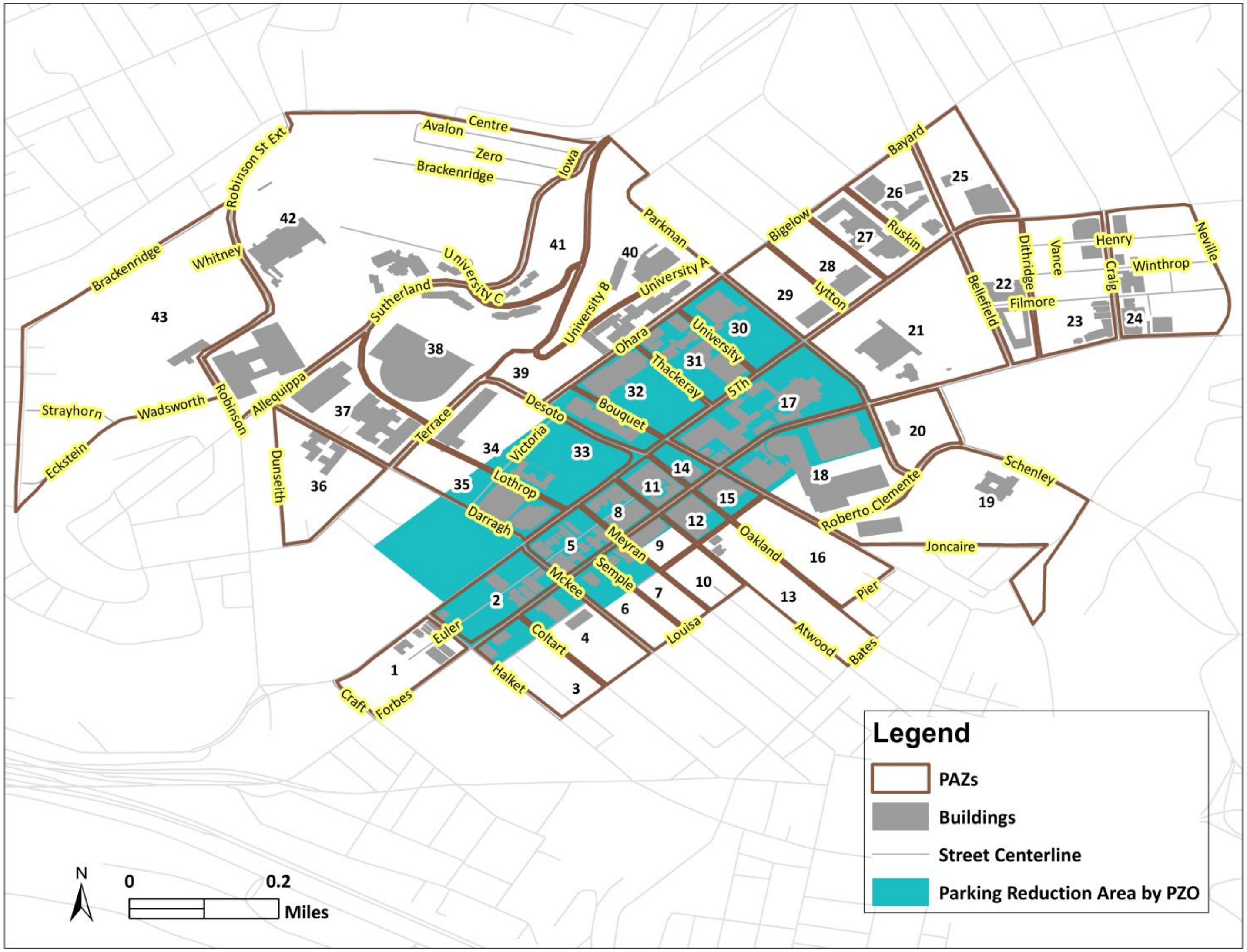

Figure 19. Parking reduction area by PZO in the study area

Table 16. Traditional Demand of PAZs considering the reduction factor of PZO

PAZ No	Traditional Demand, spaces (Considering 50% reduction factor of PZO)	PAZ No	Traditional Demand, spaces (Considering 50% reduction factor of PZO)
1	58	23	204
2	43	24	92
3	41	25	78
4	74	26	286
5	183	27	220
6	4	28	122
7	30	29	96
8	132	30	66
9	114	31	334
11	161	32	346
12	51	33	302
13	5	34	150
14	16	35	681
15	160	36	136
17	830	37	318
18	726	38	439
19	106	39	219
20	4	40	157
21	414	41	22
22	179	42	435
		43	13
Total Traditional Demand, spaces (Considering 50% reduction factor of PZO)		**8,047**	

4.1.6 Demand Adjusted for Travel Characteristics

After calculating traditional parking demand or persons present during the peak period, adjusted demand was calculated using the travel demand data. The PZO reduction factor data was not used for the model demand. After calculating the minimum parking demand, travel characteristics data were incorporated in the calculation. Neither population nor traditional parking demand were possible to differentiate between employees and shoppers of the business areas. It was assumed that the PZO traditional demand for these land uses includes both employees and shoppers. For the model, auto occupancy data for both shoppers and employees was considered as 1.82 which was auto occupancy for shoppers. Mode split data was used based on the trip purposes of the population of the buildings. Finally, the new demand calculation procedures based on the methodology of this research can be expressed as below equation.

$$APD = TD \times MS \div AO$$

Where, APD is the Adjusted Parking Demand, TD is Traditional Demand, MS is Mode Split Percentage and AO is the Auto Occupancy.

For adjusted demand calculations using the above equation, Geographical Information Systems software (ArcGIS) was used to illustrate the locations of demand and supply in the study area. An Adjusted Parking Demand (APD) model was developed using the model builder feature of ArcGIS. The model contains spatial data layers and non-spatial tables. The spatial data layer was the buildings data with the building categories, GFA and operation characteristics types. Non-spatial tables were the mode split and auto occupancy data for different categories of the buildings. The model was developed to give an output of demand by buildings and PAZs in a feature class dataset and demand by PAZs in a table format. A sample calculation of the buildings of the PAZs is tabulated in Table 17.

Table 17. Adjusted demand calculation

Building Name	**Benedum Hall**	**CVS Pharmacy**
PAZ No	32	4
Category	Institutional	Retail
GFA	536,596	14,014
Minimum Parking Requirement (1 per sf)	491	500
Traditional Demand	671	28
ACP	19.09	5
Auto Occupancy	1.18	1.82
Adjusted Parking Demand	109	3

The results show that for the buildings, the application of the ACP and auto occupancy rate results in a lower parking demand than application of the 50% PZO adjustment factor. The total demand was 3,016 spaces after considering the ACP and auto occupancy. Process of estimating adjusted demand is illustrated in Figure 20.

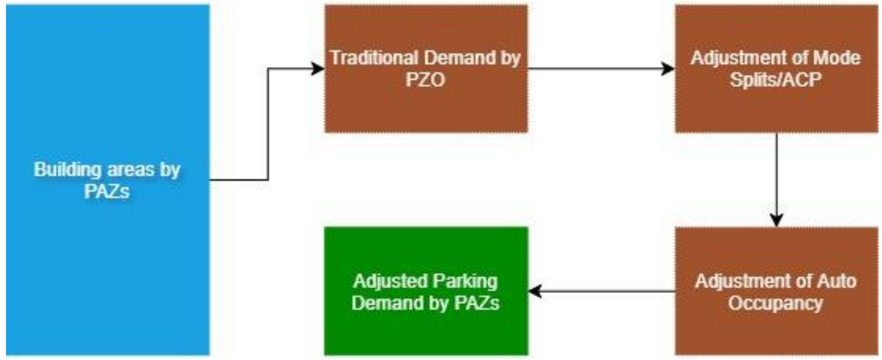

Figure 20: Flow chart of Adjusted demand Calculation

Comparison with Supply Usage: Total demand from the new demand model is estimated to be 3,016 spaces which is the peak demand for all the PAZs of the study area. From the directly collected hourly usage data of the PAZs, as mentioned in section 3.2.3 of this report, the peak parking usage of this area was 5,166 which was 84.10 percent of total parking spaces. The measured peak demand occurred at 1 PM to 2 PM. Comparing the estimated model demand to the peak usage of supply in the PAZs, it can be observed that peak supply usage was higher than demand. From these observations it was concluded that the model assumptions need to be calibrated.

4.2 MODEL CALIBRATION

Because the initial model results did not replicate current conditions it was necessary to calibrate the model. For a model to be used as a tool to evaluate parking future scenarios replication of current conditions is essential. For calibration purposes, different assumptions of the model were reconsidered for changes relative to their accuracy. In the first iteration, travel characteristics were considered.

Auto Occupancy: Auto occupancy was reconsidered based on the populations' trip purposes of the PAZs and auto occupancy values that were collected from the national level data. As the trip purposes cannot be changed, only auto occupancy values can be changed. But no local level data was available for the study area. So, it was not possible to calibrate the model using auto occupancy characteristics without collecting localized data which was beyond the scope of the initial data collection plan.

Mode Split: Though local level mode split data were used in the model; a modified mode split data ACP was developed and applied for the populations of the University of Pittsburgh. This original ACP was calculated based on the total number of students, 25,795 and faculty/staffs, 11,163 of the university. This data did not consider the absentee rate or actual occupancy during a typical day that is influenced by many factors such as absentee rate, class schedules for students and faculty/staff work schedules. However, direct data was available for students measuring the actual class schedules for a typical day as to the number of students scheduled for classes at the park time period.

A review revealed that there was no directly available data source to adjust the absentee rate of the university faculty/staff which would include the aforementioned factors. However, a model could be developed for a composite absentee rate and could be calculated from the off-street parking usage data of faculty/staff parking usage. A model was developed based upon the occupancy data of the lease spaces of Soldiers and Sailor's garage of the university. This facility represents the single largest parking facility for faculty/staffs. It was observed that a maximum occupancy rate 80.77% of the lease parking occurred on 11th April 2018. The lease data for that day is tabulated in Table 18. It is noted that this is the same data used to estimate the time distribution of faculty/staffs. This date was selected because it coincided with the general data collection period of the research.

Table 18. Parking data of Soldiers and Sailor's garage

Time	Occupied spaces	% Full
7:00 AM	204	31.38%
8:00 AM	409	62.92%
9:00 AM	494	76.00%
10:00 AM	513	78.92%
11:00 AM	518	79.69%
12:00 PM	525	80.77%
1:00 PM	524	80.62%
2:00 PM	515	79.23%
3:00 PM	449	69.08%
4:00 PM	284	43.69%
5:00 PM	136	20.92%
6:00 PM	62	9.54%
7:00 PM	33	5.08%
Total lease spaces	650	

From this data, an absentee rate of 19.23% was used for adjusting the typical attendance of faculty/staffs during a peak hour of demand. Considering these maximum attendances of students and faculty/staffs, the ACP was adjusted. The adjusted ACP is calculated in Table 19.

Table 19. Adjusted ACP calculation for the population of the University of Pittsburgh

Population Category	Revised Total Number	Mode Split-Auto (Percentage)	Revised ACP
Student	8,320	11	24.52
Faculty/staffs	9,016	37	

Person Density of University Buildings: Because the University buildings represent the largest buildings areas in the model, a reconsideration of how the PZO estimates the peak person occupancy in each building was considered. For the University buildings, which are classified as institutional buildings per the PZO, the PZO minimum parking requirement, which estimates peak person occupancy is 1 space per 800 sf of GFA. This calculation was evaluated relative to its accuracy.

Data was available on the total GFA of university buildings, which is 10,431,340.00 sf. From the class schedule data peak students, scheduled for classes, are 8,320. But for the faculty/staffs, it was assumed that parking spaces were needed for every person, regardless of whether they were on campus. So, total number of faculty/staffs, 12,942 was used without any adjustment. These considerations gave a total population of (8,320 +12,942) = 21,262 persons in the university buildings. From this data the average person density of the buildings was calculated to be 0.0020 persons per square feet or 1 person per 491 square feet of GFA. In comparison, the PZO is calculating this density as 1 person per 800 sf of GFA. Considering this more accurate peak person density of one person per 491 sf in the institutional buildings and the recalibrated ACP of 24.52 for the institutional area, the APD model of adjusted new demand was recalculated. The conclusions were that the total population and GFA of the University institutional buildings was higher than the estimate from the PZO.

The adjusted new peak parking demand was 5,402 spaces, when compared to the peak usage of 5,166 spaces the demand was 236 spaces higher than measured usage. This difference is hypothesized to represent latent demand that is being met outside of the study area. Adjusted demand by PAZs is illustrated in Figure 21.

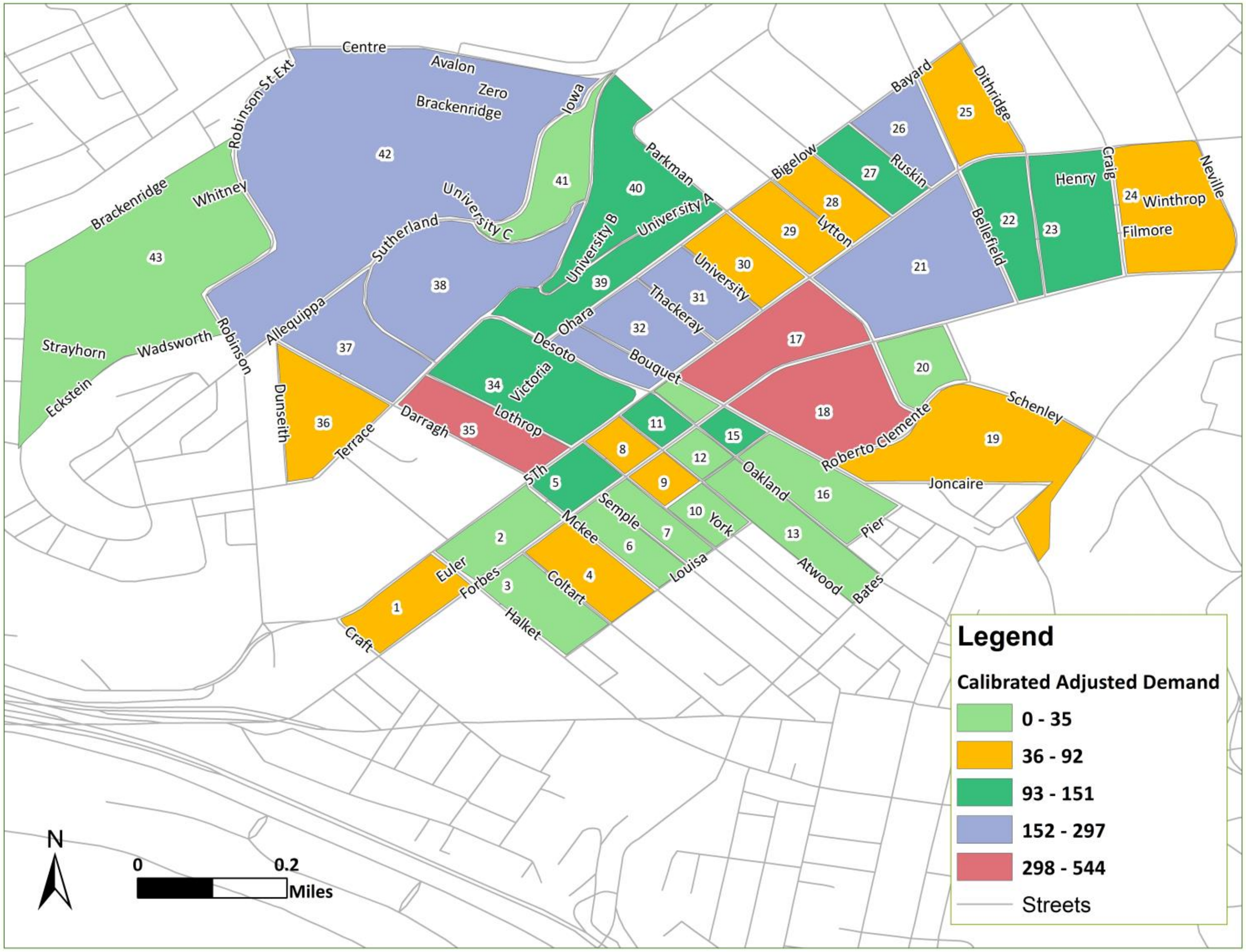

Figure 21: Adjusted Parking demand by PAZs

5.0 MODEL RESULTS AND APPLICATIONS

Results of this methodology and its application to the selected study area, can be summarized as travel characteristics-based parking demand model will give more accurate demand prediction than traditional demand for an institutional urban area. This section of the thesis describes the results, comparisons with the supply and traditional demands and application of the model.

5.1 COMPARISON WITH TRADITIONAL DEMAND

As described in the section 4.1.5 of this report, total traditional demand is 8,047 spaces for the study area considering the 50 percent reduction factor of PZO. From the APD model, peak parking demand of the study area is 5,402 spaces, which is around 67 percent of the traditional demand. A comparison of these two demands was determined by the PAZs which is illustrated in Figure 22.

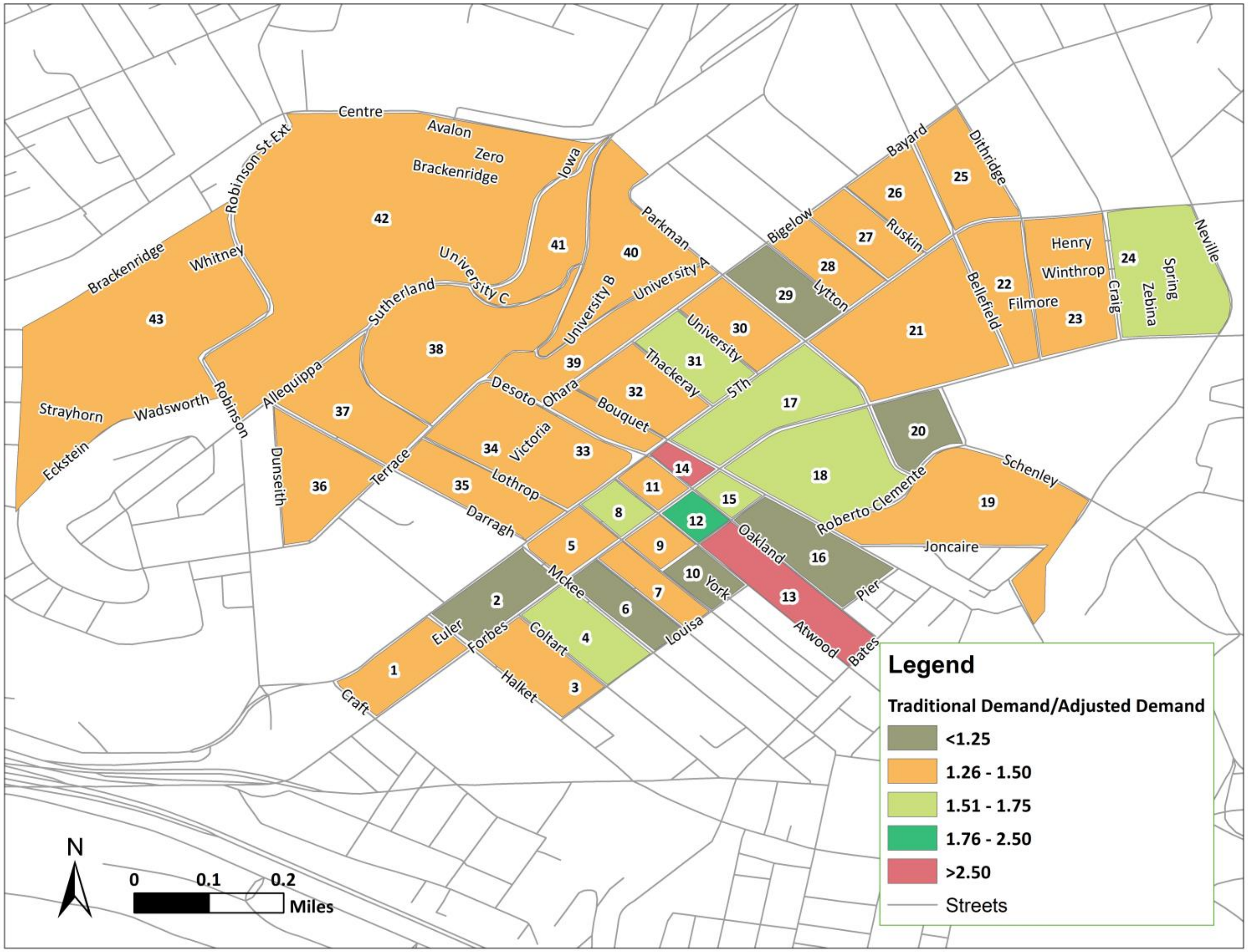

Figure 22. Comparison of traditional demand by PZO and adjusted demand

The comparison map shows that traditional demand in most of the institutional PAZs are about 1.5 times higher than the demand calculated based on the APD model. But the ratios are highly varying in the business area PAZs. In the business areas, there are more variations in the types of buildings, which includes institutional, retail and offices. As the travel characteristics were different for different building categories and usage characteristics, this variation is confirmed by the model.

Without considering the reduction factor of PZO, the demand calculated by APD model was more than 100 percent less than the tradition demand.

5.2 COMPARISON OF SUPPLY AND ADJUSTED DEMAND BY TIME OF DAY

Hourly usage data was collected from 7 AM to 7 PM and total supply was calculated by summing the off-street parking and on-street parking. PAZs were created based on the blocks and on-street parking on the adjacent roadside was considered the respective PAZs supply. Based on total supply data presented in section 3.2.3, total supply of the study area was 6,085 spaces, where based on the APD model demand of the study area was 5,254 spaces. But from the hourly usage of the supply data it was observed that a maximum 5,166 spaces were used in the peak hour of 1 PM to 2 PM, which is 84.10 percent of the total supply. For the deficit calculation, this 84.10 percent was considered as the efficiency factor of the parking in the study area. Supply were adjusted by the PAZs based on the efficiency factor. From the output of the APD model, adjusted demand was compared with the supply by PAZs. The calculation is tabulated in Table 20.

Table 20: Comparison of adjusted demand and supply by PAZs

PAZ No	PAZ Category	Adjusted Model Demand (Spaces)	Adjusted Supply (Spaces)	Difference
1	Business	41	47	-6
2	Business	35	28	7
3	Business	28	34	-6
4	Business	44	58	-14
5	Business	127	51	76
6	Business	0	28	-28
7	Business	20	389	-369
8	Business	76	41	35
9	Business	78	9	69
10	Business	0	8	-8
11	Business	122	21	101
12	Business	22	51	-29
13	Business	1	25	-24
14	Business	5	36	-31
15	Business	105	100	5
16	Business	0	6	-6
17	Institutional	544	127	417
18	Institutional	454	424	30

Table 20 (continued)

PAZ No	PAZ Category	Adjusted Model Demand (Spaces)	Adjusted Supply (Spaces)	Difference
19	Institutional	72	163	-91
20	Institutional	0	70	-70
21	Institutional	279	24	255
22	Institutional	135	66	69
23	Business	146	183	-37
24	Business	59	91	-32
25	Institutional	62	198	-136
26	Institutional	194	217	-23
27	Institutional	150	52	98
28	Institutional	83	33	50
29	Institutional	77	24	53
30	Institutional	45	816	-771
31	Institutional	219	87	132
32	Institutional	233	45	188
33	Institutional	204	154	50
34	Institutional	102	23	79
35	Institutional	461	0	461
36	Institutional	92	98	-6

Table 20 (continued)

PAZ No	PAZ Category	Adjusted Model Demand (Spaces)	Adjusted Supply (Spaces)	Difference
37	Institutional	215	46	169
38	Institutional	297	8	289
39	Institutional	151	406	-255
40	Institutional	106	116	-10
41	Institutional	15	23	-8
42	Institutional	294	713	-419
43	Institutional	9	30	-21
Total		5,402	5,169	233

It was observed that for some PAZs supply was higher than PAZ demand. This can be explained in two ways. For the study area, as it is containing an institutional area, a PAZ does not necessarily need to have its supply within the PAZ's boundary or adjacent roads. For a large negative number in the difference of demand and supply, can be easily explained that there might be large garage or university parking lot. For example, in the PAZ 42, supply was 419 spaces higher than demand. This is because there is a large parking lot of the university. In PAZ 7 on the business area, supply is 369 spaces higher than demand. This is because the only public garage "Forbes and Semple Garage" is situated in that PAZ.

Another cause of the very close difference between the supply and demand is the accuracy of the supply data. As there are several other institutions and residential areas in the study area which were not considered in this research. These buildings were considered to be self-contained in terms of parking supply and demand. But because those are in the study area, collected supply, especially on-street and off-street private parking facilities, also serve as some portion of those building's supply. The total difference of demand and supply could be higher if it would be possible to distinguish the supply of the buildings which were not counted in the research. But it was not possible to distinguish the supply.

5.3 LATENT DEMAND

The difference between the total demand and supply is 233 spaces, which is the estimated latent demand in the study area. Based on the traditional or PZO determined demand of the study area, the latent demand should be much higher than this number because all supply is fully utilized. The explanation of this latent demand proves that the model was accurate, and the research hypothesis was correct.

5.4 APPLICATION OF THE MODEL

Based on the hypothesis and the result of the APD model, it can be said that this model will estimate parking demand of any facilities more accurately than the tradition demand. APD model can be used for different purposes such as parking demand calculation of new developments and as well as parking management of any facilities or areas. As this APD model has been developed based on the data of the study area, several parking scenarios can be evaluated by this model. Some of the potential applications are described.

5.4.1 Parking Supply Deficit Calculation

One of the applications of the APD might be to calculate the parking supply deficit of a more specific area within the study area, by comparing the existing peak supply and demand of the area. Considering the two different types of PAZs, institutional and business PAZs in the study area, localized deficits can be calculated. Based on total supply data mentioned in the section 3.2.3, total supply of the study area was 6,146 spaces and based on the APD model of the study area the demand was 5,254 spaces. But from the hourly usage of the supply data it was observed that maximum 5,166 spaces were used in the peak hour of 1 PM to 2 PM, which is 84.10 percent of the total supply. For the deficit calculation, this 84.10 percent was considered as total utilization and the efficiency factor of the parking in the study area. Supply were adjusted by each of the PAZs based on the efficiency factor. From the output table of the model, calculation of the total supply and demand of the PAZs categories which is tabulated in Table 21 it is observed that supply is more than the demand in the business PAZs. But as described earlier supply of this area also meets the demand of the institutional demand within the complete study area. This illustrates the model could be an effective tool to calculate the localized deficit.

Table 21. Parking Supply deficit by the PAZs

PAZ Category	Demand (Spaces)	Supply (Spaces)	Surplus/Deficit (Spaces)
Business Area	909	1,206	297 (surplus)
Institutional Area	4,493	3,963	-800 (deficit)

5.4.2 Parking Management

Using this APD model, demand fluctuation by time of day can be determined, which can be an effective tool for parking management. Also, because of the constraints of a parking supply, demand to supply ratios can be modified by decreasing the demand. Using this tool, one can determine the required change in travel characteristics for maintaining the demand supply ratio.

Changing the travel Characteristics: If university could achieve a goal to decrease the demand instead of increasing supply to meet the needs of expansion, they could decrease the ACP by increasing transit of other non-auto mode users. If university can increase transit usage by 5 percent for faculty/staffs, that will result in a decrease of the mode split for faculty/staffs. The result would be that the ACP will be changed, predicting the decrease in the demand. Using the calculations of Table 19 of section 4.2, the new ACP for the university population will be 21.92. Running the APD model with new ACP, adjusted demand can be calculated. Calculating from the output table of the model, the new demand for increasing the 5 percent transit user among the faculty/staffs of the university will be 4,919 spaces. This compares to the current demand for 5402 spaces or a decrease in demand of 483spaces. Similarly, the predicted decrease by increasing auto occupancy can be estimated, as a result of introducing more carpool and vanpool usage. Required changes in travel characteristics can be determined from the model by iteration of these factors.

Future demand calculations: If the university planned to increase the student enrollment and corresponding faculty/staffs' levels, new additional demand could be calculated from this model. From the Factbook 2018 of the University of Pittsburgh, student faculty ration is 14:1[24]. For example, if university want to increase the students by 14 percent and faculty/staffs by 1 percent with existing building and parking infrastructure facilities, the new ACP would be 23.67. For ACP calculation, it was considered that these 14 percent will increase peak presence of the students by 14 percent. After increasing the population, new person density will be 1 person per 440 spaces. For the new ACP and person density, new total demand of the institutional PAZs will be 4822 spaces. Based on this estimation, measures can be taken to increase the supply or decrease the demand by changing travel characteristics.

5.4.3 Adjustment in the PZO

The APD model could be an efficient tool to introduce the reduction factors in different areas. The PZO could be adjusted to reflect reduction factors with more accuracy than current factors. In the study area, PZO introduced 50 percent reduction factor which results in a demand of 8,047 spaces. This calculation was done assuming that the reduction factors applies to the whole study area. But from the map shown in Figure 19 it was observed that only Forbes avenue and lower campus of the University of Pittsburgh is within the reduction areas. From all the calculation throughout the whole study it is now evident that this 50 percent reduction factor can be increased for a greater portion of the study area. Considering the whole study area, the tradition demand is 16,105 spaces based on the off-street parking requirement of the PZO and without considering the 50 percent reduction. The model adjusted demand is 5,402 spaces. Based on this comparison it can be said that adjusted demand is around 67 percent less than traditional demand. So, if the PZO would use the 67 percent reduction factor instead of 50 percent for the whole study area the resulting demand would be closer to the model predictions. A further refinement of the PZO would be to introduce different factors for different smaller areas categorized by PAZs or group of PAZs by the building categories and operation characteristics of the PAZs.

5.4.4 Hotspot Map

From the output of the model, a hotspot map can be created to find the critical areas within the study area of supply deficit. A map calculating demand to supply ratio is illustrated in Figure 23for each PAZ. From the Figure 23 it is possible to locate the critical PAZs in terms of demand to supply ratio. Further study is needed to create this type of hotspot map. This type of data could be used to locate new parking facilities closer to demand generators. This information is useful because the PAZs considered in this research do not need to have supply in the same PAZs to meet the demand. For this study, on-street supply of the adjacent roadsides of PAZs are considered as supply of respective PAZs. In the institutional area, supply can be available within the several minutes walking distance from the demand PAZs. For the business area, this distance can be within one or two blocks. A buffer zone needs to be introduced to create such kind of hotspot map to get the accurate data on critical PAZs. Finally, it can be said that APD model can be an effective tool for parking demand calculation as well as urban planners.

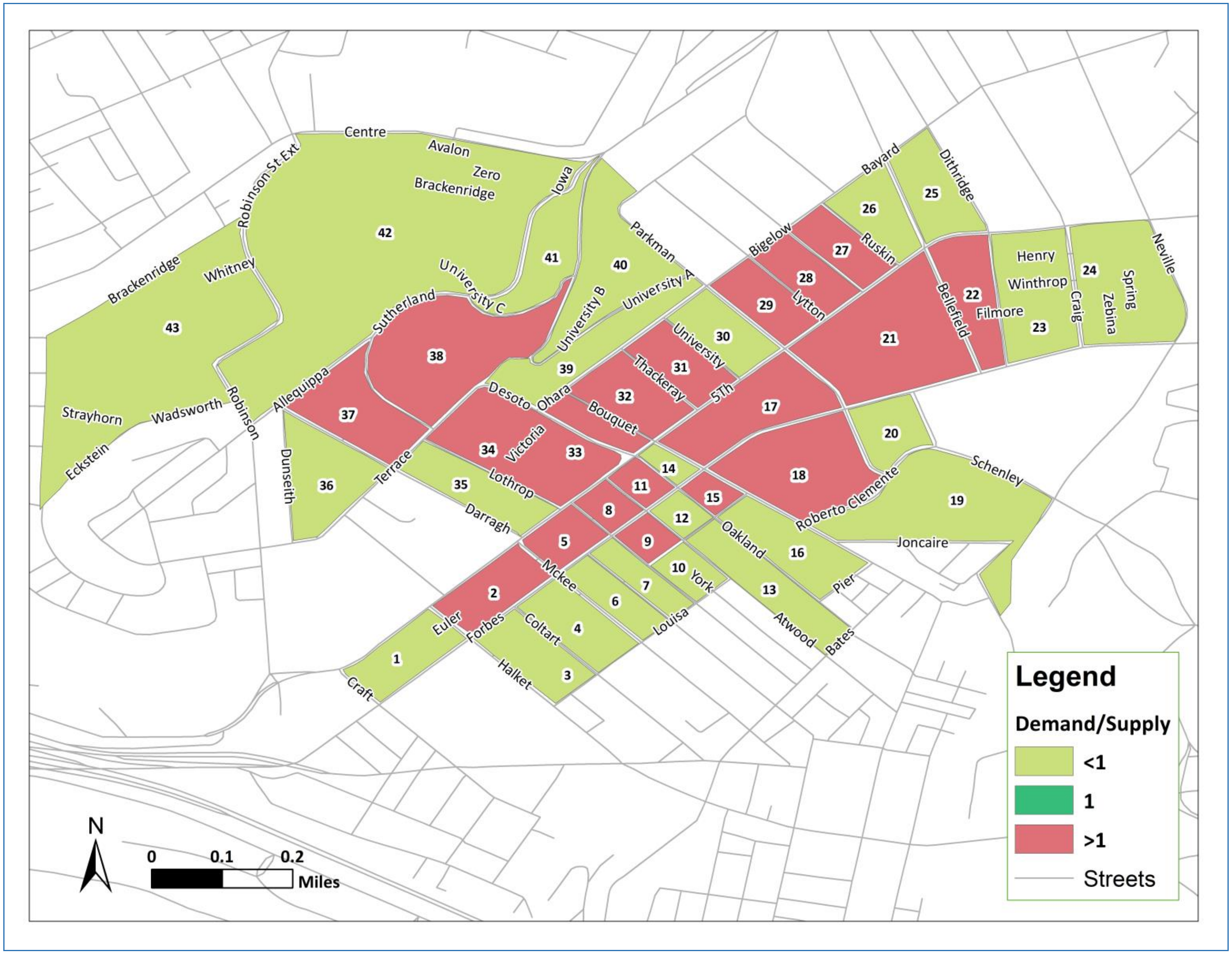

Figure 23. Demand to supply ratio

6.0 SUMMARY AND CONCLUSION

The main purpose of this research was to develop a parking demand model for an institutional urban area with mixed land uses based on travel characteristics. Several assumptions were made throughout the completion of the research, some of which were also changed during the calibration of the model for a better model estimation. Finally, a calibrated model was completed and used for determining the peak and off-peak parking demand of an urban institutional area.

The hypothesis of the research was that travel characteristics-based parking demand modeling might be a more accurate way to estimate the demand an institutional urban area. For testing this hypothesis, a model based upon a methodology was developed to estimate the demand from data on the population of the specific areas or buildings. However, it was not possible to obtain all of the population data required for the modeling. This is a common problem in all types of transportation planning analysis when person-trips are the first step in developing travel models. This issue was addressed by estimating building populations.

Travel characteristics were incorporated with the traditional demand, or zoning demand, which was a deviation from the original methodology. Because, traditional parking demand calculations are based on anticipated building populations using only the auto mode they are not accurate for an urban area. In addition, for the traditional parking demand calculations, all building GFA needs to be calculated, this methodology did gather that data using a GIS based platform for both institutional and business buildings. Because travel characteristics data varies depending on the regions or urban area, an extensive review was done to find the required data for this model, but the model allows these to be varied based upon local conditions. In addition to the variance of local mode choice conditions, based upon location, it can also vary based upon the trip purpose, which is reflected in the land use and traveler types as workers, students and shoppers. Different mode split data was used for all categories of travelers and was collected from both direct measurement through surveys and available data. Several sub-models were also developed based upon available data to reach the logical arguments and explanation so that the actual scenario could be modeled.

The business area's mode split data was collected from in-person interview surveys, which gave the actual scenario data of the business area PAZs of the study area. This business area was very different from the typical business areas for travel characteristics. Demand for the business districts using the empirical data from other business areas would not replicate the actual demand. An extensive review of available data revealed that localized auto occupancy data was not available and nationals level data was used for the demand calculation.

A GIS model was developed to supplement the mathematical model to incorporate the travel characteristics in the calculation and perform the analysis from a spatial perspective also. From the results it was clearly proven that tradition demand is much higher than the adjusted demand for an urban area. Also, from actual hourly usage data in the study area, it was observed that tradition calculated parking demand was higher than the actual demand measured. In urban areas where all supply is utilized during peak periods the estimate of latent demand is extremely helpful in parking analysis. Though latent demand was found very small in the study area, the model does provide a methodology to determine what the shortage of parking might be in a study area during peak periods.

Though every institutional area maybe similar same in terms of building types and land use area, every urban institution is different relative to travel characteristics of its population. Because parking demand is a function of the use of the auto mode using travel characteristics is essential to demanding parking demand. This research hypothesized that because travel characteristics are different for different regions, trip types, land use areas and sub-areas the use of travel characteristics in parking models is essential to accurate estimates. Therefor a demand prediction model, based on incorporating travel characteristics and geographic locations, will give a more accurate demand than the tradition demand prediction methods currently used.

6.1 LIMITATION AND FUTURE RESEARCH

Though an extensive effort was completed for testing the hypothesis of the research, it was not possible to obtain all of the data needed to proceed with the initial methodology. Several assumptions were made without deviating from the original methodology. A more extensive dataset would produce a more accurate model to test. However, the following recommendations are made to future enhancement of the methodology and models to improve accuracy of the results.

1. It was not possible to obtain the actual peak period population data of the buildings which might give a more accurate model to test the hypothesis. Methods to measure persons that are occupying the buildings by time of day and type of trip purpose could be developed to improve the model. A detailed survey can be designed to collect this data for all the buildings of the study area.

2. Although institutional areas' building GFA data were collected from the university and considered to be accurate, business areas GFA collected from the building footprint and direct observation of the heights of the buildings was not considered to be as accurate. As there were several businesses of several categories in many buildings, it was not possible to get the actual data by business types or business numbers. Buildings were divided based on the assumptions from the google map satellite view. A more accurate data would give more accurate model. In urban areas where more accurate building data is available from sources such as building occupancy permits would enhance this dataset.
3. For purpose of the zoning and person density calculations all businesses were assumed as retail. But in this area, there is many restaurants and the traditional demand of the restaurants is higher than general retail and use assumptions However, to be more accurate the model would need to have available the restaurant service areas and store areas separately to calculate the traditional demand, which was not available. For future research this data could be found from some of the private organizations who worked to estimate parking of these restaurant or from the architectural plans. Also, all the upper floors from the business district buildings were assumed to be office area. It was not possible to verify that data, which would result in a more accurate model.
4. The parking supply data was considered only for the selected institutions and businesses in the model area. But as there were many other buildings of other institutions or unique land uses in the study area, this supply also meets those building's demand through private parking facilities not available to the public.

For the future research these limitations can be overcome. Auto occupancy data can be found from a detailed survey on the population of the study area. Though the study area has several institutions such as several universities, museums, churches and other non-university related land uses primarily the University of Pittsburgh's area was considered as institutional uses for the model. Considering all the institutions in one model would be an enhancement of the model to calculate the demand.

APPENDIX A

BUILDING AREA DATA OF THE UNIVERSITY OF PITTSBURGH

All the data collected from the university of Pittsburgh is listed below Table 22.

Table 22: Building area data of the University of Pittsburgh

Building Name	Building Code	GFA (square feet)
3343 Forbes	71	33,808
Allen Hall	461	58,092
Alumni Hall	14	196,127
Amos	477	63,257
Barco Law	426	145,947
Bellefield Hall	576	113,087
Benedum Hall	438	536,596
Biomedical Science Tower 3	753	309,672
Brackenridge Hall	478	55,569

Table 22 (continued)

Building Name	**Building Code**	**GFA (square feet)**
Bruce Hall	479	130,503
Cathedral of Learning	424	631,816
Charles E. Cost Center	678	82,977
Chevron Science Center	464	194,896
Clapp Hall	428	89,816
Craig Hall	680	65,524
Crawford Hall	458	97,085
Darraugh Street Apartments	780	107,789
David Lawrence Hall	425	78,757
Eberly Hall	422	56,051
Engineering Auditorium	651	15,093
Eureka Building	64	36,607
Falk School	445	85,563
Fitzgerald Field House	446	105,045
Forbes Craig Apartments	444	55,188
Forbes Pavilion	487	87,114
Forbes Tower	135	89,387
Frick Fine Arts Building	447	83,347
Gardner Steel Conf. Cntr (GSCC)		26,714
Graduate School of Public Health Crabtree (GSPH)	449A	69,317

Table 22 (continued)

Building Name	Building Code	GFA (square feet)
Graduate School of Public Health Parran (GSPH)	449	224,079
Hillman Library	451	260,358
Holland Hall	480	136,958
Information Sciences	502	114,762
K. Leroy Irvis Hall	745	128,788
Langley Hall	453	103,503
Learning Rsrch & Devel Cntr	420	96,734
Life Sciences Annex	765	62,940
Litchfield Tower A	658	155,131
Litchfield Tower B	659	155,131
Litchfield Tower C	660	155,131
Loeffler Building	584	29,544
Log Cabin	522	2,819
Lothrop Hall	411	239,960
McCormick Hall	481	43,686
McGowan Center	722	46,212
Mervis Hall	432	86,908
Music Building	493	21,275
Norenberg Hall		210,362
O'Hara Student Center	705	37,339

Table 22 (continued)

Building Name	**Building Code**	**GFA (square feet)**
Old Engineering Hall	439	67,859
Oxford Building	715	105,581
Panther Hall	759	161,317
Parran Hall	449P	189,535
Petersen Events Center	732	413,847
Petersen Sports Complex	795	20,840
Pitt Sports Dome	872	105,608
Ruskin Hall	473	193,141
Salk Annex	657	128,767
Salk Hall	470	205,228
Salk Pavilion	866	70,913
Scaife Hall	472	651,024
Sennott Square	733	247,495
Space Rsrch Coordination Cntr (SRCC)	465	41,849
Stephen Foster	488	27,182
Sutherland Hall	332	223,903
Thackeray Hall	418	102,179
Thaw Hall	489	51,379
Trees Hall	463	244,412
University Club	39	96,591

Table 22 (continued)

Building Name	**Building Code**	**GFA (square feet)**
University Public Safety Building	777	29,339
Van de Graaff Building	491	36,691
Victoria Building	518	128,844
Weasley W. Posvar Hall	434	735,493
William Pitt Union	475	179,136

APPENDIX B

SHOPPERS SURVEY FOR BUSINESS AREA DATA

Parking Survey Shoppers

Start of Block: Opening Statement

Q1

To better understand the current parking conditions and parking demands in Oakland, the University of Pittsburgh is working in partnership with the Oakland Business Improvement District and the Oakland Transportation Management Association to conduct a survey project that will contribute to the long-term growth and viability of the Central Oakland business district. This research will develop a parking demand model for Oakland based on travel characteristics and activities. All information provided in this survey will be confidential and anonymous. We appreciate your feedback towards this process. Thanks.

End of Block: Opening Statement

Start of Block: Block 1

Q2 1. Which one is your current location?

- ○ Redhawk Coffee- Meyran Ave (1)
- ○ Fuel and Fuddle-Oakland Ave (2)
- ○ Stack'd- Forbes/ Oakland (3)
- ○ Popeye's- Fifth Ave. (4)
- ○ Maggie and Stella's- Fifth Avenue (5)
- ○ Sushi Fuku-Oakland Avenue (6)
- ○ Dollar Bank- Fifth Ave (7)
- ○ Irish Design Center-Craig Street (8)
- ○ Starbucks-Craig Street (9)
- ○ Subway-Craig Street (10)
- ○ Pitt Store-Fifth (11)

Q3 2. What is your purpose of being here in Oakland today?

- ○ Shopping (1)
- ○ Dining (2)
- ○ Work (3)
- ○ Study (4)
- ○ Tourism/Recreation (5)
- ○ I live in Oakland (6)
- ○ Passing by through Oakland (7)

Q4 3. Which travel mode do you typically use when you come to the Oakland business district?

- ○ Drive alone (1)
- ○ Drive with others (2)
- ○ Public transit (3)
- ○ Biking (4)
- ○ Walking (5)
- ○ Other (6)

Q5 4. If you drive, where do you park typically?

- ○ Private parking facilities (1)
- ○ Public Parking-On-street (2)
- ○ Public Garage (3)
- ○ Not Applicable (4)

APPENDIX C

PARKING SUPPLY AND HOURLY USAGE DATA

This section provides the collected off-street and on-street parking usage data of the study area.

Table 23: Off-street hourly usage data by PAZs

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
1	30	22	25	27	28	29	29	29	29	12	9	10	9	6
2	19	0	3	5	3	7	6	7	7	6	7	1	0	0
3	41	34	35	37	41	37	35	35	35	36	33	24	25	23
4	69	36	47	53	45	59	60	54	57	47	27	17	14	12
5	47	15	22	28	30	41	40	40	41	33	27	16	25	8
6	23	22	23	20	23	23	23	23	23	20	6	13	3	14
7	449	192	322	382	420	422	420	420	426	365	306	208	156	132
8	32	6	11	15	17	22	21	24	22	21	19	13	13	13

Table 23 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	44	44	44	44	44	44	44	44	44	44	44	44	44	44
13	16	3	5	9	8	8	10	10	9	13	13	7	6	4
14	20	7	11	17	18	20	20	19	19	18	19	14	14	14
15	98	24	68	73	83	80	84	82	84	78	62	48	43	26
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	107	86	85	85	85	86	86	85	84	85	85	81	83	80
18	481	158	343	405	429	380	380	380	414	366	262	174	128	78
19	141	40	90	105	112	116	116	116	108	96	67	44	32	21

Table 23 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	15	6	7	6	7	8	8	7	10	8	8	5	5	4
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	159	43	64	99	100	110	108	117	102	101	66	35	32	23
24	73	26	29	47	33	44	46	45	39	43	32	23	20	18
25	204	204	204	204	204	204	204	204	204	204	204	204	204	204
26	226	140	179	208	211	189	186	185	204	193	171	144	134	119
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	3	0	0	0	1	2	3	3	3	3	3	1	1	1
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	941	315	662	798	852	849	849	856	817	728	521	321	207	127

Table 23 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
31	51	25	35	43	41	42	44	43	39	33	31	27	16	15
32	14	1	10	10	11	12	12	12	12	11	11	1	2	4
33	150	23	54	83	100	113	116	103	116	110	87	47	32	20
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	58	38	30	35	35	36	35	37	40	39	40	41	40	42
37	55	23	26	31	38	36	36	34	35	36	29	19	18	13
38	9	0	1	6	6	5	6	6	6	7	6	6	6	4
39	483	184	305	407	434	436	435	428	405	342	235	136	70	36
40	68	13	23	35	45	47	44	42	47	42	39	19	15	12

Table 23 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
41	27	1	8	18	22	23	23	21	21	21	18	14	9	7
42	795	297	580	693	727	726	728	733	711	644	485	333	260	181
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 24: On-street hourly usage data by PAZs

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
1	26	15	15	17	20	22	19	19	19	19	18	18	20	18
2	14	12	12	11	9	11	11	11	11	8	3	5	7	8
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	14	9	9	12	14	11	14	14	14	14	14	10	14	12
6	10	7	8	9	10	10	10	10	10	10	10	10	10	10
7	14	3	7	10	12	11	11	10	10	14	14	7	9	9
8	17	7	8	10	11	13	13	15	15	14	13	9	16	12

Table 24 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
9	11	4	8	9	8	8	10	10	8	6	8	8	10	9
10	10	1	2	7	9	9	9	10	10	6	6	8	7	8
11	25	7	10	8	15	18	20	20	23	23	17	15	23	21
12	17	2	3	8	13	17	17	17	17	16	16	17	15	11
13	14	2	3	10	12	12	10	10	8	11	10	10	11	10
14	23	5	7	13	13	19	22	21	21	19	19	19	23	22
15	21	6	11	12	20	21	19	21	20	20	20	21	20	17
16	7	0	2	5	7	7	7	7	7	5	6	3	5	2
17	44	20	16	23	32	36	37	35	34	37	27	36	38	40
18	23	11	13	17	20	21	22	23	22	22	19	19	23	23

Table 24 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
19	53	16	17	18	43	44	51	46	43	42	47	49	51	53
20	83	14	22	41	56	56	51	56	55	53	58	62	64	64
21	13	7	5	6	9	8	7	6	7	9	8	9	12	11
22	79	23	25	36	38	38	56	54	49	44	49	53	56	62
23	59	11	15	24	33	46	52	49	40	36	34	45	48	47
24	35	14	23	29	30	35	25	34	31	30	32	6	32	31
25	31	3	4	15	19	15	9	10	11	11	13	7	6	4
26	32	7	7	24	26	30	27	25	24	25	24	27	22	25
27	62	10	31	36	42	43	41	50	61	47	47	57	58	51
28	36	13	18	22	27	34	35	33	33	29	32	31	31	34

Table 24 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
29	28	6	7	15	17	18	12	19	19	11	14	20	22	11
30	29	8	13	22	27	28	28	27	27	25	25	27	28	23
31	52	17	29	46	47	46	46	43	38	36	38	44	48	47
32	39	19	27	30	32	33	34	35	27	29	27	29	31	26
33	33	19	18	25	27	26	25	24	24	22	22	24	24	21
34	27	20	17	19	18	20	18	20	21	25	22	17	17	26
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	58	35	44	47	45	46	46	44	38	36	37	40	38	45
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 24 (continued)

PAZ	Total Capacity	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	70	14	23	29	37	34	34	38	36	36	37	37	31	25
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	53	10	15	40	40	40	35	35	38	33	29	30	34	32
43	36	5	9	15	15	20	22	21	20	21	21	18	23	20

BIBLIOGRAPHY

[1] D. C. Shoup, *The High Cost of Free Parking*. Chicago: Planners Press, American Planning Association, 2005.

[2] D. C. Shoup, "Cruising for parking," *Transp. Policy*, vol. 13, no. 6, pp. 479–486, 2006.

[3] National Parking Association, "Parking Demand Report." [Online]. Available: https://weareparking.org/page/Parking_Demand. [Accessed: 06-Nov-2018].

[4] "Victoria Transport Institute - Online TDM Encyclopedia." [Online]. Available: http://www.vtpi.org/tdm/. [Accessed: 30-Oct-2018].

[5] National Parking Association, "Recommended Zoning Ordinance Provisions," 2012.

[6] Q. Rachel, "The Parking Problem That Wasn't — Strong Towns." [Online]. Available: https://www.strongtowns.org/journal/2018/3/13/the-parking-problem-that-wasnt. [Accessed: 06-Nov-2018].

[7] Parking Database, "Comparison Report | GreenTRIP Parking Database." [Online]. Available: http://database.greentrip.org/. [Accessed: 06-Nov-2018].

[8] G. Caudney, "Parking Structure Cost Outlook for 2013," *Ind. Insights*, 2013.

[9] ITE, *Parking Generation*, 3rd Editio. Washington, D.C.: Institute of Transportation Engineers, 2010.

[10] Urban Land Institute, *The Dimensions of Parking*. 2014.

[11] American Planning Association, *Parking Standards*, no. 510. APA Planning Advisory Service, 2002.

[12] E. M. Whitlock, *Parking for Institutions and Special Events*. Westport, Connecticut: Eno Foundation for Transportation Inc, 1982.

[13] G. V. Da Silva and K. Mackiewicz, "Parking Demand at an Urban College; Estimating True Parking Demand for Severe Undersupply of Parking Spaces," *ITE 1991 Compend. Tech. Pap.*, pp. 579–584, 1991.

[14] K. M. Nurul Habib, C. Morency, and M. Trépanier Martin, "Integrating parking behaviour in activity-based travel demand modelling: Investigation of the relationship between parking type choice and activity scheduling process," *Transp. Res. Part A Policy Pract.*, vol. 46, no. 1, pp. 154–166, 2012.

[15] S. C. Wong, C. O. Tong, W. C. H. Lam, and R. Y. C. Fung, "DEVELOPMENT OF PARKING DEMAND MODELS IN HONG KONG," *J. URBAN Plan. Dev.*, vol. 126, no. 2, pp. 55–74, 2000.

[16] C. Weis, "Influence of parking on location and mode choice," *Transp. Res. Board 91st Annu. Meet.*, vol. 4, no. September, pp. 1–29, 2012.

[17] R. Waraich and K. Axhausen, "Agent-Based Parking Choice Model," *Transp. Res. Rec. J. Transp. Res. Board*, vol. 2319, pp. 39–46, 2012.

[18] "Code of Ordinances, Pittsburgh, PA, Municode Library," 2018. [Online]. Available: https://library.municode.com/pa/pittsburgh/codes/code_of_ordinances?nodeId=PIZOCO_TITNINEZOCO_ARTVIDEST_CH914PALOAC_914.02OREPASC. [Accessed: 30-Aug-2018].

[19] "Title 33, Planning and Zoning, Zoning Code, City of Portland, Oregon," 2018. [Online]. Available: https://www.portlandoregon.gov/bps/article/53320. [Accessed: 30-Aug-2018].

[20] "Section 5220 - Minimum parking required and maximum parking allowed., Code of Ordinances, Blacksburg, VA, Municode Library," 2018. [Online]. Available: https://library.municode.com/va/blacksburg/codes/code_of_ordinances?nodeId=CO_APXAORNO1137BLZOOR_ARTVDEST_DIV2OREPASTLO_S5220MIPAREMAPAAL. [Accessed: 30-Aug-2018].

[21] "Pittsburgh Zoning." [Online]. Available: http://gis.pittsburghpa.gov/zoning/. [Accessed: 18-Sep-2018].

[22] Western Pennsylvania Regional Data Center, "Allegheny County Building Footprint Locations - Datasets." [Online]. Available: https://data.wprdc.org/dataset/allegheny-county-building-footprint-locations. [Accessed: 12-Sep-2018].

[23] Register Office of University of Pittsburgh, "Class Schedule of Fall 2017," 2017.

[24] University of Pittsburgh, *Fact Book 2018*. 2018.

[25] VHB, "University of Pittsburgh Transportation Survey," Pittsburgh, Pennsylvania, 2017.

[26] "University of Pittsburgh | Scorecard | Institutions | AASHE STARS." [Online]. Available: https://stars.aashe.org/institutions/university-of-pittsburgh-pa/report/2018-02-28/. [Accessed: 19-Sep-2018].

[27] "Make My Trip Count Commuter Survey." [Online]. Available: https://www.makemytripcount.org/#mmtc. [Accessed: 12-Sep-2018].

[28] U.S. Department of Transportation and Federal Highway Administration, “2017 National Household Travel Survey.” [Online]. Available: http://nhts.ornl.gov.

[29] M. Smith, “Parking Standards,” 1985.