Identifying Energy Efficient Urban Planning Approaches for Kathmandu Based on Influence of Urban Form on Travel Energy Consumption

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Identifying Energy Efficient Urban Planning Approaches for Kathmandu Based on Influence of Urban Form on Travel Energy Consumption

(都市環境による移動エネルギー消費への影響評価に基づくカトマンズ市の低環境負荷型都市計画手法に関する研究)

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January, 2019

ABSTRACT

This research is very important in the present context of Nepal as the country is facing financial burden due to ever increasing fuel import. Kathmandu's up surging travel energy consumption and deteriorating environment demands the search for a solution to reduce energy consumption. Therefore, Kathmandu city is taken as a case study for this research. Globally, in recent years, increasing concerns over climate change and transportation energy consumption have sparked research into the influences of urban form and land use patterns on travel behavior and energy consumption. However, most of the research are based on developed countries belong to the Western countries. Whereas, developing countries, many of which are constructing the energy efficient decisions based on those international studies since developing countries have the opportunity of 'leapfrogging'. Even though, among the developed countries, the cities in Western and Asian have many differences in characters. So, this research has taken Fukuoka city as a case study from a developed Asian country.

This research has several important implications for land use planning and policy-making to reduce travel energy consumption in Kathmandu. Also, this research has contributed to the current literature by establishing a new framework and applying two different analysis methods: Cluster analysis and Multiple linear regression model (MLRM) analysis, for understanding the indirect and complex interrelationship between multiple variables of urban form and travel energy consumption in an integrated way. This study dealt with the methodological challenges for modeling and analyzing complex relationships between urban form, travel purpose, mode choice, travel distance and energy consumption.

This research has identified the influence of multiple variables of urban form (5Ds) on travel energy consumption. The research results highlighted that the motorcycle use is the most influencing factor for the increase in travel energy consumption in Kathmandu. Likewise, this study highlighted that density has a key role in the motorcycle use reduction. This research has identified that Kathmandu city can be divided into three cluster groups based on the heterogeneity characteristics. Also, this research has identified the target area (specific ward) and measures for Kathmandu

city for reducing travel energy consumption that has different condition and limitation compared with a city in developed country.

This thesis consists of five chapters. Chapter 1 provides a general background to the thesis. It discusses the rationale for this research topic, the research objective and thesis structure. Then, this chapter provides an extensive literature review of the existing studies on the energy consumption in cities; and the influence of urban planning and transportation on travel energy consumption. Also, it introduces recent approaches to energy efficient planning and 5Ds framework.

Chapter 2 introduces Fukuoka city as a case study from a developed country and discusses the rationale for its selection. Then, research data type and source are introduced. This chapter contains three sections. First, Section 2.5 performs an empirical analysis of urban form at micro-scale by applying "5Ds" framework. Then, it analyzes the relationship between urban form, travel mode choice and travel energy consumption to identify the influencing factors which affect travel and travel energy consumption by using *k*-means Cluster analysis method. The cluster results revealed that residential zone has the direct effect on travel energy consumption. This study highlights that provision of bus stops and rail stations are essential with increase in road connectivity to promote public mode, reduce private mode use and travel energy consumption. The result indicates that improvement in transit accessibilities is necessary along with compact planning. Then, Section 2.6 analyzes empirically the flow of trip for different travel purposes at both trip origin and trip destination. The effect of urban form and socio-demography on purpose wise non-motorized travel, motorized travel and travel energy consumption at both trip origin and trip destination were identified by applying MLRM analysis. Similarly, Section 2.7 provides additional insights on how urban form affects travel energy consumption by using comprehensive research framework which is modified version of Section 2.6.

Chapter 3 introduces Kathmandu city as case study from a developing country and discusses the rationale for its selection. Then, research data type and source based on Kathmandu are introduced. As Nepal has no travel data like Person trip survey data in Fukuoka, a structured questionnaire survey was conducted in all 35 wards of Kathmandu city to obtain one-day travel data. This chapter contains two sections. First, Section 3.5 performs an empirical analysis of urban form at micro-scale by applying "5Ds" framework. Then, *k*-means Cluster analysis is performed to analyze the relationship between urban form and travel energy consumption through intermediate variables: mode choice and travel distance. The cluster results revealed the similar conclusions as in the Fukuoka study. Another section; Section 3.6 performs MLRM analysis by applying the research framework introduced in Section 2.7 for Fukuoka. The MLRM result highlights the causal relationship between urban form and travel energy consumption for promoting a reduction in private mode and associated travel energy consumption in Kathmandu.

Chapter 4 provides a synthesis of the obtained results to identify urban form driving factors for travel energy consumption at micro-scale and at city scale. First, comparative analysis based on cluster results of both case studies was performed. The clusters were found almost the same for both case studies. So, this study concludes that any city if analyzed at micro-scale considering the variables of urban form, travel behavior and travel energy consumption, then a city can be analyzed in terms of three main clusters: Cluster 1- Low residential and lower energy consumption, Cluster 2- Highly connected and higher energy consumption, and Cluster 3- Highly compact and lower energy consumption. This research highlights that the implementation of any single energy efficient approach in overall city is not logical and effective as the city has heterogeneity characteristics. Then, comparative analysis based on MLRM results of both case studies was performed and found that density (D1) the most influencing factor for reducing private mode and energy consumption. The result outcomes of the research using both methods are same which shows the validity of the methods in such type of research. So, the research framework used in this study could be applied to understanding the relationship between urban form, travel variables and travel energy consumption. Lastly, in this chapter, energy efficient planning approaches for Kathmandu are identified based on the results of cluster and MLRM analysis. Further, ward wise and cluster wise energy efficiency are evaluated based on Multiple Regression Equation.

Finally Chapter 5 presented the conclusions of the research findings by revisiting research objectives stated in Chapter 1. A reflection on the main contributions of this research is provided. Then, the limitations of this research and prospect for future research are presented.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

3Ds	3 Dimensions
5Ds	5 Dimensions
BREEAM	Building Research Establishment Environmental Assessment Method
BRT	Bus Rapid Transit
BT	Business Trip
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CBD	Central Business District
CO_2	Carbon Dioxide
D1	Density
D2	Diversity
D3	Design
D4	Destination Accessibility
D5	Distance to Transit
Ds	Dimensions
EC	Energy Consumption
EJ	Exajoule
GDP	Gross Domestic Product
GIS	Geographic Information System
IC card	Integrated Circuit Card
IEFS	International Eco-city Framework and Standards
ILFI	International Living Future Institute
IT	Information Technology
ITDP	Institute of Transportation and Development
JICA	Japan International Cooperation Agency

JR	Japan Railway
km^2	Kilometer Square
LBC	Living Building Challenge
LEED	Leadership in Energy and Environmental Design
LEED-ND	Leadership in Energy and Environmental Design- Neighborhood development
Max	Maximum
Min	Minimum
MJ/person-km	Megajoule/person-kilometer
MLIT	Ministry of Land, Infrastructure and Transport
MLRM	Multiple Linear Regression Model
MoPIT	Ministry of Physical Infrastructure and Transport
NOx	Nitrogen Oxides
OD	Origin-Destination
Pb	Lead
PT	Private Trip
PTS	Person Trip Survey
SC	Standardized Coefficient
SD	Standard deviation
Sig.	Significant
SO_2	Sulfur Dioxide
SPSS	Statistical Package for the Social Sciences
SQL	Structural Query Language
ST	Study Trip
Std.	Standardized Value
TD	Travel Distance

TOD	Transit-oriented Development
VIF	Variance Inflation Factor
VMT	Vehicle Miles Traveled
WHO	World Health Organization
WT	Work Trip
#	Number of ～

CHAPTER 1: INTRODUCTION

1.1 Background

Urbanization is the leading sector where the population is constantly moving into urban areas. Consequently, sensitivity to urban areas' issues related to urban transport, energy, environmental and sustainability become a vital issue when addressing urbanization. With the growth in automobile use and the potential limits to the availability of gasoline, the shares of energy consumption by transportation sector is significant and increasing. The transportation energy consumption increases by 1.4% per year [1]. Particularly, passenger or personal mobility-related fuel consumption shows the highest share of transportation energy, accounted for 61% of total world transportation energy consumption. Traditionally also, the focus of urban transportation has been on passengers as cities were viewed as locations of utmost human interactions with intricate traffic patterns linked to commuting, commercial transactions and leisure/cultural activities [2]. In fact, the emerging transportation pattern (trip frequencies, choices of destinations, modes of traveling) is a result of people's resources, needs and wishes, modified by the constraints and opportunities of urban form characteristics as well as other structural conditions of society [3].

In developing economies where walking once was the key mode for low-income residents, rapid urban development and motorization have turned city planning into a race to accommodate the rising number of vehicles, accompanied by traffic jams, air pollution and noise [4]. As a result, the urban transportation sector accounts for approximately 33 percent of total CO_2 emissions from fossil fuel combustion, the largest share of any end-use economic sector [5]. In addition to the environmental negative externalities, the extensive transport emissions caused by the increased automobile usage also results in public health problems [6]. Particularly the cities in developing countries of Asia, suffer from high concentration of air pollutants, exceeding well over World Health Organization (WHO) guidelines [7-11]. For these reasons, energy efficiency in transportation sector is vital for sustainable urban transport [12]. However, both developed and developing countries have used information, education, persuasion and awareness-raising campaigns in favor of sustainable urban transport with various, but generally limited degrees of success.

Typically, the more effective a measure is, the more resistance it evokes [13]. Social mechanisms and processes, such as status seeking (i.e., the automobile as a status symbol), freedom-seeking, or lack of trust in others' cooperativeness perpetuate urban transport problems, especially in the developing world [14]. In the collective consciousness, private motorized vehicles have been long associated with pleasure, comfort, speed, convenience, power, protection, superiority, individuality, hedonism, and freedom [15].

Efforts to deal with the problems associated with increasing automobile and travel energy consumption include the use of higher-efficiency automobiles, the shift from the automobile to public transportation and a restructuring of cities to encourage the development of new urban centers in a more energy-conserving manner [16]. Also, many studies show that fuel types, vehicle fuel efficiency and vehicle miles traveled could induce less energy consumption [17–19]. However, an increasing consensus among international scholars shows that a single technological fix will not resolve the complex transportation energy use and environmental problem; efforts from different fields are warranted [18]. It has been acknowledged that technical improvements carried out in isolation tend to have a lower impact on saving energy as do ones combined with measures intended to encourage behavior change [20]. According to Troy [21], technological interventions and modal shift have low impact in reducing energy consumption without accompanying planning strategies. According to Owens [22], "The case for including energy considerations in the planning process is strongly reinforced by the fact that physical structures are relatively permanent, but the energy future is at best uncertain. Therefore, planners should be aware of the energy implications of alternative development policies, should include energy efficiency among their objectives and may be able to make a more positive contribution to energy planning through urban design which is compatible with particular supply and conservation options." So, it is often concluded that how urban form is planned and organized determines travel energy consumption to large extent.

Land use planning is widely considered as a fundamental and long-term strategy to reduce automobile use as it determines the basic spatial settings for various activities [18,23]. It is generally accepted that compact urban forms are more energy efficient compared to extended urban sprawl, although several factors determine this, including the quality and use of public transport systems and levels of congestion in the city layout [24]. Similarly, many studies show evidence that land use and urban design solutions, such as compact development, transit-oriented development, neo-traditional neighborhood design, new urbanism and smart growth [25-28] could induce fewer automobile trips and reduce corresponding travel energy consumption and emissions [17,29,30]. However, the mechanism is unclear on how the urban form affects travel energy consumption [17,31-33] as there has been relatively little research and findings are less conclusive. At the same time, the urban land use-transportation system is such a complex entity that all the components in the system work collaboratively rather than separately [34]. There is limited evidence on how multiple variables of urban form affects travel energy consumption. This dissertation contributes to the current literature by establishing a new framework and applying two different analysis methods: Cluster analysis and Multiple linear regression model (MLRM) analysis, for understanding the interrelationship between the multiple variables of urban form, travel behavior and travel energy consumption to provide insights on how urban form affects travel energy consumption.

1.2 Research Problem

Worldwide, energy demand for urban transportation is ever increasing in a large number of cities and Nepal is no exception. In Nepal, urban transportation energy consumption is a large ultimate driving force of energy use. Like in many developing countries, rapid urbanization and motorization are causing the demand for energy to rise sharply. So, the highest share of energy demands in urban areas is endangering the overall economic development of the country. Today, Nepal has a population living in urban areas 17% and it is projected to be about 50% by 2030. Population growth rate is 1.40% per year whereas in urban, the growth rate is 3.38% per year [35]. This shows Nepal has to face immense pressure on energy supply and is expected to increase at a faster pace in the future.

Nepal does not have its own sources of petroleum fuel. Almost all energy used in Nepal is sourced from non-renewable energy resources. All commercial petroleum fuels are either imported from India or from international markets. The transport sector consumes about 63% of total imported petroleum fuel [36]. Each year the country is spending a huge amount of currency earned from export earnings and remittance in the import of fuel. The import of petroleum fuel, which was 34% of the total annual earnings from the export in 2000/01 has increased to 143% of the total annual earnings from the export in 2012/13 and it is increasing each year [37,38]. Nepal is now facing the financing burden due to increasing trend of fuel import. Therefore, the economy of Nepal cannot sustain the use of petroleum fuel in the long run. However, the government of Nepal so far has not proposed any plans to reduce the over-reliance on the petroleum fuel.

The Kathmandu valley that comprises five cities including Capital City Kathmandu, the home of 2.5 million people, is one of the fastest growing metropolitan cities in South Asia [39]. As the central hub for education, employment, business and state administration it attracts a continuous flow of people from other parts of the country. This rapid urbanization in the valley has caused a tremendous increase in the vehicle numbers, especially private modes in recent years. The vehicles registered in the Kathmandu valley comprises 66% of the total vehicles registered in Nepal [40]. Out of the total registered vehicles in the valley, more than 90% are private modes, mainly motorcycles (80%) and light duty vehicles like car, jeep, van and taxi (12.5%). According to the Department of Transport Management report, over the past 10 years, motorization has increased by 12% per year [41], while the modal share of public transport has remained stagnant. This has led to a huge challenge to support transportation energy demand of larger population while limiting their impact on energy.

In addition to the energy challenges, increasing population and rising vehicle ownership, the roads become narrower and commute time become longer that causes the problem of traffic congestion in Kathmandu. Frequent traffic congestion, fumes and excessive noise have shown possible consecutive problems in the areas of public health. Kathmandu suffers from serious air pollution [7, 42-45] and the studies have reported that transportation sector is the major contributor [7, 42] in Kathmandu. As the private mode has been found consuming 8-10 times more fuel, run 35 times the mileage and produce 30-50 times air pollution in comparison to public transport in developing countries [46]. So far, Kathmandu has no success in promoting public transportation; no efforts have been made to discourage private modes too.

Kathmandu city where walking was the key mode of travel has been evaluated as one of the least walkable cities in Asia, receiving one of the lowest walkability ratings. The average walkability rating of Kathmandu is 40.12 (out of 100), and the city is categorized as 'Not Walkable' [47]. However, the Walkability rating was based on urban form parameters such as availability of crossings, pedestrian amenities, disability infrastructure, attractive and safe pedestrian roads. Also according to MoPIT/JICA [48], walking has significantly declined in Kathmandu from 53.1% in 1991 to 40.7% in 2012 and it further forecasted that walking mode share will decline to 38.8% in 2020 whereas motorcycle has increased almost 3 times, from 9.3% to 26%. A large part of walking and cycling has been replaced by motorcycles [48], whereas the mode share of public transport has almost remained the same. It has not been supplemented with adequate construction and management of pedestrian road networks and quality of public transportation.

Therefore, Kathmandu's up surging travel energy consumption and deteriorating environment demands the search for a solution to reduce energy consumption via various possible approaches. Globally, in recent years, increasing concerns over climate change and transportation energy consumption have sparked research into the influences of urban form and land use patterns on travel behavior and energy consumption [49]. Travel behavior is the interaction between people and transport, which impacts to fuel consumption and CO_2 emission [50,51]. However, such kind of studies focusing on urban form, travel behavior and travel energy consumption have not been done in any city of Nepal until today. This dissertation contributes to identifying the influencing factors for travel energy consumption by understanding the comprehensive interrelationship between urban form and travel energy consumption through affecting factors - Travel purpose, mode choice and travel distance.

1.3 Objective

The goal of this research is to identify energy efficient urban planning approaches for Kathmandu based on identifying influence of urban form on travel energy consumption. Since urban form does not have a direct effect on travel energy consumption, it requires other intermediate factors to be considered that has a direct effect on both urban form and travel energy consumption. Therefore, we analyzed the relationship between urban form and travel energy consumption via other intermediate variables: Travel purpose, travel mode and travel distance as the travel behavior variables (Figure 1.1).

To achieve the goal, the following objectives were set out:

- To explore micro-scale analysis of urban form, travel behavior and travel energy consumption.
- To identify influencing mechanism of urban form on travel energy consumption.
- To identify and evaluate energy efficient urban planning approaches for Kathmandu based on micro-scale analysis and influencing mechanism analysis of urban form on travel energy consumption.

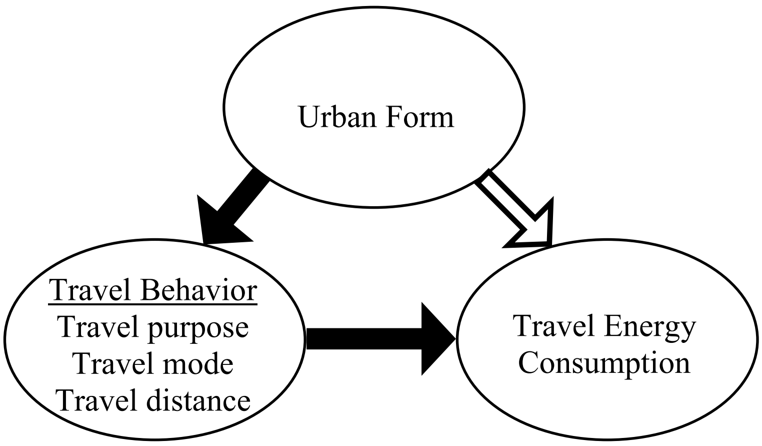

Figure 1.1 Direct and indirect relationship between urban form, travel behavior and travel energy consumption

1.4 Thesis Structure

This thesis consists of five chapters. Section 2.5-2.7, section 3.5, section 3.6 and section 4.2 have been published as peer-reviewed papers in journals and conferences.

The contents of these published papers have been reorganized in this thesis to make this thesis as a single research; not as a compilation of research papers. This attempt has been useful to eliminate the possibility of repeating figures, equations and explanations of some contents like study area, research data type and source. Figure 1.2 shows the coherence of the thesis chapters and their relationship. The following is a brief summary of each chapter:

Chapter 1: provides a general background to the thesis. It discusses the rationale for this research topic under the title- research problem. Also, the research objective and thesis structure are introduced here. Then, this chapter provides an extensive literature review of the existing studies on the energy consumption in cities and the influence of urban planning and transportation on travel energy consumption. Also, it highlights recent approaches to energy efficient planning in cities and neighborhood via three ways: Integrated Land use-Transport; improving infrastructure and urban services, and applying the sustainable framework. Then, this chapter introduces the "5Ds" framework (density, diversity, design, destination accessibility and distance to transit) for the inclusion of multiple urban form variables in the research.

Chapter 2: introduces the study area (Fukuoka city) from a developed country and discusses the rationale for the selection as a case study. Then, research data type and source are introduced. It describes the collection and simulation of the data to construct a comprehensive dataset that includes urban form, travel behavior and travel energy consumption. This chapter contains three sections based on published research papers.

Section 2.5 overviews the urban form of Fukuoka city at micro-scale by applying "5Ds" framework. Then, it represents a distinct group of urban form and travel mode choice with highly correlated variables by applying Factor analysis method separately. Lastly, it analyzes the relationship between urban form, travel mode choice and travel energy consumption to identify the influencing factors which affect travel and travel energy consumption by using *k*-means Cluster analysis method.

Section 2.6 analyzes empirically the flow of trip for different travel purposes at both trip origin and trip destination in Fukuoka. Multiple Linear Regression Model

(MLRM) analysis is applied to identify the effect of urban form and socio-demography on purpose wise non-motorized travel (walk and bicycle) and motorized travel (motorcycle, car, bus, rail and taxi) at the trip origin and destination simultaneously. Also, it explores the effect factors of urban form and socio-demography on travel energy consumption while traveling for different purposes by applying MLRM analysis.

Section 2.7 provides additional insights on how urban form affects travel energy consumption by using comprehensive research framework based on Fukuoka. The research framework established in section 2.6 is modified in section 2.7. The analysis framework consists threefold: first, this research analyzes the relationship between urban form on travel mode choice (non-motorized mode, motorcycle, car, bus and rail) by using travel purpose (work trip, study trip, business trip and private trip) as the controlling variable. Second, it analyzes the relationship between mode choice on travel energy consumption by using travel distance as the controlling variable. Third, it analyzes the interrelationship between urban form, mode choice and travel energy consumption and further identifies the influencing factors of travel energy consumption.

Chapter 3: introduces study area (Kathmandu city) from a developing country and discusses the rationale for the selection as a case study for the research. Then, research data type and source are introduced. It describes the collection and simulation of the data to construct a comprehensive dataset that includes urban form, travel behavior and travel energy consumption. This chapter contains two sections based on published research papers.

Section 3.5 performs an empirical analysis of urban form characteristics based on Kathmandu city by applying "5Ds" framework at the micro-scale. Then, *k*-means Cluster analysis is performed in order to regroup 35 wards into *k*- homogeneous clusters according to the characteristics based on 5Ds and travel energy consumption. Lastly, it analyzes the relationship between urban form and travel energy consumption through intermediate variables: mode choice and travel distance.

Section 3.6 highlights the causal relationship between urban form and travel energy consumption for promoting a reduction in private mode and associated travel energy consumption in Kathmandu. This chapter applies the research framework introduced in section 2.7 for Fukuoka case study. By using MLRM, this study analyzes the relationship between urban form on travel mode choice (non-motorized mode, motorcycle, car and transit) by using travel purpose (work trip, study trip, business trip and private trip) as the controlling variable. Second, it analyzes the relationship between mode choice on travel energy consumption by using travel distance as the controlling variable. Third, it analyzes the interrelationship between urban form, mode choice and travel energy consumption and assists to identify the influencing factors of travel energy consumption.

Chapter 4: provides a synthesis of the obtained results. First, it compares the cluster results based on Fukuoka (section 2.5) and Kathmandu (section 3.5) and identifies the urban form driving factors of travel energy consumption. Then, it compares the MLRM results based on Fukuoka (section 2.7) and Kathmandu (section 3.6) and identifies the urban form driving factors for travel energy consumption. Based on the findings of MLRM analysis, energy efficient planning approaches for Kathmandu is identified section 3.5. Then, in section 3.6, energy efficiency is predicted in each ward and cluster by applying Multiple Regression Equation based on proposed recommendation in section 3.5.

Chapter 5: The conclusions of the research findings are presented in this chapter as a summary of results and revisited research objectives stated in chapter 1. A reflection on the main contributions of this research is provided. Then, the limitations of this research are presented and recommendations are given for further research.

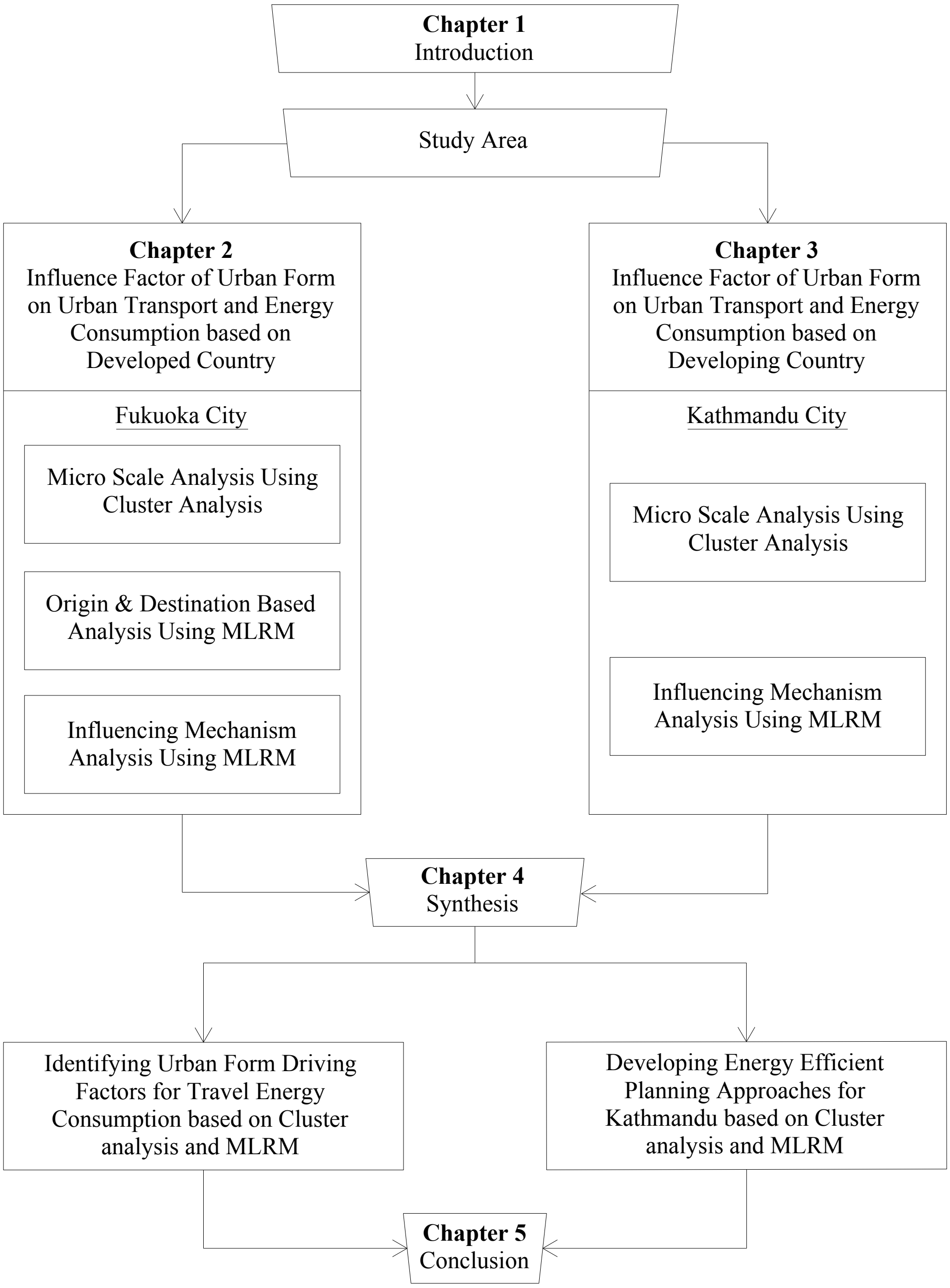

Figure 1.2 Coherence of the thesis chapters and their relationship

1.5 Literature Review

1.5.1 Energy Consumption in Cities

With most of the population and activities concentrated, cities are the largest energy consumer accounted for 75% of the world's energy and produce 80% of greenhouse gas emissions [52,53]. The metabolism of a city involves physical inputs- energy, water and materials that are consumed and transformed by means of technological and biological systems into wastes and goods or the city's outputs. Cities generate a large share of nations' GDP, which typically translates into high levels of energy consumption for industrial processes compared to non-urban areas. Built-up areas in cities also consume a large amount of the world's energy. So, attention has been drawn to the importance of urban planning as a means through which to address the global environmental challenges given rise to by cities, and transforming urban areas into sustainable communities is becoming an increasingly common vision [54,55].

Cities influence patterns of energy and land use in the surrounding and more distant areas that affect the livelihoods and quality of life of people who live even outside city boundaries [56]. In recent decades, cities have expanded dramatically due to rapid urbanization processes. Consequently, several issues associated with the management of urban built environments, such as unplanned urban sprawl, unfair distribution of land uses and inappropriate utilization of infrastructures have emerged [57,58]. Nowadays, a significant rise in the use of private cars over public transit is one of the most conspicuous issues in many cities. This issue can lead to both environmentally and non-environmentally harmful consequences, such as traffic congestion, global warming, climate change, environmental pollution, and socio-economic problems [59,60]. On the other hand, in most developing countries, the existing public transportation services are unsuccessful in attracting people because land use characteristics are not considered when planning and designing public transit. Therefore, it is necessary to integrate land use and public transportation planning into a comprehensive index to facilitate decision-making processes in urban areas [60-63].

By 2030, over 60% of people will live in cities [64]. This rapid urbanization is particularly taking place in cities of the developing world. It is expected that cities in developing countries will absorb 95% of this increase [65]. In this face of an ever-growing population and energy demand in cities, cities could also lead to potential initiatives in reducing urban energy use and make energy use more sustainable [66,67]. For this, it is important to understand which sectors consume the most energy to take appropriate remedial actions [56]. According to World Bank [56], the growing energy needs that countries face in the transport sector, especially in urban transport in developing countries, present major challenges in terms of energy security and the environmental externalities associated with emissions. In the wealthier cities in the industrialized world, most energy is used to heat and light residential and commercial buildings; transport and industry follow as the second and third greatest consumers of energy [56] as shown in Figure 1.3.

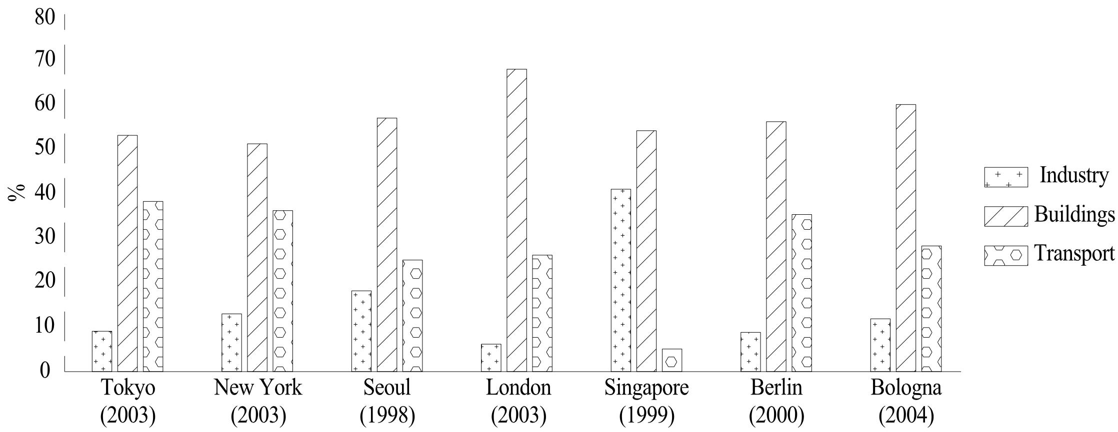

Figure 1.3 Energy consumption in selected cities in high-income cities [56]

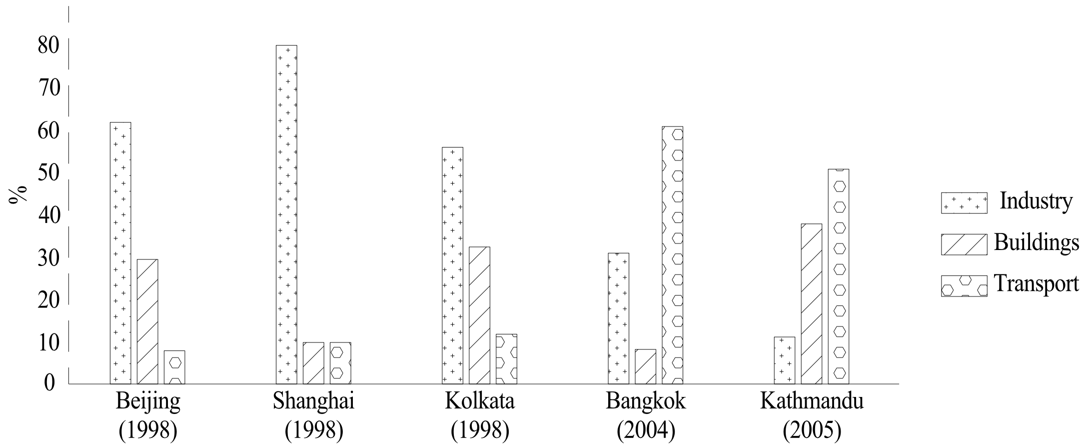

Figure 1.4 Energy consumption in selected Asian cities [56]

Cities in the developing world show different energy end-use distribution according to their size and their stage of economic development. In megacities such as Beijing, Shanghai and Kolkata, industries consume more than 50% of total energy uses, reflecting the fast growth of Chinese and Indian economies, while in large cities of countries whose economies are growing at a slower pace, the transport sector consumes more than half of the total energy used [56]. Figure 1.4 shows that in the case of Kathmandu, transport consumes more energy which is followed by buildings and the industry.

According to Troy [21], there are three factors that determine how transportation energy differ from city to city. The first is the way that people get around, also known as a travel mode. The second is how far people have to travel in a given day to get to where they need to go. And, the third is the amount of traffic delay. Changing infrastructure and urban planning can lead to a decrease in car use in dense urban areas, and by doing so reducing health risks to city dwellers [68-71]. With respect to cities and their role in the global arena, according to Creutzig et al. [72], the global urban population consumed around 240 EJ of energy at end use. They expect that by 2050, the total energy consumption of cities could increase to 730 EJ. Hence, as the world continues to urbanize, a significant improvement in the energy efficiency of cities- particularly in megacities and those countries where urbanization processes are expected to be faster- is a crucial first step towards a sustainable future [73].

1.5.2 Influence of Urban Planning on Travel Energy Consumption

Urban design philosophies- new urbanism, transit-oriented development, traditional town planning, has gained popularity in a few decades ago, as ways of shaping travel demand. All these share three common transportation objectives [29]: (1) reduce the number of motorized trips, what has been called trip degeneration; (2) of trips that are produced, increase the share that is non-motorized (i.e. by foot or bicycle); and (3) of the motorized trips that are produced, reduce travel distances and increase vehicle occupancy levels (i.e. encourage shorter trips and more travel by transit, paratransit, and ride-sharing). In recent years a great number of studies, particularly in Western European and North American cities, have concluded that urban form and land use characteristics affect travel choices and are the primary influence on the amount that people drive [74]. According to Owens [22], more than half of the energy demand in the developed world can be assigned to the arrangement of land uses. Land use refers broadly to how we modify or conserve land, as for example in agriculture, industry, housing, transportation, recreation and open space. Today, land use has been recognized as one of the factors in transportation that can help shift transportation choice away from single occupant automobile travel. Recent studies with more advanced perspectives have focused on the combined features of street layout and other built environments to generate variations in walking and cycling [75].

Traditionally, human settlements have developed in mixed-use patterns. Walking was the primary way that people and goods were moved about, sometimes assisted by animals such as horses or cattle. Most people dwelt in buildings that were places of work as well as domestic life, and made things or sold things from their own homes. People lived at very high densities because the amount of space required for daily living and movement between different activities was determined by walkability and the scale of the human body. This was particularly true in cities, and the ground floor of buildings was often devoted to some sort of commercial or productive use, with living space upstairs. So, mixed land use in a neighborhood is important, as it reflects the availability of destinations to which residents can walk or ride bicycles [26]. The research by Christian et al. [76] also showed that different representations of land use diversity impact the association between neighborhood design and specific walking behaviors. Mixed land use, especially the proximity of shopping, work, and other non-residential land use to housing, appears related to greater walking/cycling among residents. There would be less need to go to work, school or shopping centers by car if these facilities were within walking distance [77]. The research by Brian et al. [78] showed that commuting to work by walking/cycling was higher in areas with mixed land use and where commercial facilities existed nearby less than 300 ft or 0.1 km. Breheny [79] also presented planning for more compact cities is one of the most important ways of reducing energy consumption and environmental pollution.

Similarly, many previous studies have demonstrated a strong correlation between urban density and energy consumption. A study by Newman and Kenworthy [80] is the first attempt to explore the connections between density and travel energy consumption. Their research analyzes 32 major cities in four continents, finding a negative correlation between urban density and the annual gasoline use per capita (Figure 1.5). This finding suggests that strong policies which promote the planning and development of more compact cities should be given high priority.

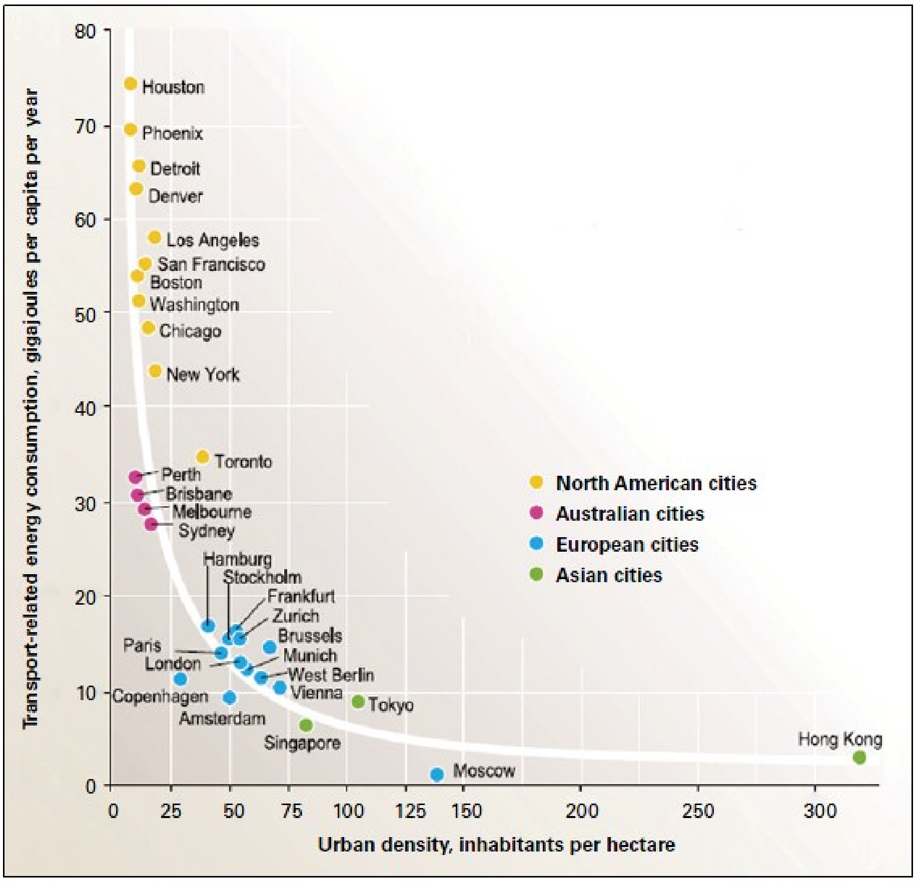

Figure 1.5 Urban density and transport related energy consumption [81]

Similarly, the research by Banister et al. [82] used density as the urban form variable and their result showed that there were significant relations between urban form and energy consumption. Likewise, the study by Susilo and Stead [83] showed that commuters who reside in denser urban areas consume less energy compared to commuters who reside in less urbanized areas which are found similar to the research result by Brownstone and Golob [84]. Whereas, Holden and Norland [85] found that residents living in high-density areas consume more energy for long-distance travel. Karathodorou et al. [86] found that increasing urban density by 10% reduces fuel consumption per capita by 3.4%, car ownership by 1.2% and the annual distance driven by car by 2.3%. Cervero [87] concluded that neighborhood densities had a stronger influence than mixed land uses on all commuting mode-choices, except for walking and bicycling. The US cities consume 3.6 times much transport energy per capita than European cities [88]. On average, when comparing 10 major cities in the US with 12 European cities, European cities are five times as dense. So the result concludes that dense cities are low energy cities. However, an analysis of density is not sufficient to explain the relationship between urban form and travel energy consumption. In particular, factors such as the relative location of residents, workplaces, services and amenities, transport options and network connectivity have a significant impact on the number and length of trips.

Therefore, Van de Coevering and Schwanen [89], Stead [90] and Kitamura et al. [91] had different conclusions that urban density is not the main factor for travel energy consumption. Their conclusions are satisfied with some studies that revealed the impact of density on travel is negligible [33]. The research using only density as a characteristic of urban form is less conclusive in establishing the relationships between the urban form and travel energy consumption. Apart from these arguments, the most important point is that urban form does not have a direct effect on travel energy consumption [34]. It means that urban form affects travel energy consumption through other intermediate variables such as mode choice and travel distance. In the case of mode choice, travel energy consumption varies greatly for different travel modes; energy consumption for cars is 1.08 tons of standard coal, which is 12 times that of rail transit and 5 times that of buses [92]. Whereas, in the case of travel distance, as the distance from the residence to the city center lengthens, individual travel energy consumption increases [93,94].

1.5.3 Influence of Transportation on Travel Energy Consumption

Some 27% of all global energy consumption is caused by transportation of goods and people [95]. At the regional and local level, urban structures such as the location of services and working places relative to residential areas influence transportation needs and energy consumption. Transportation networks determine how people travel between land uses. According to Liu [96], directed transportation networks can control density and growth and consequently divert automobile-dependent city to walkable city. In such a case, reduction in travel energy consumption is possible as higher transit accessibility (availability of public transport mode) is associated with longer travel distance. According to Naess [97], transportation sector can promote energy efficiency in three basic ways: (1) by reducing the movement of people and goods; (2) by transferring from energy demanding to more energy efficient means of transportation (for instance from private cars to public transport); and (3) by making the different means of transportation more energy efficient (through improved vehicle technology, a higher capacity utilization, better traffic flow, a “softer” way of driving etc.).

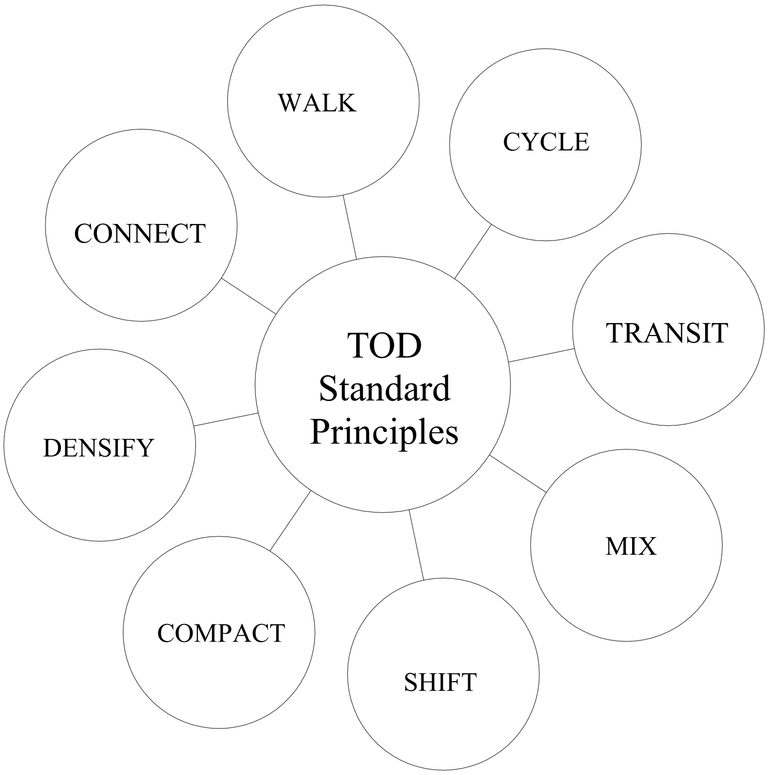

Figure 1.6 Transit-oriented development (TOD) standard principles

A great number of studies have concluded that sustainable transportation system like transit-oriented development (TOD), bus rapid transit (BRT) and bicycle sharing system can promote compact, transit and pedestrian friendly development; provides more urban benefits including reduction of auto dependency and energy usage. TOD include a mix of residential, office and retail uses, as well as higher densities closer to the station, to facilitate transit ridership. In particular, high density neighborhoods are correlated with fewer auto trips than their lower density counterparts [98]. Thus, previous studies have shown that TOD can create built forms that are energy efficient and reduce transport energy use [99]. According to Cervero and Kockelman [29], elements of TOD that lead to these results include density, diversity of uses, and pedestrian-friendly urban design. ITDP came up with 8 principles (Walk, cycle, connect, transit, mix, densify, compact and shift) as shown in Figure 1.5, to inform the TOD standard, a guide and tool to help shape and assess urban development [100].

Bus rapid transit (BRT) is understood as a system that emphasizes priority and rapid movement of buses by securing segregated busways, that differs from local bus service. The research by Hossain and Kennedy [101] showed that implementing a BRT system results in significant improvements in energy efficiency for the urban road corridor. According to their research, it reduces the total fuel consumption in the corridor by 24 percent in 2010 and estimated about 36 percent (Lane extension case) to 40 percent (Non-lane extension case) in 2020.

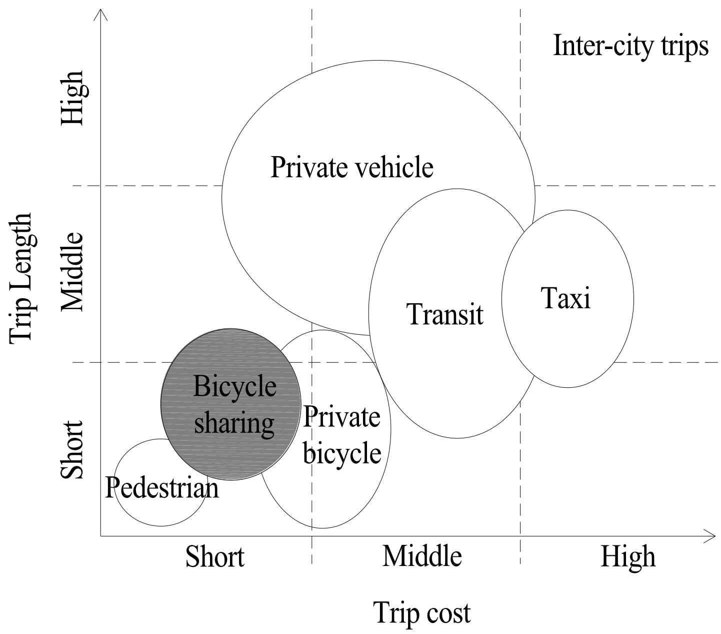

Figure 1.7 The role of bicycle sharing systems in urban mobility [103]

The principle of bicycle-sharing is simple: individuals use bicycles on “as-needed” basis without the costs and responsibilities of bicycle ownership. The bicycle-sharing system promotes the viability of public transport by providing an “extension service” for the “first/last mile” - the distance which many consider to be too far to walk between home and public transport and/or public transport and the workplace [102]. Although travel distance by mode varies from country to country and city to city, most people are willing to walk up to 10 minutes. Cycling distances generally fall within the 1km to 5km range. Bicycle sharing can, therefore, fill an important niche in the urban transportation system in terms of trip length and costs as shown in Figure 1.7 [103]. On the basis of the other literature, the threshold distance for bicycling is about 2.5 miles (0.8km) [104,105].

Global energy use in the transport sector is forecast to increase on average by 1.6% annually up to 2030 unless significant policy action is taken [106]. According to Lefevre [107], a policy integrating transportation and urban planning can significantly lower the trajectories of energy consumption associated with urban transportation. An important policy goal in transport energy efficiency is to shift passengers from roads to more sustainable modes of transport such as walk, bicycles and public transport. But without quality public transport, densification is not possible; and without quality and densification, public transport is not sustainable [108]. There have been many studies documenting the impact that policies can have on increasing public transport usage [109-111]. Also, the policy can influence consumers' vehicle purchasing behavior occurred when fuel economy and CO_2 emissions labels were combined with fiscal incentives, as was done in the Netherlands and the United Kingdom [112]. According to Henning et al., affordability is one of the primary drivers of public transport patronage in transition and developing countries [113]. In the study conducted in 25 megacities [64], parking policy is commonly viewed as a complementary measure to reduce car use when combined with other initiatives. As an example, in the city of Munich, the parking policy has reduced car use by 14%, bicycle use increased with 75% and walking by 61% [114].

1.5.4 Recent Approaches to Energy Efficient Planning in Cities and neighborhood

1.5.4.1 Integrated Land Use-Transport

There is a mutual relationship between transportation and land use. For instance, land uses affect travel demand, while transportation networks have a prominent impact on the patterns of land use [115-117]. Therefore, transportation and land use should be considered in relation to one another, as a way of efficiently addressing urban planning from the perspective of sustainable development [63,118,119]. Several models have been developed to accomplish sustainable urban planning in cities. Among these sustainable models, transit-oriented development (TOD) has proven to be quite successful [119-121]. Various definitions have been offered for the TOD concept [122]. There are, however, some common elements to all of them, such as a compact mixed-use development pattern, pedestrian-friendliness, being close to public transit services, and being well-served by these services [123-126]. Additionally, the TOD concept uses several scales, which show its multi-scale character [127,128]. The results of the TOD planning help decision-makers in land use and transportation planning. For instance, by using TOD levels, TOD planning can be used to determine high potential neighborhoods for developing public transit services [119].

1.5.4.2 Improving Infrastructure and Urban Services

Planning to promote energy efficiency in cities is highly related to infrastructure and urban services. For the walkable neighborhood, it should build an infrastructure that makes people easy to walk, cycling and make glad to get out of their automobiles and enjoy the fresh air as urban form has direct effects on travel behavior [96]. Both international and Finnish experiences show that the popularity of walking and cycling depends on the ease and practicality of undertaking daily journeys [129]. Also, a pleasant urban environment is even more significant for pedestrians. The key measures for promoting walking and cycling include: Building an attractive environment for pedestrian traffic and introducing traffic calming measures for motor vehicles; improving the quality of cycling routes and adding the missing route links on the basis of short distances and mixed functions; providing appropriate bicycle stands and similar facilities; and ensuring proper maintenance of pavements and bicycle paths [129]. In Germans, there is an increasing number of "bicycle streets," where cars are permitted but cyclists have strict right-of-way over the entire breadth of the roadway [130]. Despite its importance, non-motorized transport policy [131,132] and its related infrastructure are often neglected in policy-making in developing cities. Among the different tools promoted to reduce road transport energy consumption, improvement of public bus systems is commonly recognized as a cost-effective option that can be implemented [133]. Similarly, high quality bus rapid transit (BRT) systems are found as effective as rail-based systems [134].

1.5.4.3 Applying Sustainability Framework

Sustainability Framework, such as Eco-city, the American LEED for Neighborhood Development, the Living Building Challenge (LBC), the British BREEAM for Communities and the Japanese CASBEE for Urban Development are already being used for the certification and benchmarking of urban areas. Sustainable communities are promoted as a desirable policy goal and local authorities are encouraged to contribute to, in particular, climate change mitigation through urban planning [54,135]. Unless achieving a reduction in travel energy consumption, urban areas cannot achieve environmental sustainability. Urban planners often appear to struggle with the issue of how to promote area-specific urban environmental quality through municipal land use planning [136,137].

Basically, a sustainability framework is based on the elements of smart growth and new urbanism, producing a rating system that values compact, connected neighborhoods located near existing developed areas and infrastructure. For instance, an eco-city provides the majority of its residents with walkable access from housing to basic urban services and transit access to close by employment options. Similarly, LEED-ND (LEED for Neighborhood Development) encourage development within established communities and near public transit. LEED-ND defines the location of the project within a ¼ mile walking distance from building's entrance to a bus stop or rail station or within ½ mile walking distance of at least six diverse land uses. This criteria promotes transit-oriented development (TOD). In this way, applying Sustainability Framework would be expected to reduce automobiles, promote higher walk, bicycle and transit use.

1.5.5 "5Ds" Framework

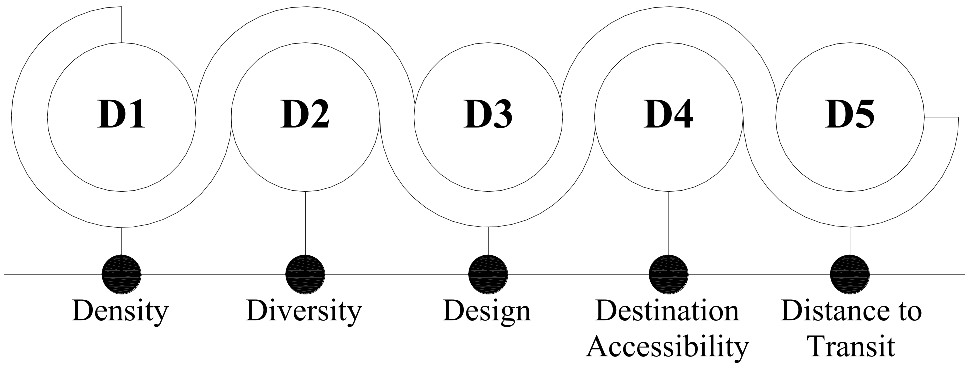

Figure 1.8 5Ds Framework

The research using only one or limited variables as a characteristic of urban form is less conclusive in establishing the relationships between the urban form and travel energy consumption. The influence of the energy system on a spatial structure is complex and involves a large number of variables; it is difficult to envisage how energy system changes might influence the way in which settlement structures evolve [22]. The previous studies examine either the connections of urban form and travel energy consumption [30,82,83] or connections of urban form and travel mode choice

[138-141] considering only single or limited measures of urban form in an isolated way and do not represent the reality.

Therefore, this study attempts to include a multiple of urban form measures to understand the relationships between urban form, travel behavior and travel energy consumption in an integrated way. Many different measures are available to characterize urban form; it is logical to follow the standard framework instead of a random selection. Therefore, we applied the “5Ds” framework, which is accepted as a standard method and extensively used to characterize land-use characteristics at the micro-scale in travel behavior research [142-144]. Furthermore, this dissertation intends to analyze the entire city of Fukuoka at the micro-scale based on 108 zones and in the case of Kathmandu based on 35 wards. So, the “5Ds” framework is ideally suited for measuring all aspects of urban form that effect on travel behavior. The “5Ds” framework includes five dimensions of urban form: density, diversity, design, destination accessibility and distance to transit. Cervero and Kockelman [29] first introduced the “3Ds”- density, diversity and design as measures of the urban form that influence travel. Later, two more “Ds” were developed - destination accessibility and distance to transit [32]. All the Ds are described below.

1.5.5.1 Density (D1)

Density is always measured as the variable of interest per unit of area. In political discussion, the term urban density is often taken to roughly represent an appropriate combination of the more specific indicators for urban form [145]. The area can be gross or net and the variable of interest can be population, dwelling units, employment or building floor area. Population and employment are sometimes summed to compute an overall activity density per area unit. Higher density means that more people live in a specific neighborhood. High-density areas have the potential to incorporate walking, cycling, a lively community, and an optimum usage of public transit. Therefore, developing high-density areas is necessary for TOD planning [121]. Dense neighborhoods tend to be safer due to more “eyes on the street” and more accessible services [146].

1.5.5.2 Diversity (D2)

Diversity is a prominent indicator in urban planning for determining the level of heterogeneity of land uses. Diversity measures pertain to the number of different land uses in a given area and the degree to which they are represented in land area, floor area, or employment. Different land uses in an area will support the various requirements of the relevant inhabitants, ensuring a lively and friendly community. Additionally, this indicator has a pivotal effect on trips modalities. For instance, a decrement of this indicator causes people to use private cars to meet their requirements. On the other hand, an increment of this indicator means that there will be more walking and cycling in the community. Therefore, a mix of residential, commercial, office and other spaces is positively correlated with walking and cycling, as the local diversity of daily destinations promotes walking between destinations and lower automobile use [147,148]. Cervero and Kockelman [29] believe that diversity can be used as an indicator for trip generation. Additionally, Ewing and Cervero [32] investigated the effects of the diversity factor on walking and the use of public transit. There are different approaches to measure diversity, such as entropy, Herfindahl–Hirschman Index, and the jobs-to-housing ratio and jobs-to-population ratios.

1.5.5.3 Design (D3)

Design includes street network characteristics within an area. Design measures include average block size, proportion of four way intersections and number of intersections per square mile. Design is also occasionally measured as sidewalk coverage (share of block faces with sidewalks); average building setbacks; average street widths; or numbers of pedestrian crossings, street trees, or other physical variables that differentiate pedestrian-oriented environments from auto-oriented ones [149]. Design components comprise features such as street environments, amenity, safety, and street density. Among street features, the density of street connections used as a proxy for street block size increases the propensity for walking [150]. Many studies have found that higher street density and well linked networks are positively associated with walking choices [151,152]. Since local features of street networks alter the link between street design and pedestrian volume, the street density, connectivity, and block size of given areas have been used to explain and predict variations in walking behavior [153-155]. Also, in Ewing and Cervero's [33] meta-analysis, street intersection density and street connectivity were found to be almost as influential as distance to downtown or employment concentrations on the number of vehicle kilometers traveled. Design schemes can not only make destinations more accessible and conveniently reached by foot (as with siting store entrances near curbsides and parking in the rear), but can also reward pedestrians, cyclists, and transit riders with amenities (like shade trees and civic squares).

1.5.5.4 Destination Accessibility (D4)

Destination accessibility measures ease of access to trip attractions. It may be regional or local [156]. In some studies, regional accessibility is simply distance to the central business district (CBD). In others, it is the number of jobs or other attractions reachable within a given travel time, which tends to be highest at central locations and lowest at peripheral ones. The gravity model of trip attraction measures destination accessibility. Local accessibility is different, defined by Handy [156] as distance from home to the closest store. Furthermore, easy access to the CBD meant opportunities to reach places one wants to go like to work, retail stores, entertainment facilities and decreases car use and increases the propensity to walk [157].

1.5.5.5 Distance to Transit (D5)

Distance to transit is usually measured as an average of the shortest street routes from the residences or workplaces in an area to the nearest rail station or bus stop. Alternatively, it may be measured as bus stop density [158], rail density [159], distance to the nearest bus stop [91] and distance to nearest rail station [160]. The increased access to public transit creates a favorable urban setting that increases walking volume [161,162]. In terms of public transit, access to bus stops is more associated with pedestrian volume than access to metro stations, because pedestrians tend to gather near bus-stops to transfer to metro transit [163,91].

References

[1] International Energy Outlook 2016. Available online: http://www.eia.gov/forecasts/ieo (accessed on 07 November 2017).

[2] Rodrigue, J.; Comtois, C.; Slack, B. The geography of transport systems. London: Routledge. 2005, ISBN 978-1138669574

[3] Naess, P. Urban form and travel behavior: Experience from a Nordic context. Journal of Transport and Land Use, 2012, 5(2), 21-45. DOI: 10.5198/jtlu.v5i2.314

[4] Ng, S.; Lau, W.; Brown, F.; Tam, E.; Lao, M.; Booth, V. Walkable City, Living Streets. [online] Hong Kong: Civic Exchange. 2012, Available online: http://civic-exchange.org/wp-content/uploads/2016/01/20121031URBAN_Walkability_en-1.pdf [Accessed 16 Apr. 2018].

[5] Energy Information Administration (EIA). Annual Energy Outlook 2007. Washington D.C: U.S. Department of Energy.

[6] Xue, X.; Ren, Y.; Cui, S.; Lin, J.; Huang, W.; Zhou, J. Integrated analysis of GHGs and public health damage mitigation for developing urban road transportation strategies. Transportation Research Part D: Transport and Environment. 2015, 35, pp.84-103.

[7] World Bank, Washington, DC. Urban air quality management strategy in Asia: Kathmandu Valley Report. In: Shah, J.J., Nagpal, T. (Eds.), 1997a, Technical Paper No. 378.

[8] World Bank, Washington, DC. Urban air quality management strategy in Asia: Greater Mumbai Report. In: Shah, J.J., Nagpal, T. (Eds.), 1997b, Technical Paper No. 381.

[9] World Bank, Washington, DC. Urban air quality management strategy in Asia: Jakarta report. In: Shah, J.J., Nagpal, T. (Eds.), 1997c, Technical Paper No. 379.

[10] World Bank, Washington, DC. Urban air quality management strategy in Asia: Metro Manila Report. In: Shah, J.J., Nagpal, T. (Eds.), WB, 1997d, Technical Paper no. 380.

[11] R.K. Bose; Srinivasachary V. Policies to reduce energy use and environmental emissions in transport sector: A case of Delhi city Energy Policy, 25 (14/15) 1997, pp. 1137-1150

[12] World Bank; ESMAP. Formulating an Urban Transport Policy: Choosing between Options. Written by O.P. Agarwal, Gouthami Padam, and Cholpon Ibraimova. Washington, DC: Energy Sector Management Assistance Program, 2014, The World Bank.

[13] Stead, D. Effectiveness and Acceptability of Urban Transport Policies in Europe. Int. J. Sustain. Transp. 2008, 2, 3–18.

[14] Vlek, C. Essential Psychology for Environmental Policy Making. Int. J. Psychol. 2000, 35, 153–167.

[15] Diekstra, R.; Kroon, M. Cars and Behavior: Psychological Barriers to Car Restraint and Sustainable Urban Transport. In The Greening of Urban Transport; Tolley, R., Ed.; Wiley & Sons: Sussex, UK, 1997, pp. 147–157.

[16] Romanos, M.; Prastacos, P.; Hatmaker, M. Transportation Energy Effect on Urban Growth: Results of Simulations. Transp. Res. Rec. 1974, 480, 60–70.

[17] Cervero, R.; Murakami, J. Effects of Built Environments on Vehicle Miles Traveled: Evidence from 370 US Urbanized Areas. Environ. Plan. A 2010, 42, 400–418.

[18] Ewing, R.; Bartholomew, K.; Winkelman, S.; Walters, J.; Chen, D. Growing Cooler: The Evidence on Urban Development and Climate Change; Urban Land Institute: Washington, DC, USA, 2008; ISBN 978-0-87420-082-9.

[19] Litman, T. Efficient vehicles versus efficient transportation. Comparing transportation energy conservation strategies. Transp. Policy 2005, 12, 121–129.

[20] Achieving energy efficiency through behavior change: What does it take? EEA Technical report, 2013, EEA.

[21] Troy, A. The Very Hungry City: Urban Energy Efficiency and the Economic Fate of Cities; Yale University Press: New Haven, CT, USA; London, UK, 2012, ISBN 978-0-300-19835-5.
[22] Owens, S. Land-use planning for energy efficiency. Applied Energy, 1992, 43(1-3), pp.81-114.
[23] Hong, J.; Shen, Q.; Zhang, L. How do built environment factors affect travel behavior? A spatial analysis at different geographic scales. Transp. J. 2014, 41, 419–440.
[24] Bose, S. N. The Imperative of Efficient Energy Use in Cities: Analytical Approaches and Good Practices. In R. K. Bose, Energy Efficient Cities: Assessment Tools and Benchmarking Practices 2010, (p. 250). Washington DC, The World Bank.
[25] Congress for the New Urbanism; Talen, E. Charter of the New Urbanism, 2nd ed.; McGraw-Hill Education: New York, NY, USA, 2013, ISBN 978-0071806077.
[26] Duncan, M. J.; Winkler, E.; Sugiyama, T.; Cerin, E.; Dutoit, L.; Leslie, E.; Owen, N. Relationships of Land Use Mix with Walking for Transport: Do Land Uses and Geographical Scale Matter? Journal of Urban Health, 2010, 87(5), 782-795
[27] Duany, A.; Speck, J.; Lydon, M. The Smart Growth Manual, 1st ed.; McGraw-Hill Education: New York, NY, USA, 2009, ISBN 9780071376754.
[28] Crane, R. The influence of urban form on travel: An interpretive review. J. Plan. Lit. 2000, 15, 3–23.
[29] Cervero, R.; Kockelman, K. Travel demand and the 3Ds: Density, Diversity and Design. Transp. Res. D 1997, 2, 199–219.
[30] Newman,W.G.; Kenworthy, J.R. Gasoline consumption and cities. J. Am. Plan. Assoc. 1989, 55, 24–25.
[31] Boarnet, M.G. A broader context for land use and travel behavior, and a research agenda. J. Am. Plan. Assoc. 2011, 77, 197–213.
[32] Ewing, R.; Cervero, R. Travel and the built environment: A synthesis. Transp. Res. Rec. Transp. Res. Board 2001, 1780, 87–114.
[33] Ewing, R.; Cervero, R. Travel and the built environment: A meta-analysis. J. Am. Plan. Assoc. 2010, 76, 265–294.
[34] Liu, C.; Shen, Q. An empirical analysis of the influence of urban form on household travel and energy consumption. Comput. Environ. Urban Syst. 2011, 35, 347–357.
[35] National Population and Housing Census 2011. Government of Nepal, Central Bureau of Statistics, 2012 Kathmandu, Nepal. https://unstats.un.org/unsd/demographic-social/census/documents/Nepal/Nepal-Census-2011-Vol1.pdf (accessed on 6 February, 2016).
[36] Water and Energy Commission Secretariat (WECS), Energy Sector Synopsis Report. Government of Nepal, 2010. (accessed on 19 July 2012) < http://www. wecs.gov.np/pdf/snyopsis.pdf >.
[37] Government of Nepal, Ministry of Finance (MoF), Economic Survey, Table 10, Vol. 1; 2010/11. (accessed on 23 August 2012), http://www.mof.gov.np/uploads/document/file/english_full_20130715042623.pdf.
[38] Government of Nepal, Ministry of Commerce and Supplies, Trade and Export Promotion Center, Foreign Trade Statistics of Nepal, Comparison of total imports of some major commodities in the first ten months of the Fiscal Year 2012/13 and 2013/14. (accessed on 20 December 2014). http://www.tepc.gov.np/news-events/details.php?id=26.
[39] The World Bank website: http://www.worldbank.org/en/news/feature/2013/04/01/managing-nepals-urban-transition (accessed on 20 May 2018).
[40] Ministry of Physical Infrastructure and Transport, Department of Transport Management, Government of Nepal, Registration of Transport in Bagmati, Fiscal Year 2046/47-070/71 office wise.

https://www.dotm.gov.np/uploads/files/transport_registration_fiscal_year_2046_47_070_71_typewise.pdf (accessed on 12 February 2018)
[41] DoTM, Vehicle registration statistics, Department of Transport Management, Government of Nepal, Kathmandu, http://www.dotm.gov.np/uploads/files/Details _of_Registration _of_Tr anspor t_Ty peWise -up _to_2070_71.pdf (accessed on13 October 2016)
[42] Shrestha, R.M.; and S. Malla. "Air Pollution from Energy Uses in a Developing Country City: The Case of Kathmandu Valley Nepal." Energy 1996, 21: 785–794.
[43] Dhakal, S. Implications of transportation policies on energy and environment in Kathmandu Valley, Nepal, Energy Policy 2003, 31(14), 1493-1507.
[44] Devkota, S.R. "Ambient Air Quality Monitoring in Kathmandu Valley." Report prepared by the Kathmandu Valley Vehicular Emission Control Programme, United Nations Development Programme, Kathmandu. 1993.
[45] LEADERS (Society for Legal and Environmental Analysis and Development Research). "A Comparative Study of Air Pollution in Three Major Cities of Nepal." Kathmandu. 1999.
[46] AITD. Energy—transport nexus: strategy towards sustainability. Asian Institute of Transport Development. 2002.
[47] Leather, J.; Fabian, H.; Gota, S.; Mejia A. Walkability and Pedestrian Facilities in Asian Cities- Status and Issues. Asian Development Bank 2011.
[48] MoPIT/JICA: Final Report- Data Collection Survey on Traffic Improvement in Kathmandu Valley, Ministry of Physical Infrastructure and Transport. 2012.
[49] Ding, C.; Wang, Y.; Xie, B.; & Liu, C. Understanding the Role of Built Environment in Reducing Vehicle Miles Traveled Accounting for Spatial Heterogeneity. Sustainability, 2014, 6(2), 589-601. doi:10.3390/su6020589
[50] Anable, J. Complacent car addicts' or aspiring environmentalists? Identifying travel behavior segments using attitude theory. Transp. Policy 2005, 12, 65–78.
[51] Yang, R.; Long, R.; Bai, Y.; Li, L. The influence of household heterogeneity factors on the green travel behavior of urban residents in the East China region. Sustainability 2017, 9, 237.
[52] IEA (International Energy Agency)World Energy Outlook 2008 OECD/IEA, Paris 2008.
[53] Seto, K.C.; Dhakal, S.; Bigio, A.; Blanco, H.; Delgado, G.C.; Dewar, D.; Huang, L.; Inaba, A.; Kansal, A.; Lwasa, S.; McMahon, J.E.; Müller, D.B.; Murakami, J.; Nagendra, H.; Ramaswami, A. Human Settlements, Infrastructure and Spatial Planning. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014. https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter12.pdf (accessed on 29 May 2018)
[54] Bulkeley, H.; Betsill, M. Rethinking Sustainable Cities: Multilevel Governance and the Urban Politics of Climate Change. Environ. Politics 2005, 14, 42–63.
[55] Shane, A.M.; Graedel, T.E. Urban environmental sustainability metrics: A provisional set. J. Environ. Plan. Manag. 2000, 43, 643–663.
[56] UN-Habitat. STATE OF THE WORLD'S CITIES 2008-2009: HARMONIOUS CITIES. https://sustainabledevelopment.un.org/content/documents/11192562_alt-1.pdf (accessed on 20 November, 2016)
[57] Bertolini, L.; Le Clercq, F.; Kapoen, L. Sustainable accessibility: A conceptual framework to integrate transport and land use plan-making. Two test-applications in The Netherlands and a reflection on the way forward. Transp. Policy 2005, 12, 207–220.
[58] Chawla, L. Growing Up in an Urbanizing World; Routledge: New York, NY, USA, 2016.

[59] Sung, H.; Oh, J.-T. Transit-oriented development in a high-density city: Identifying its association with transit ridership in Seoul, Korea. Cities 2011, 28, 70–82.
[60] Shirzadi Babakan, A.; Alimohammadi, A.; Taleai, M. An agent-based evaluation of impacts of transport developments on the modal shift in Tehran, Iran. J. Dev. Eff. 2015, 7, 230–251.
[61] Singh, Y.; Zuidgeest, M.; Flacke, J.; van Maarseveen, M. A design framework for measuring transit oriented development. WIT Trans. Built Environ. 2012, 128, 719–730.
[62] Evans, I.; Pratt, R.H.; Stryker, A.; Kuzmyak, J.R. Transit-Oriented Development—Traveler Response to Transportation System Changes; Transportation Research Board: Washington, DC, USA, 2007.
[63] Babakan, A.S.; Taleai, M. Impacts of transport development on residence choice of renter households: An agent-based evaluation. Habitat Int. 2015, 49, 275–285.
[64] GlobeScan; MRC McLean Hazel. "Megacity Challenges: A stakeholder perspective," Siemens AG, Munich, 2007.
[65] Khalil, H. Energy Efficiency Strategies in Urban Planning of Cites. 7th International Energy Conversion Engineering Conference. 2009.
[66] Girardet, H. Cities People Planet: Urban Development and Climate Change
(second edition), John Wiley & Sons Ltd., England 2008
[67] Beatley, T. Green Urbanism: Learning from European Cities. Island Press, Washington DC. 2000.
[68] Jackson, L. The relationship of urban design to human health and condition Landscape Urban Plann., 64 (4) (2003), pp. 191-200
[69] Heath, G.W.; Brownson, R.C.; Kruger, J.; Miles, R.; Powell, E.K.; Ramsey, L.T. The effectiveness of urban design and land use and transport policies and practices to increase physical activity: a systematic review. J. Phys. Act. Health, 2006, 3 (1) pp. S55-S76
[70] Hartogm J.J. de; Boogaard, H.; Nijland, H.; HoekDo, G. The health benefits of cycling outweight the risks? Environ. Health Perspect. 2010, 118 (8) pp. 1109-1116
[71] Tight; Timms, P.; Banister, D.; Bowmaker, J.; Copas, J.; Day, A.; Drinkwater, D.; Givoni, M.; Gühnemann, A.; Lawler, M.; Macmillen, J.; Miles, A.; Moore, N.; Newton, R.; Ngoduy, D.; Ormerod, M.; Ósullivan, M.; Watling, D. Visions for a walking and cycling focused urban transport system. J. Transp. Geogr., 2011, 19 (6), pp. 1580-1589
[72] Creutzig, F.; Baiocchi, G.; Bierkandt, R.; Pichler, P.P.; SetoGlobal, K.C. Typology of urban energy use an potentials for an urbanization mitigation wedge. Proc. Natl. Acad. Sci. U. S. A., 2015, 112 (20), pp. 6283-6288
[73] Kennedy, C.A.; Stewart, I.; Acchini, A.; Cersosimo, I.; Mele, R.; Chen, B.; Uda, M.; Kansal, A.; Chiu, A.; Kwi-gon, K.; Dubeux, C.; Lebre La Rovere, E.; Cunha, B.; Pincetl, S.; Keirstead, J.; Barles S.; Pusaka S.; Gunawan J.; Adegbile M.; Nazariha M.; Hoque S.; Marcotullio, P.J.; González Otharán, F.; Genena, T.; Ibrahim, N.; Farooqui, R.; Cervantes, G. A. Duran Sahin Energy and material flows of megacities. Proc. Natl. Acad. Sci., 2015, 112, pp. 5985-5990
[74] Inturri, G.; Ignaccolo, M. SPECIAL Expert Paper 3: Making the Connection – Energy,Transport and Urban Planning. An Integrated Approach to Improving the Energy Efficiency in Transport Systems. Town and Country Planning Association, 2 March 2016.http://www.ectp-ceu.eu/images/stories/PDF-docs/TCPA_SPECIAL_ExpertP_Giuseppe%20Inturri%20and%20Matteo%20Ignaccolo.pdf (accessed on 12 September 2018)
[75] Vale, D. S.; Saraiva, M.; Pereira, M.; Active accessibility: A review of operational measures of walking and cycling accessibility. Journal of Transport and Land Use. 2015, doi:10.5198/jtlu.2015.593

[76] Christian, H. E.; Bull, F. C.; Middleton, N. J.; Knuiman, M. W.; Divitini, M. L.; Hooper P.; Giles-Corti, B. How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. International Journal of Behavioral Nutrition and Physical Activity, 2011, 8(1), 55. doi:10.1186/1479-5868-8-55
[77] Wachter, P.; Ornetzeder, M.; Rohracher, H.; Schreuer, A.; Knoflacher, M. Towards a sustainable spatial organization of the energy system: Backcasting experiences from austria. Sustainability 2012, 4, 193–209.
[78] Brian E. Saelens; James F. Sallis; Lawrence D. Frank. Environmental Correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures. Annals of Behavioral Medicine, 2003, Volume 25, 2 Number 2003.
[79] Breheny, M. The Compact City and Transport Energy Consumption. Transactions of the Institute of British Geographers, 1995, 20(1), 81. doi:10.2307/622726
[80] Newman,W.G.; Kenworthy, J.R. Cities and Automobile Dependence: An International Sourcebook Avebury Technical, Great Britain, 1989.
[81] J.R. Kenworthy; F.B. Laube: 'Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy'. Transportation Research Part A, 1999,Vol. 33, 691-723. [Retrieved from; http://www.ectp-ceu.eu/images/stories/PDF-docs/TCPA_SPECIAL_ExpertP_Giuseppe%20Inturri%20and%20Matteo%20Ignaccolo.pdf]
[82] Banister, D.; Watson, S.; Wood, C. Sustainable Cities: Transport, Energy, and Urban Form. Environ. Plan. B Plan. Des. 1997, 24, 125–143.
[83] Susilo, Y.O.; Stead, D. Urban form and the trends of transportation emissions and energy consumption of commuters in the Netherlands. In Proceedings of the 87th Annual Meeting of the Transportation Research Board,Washington, DC, USA, 13–17 January 2008.
[84] Brownstone, D.; Golob, T.F. The impact of residential density on vehicle usage and energy consumption. J. Urban Econ. 2009, 65, 91–98.
[85] Holden, E.; Norland, I.T. Three challenges for the compact city as a sustainable urban form: Household consumption of energy and transport in eight residential areas in the greater Oslo region. Urban Stud. 2005, 42, 2145–2166.
[86] Karathodorou, N.; Graham, D.J.; Noland, R.B. 'Estimating the effect of urban density on fuel demand'. Energy Economics, 2010, Vol. 32 (1), 86-92
[87] Cevero, R.; Mixed land-uses and commuting: evidence from the American housing survey. Transportation Research, 1996, A 30 (5), 361-377.
[88] Marechal, K. An Evolutionary Perspective on the Economics of Energy Consumption: The Crucial Role of Habits. Journal of Economic Issues, 2009, 43(1), 69-88. doi:10.2753/jei0021-3624430104
[89] Van de Coevering, P.; Schwanen, T. Re-evaluating the Impact of Urban Form on Travel Patterns in Europe and North-America. Transp. Policy 2006, 13, 229–239.
[90] Stead, D. Relationships between land use, socioeconomic factors, and travel patterns in Britain. Environ. Plan. B Plan. Des. 2001, 28, 499–528.
[91] Kitamura, R.; Mokhtarian, P.L.; Laudet, L. A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. Transp. J. 1997, 24, 125–158.
[92] Wang, B.; Shao, C.; Ji, X. Influencing Mechanism Analysis of Holiday Activity-Travel Patterns on Transportation Energy Consumption and Emission in China. Energies 2017, 10, 897.
[93] Jiang, Y.; Zegras, P.C.; He, D.; Mao, Q. Does energy follow form? The case of household travel in Jinan, China. Mitig. Adapt. Strateg. Glob. Chang. 2015, 20, 701–718.
[94] Naess, P. Residential location, Travel, and Energy Use: In the Hangzhou metropolitan area. J. Transp. Land Use 2010, 3, 27–59.

[95] Ahonen Anna-Maija; David Thomas; Dorfner Johannes; Nagy Zsofia; Nuorkivi Arto; Peters Christoph; Schönsteiner Karl; Vautz Sarah; Wiltshire Robin; Zold Andras. Making Cities Energy Efficient: Urban and Regional Planning Adopting RES. Publication. Helsinki: Aalto University, 2013.
[96] Liu, C. Exploring The Influence Of Urban Form On Travel And Energy Consumption, Using Structural Equation Modeling. PhD thesis,University of Maryland,School of Architecture,Planning, and Preservation, Department of Urban Studies and Planning. 2012, https://drum.lib.umd.edu/handle/1903/12714 (accessed on 6 March 2013)
[97] Naess, P. Transportation and Urban Planning. Description of a research program at Aalborg University. Aalborg: Aalborg University 1999.
[98] Forkenbrock, D. Transportation Investments and Urban Form. Transportation Research Record: Journal of the Transportation Research Board, 2002, 1805, 153-160. doi:10.3141/1805-17
[99] Burchell, R.; Shad, N.; Listokin, D.; Phillips, H.; Downs, A.; Seskin, S.; Davis, J.; Moore, T.; Helton, D.; Gall, M. The Cost of Sprawl—Revisited; Report No. 39; Transit Cooperative Research Program, Transportation Research Board, National Research Council, National Academy Press: Washington, DC, USA, 1998. Available online: http://onlinepubs.trb.org/onlinepubs/tcrp/ tcrp_rpt_39-a.pdf (accessed 30 January 2013).
[100] TOD Standards. 3rd ed. New York: ITDP, 2017 (https://3gozaa3xxbpb499ejp30lxc8-wpengine.netdna-ssl.com/wp-content/uploads/2017/06/TOD_printable.pdf) (Accessed on 04 September 2018)
[101] Hossain, M.; Kennedy, S. Estimating Energy Savings from Bus Improvement Options in Urban Corridors. Journal of Public Transportation, 2008, 11(3), 19-40. doi:10.5038/2375-0901.11.3.2
[102] Shaheen; Susan.; Guzman, S.; Zhang, H. Bikesharing in Europe, the Americas, an Asia: Past, Present, and Future. Washington D.C.: Transportation Research Board Annual Meeting, 2010.
[103] Quay Communications Inc. TransLink Public Bike System Feasibility Study. Vancouver, 2008.
[104] Daddio, D. W. Maximizing Bicycle Sharing: An Empirical Analysis of Capital Bikeshare Usage. University of North Carolina at Chapel Hill, 2012.
[105] Witte, A., and P. Dorby. Characteristics of Successful Public Bike Systems. Presented at the Canadian Institute of Transportation Engineers Annual Meeting, Montreal, Quebec, Canada, 2009.
[106] IEA 2009a, World Energy Outlook 2009, OECD/IEA, Paris.
[107] Lefevre B. Assessment of integrated 'Transport - Land Use' policies potential to reduce long term energy consumption of urban transportation. A prospective simulation in Bangalore, India. Sweden: N. p., 2009.
[108] Ben-Akiva, M.; Morikawa, T. Comparing Ridership Attraction of Rail and Bus. Transp. Policy 2002, 9, 107–116.
[109] Hensher, D.A. Bus Transport: Economics, Policy and Planning Research in Transportation Economics, p. 507, Elsevier, Oxford, 2007.
[110] Nurdden, A.; R.A.O.K. Rahmat; Ismail A. "Effect of transportation policies on modal shift from private car to public transport in Malaysia", Journal of Applied Sciences, 2007, 7 (7), pp. 1013-1018.
[111] De Witte, A.; Macharis C.; Mairesse O. How persuasive is free public transport?: A survey among commuters in the Brussels Capital Region. Transport Policy, 2008, 15, pp. 216-224.
[112] European Commission (EC) and ADAC Study on the effectiveness of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and

CO2 emissions in respect of the marketing of new passenger cars, 2005. http://ec.europa.eu/environment/air/transport/co2/report/final_report.pdf.
[113] Henning, Theuns; Essakali, Mohammed Dalil; Oh, Jung Eun. A Framework for Urban Transport Benchmarking. World Bank, Washington, DC, 2011. https://openknowledge.worldbank.org/handle/10986/12847 Accessed on April24, 2018
[114] Kodransky, M.; Hermann, G. Europe's Parking U-Turn: From Accommodation to Regulation. ITDP, 2011
[115] Waddell, P.; Ulfarsson, G.F.; Franklin, J.P.; Lobb, J. Incorporating land use in metropolitan transportation planning. Transp. Res. Part A 2007, 41, 382–410.
[116] Yim, K.K.; Wong, S.; Chen, A.; Wong, C.K.; Lam, W.H. A reliability-based land use and transportation optimization model. Transp. Res. Part C 2011, 19, 351–362.
[117] Shirzadi Babakan, A.; Alimohammadi, A. An Agent-Based Simulation of Residential Location Choice of Tenants in Tehran, Iran. Trans. GIS 2016, 20, 101–125.
[118] Cervero, R. Integration of urban transport and urban planning. In The Challenge of Urban Government: Policies and Practices; World Bank Publications: Washington, DC, USA, 2001; pp. 407–427, ISBN 978-0-8213-4738-6.
[119] Singh, Y.J.; Fard, P.; Zuidgeest, M.; Brussel, M.; van Maarseveen, M. Measuring transit oriented development: A spatial multi criteria assessment approach for the city region Arnhem and Nijmegen. J. Transp. Geogr. 2014, 35, 130–143.
[119] Cervero, R. Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects; Transportation Research Board: Washington, DC, USA, 2004; Volume 102.
[120] Cervero, R. Transit-oriented development and land use. In Transportation Technologies for Sustainability; Springer: New York, NY, USA, 2013; pp. 947–958.
[121] Cervero, R.; Dai, D. Brt tod: Leveraging transit oriented development with bus rapid transit investments. Transp. Policy 2014, 36, 127–138.
[122] Nasri, A.; Zhang, L. The analysis of transit-oriented development (TOD) in Washington, DC and baltimore metropolitan areas. Transp. Policy 2014, 32, 172–179.
[123] Calthorpe, P. The Next American Metropolis: Ecology, Community, and the American Dream; Princeton Architectural Press: New York, NY, USA, 1993.
[124] Cervero, R.; Ferrell, C.; Murphy, S. Transit-Oriented Development and Joint Development in the United States: A Literature Review; Transportation Research Board: Washington, DC, USA, 2002.
[125] Belzer, D.; Autler, G. Transit Oriented Development: Moving from Rhetoric to Reality; Brookings Institution Center on Urban and Metropolitan Policy: Washington, DC, USA, 2002.
[126] Parker, T. Statewide Transit-Oriented Development Study: Factors for Success in California; California Department of Transportation (Caltrans): Sacramento, CA, USA, 2002.
[127] Dur, F.; Yigitcanlar, T.; Bunker, J. A spatial-indexing model for measuring neighbourhood-level land-use and transport integration. Environ. Plan. B 2014, 41, 792–812.
[128] Zimbabwe, S.; Anderson, A. Planning for TOD at the Regional Scale: The Big Picture; The Center for Transit-Oriented Development: Washington, DC, USA, 2011.
[129] The National Action Plan for Walking and Cycling 2020. Finnish Transport Agency, Traffic Planning, Helsinki 2012
[130] Pucher, J.; Dijkstra, L. "Making Walking and Cycling Safer: Lessons From Europe," Transportation Quarterly 54, 2000 : 25–50. A version without photos is available as a pdf file at: http://www.vtpi.org/puchertq.pdf. (accessed on 15 December 2002).

[131] Pucher, J.; Dijkstra, L. Promoting Safe Walking and Cycling to Improve Public Health: Lessons From The Netherlands and Germany. Am. J. Public Health 2003, 93, 1509–1516.
[132] Pucher, J.; Buehler, R. Making Cycling Irresistible: Lessons from The Netherlands, Denmark and Germany. Transp. Rev. 2008, 28, 495–528.
[133] Hensher, D. Sustainable public transport systems: Moving towards a value for money and network-based approach and away from blind commitment. Transport Policy, 2007, 14:98–102
[134] Graham, C. The demand performance of bus rapid transit. Journal of Public Transportation, 2005, 8(1).
[135] Gunnarsson-Ostling, U.; Hojer, M. Scenario Planning for Sustainability in Stockholm, Sweden: Environmental Justice Considerations. Int. J. Urban Reg. Res. 2011, 35, 1048–1067.
[136] Kytta, M.; Broberg, A.; Tzoulas, T.; Snabb, K. Towards contextually sensitive urban densification: Location-based softGIS knowledge revealing perceived residential environmental quality. Landsc. Urban Plan. 2013, 113, 30–46.
[137] Runhaar, H.; Driessen, P.P.J. Sustainable urban development and the challenge of policy integration: An assessment of planning tools for integrating spatial and environmental planning in the Netherlands. Environ. Plan. B 2009, 36, 417–431.
[138] Bhat, C.R.; Singh, S.K. A Comprehensive Daily Activity-Travel Generation Model System for Workers.Transp. Res. A 2000, 34, 1–22.
[139] Dunphy, R.T.; Fisher, K. Transportation, Congestion, and Density: New Insights. Transp. Res. Rec. J. Transp.Res. Board 1996, 89–96.
[140] Bhat, C.R.; Pozsgay, M.A. Destination Choice Modeling for Home-Based Recreational Trips: Analysis and Implications for Land-use, Transportation, and Air Quality Planning. Transp. Res. Rec. 2002, 1777, 7–54.
[141] Bhat, C.R.; Zhao, H. The Spatial Analysis of Activity Stop Generation. Transp. Res. B 2002, 36, 593–616.
[142] Lee, G.; Jeong, Y.; Kim, S. Impact of individual traits, urban form, and urban character on selecting cars as transportation mode using the hierarchical generalized linear model. J. Asian Archit. Build. 2016, 15, 223–230.
[143] Lee, J.; Jin, N.; Lee, S. Built Environment impacts on Individual Mode Choice: An Empirical Study of the Houston-Galveston Metropolitan Area. Int. J. Sustain. Transp. 2012, 8, 447–470.
[144] Boarnet, M.G.; Joh, K.; Siembab,W.; Fulton,W.; Nguyen, M.T. Retrofitting the Suburbs to IncreaseWalking: Evidence from a Land-use-travel Study. Urban Stud. 2011, 48, 129–159. [PubMed]
[145] Boyko, C.T.; Cooper, R. Density and Decision-Making: Findings from an Online Survey. Sustainability 2013, 5, 4502–4522.
[146] Loo, B.; Chow, S. Sustainable Urban Transportation: Concepts, Policies, and Methodologies. Journal of Urban Planning and Development, 2006, 132(2), pp.76-79.
[147] P.P. Koh; Y.D. Wong. Comparing pedestrians' needs and behaviours in different land use environments. Journal of Transport Geography, 2013, 26, pp. 43-50
[148] Manaugh, K.; Kreider T.; What is mixed use? Presenting an interaction method for measuring land use mix Journal of Transport and Land Use, 2013, 6 (1), pp. 63-72
[149] Hickman, R.; Govoni, M.; Bonilla, D.; Banister, D. Handbook on Transport and Development. Retrieved on 8 August 2018, from https://www.elgaronline.com/view/978085793 7254.xml (accepted on 17 August 2018)
[150] Jacobs, J. The death and life of great American cities. New York: Random House.

[151] Crane, Randall, and Richard Crepeau. 1998. "Does Neighborhood Design Influence Travel?: A Behavioral Analysis of Travel Diary and GIS Data1." Transportation Research Part D: Transport and Environment, 1961 3 (4): 225-238.
[152] Song, Yan; Gerrit-Jan Knaap. New Urbanism and Housing Values: A Disaggregate Assessment. Journal of Urban Economics, 2003, 54: 218–238.
[153] Baran; Perver K.; Rodríguez; Daniel A.; Khattak, J. AsadSpace syntax and walking in a new urbanist and suburban neighbourhoods Journal of Urban Design, 2008, 13 (1), pp. 5-28
[154] Ozbil, A.; Peponis, J.; Stone, B. Understanding the link between street connectivity, land use and pedestrian flows. URBAN DESIGN International, 2011, 16(2), 125-141. doi:10.1057/udi.2011.2
[155] Molster, A.; Schuit, S. Voetsporen rond het station. In Proceedings of the Het National Verkeerskunde Congres, Rotterdam, The Netherlands, 21–22 November 2013.
[156] Handy, S. 1993. Regional versus local accessibility: Implications for network travel. Transportation Research Record, 1400(58-66).
[157] Cervero, R. Alternative approaches to modeling the travel demand impacts of smart growth. Journal of the American Planning Association, 2006, 72(3), 285–295.
[158] Ewing, R.; Guang, T.; Goates, J.P.; Zhang, M.; Greenwald, M.J.; Joyce, A.; Greene,W. Varying Influences of the Built Environment on Household Travel in Nine Diverse Regions of the United States. Urban Stud. 2014, 52, 2330–2348.
[159] Sung, H.; Sugie, L.; Sungwon, J. Identifying the Relationship between the Objectively Measured Built Environment and Walking Activity in the High-density and Transit 34 oriented City, Seoul, Korea. Environ. Plan. B Plan. Des. 2014, 41, 637–660.
[160] Naess, P. Residential Location Affects Travel Behavior—But How and Why? The Case of Copenhagen Metropolitan Area. Prog. Plan. 2005, 63, 167–257.
[161] Bento; A. M.; Cropper M. L.; A. M. Mobarak; Vinha, K. The Effects of Urban Spatial Structure on Travel Demand in the United States. The Review of Economics and Statistics, 2005, 87 (3): 466–478. doi: 10.1162/0034653054638292
[162] Rajamani, J.; Bhat, C. R.; Handy S.; Knaap G.; Song Y. Assessing Impact of Urban Form Measures on Nonwork Trip Mode Choice After Controlling for Demographic and Level-of-Service Effects. Transportation Research Record, 2003, 1831: 158–165. doi: 10.3141/1831-18
[163] Targa, F.; K. Clifton. The Built Environment and Trip Generation for non-Motorized Travel. Journal of Transportation and Statistics, 2005, 8 (3): 55–70.

CHAPTER 2: INFLUENCE FACTOR OF URBAN FORM ON TRAVEL BEHAVIOR AND TRAVEL ENERGY CONSUMPTION BASED ON DEVELOPED COUNTRY- FUKUOKA CITY

2.1 Introduction

The potential limits to the availability of gasoline and the increasing rate of dependence on the automobile for travel is a growing concern regarding how travel energy consumption in a city can be reduced. In addition to the threat of gasoline insecurity, extensive automobile usage also causes problems in areas of public health and social equity [1] as the transportation sector is responsible for over half of the CO_2 emissions from fossil fuel combustion [2].

There are two potential solutions that have been proposed to deal with the burning issues of the growth of energy consumption and emissions [3]. One potential solution is sustainable mobility (e.g., introduction of low-carbon fuels and new technologies that increase fuel efficiency). Another solution is sustainable urbanism (redesigning our cities so there is less need to drive). Ewing et al. [4] found that the transportation sector cannot achieve emission targets merely through improvements in technology. It is necessary to concentrate on land use planning as it has long term effect on transportation energy consumption and environmental because it determines the basic spatial settings for human activities [5]. In particular, an effective planning strategy for increasing the efficiency of public transportation and decreasing the dependence on automobiles enables people to have more community oriented social exchanges [6], which typically involves shorter travel distances and more usage of non-motorized modes.

Many previous studies have focused the relationship between land use and travel behavior due to the topic's great importance in public policy-making [7-14]. The topic has been addressed in connection to a wide range of environmental and social concerns [4,15-18]. In contrast, there are little studies on the relationship between land use, travel behavior and travel energy consumption. The importance of urban planning as a tool to reduce travel energy consumption has been underestimated, possibly because the disciplines of urban planning and travel behavior are traditionally considered as separate issues. And, also it might be because of the challenges in analysis due to the complex interrelationships between urban form, travel behavior and travel energy consumption [19]. Therefore, this chapter attempts to explore the influence factor of urban form on travel behavior and travel energy consumption by applying two separate analysis methods: Cluster analysis and Multiple Linear Regression Model (MLRM) analysis based on the case study from a developed country- Fukuoka city.

2.2 Rationale of Selection

Similar to Nepal, Japan also has no known oil, gas or coal deposits. All commercial fossil fuels are imported from international markets. Similar to Kathmandu city, Fukuoka city is undergoing rapid urbanization and motorization process as it is the center of Fukuoka prefecture. Even with high motorization rates, Fukuoka has high non-motorized (walk and bicycle) and public transport mode shares. Fukuoka city is known as one of the good examples where both bus and rail service in the best way. Public mode is well facilitated with information technology (IT) that provides the users' information on timetable, fare, and transfer that can easily get on mobile devices in Japanese and English language. The fare collection in all bus and rail in Fukuoka is with IC card that takes short time to get on and off. That not only reduces the time of passengers but also reduces the traffic jams and energy consumption. However, one can pay in cash too. Due to the quality service in public transport and higher use of walk and bicycle along with other criteria, Fukuoka City was ranked 10th of the world’s most livable cities in 2014, ranked 12th in 2015, 7th in 2016 and 14th in 2017 in the Monocle quality of life survey.

However, in recent decades, temperature rise has been observed in Fukuoka alongside increasing global warming. Also, carbon dioxide emissions are increasing compared with the base year 1990. Therefore, an effort to reduce emission and fuel consumption has become important in Fukuoka as in the case of Kathmandu. But without delaying the Fukuoka city government has initiated some strategies such as operation of bus rapid transit (BRT) system, improvement on pedestrian roads, bicycle networks and park-and-ride schemes to promote public mode and to encourage people to walk and cycle. In the recent year 2017, BRT service has been implemented in central areas of Fukuoka City. Comparative assessments of BRT throughout the world have found that most systems have greatly improved their local travel conditions and the quality and performance of public transport, especially in travel time savings and enhanced reliability [20]. As a result of BRT systems significantly reduce energy consumption and emissions as compare to the local normal bus. Though, BRT has some conditions (dedicated lane, match the floor height of the bus and height of the bus stop platform to make it easy to get on and off, collect the fare outside the bus etc.) to fulfill, BRT in Fukuoka does not fulfill these conditions as it is not possible to materialize at the present context.

The extensive research regarding urban form, travel behavior and travel energy consumption are mostly based on developed countries, among them most of the western countries. Whereas, developing countries, many of which are constructing the energy efficient decisions based on those international studies since developing countries have the opportunity of 'leapfrogging' [21]. In terms of energy planning, developing countries need not repeat the same phase of highly industrialized countries in creating an energy infrastructure based on fossil fuels, but 'jump' directly to renewable energy sources and more efficient technologies. Even though, among the developed countries, the cities in Western and Asian have many differences in characters. So, this research has taken Fukuoka as a case study from a developed country.

2.3 Introduction: Fukuoka City

Fukuoka City is the capital of Fukuoka Prefecture, located along the northern shoreline of Kyushu Island, Japan. The city covers the area of 340.03 square kilometers, with a registered population of 1.53 million as of 2015 census (Statistics Bureau Japan). Fukuoka first came to be known as the political, economic, and cultural center of Kyushu in the 1930s. Today, it is a home to various international organizations, governmental organizations and private enterprises, occupying a central role in travel, information, entertainment and international business. It is the biggest city in Kyushu and is one of Japan's eight largest cities. It includes 7 wards (ku):

Chuo-ku, Hakata-ku, Higashi-ku, Jonan-ku, Minami-ku, Nishi-ku and Sawara-ku (Figure 2.1).

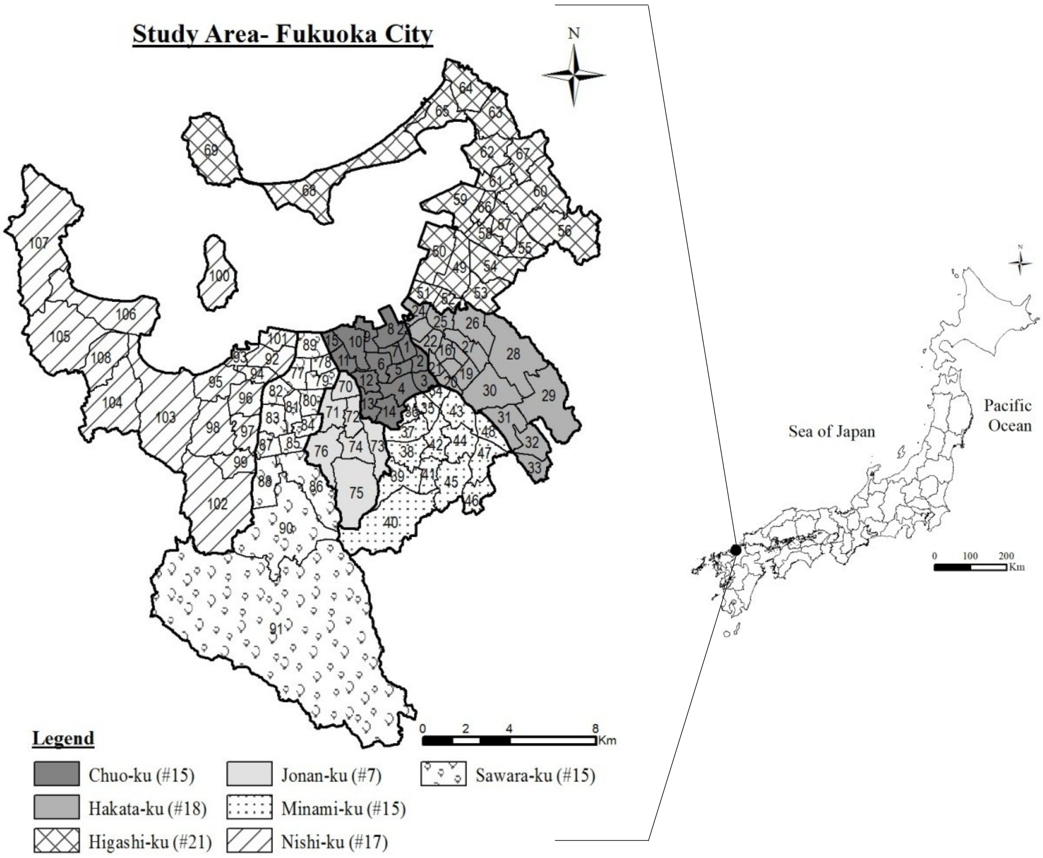

Figure 2.1 Study area- Fukuoka city

For micro-level analysis in this research, we analyzed the entire Fukuoka via 108 zones (Figure 2.1). These zones were referred to the PTS (Person Trip Survey) zone, which is based on the zoning of the Road Traffic Census held in 2005. However, all the PTS zones do not coincide with the Road Traffic Census. In addition, due to unavailability of the PTS zone's boundary shape file, we traced the map in GIS (Geographic Information System (ArcGIS, 10.3.1, Esri Inc., Redlands, California, United States) provided by Fukuoka City Government in which 2007 PTS zones were demarcated. Then, we developed a database for each zone using GIS for conducting our research. Basically, these zones are formed based on the elementary school districts to create local communities centered on local government councils. Therefore, individual zone information provides an image of local community and a foundation that can be helpful to undertake development activities in a community. As our research intends to analyze the relationships between urban form, travel behavior and energy consumption at a micro-scale, the zone-wise information is ideally suited for our research.

2.4 Research Data Type and Source

This section describes the collection and simulation of the data to construct relevant variables for the research. An integrated dataset that includes urban form, travel behavior and travel energy consumption is vital for the purpose of this study. Each dataset is explained below.

Table 2.1 Descriptive result summary-urban form variables

	Mean	SD	Minimum	Maximum
‘5Ds’ Urban form variables				
D1 (Density in terms of central tendency of population density and household density)	1,517.35	837.84	1.47	4,465.68
D2 (Diversity in terms of land use mix index)	0.50	0.13	0.08	0.71
D3 (Design in terms of central tendency of 3-way and 4-way road intersection)	225.32	149.82	14.00	963.00
D4 (Destination accessibility in km)	7.75	5.44	0.54	33.28
D5 (Distance to transit in terms of central tendency of bus accessibility and rail accessibility)	3.70	2.52	0.00	14.98
Urban form variables used for measuring ‘5Ds’				
Population density (population per km^2)	2,965.10	1,642.92	2.20	8,827.70
Household density (household per km^2)	69.59	51.31	0.57	204.53
Residential (km^2)	620,424.30	377,577.69	3,960.74	1,593,349.49
Commercial (km^2)	141,532.94	115,696.76	10,996.62	701,403.56
Industrial (km^2)	43,025.45	77,121.95	0.00	414,676.16
Utility facility (km^2)	163,001.74	119,038.56	22,143.02	596,110.10
Public open space (km^2)	135,147.15	357,009.31	0.00	3,123,214.52
No. of road intersection 3-way	363.11	263.65	24.00	1,746.00
No. of road intersection 4-way	87.54	45.83	4.00	218.00
No. of bus stops	9.61	5.16	0.00	27.00
Influence of rail station (km^2)	455,843.81	496,092.78	0.00	2,252,447.65
Bus accessibility (bus stops per km^2)	7.07	4.92	0.00	28.95
Rail accessibility(influence of rail station per km^2)	0.34	0.36	0.00	1.46

2.4.1 Urban Form Data

The 2007 Person Trip Survey (PTS) data is the latest available data in the case of Fukuoka City. Therefore, we collected urban form data also from 2007 to get the research results more reliable and accurate. This study included five dimensions, "5Ds" (density, diversity, design, destination accessibility and distance to transit) of urban form. The descriptive results of all urban form related data are shown in Table 2.1. Each Ds are explained below.

2.4.1.1 Density (D1)

The population density of each of the 108 zones was extracted by using a GIS shape file collected from the Fukuoka City government. To calculate household density, first, we extracted the number of households of each zone and then divided it by the occupied residential area of that zone. Equation 2.1 is utilized to compute household density. The descriptive result in Table 2.1 shows that population density ranges from 2.20 to 8,827.70 person per km^2. The household density is found to range from 0.57 to 204.53 household per km^2. D1 as the central tendency of population density and household density showing its mean value is 1,517.35.

Household density = No. of Household/ Residential area (km^2) Equation 2.1

2.4.1.2 Diversity (D2)

There are many ways to simulate Diversity (D2) as described in section 1.5.5.2. In this study, the land use mix index (entropy) method is utilized, as it has some advantages over other methods: (1) not requiring the use of some require demographic data that is hard to access, such as number of jobs; (2) being widely used in urban planning and travel studies and presenting a high reliability within these areas; and, (3) being able to incorporate more than two types of land uses, while other methods cannot [22-24]. These reasons bring us to conduct an estimation of diversity by using the entropy indicator, which is presented in Equation 2.2. The entropy ranges from 0 to 1. The value of 0 represents single land use environment (homogeneity) whereas 1 represents the perfect even distribution of all land uses within the area (heterogeneity). Higher value of land use mix index indicates a more balanced land use pattern. In this research, mainly 5 land use types (residential, commercial, industrial, utility facility and public open space) were included in accordance with the highest relevance for daily travel activities. The descriptive result in Table 2.1 shows that residential land use has the highest share (620,424.30) followed by utility facilities (163,001.74) and commercial land use (141,532.94). In Fukuoka, the entropy ranges from 0.08 to 0.71.

$$\text{Land use mix index (Entropy)} = -\left\{\left(\sum_k \left(P_i \times \left(\ln p_i\right)\right)\right) / \ln(k)\right\} \qquad \textbf{Equation 2.2}$$

where,

P_i = proportions of each of the land use types (in this research; Residential, commercial, industrial, utility facility and public open space) of the total land area

k = number of land use types (in this research; 5)

2.4.1.3 Design (D3)

According to Ewing and Cervero [25], design characterizes how friendly the local environment to non-motorized travel. Design includes street network characteristics such as average block size and connectivity; pedestrian and bicycle network factors (e.g., sidewalk coverage, pedestrian crossings); pedestrian and bicycle amenities (e.g., street trees, parking); and site design metrics such as building setbacks and placement of parking. However, in the case of Fukuoka City, there are no comprehensive databases that gauge the quality of walking environments, parking supplies, landscaping provisions and other detailed features. Therefore, following Ewing and Cervero [25], Chatman [26] and Zhang [27], we calculated D3 in terms of road intersection. We were provided with the road shape file with dual lines; however, to calculate a number of intersections, we require center line of the road. Therefore, we produced the center line of the road network by using Cartography tools in GIS and then a number of road intersections (both 3-way and 4-way) were calculated using the Spatial Statistics tools in GIS. A road of 1.2 m was also included in the simulation of road intersections, considering travel by walking and cycling as well. It is found that a 3-way road intersection is 4 times more likely than a 4-way road intersection (Table 2.1). D3 as the central tendency of 3-way and 4-way road intersection showing its mean value is 225.32.

2.4.1.4 Destination Accessibility (D4)

Destination accessibility measures ease of access to trip attractions where a number of jobs or shopping opportunities are available. Following Boarnet et al. [28] and Comendador et al. [29], we measured D4 in terms of the central business district (CBD). The CBD is the location with maximum employment density, the maximum number of trip ends and the maximum rent. With these characteristics, the existing location of Fukuoka City Hall is taken as the CBD for this research. In most of the research, the distance to the CBD is measured as the straight-line distance from the CBD, which does not provide a realistic value. Therefore, we measured the distance to the CBD (D4) from the centroid of each zone by using OD Cost Matrix Analysis in GIS, where the shortest distance is identified in the road map and the distance to the CBD is estimated. The result of the descriptive analysis in Table 2.1 shows that the distance to the CBD ranges from 0.54 to 33.28 km.

2.4.1.5 Distance to Transit (D5)

Distance to transit measures access to the nearest transit or transit stop. In this study, D5 is estimated in terms of bus accessibility and rail accessibility as in the study by Lee et al. [30]. To measure bus accessibility, first, we calculated a number of bus stops in each zone by using Spatial Statistics tools in GIS. Then, bus accessibility is defined as the total number of bus stops in a zone divided by its land area as shown in Equation 2.3. In Fukuoka City, three major bus companies operate: Nishitetsu, Showa and JR Kyushu. Nishitetsu Bus covers almost all of Fukuoka, while Showa Bus operates in the western region and JR Kyushu operates in the eastern region. Express buses are also available through Nishitetsu and JR Kyushu and they connect Fukuoka to other major cities within and outside Kyushu.

$$\text{Bus accessibility} = \text{No. of bus stops/Total land area (km}^2\text{)} \qquad \textbf{Equation 2.3}$$

$$\text{Rail accessibility} = \text{Influence of rail station (km}^2\text{)/Total land area(km}^2\text{)} \qquad \textbf{Equation 2.4}$$

To estimate rail accessibility, first, we calculated a station area of influence equal to a circle with a radius of 0.55 km (average walking distance) whose center is a subway or rail station [30]. Then rail accessibility is estimated as the influence of rail station in a zone divided by its total land area as shown in Equation 2.4. The subway system in

Fukuoka has three lines. There are two railway companies: JR Kyushu and Nishitetsu. Nishitetsu operates several lines in Fukuoka Prefecture. JR Kyushu is one of the privatized companies of Japan National Railways which provides a network of railway lines to the whole of Kyushu. Construction and improvement of rail stations and bicycle parking lots have been carried out to facilitate efficient coordination between railway systems.

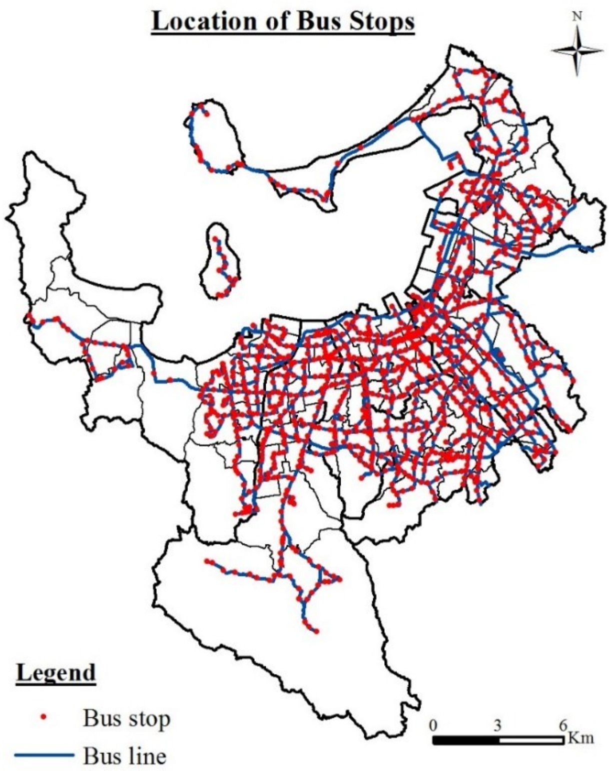

Figure 2.2 Location of bus stops

Figure 2.2 shows the location of bus stops and bus routes in Fukuoka City, whereas Figure 2.3 shows the rail stations, rail routes and station area of influence. The descriptive result (Table 2.1), Figures 2.2 and 2.3 demonstrate that some zones do not have bus and rail facilities and also it reflects that rail accessibility is very low when compared to bus accessibility in Fukuoka City. D5 is defined as the central tendency of bus accessibility and rail accessibility, showing its mean value is 3.70.

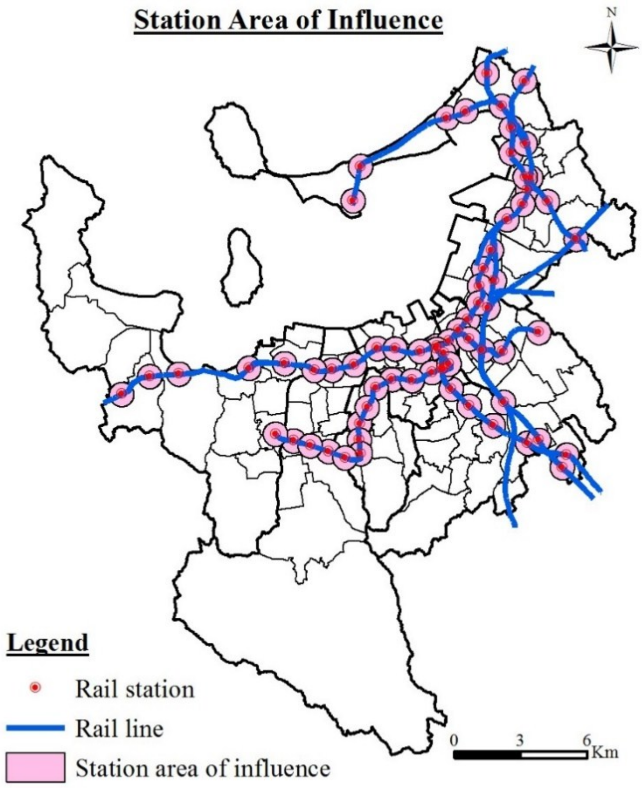

Figure 2.3 Station area of influence

2.4.2 Person Trip Survey (PTS) Master Data

This study utilizes micro data at the 4% level of the 2007 PTS data; provided by the Fukuoka City Transportation Planning Section. In this research, we used PTS data from the 2007 survey, which is the latest survey data available for Fukuoka City. PTS is a person-based travel survey conducted every ten years by the Ministry of Land, Infrastructure and Transport (MLIT). Daily travel is collected using one-day trip diaries for all household members in selected households. This research covered 135,302 respondents in which the male population was found to be 63,298 and female population was 72,004. The minimum, mean and maximum age is 5, 42 and 103 years respectively. We considered all the age groups in this research as we analyze the influence of various travel purposes on different mode choices. For example, a 6-year-old child may go to school by walking, whereas a 42-year-old man may go to work by private car or rail due to the long distance. This study considered the travel that was generated only within Fukuoka City and the total travel trips included in this research was 5,559,737.

Table 2.2 Descriptive result summary- travel variables

	Mean	SD	Minimum	Maximum
Travel mode				
Walk	11,377.15	7,288.11	419.00	55,410.00
Bicycle	7,388.93	4,664.86	64.00	23,657.00
Non-motorized mode	18,766.07	11,292.24	552.00	76,000.00
Motorcycle	1,712.29	1,090.39	0.00	7,510.00
Car	20,328.07	9,920.83	1,258.00	60,297.00
Bus	4,742.15	6,726.95	52.00	65,870.00
Rail	5,302.06	7,677.31	0.00	72,111.00
Travel purpose				
Work Trip (WT)	8,648.35	5,912.59	179.00	49,975.00
School Trip (ST)	3,720.44	2,411.98	0.00	12,313.00
Business Trip (BT)	8,630.81	7,020.09	692.00	54,547.00
Private Trip (PT)	10,960.44	9,492.27	314.00	90,391.00

We included both walk and bicycle under non-motorized mode type. From the results of the descriptive analysis (Table 2.2), car is found to be the most highly used mode for travel in the sample with a mean of 20,328.07 and standard deviation of 9,920.83, followed by non-motorized mode and rail. However, the minimum trip value for rail use is also 0 (Table 2.2), which meant in some zones, people do not use rail for travel at all. This is due to unavailability of rail stations in these zones. This result is supported by the descriptive result summary of urban form data in Table 2.1. In the case of bus use, the minimum trip value is 52 (Table 2.2) whereas Table 2.1 shows that some zones do not have bus stops and so bus accessibility has a minimum value of 0. This highlights that people use bus as a travel mode even if the trip origin has no bus accessibility. Likely they must walk or cycle or park-and-ride to use the bus. Among other travel modes, motorcycle use was found to be very low (Table 2.2). This is likely due to the higher aging population in Fukuoka City. In the case of travel purpose, private trip had a mean value of 10,960.44 and standard deviation of 9,492.27, showing that people travel most for private purposes, followed by work and business (Table 2.2). Furthermore, a number of work trips and business trips are almost the same, which indicates that Fukuoka City is a hub to various organizations, private enterprises, local and international businesses.

2.4.3 Travel Energy Consumption Estimates

Travel energy consumption of one day by an individual in each zone was estimated using Equation 2.5 as defined in the study by Jiang et al. [31]. We summed up each motorized mode for each purpose and multiplied by distance traveled for that purpose and energy intensity for that mode type as shown in Equation 2.5. The difference to the study by Jiang et al. [31] is that they calculated the mode's energy intensity using the vehicle's fuel economy and the fuel energy content factor. However, in Japan, the integration of energy intensity and the trip length is generally used [32] to estimate transportation energy consumption. We collected the energy intensity data also from 2007 to make the research result more consistent (Table 2.3). The travel distance is the shortest travel distance calculated by using OD Cost Matrix Analysis in GIS. The estimated total travel energy consumption per zone ranges from 21,049.16 to 921,277.26 MJ/person/day.

Table 2.3 Energy intensity factor for travel modes

Travel mode	Motorcycle	Car	Bus	Rail
Energy intensity factor (MJ/person-km)	1.2	2.41	0.72	0.20

$$EC = \sum_{j=1}^{j=n} \sum_{i=1}^{i=m} T_{ij} \times D_i \times EI_j \qquad \textbf{Equation 2.5}$$

where,

EC = Total Travel Energy consumption (MJ/person/day)

n = Total number of travel mode

j = Travel mode type {Motorcycle, Car, Bus, Rail}

m = Total number of travel purpose

i = Travel purpose {Work, School, Business, Private}

T_{ij} = Travel for purpose 'i' by mode 'j'

D_i = Travel Distance for travel purpose 'i' (km)

EI_j = Energy Intensity factor for travel mode '$\boldsymbol{j}$' (MJ/person-km)

2.5 . Micro-Scale Analysis of Urban Form, Travel Behavior and Travel Energy Consumption Based on Fukuoka Using Cluster Analysis

2.5.1 Introduction

The increasing threat of energy insecurity and environmental issues has led increasingly getting attention in the seeking of the potential contribution of urban planning in reducing travel energy consumption. Most existing research in this area focuses to examine the connection between urban form and travel behavior [11,25,33,34]. Only a few studies have explored the influence of urban form on energy consumption. However, those earlier studies consider only a few measures of urban form (in most of the cases only one measure) to examine the effect of urban form on travel behavior. For example, Newman and Kenworthy [35], Banister et al. [36], Dunphy and Fisher [37] and Bhat and Singh [38] have used density whereas Bhat and Pozsgay [39] and Bhat and Zhao [40] have focused on a single measure of accessibility. Some researchers have considered multiple urban form measures jointly; for example, Frank and Pivo [41] consider density and land use, and Kitamura et al. [42] use the density and accessibility measures. Even with many mixed findings [22,33-35], there has been a growing recognition that changes in urban form characteristics have a significant impact on people's travel behavior and reduction of travel energy consumption.

Therefore, this study aims to explore the relationship between urban form, travel behavior and travel energy consumption based on a multitude of urban form variables. This study considers five dimensions of urban form; "5Ds" (density, diversity, design, destination accessibility and distance to transit) which are widely used to characterize land-use characteristics at the micro-scale in travel behavior research [30,43,44].

2.5.2 Analysis Method

The analysis method to achieve the aim of this research is threefold (Figure 2.4). First, this research attempts to overview the urban form of Fukuoka city at micro-scale by applying empirical analysis based on 5Ds. Second, represents distinct group of urban form and travel mode choice with highly correlated variables by applying factor analysis separately. Third, analyzes the relationship between urban form, travel mode choice and travel energy consumption to identify the influencing factors which affect travel and travel energy consumption by using cluster. Each analysis method is described below.

2.5.2.1 "5Ds" Empirical Analysis

Empirical analysis of the urban form characteristics of Fukuoka city is performed based on "5Ds" framework at micro-scale . The first three dimensions "3Ds"– density, diversity, and design is introduced by Cervero and Kockelman [22]; as measures of the urban form that influence travel. Two more "Ds" – destination accessibility and distance to transit [11] emerged later. Based on 5Ds, in total 8 urban form variables (population density, household density, land use mix index, 3-way road intersection, 4-way road intersection, distance to Central business district (CBD), bus accessibility and rail accessibility) are identified for this research. The decomposed urban data into 108 zones were ranked into 7 classes from low to high by using SPSS and processed in GIS for the empirical analysis.

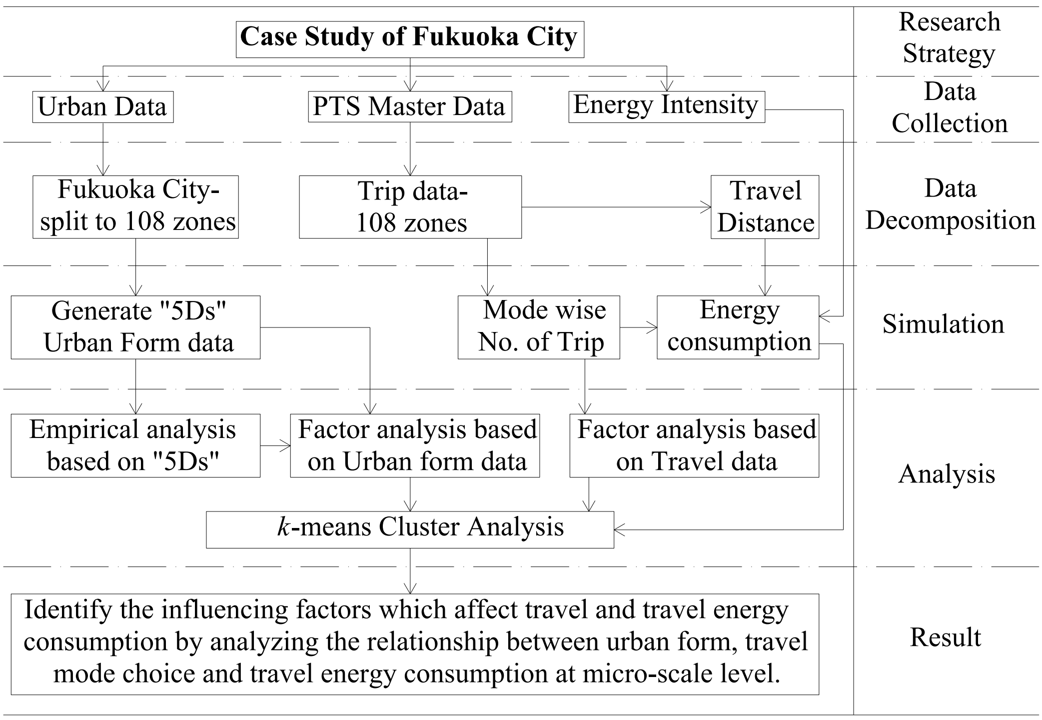

Figure 2.4 Research methodology

2.5.2.2 Factor Analysis

From the empirical analysis, we achieved an overview of urban characteristics of Fukuoka city. But, it is less possible to achieve accuracy in an interpretation and clear linkup with travel mode choice and travel energy consumption due to the large variation among the 5Ds variables for 108 zones. So, to represent the group with highly correlated variables, we applied Factor analysis method. Two separate factor analyses are performed in this study using statistical tool SPSS: the first includes 8 variables of urban form (population density, household density, land use mix index, 3-way road intersection, 4-way road intersection, distance to Central business district (CBD), bus accessibility and rail accessibility) and the second includes 7 variables (rail, bus, taxi, car, motorcycle, walk and bicycle) of travel mode choice. The result provides a small set of components representing highly correlated variables. Rogerson [45] has explained that Factor analysis is a commonly used data reduction technique; it reduces a dataset of many correlated variables to a smaller, more manageable set of factors that correspond to a significant portion of the variability of the full dataset. We excluded two zones (zone 1 of Chuo-ku and zone 64 of Higashi-ku) due to its extremely large variation for studied variables. The factor analysis for both data type was repeated several times but the three factor components were found to yield the best results for both. Each factor component was interpreted based on the factor scores and profile them.

2.5.2.3 Cluster Analysis

After factor analysis, a *k*-means Cluster analysis is performed by using statistical tool SPSS; on the resulting factor scores of both urban form and travel variables as well as additional variable- travel energy consumption to identify groups of zones with similar characteristics. An advantage of cluster analysis is that it identifies clusters regardless of spatial location [46]. The goal of using *k*-means statistical cluster analysis technique is to maximize inter-cluster variation while minimizing intra-cluster variation. The objective is, therefore, to regroup zones into *k*-homogenous clusters having similar urban form, travel mode choice and travel energy consumption characteristics. Several attempts were made with different numbers of clusters by using ward method and finally, three clusters were found a satisfactory number. The characteristics of the three clusters (homogeneous group) are described in section 2.5.3.3. Each cluster group was interpreted based on the final cluster centroid values.

2.5.3 Analysis Result

The research results from each analysis methods are described below.

2.5.3.1 "5Ds" Empirical Analysis Result

5Ds empirical analysis result based on 108 zones of Fukuoka is described below.

2.5.3.1.1 Density (D1)

Population Density and household density are found higher (Figure 2.6) where bus and rail accessibilities are higher. Most of the zones from Nishi-ku, Sawara-ku and Higashi-ku have a low population density. Household density analysis showed that the highest density was in Minami-ku (#1), Chuo-ku (#2) and Hakata-ku (#1).

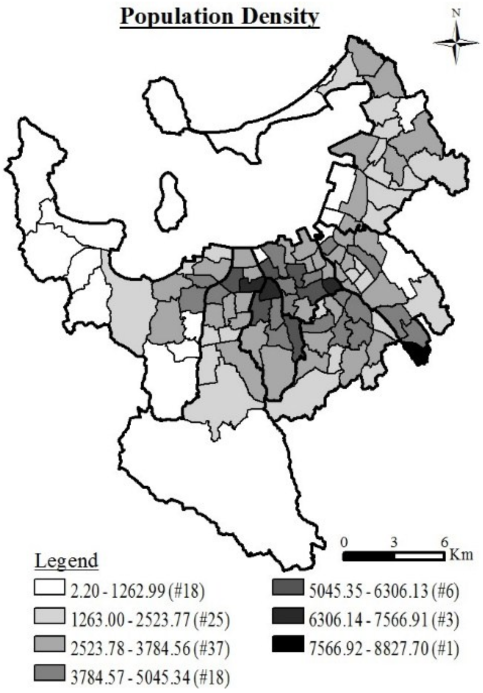

Figure 2.5 D1- Population density

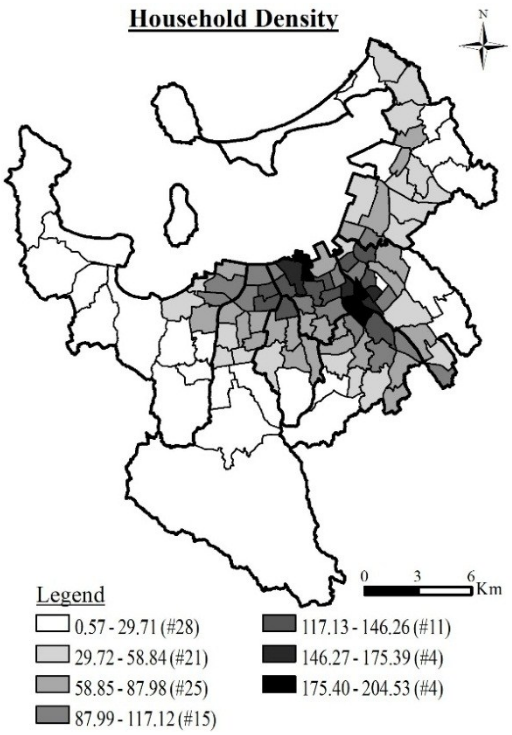

Figure 2.6 D1- Household density

2.5.3.1.2 Diversity (D2)

D2 analysis result demonstrated that land use mix index ranged from 0.08 to 0.71 in Fukuoka city (Figure 2.7). The most balance land use (more than 0.63) was found in Chuo-ku (#6), Hakata-ku (#4) and Higashi-ku (#1) which is nearer to CBD. Whereas, most of the zones of Sawara-ku and Nishi-ku have low land use mix covered with mostly residence.

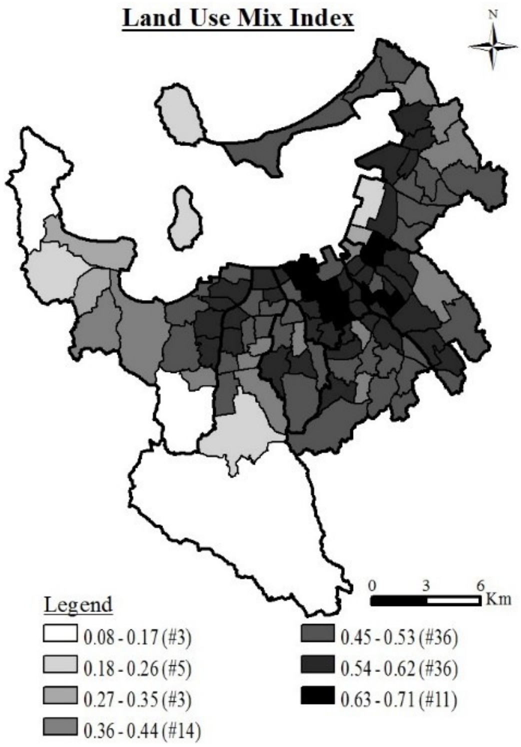

Figure 2.7 D2- Land use mix index

2.5.3.1.3 Design (D3)

Empirical analysis showed that even in the less dense and poor transit accessible areas, street connectivity is better in Fukuoka. Analysis showed that 3-way road intersections were higher than 4-way. The result showed that 3-way intersections are highest in zone 103 of Nishi-ku and Sawara-ku's zone 90 and 91 (Figure 2.8). In the case of 4-way intersection, zone 103 of Nishi-ku and 56 of Higashi-ku has the highest intersection count (Figure 2.9).

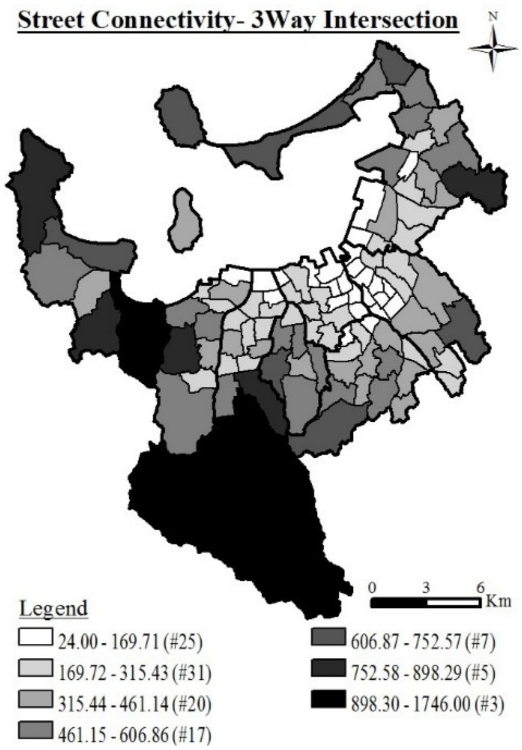

Figure 2.8 D3- 3way road intersection

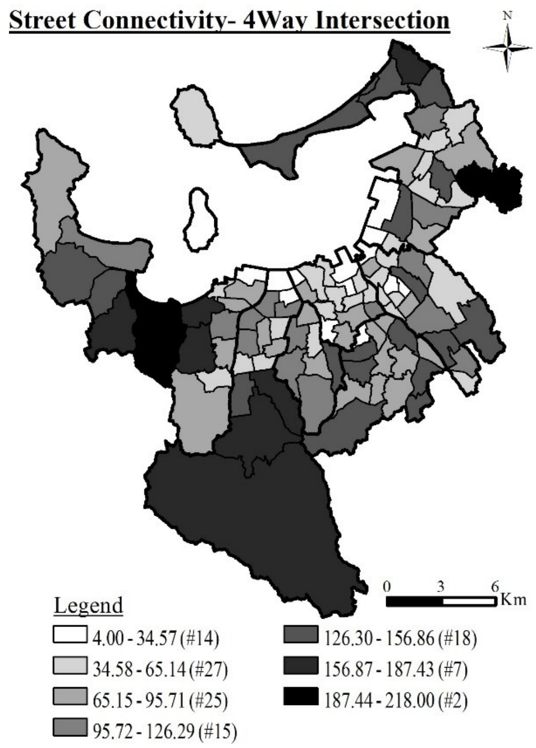

Figure 2.9 D3- 4way road intersection

2.5.3.1.4 Destination Accessibility (D4)

The CBD lies in zone 1 of Chuo-ku which has land use mix index 0.6. Distance to CBD is found longer in the zones where less density and less land use mix. It was found that the zone 107 of Nishi-ku and Higashi-ku zone 69 and 68 have a poor access to CBD (Figure 2.10) that meant travel from these zones to CBD are at increasingly long distances. Almost all zones of Chuo-ku to CBD have shorter travel distance.

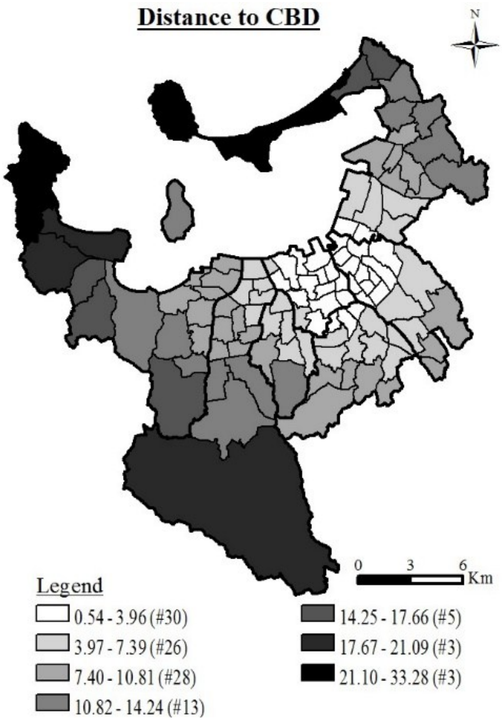

Figure 2.10 D4- Distance to CBD

2.5.3.1.5 Distance to Transit (D5)

D5 was measured by using bus accessibility and rail accessibility (Equation (3), (4)). Higher bus accessibility is found in the zones where higher household density and near to CBD areas. The result of bus accessibility showed that 24 zones out of total 108 have poor accessibility ranging accessibility value from 0 to 2.69 (Figure 2.11). Mostly zones in Higashi-ku, Nishi-ku and Sawara-ku have poor bus accessibility whereas zone 7 and 1 (CBD lies) of Chuo-ku has the highest bus accessibility with the maximum number of bus stops. Similarly, 52 zones out of 108 have the low rail accessibility ranging from 0-0.15 (Figure 2.12). Higher rail accessibility was found where greater land use mix; mostly in the zones of Chuo-ku (#5), followed by Hakata-ku (#3) and zone 52 of Higashi-ku.

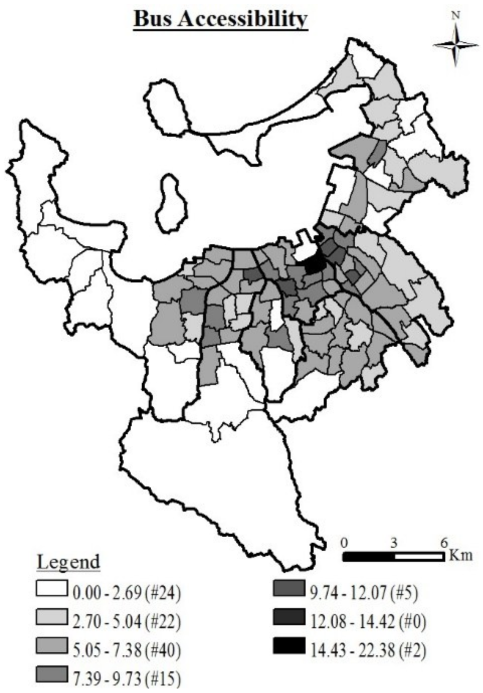

Figure 2.11 D5- Bus accessibility

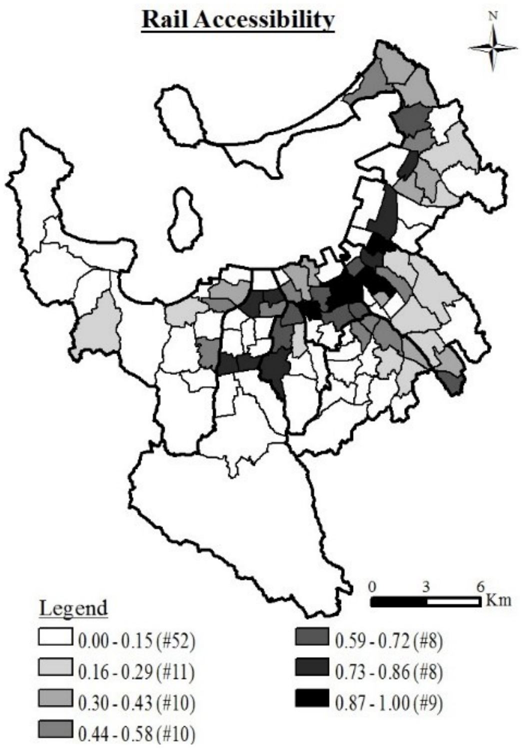

Figure 2.12 D5-Rail accessibility

2.5.3.2 Factor Analysis Result

2.5.3.2.1 Urban Form Factor Analysis Result

The first factor analysis showed that Factor 1 (F1*u*) accounts for a large proportion (55.90%), followed by Factor 2 (16.25%) and Factor 3 (8.49%) as in Table 2.4. Every three factors' components are described below.

Table 2.4 Total variance explain- urban form

Factor component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
F1*u*	4.472	55.902	55.902
F2*u*	1.300	16.256	72.158
F3*u*	0.679	8.490	80.648

Compact zones: Factor 1 (F1*u*) represents higher population density (0.863), higher household density (0.724) and higher mix land use (0.693) with a greater positive factor loading (Figure 2.13). So, this group is identified as compact zones; attributed to higher density (D1) and diversity (D2). The negative loading to destination accessibility (D4; -0.678) showed that the zones are closer to CBD.

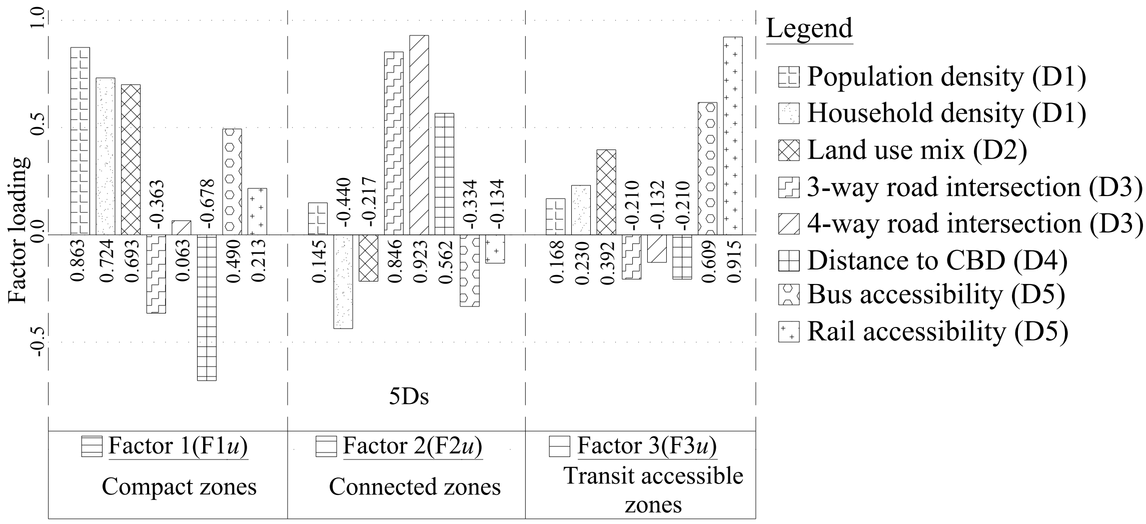

Figure 2.13 Factor components of urban form variables

Connected zones: The loading scores of Factor 2 (F2*u*) represents connected zones (Figure 2.13). This group is mainly characterized by the higher road connectivity (D3) with a higher positive loading for road intersection 3-way (0.846) and 4-way (0.923). The positive loading to destination accessibility (D4; 0.562) showed that the zones are further away from CBD.

Transit accessible zones: Factor 3 (F3*u*) characterizes transit accessible zones indicating higher positive loadings for bus accessibility (0.609) and rail accessibility (0.915) as in Figure 2.13. So, this group is highly attributed to the fifth dimension of urban form- D5 (distance to transit). The negative loading to destination accessibility (D4; -0.21) showed that zones are far from CBD.

2.5.3.2.2 Travel Mode Factor Analysis Result

The second factor analysis for travel mode choice showed positive loading for all the variables in all the three factors groups (Figure 10). Factor 1 (F1*t*) accounts for a large proportion (62.62%), followed by Factor 2 (13.59%) and Factor 3 (7.88%) as in Table 2.5. The results are described below.

Table 2.5 Total variance explain- travel data

Factor component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
F1*t*	4.383	62.621	62.621
F2*t*	0.952	13.597	76.219
F3*t*	0.552	7.882	84.101

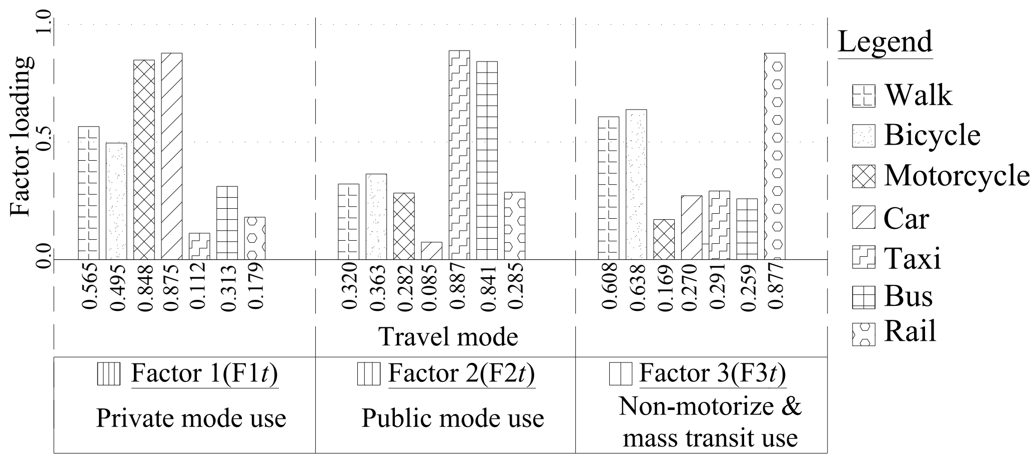

Figure 2.14 Factor components of travel mode choice

Private mode use: Factor 1 (F1*t*) represents a higher use of private car (0.875) and motorcycle (0.848) with a greater positive factor loading (Figure 2.14). It has low loading for public transport; bus (0.313), railway (0.179) and taxi (0.112).

Public mode use: Factor 2 (F2*t*) represents higher use of taxi (0.887) and bus (0.841) with a higher positive loading (Figure 2.14). Whereas, car use has the lowest factor loading (0.085).

Non-motorize and mass transit use: Factor 3 (F3*t*) has the highest positive loadings for rail (0.877), followed by walk (0.608) and bicycle use (0.638) (Figure 2.14). The loading for private mode, bus and taxi are found low in this group.

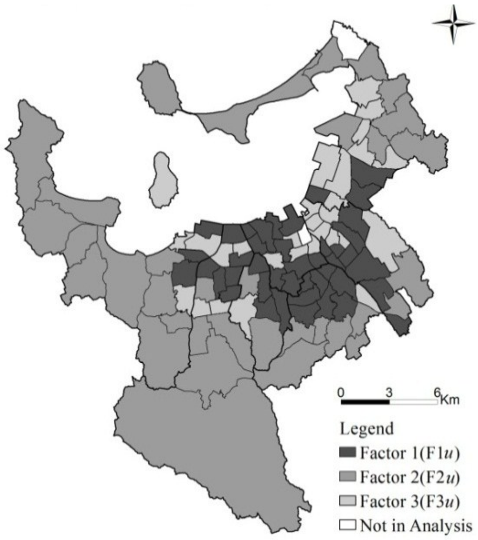

Figure 2.15 Factor analysis result- urban form

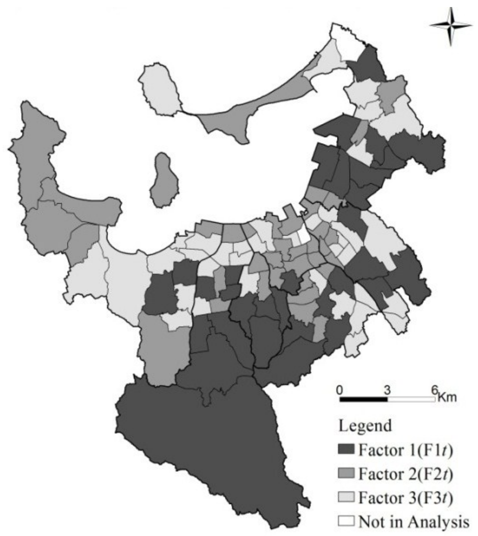

Figure 2.16 Factor analysis result- travel mode choice

2.5.3.3 Cluster Analysis Result

After identifying the distinct group from separate factor analyses (Figure 2.13- 2.16), we performed *k*-means cluster analysis by using those identified groups from factor analysis- 3 groups from urban form, 3 from travel mode choice and additional variable of travel energy consumption (Figure 2.17). A brief summary of each cluster resulting from this analysis is provided below.

2.5.3.3.1 Cluster 1- Low Residential and Lower Energy Consumption

Cluster 1 is characterized by low residential areas with strong negative input for travel energy consumption (-0.736) and private mode use (-0.731) (Figure 2.17). From the empirical analysis also, it is found that the travel trip in this cluster's zones is comparatively less due to low residential areas and highly dominant with entertainment parks, port-land and airport. This meant that the zones with low residential areas are directly related to trip reduction and consequently reduce energy consumption. Further, this cluster has the negative input for all the five dimensions of urban form (Figure 2.17). This suggests that low compact (D1 and D2), low connected (D3), further away to CBD (D4) and low transit accessibility (D5) are associated with low residential areas. This cluster represents 36 percent of the total number of wards in Fukuoka city (Figure 2.18).

2.5.3.3.2 Cluster 2- Highly Connected and Higher Energy Consumption

Cluster 2 is characterized by a strong positive input for connected zones (D3; 0.863), private mode use (0.989) and travel energy consumption (0.608) as in Figure 2.17. There has been a range of studies shows that better street connectivity resulted in increase of walking and cycling. But the result from this study is different. This result highlights that in Fukuoka, the destination is far and the street connectivity is better, so most people tend to use private mode for travel. Further, this result indicates that less compact (D1 and D2; 0.036) and poor transit accessibility (D5; -0.195) effects in the reduction of public mode use and non-motorized use. So, this result suggests that zones in cluster 2 (34%; Figure 2.18) need to increase density, greater land use mix and better transit accessibility to reduce private mode use and reduce travel energy consumption. However, due to infrastructural challenges in less dense areas, the regular service of minibus might be an effective solution to increase public mode users and reduce energy consumption.

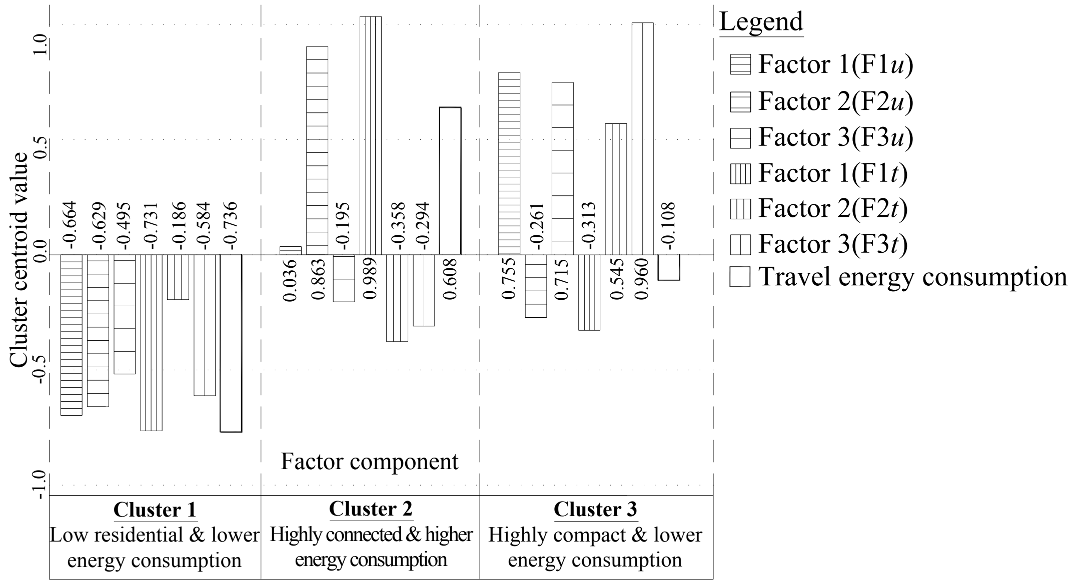

Figure 2.17 Cluster centroid values from the analysis including factor components of urban data, mode choice and energy consumption variables

2.5.3.3.3 Cluster 3- Highly Compact and Lower Energy Consumption

Cluster 3 is characterized by strong positive input for non-motorized and mass transit (0.960), followed by compact zone (D1 and D2; 0.755) and higher transit accessibility (D5; 0.715) as in Figure 2.17. This result indicates that compact planning with better transit accessibility encourage walking, bicycling and use of public transport mode. This effects in shifting of transport mode away from private mode (-0.313) that is more effectively reduce travel energy consumption (-0.108).

This study suggests that to promote public transport mode (bus and rail) in a sustainable way, the strategies like park-and-ride and bicycle sharing system need to implement. Otherwise, a number of taxi users might be increased which is not good for sustainable energy efficient planning due to higher energy intensity of taxi compare to bus and rail. The increasing percentage of taxi users (F2*t*) indicates that travel energy consumption could be increased soon in the zones of cluster 3 (30%; Figure 2.18). In the case of Fukuoka, further, we suggest that park-and-ride is feasible for high dense and far from CBD zones whereas bicycle sharing system is feasible in business zones.

2.5.4 Conclusion

This study applied 5 dimensions of urban form (5Ds: density, diversity, design, destination accessibility and distance to transit) to explore the influence of urban form on travel and travel energy consumption at a micro-scale level; studying entire Fukuoka city via 108 zones.

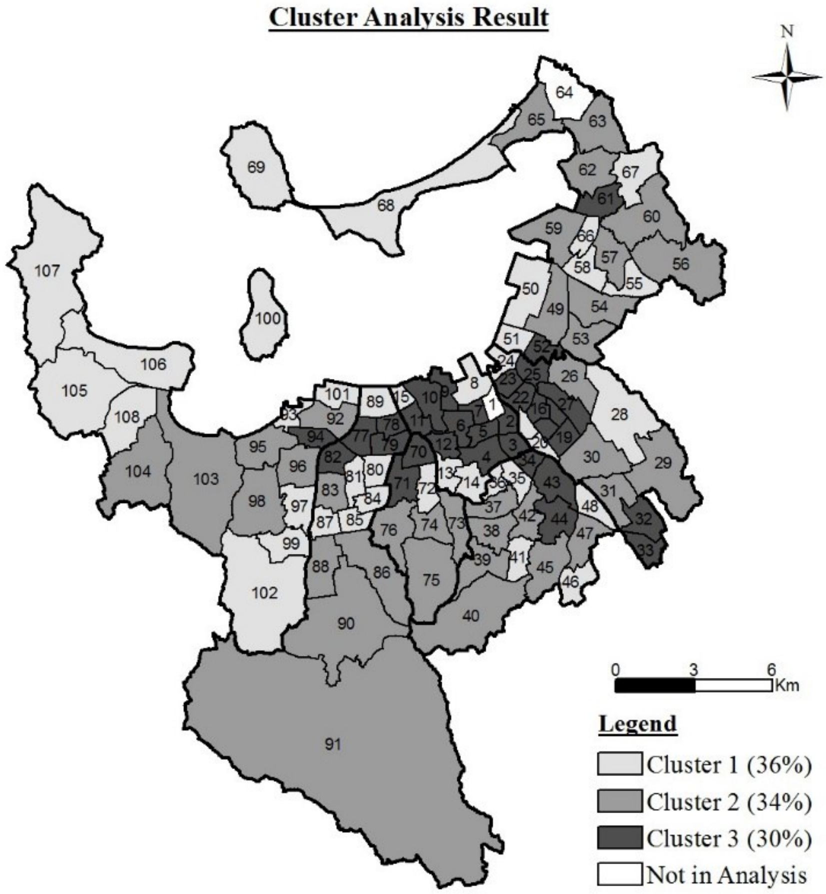

Figure 2.18 Cluster analysis result

The following are the three major findings of this research: First, cluster 1 revealed that residential zone has a direct effect on travel energy consumption. Second, the results of cluster 2 show that less compact (density D1 and diversity D2), poor transit accessibility (D5), further away CBD (D4) and highly connected zone (D3) results in increase in private mode use and rise in energy consumption due to high energy intensity of private vehicle and longer travel distance. Third, cluster 3 highlights that only compact zones; higher density (D1) and greater land use mix (D2) are not effective to reduce private mode use and travel energy consumption but simultaneously need to improve transit accessibilities (D5). This cluster also suggests that such type of planning strategy encourage walk, to use bicycle and park-and-ride. So, the findings of this study have significant planning implication concerned with cities which are under a rapid urbanization and motorization process.

2.6 Effect of Urban Form and Socio-Demography on Travel Behavior and Travel Energy Consumption at Trip Origin and Trip Destination

2.6.1 Introduction

A transition towards energy efficient cities requires an effective upgrade of individual travel behavior as it plays a huge role in reducing travel energy consumption on a city level. According to Fox [47], travel behavior is a strategy by which individuals fulfill their needs and wishes by performing activities at various locations. As a matter of course, most households select residential locations at least partly based on their travel abilities, needs and preferences [48]. A review of studies on transportation and land use interactions indicates that the aspect of urban form that most influences travel behavior is the travel purpose. A number of papers concentrate on the travel behavior involved in particular types of travel purpose, for example, local shopping trip [49], journey-to-work trips [50], maintenance trips [51] and non-work travel [52]. As the travel activity plays an important role in influencing travel energy consumption at a city level, it cannot be neglected and it is better to consider all the travel purposes. Though many researchers examine the connection between the urban form and travel behavior, there has been relatively less attention to the influence of urban form on travel energy consumption. In addition, some papers discuss the use of a particular mode of transport whereas other papers used a travel survey to capture details of all travel modes used within a particular time period. However, the majority of papers deal with the use of either the car or public transport as the primary mode of transport [51]. A few papers focus on walking or cycling activities alone [53]. Chatman [52] studied the confounding influence of modal (auto, transit, walk/bicycle) preferences in the relationship between the urban form and non-work travel. In order to achieve an overview of energy consumption in a city, it is important to include all types of travel modes in a research.

The aim of this section is to identify the effect of urban form and socio-demography on travel behavior and travel energy consumption at trip origin and trip destination in Fukuoka city. This research has analyzed all types of travel purposes (work, study, business, private and return home) and travel mode types (Non-motorized: walk and bicycle; motorized: rail, bus, taxi, car, motorcycle and others) at both trip origin and destination, for understanding the influencing mechanism of urban form on travel energy consumption.

2.6.2 Objective

- To analyze empirically the flow of trip for different travel purposes at both trip origin and destination.
- To identify the effect of urban form and socio-demography on purpose wise non-motorized travel and motorized travel at the trip origin and destination simultaneously.
- To explore the effect factors of urban form and socio-demography on travel energy consumption while traveling for different purposes.

2.6.3 Research Methodology

This study mainly uses three types of data based on Fukuoka City: Urban data, Person Trip Survey (PTS) data and Energy intensity data (Figure 2.19). PTS is a person-based travel survey conducted every ten years by the Ministry of Land, Infrastructure and Transport (MLIT). Daily travel is collected using one-day trip diaries for all household members in selected households. As the PTS data 2007 is the latest survey data of Fukuoka, we collected urban form data and energy intensity data also from 2007 to get the research result more reliable and accurate.

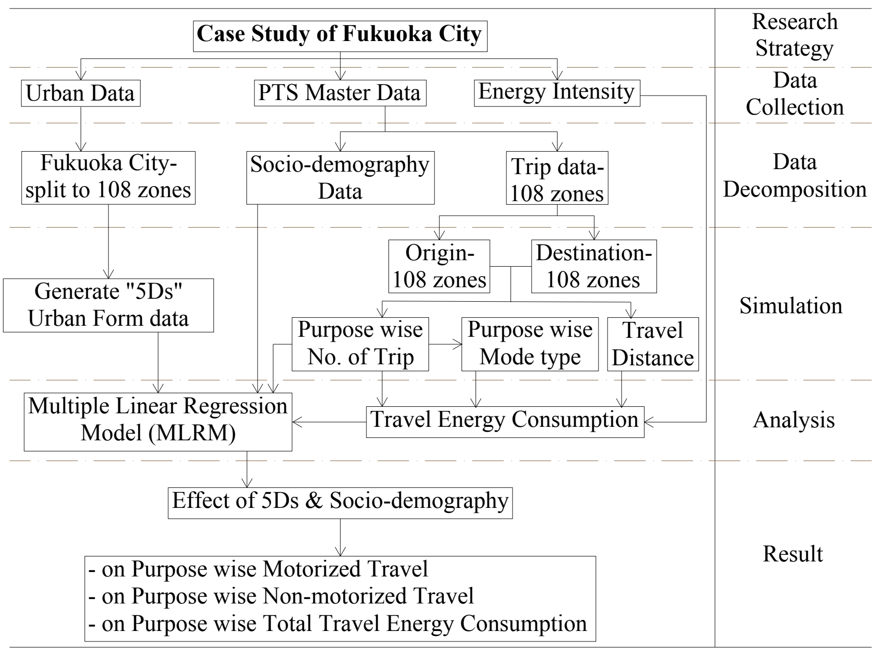

Figure 2.19 Research methodology

Urban data of Fukuoka city was decomposed into 108 zones as in Figure 2.19. Zones were referred to the PTS zone which is based on the zoning of Road traffic census held in 2005. In this research, Island City which is an artificial island built in Hakata Bay to boost the city's port functions has excluded because we had a travel data of it but the master data doesn't contain socio-demography(i. e. respondent from Island City is null). From PTS master data, socio-demography and trip data were extracted and decomposed into 108 zones. Trip data was further divided into the trip origin and trip destination. Energy intensity data was used to calculate total energy consumption for various travel purposes. Empirical Analysis and Multiple Linear Regression Model (MLRM) were applied as an analysis method. The empirical analysis was performed by using GIS and MLRM analysis was carried out by using statistical tool SPSS. It enables the identification and characterization of relationships among multiple variables. The analysis examined the effect of urban form attributes (5Ds) and socio-demography on purpose wise motorized travel, non-motorized travel and total travel energy consumption at trip origin and destination separately. This research covers 135,302 respondents and 5,559,737 total trips. This research only focused on the travel that was generated within the Fukuoka City.

2.6.4 Variables Analyzed

2.6.4.1 Dependent Variables

Dependent variables included travel behavior related variables (travel purpose and mode choice) and travel energy consumption at both trip origin and trip destination. Total travel energy consumption was calculated using a number of trips by each mode type for different purposes, travel distance and mode wise energy intensity as shown in Equation 2.5 in section 2.4.3. Travel purpose included the measure for work, study, business, private and return home. The mode choice has analyzed in term of non-motorized and motorized.

2.6.4.2 Independent Variables

Socio-demography variables (age, gender and occupation) and urban form attributes were independent variables for this research. Occupation was divided into 6 types (Agriculture, production, sales/ service, administrative, student and housewife/ others) based on PTS master data.

Table 2.6 Descriptive result summary

Variable			Mean	SD	Min	Max
Socio-Demography	Age		42.37	3.61	5.00	103.00
	Male		586.09	356.70	0.00	1,340.00
	Female		666.70	414.62	5.00	1,581.00
	Agriculture		0.62	1.84	0.00	13.00
	Production		5.18	3.81	0.00	27.00
	Sales & service		16.10	8.26	0.00	60.00
	Administrative		31.54	6.17	12.00	50.00
	Student		17.92	6.32	0.00	34.00
	Housewife/others		28.58	7.19	0.00	59.00
'5Ds' Urban form variables	D1	Population density (population per km^2)	2,965.10	1,642.92	2.20	8,827.70
		Household density (household per km^2)	69.59	51.31	0.57	204.53
	D2	Diversity (Land use mix index)	0.50	0.13	0.08	0.71
	D3	No. of road intersection 3-way	363.11	263.65	24.00	1,746.00
		No. of road intersection 4-way	87.54	45.83	4.00	218.00
	D4	Distance to CBD (km)	7.75	5.44	0.54	33.28
	D5	Bus Accessibility (bus stops per km^2)	5.48	3.35	0.00	22.38
		Rail Accessibility (influence of rail station per km^2)	0.30	0.32	0.00	0.98
at origin	Non-Motorized travel	Work trip	1,109.82	795.48	0.00	4,400.00
		Study trip	1,373.21	869.74	0.00	3,378.00
		Business trip	317.48	609.10	0.00	5,438.00
		Private trip	2,479.19	2,057.78	24.00	17,294.00
		Return home trip	4,103.43	2,429.75	105.00	12,822.00
	Motorized travel	Work trip	3,217.65	1,884.04	45.00	7,095.00
		Study trip	487.11	327.93	0.00	1,708.00
		Business trip	3,998.38	2,926.26	159.00	20,475.00
		Private trip	3,008.19	1,570.75	80.00	9,562.00
		Return home trip	5,645.37	7,391.80	108.00	72,387.00
at destination	Non-Motorized travel	Work trip	1,108.54	1,093.68	0.00	7,577.00
		Study trip	1,373.21	1,047.88	0.00	4,923.00
		Business trip	317.48	665.79	0.00	5,880.00
		Private trip	2,476.93	2,603.93	24.00	23,635.00
		Return home trip	4,106.80	2,387.70	28.00	9,525.00
	Motorized travel	Work trip	3,212.35	4,662.07	44.00	40,387.00
		Study trip	486.90	690.25	0.00	4,989.00
		Business trip	3,997.46	3,147.80	272.00	22,754.00
		Private trip	2,996.13	3,933.90	43.00	39,900.00
		Return home trip	5,663.43	3,341.16	27.00	11,866.00
Travel Energy Consumption (EC)	at origin	Work trip	29,649.53	21,257.43	111.79	82,974.38
		Study trip	3,174.37	3,719.64	0.00	31,735.05
		Business trip	52,415.86	32,993.37	2,794.05	157,342.8
		Private trip	25,771.02	24,414.20	691.26	237,688.2
		Return home trip	51,675.40	50,142.55	1,605.83	428,398.6
	at destination	Work trip	29,562.79	28,598.05	875.35	202,974.3
		Study trip	3,173.83	5,373.65	0.00	38,882.39
		Business trip	52,401.93	34,083.87	4,042.95	174,626.1
		Private trip	25,536.54	30,259.08	331.39	228,409.9
		Return home trip	52,024.09	42,680.81	12.17	307,855.3

While many different measures can be used to characterize the urban form but for this research, we used the measure- "5Ds" which is frequently used and accepted in most of the research [30,43,44]. 5Ds included density, diversity, design, destination accessibility and distance to transit. In this research, density (D1) was measured in terms of population density and household density. Diversity (D2) was measured by using land use mix index (Entropy) as shown in section 2.4.1.2, Equation (2). Design (D3) was taken as 3-way and 4-way road intersection, Destination accessibility (D4) was considered as the distance to Central business district (CBD). For this research, CBD is considered as the existing location of Fukuoka City Hall because this area has a higher transit accessibility, higher jobs and shopping opportunities. Distance to transit (D5) was measured as bus accessibility and rail accessibility. Descriptive result summary of each variable that is used in this research is shown in Table 2.6 below.

2.6.5 Analysis Results

The Empirical Analysis and Multiple Linear Regression Model (MLRM) analysis are applied for all the travel purposes separately. The analysis result of MLRM has been described here only which are identified as highly significant. With the MLRM analysis method, the explained *p*-value and the variance (R^2) at the different term are measured as a summary of model fit. The term which has *p*-value less than 0.05 and higher R^2 value is identified as statistically significant or better model fit. An independent variable that has significant (Sig.) value less than 0.05 is identified as a uniquely significant factor because changes in the independent variable's value are related to changes in the dependent variable. Likewise, standardized coefficient (SC) helps to compare different predictors to see which one is important. The negative sign of SC indicates that the independent variable is negatively associated with the dependent variable. This is vice versa for the positive sign.

2.6.5.1 Work Trip

2.6.5.1.1 Empirical Analysis for Work Trip

The empirical analysis showed that the trips for work purpose are generated from various zones but the destinations are almost the same zone i.e., zone 1 of Chuo-ku and zone 16 of Hakata-ku (Figure 2.20, 2.21). This is due to the fact that these zones are associated with the highly mixed land use area, higher bus accessibility and rail accessibility. Whereas the origin zones of work trip are found having higher proportion of residential areas with lower proportion of other facilities; indicating that origin zones for work trip are characterized as less mixed land use.

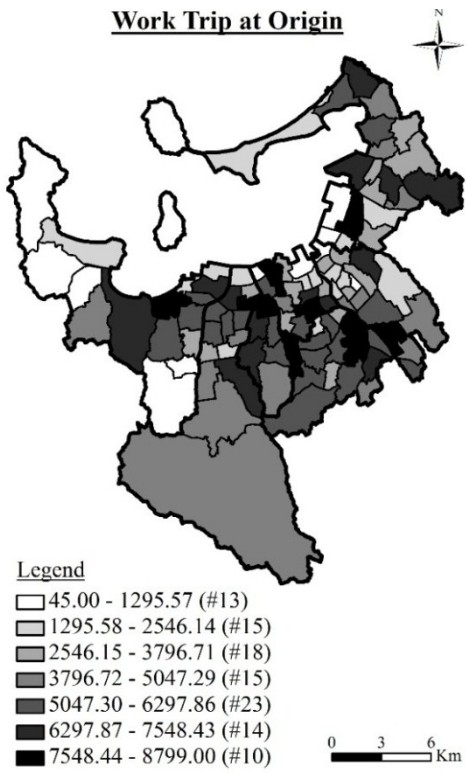

Figure 2.20 Work trip at origin

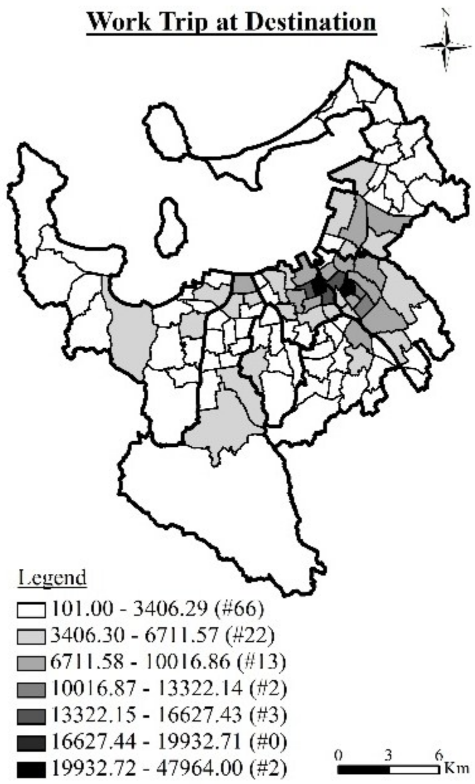

Figure 2.21 Work trip at destination

2.6.5.1.2 Multiple Linear Regression Model Analysis for Work Trip

Table 2.7 MLRM analysis for work trip

Work trip	Origin						Destination					
	Non-motorized		Motorized		EC		Non-motorized		Motorized		EC	
	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.
Population density	0.096	0.435	0.107	0.138	-0.053	0.525	-0.047	0.685	-0.057	0.668	-0.054	0.724
Household density	0.468	0.000	-0.132	0.061	-0.256	0.002	0.200	0.076	-0.031	0.812	-0.127	0.390
Land use mix	0.151	0.178	0.076	0.244	0.195	0.012	0.084	0.423	-0.006	0.960	0.126	0.362
3-way road intersection	0.006	0.966	0.042	0.591	0.451	0.000	0.212	0.096	0.110	0.457	0.183	0.278
4-way road intersection	0.327	0.006	0.237	0.001	0.160	0.044	0.104	0.339	0.164	0.195	0.192	0.183
CBD accessibility	-0.186	0.150	-0.091	0.224	-0.011	0.895	-0.084	0.485	-0.154	0.269	-0.296	0.064
Bus accessibility	-0.025	0.788	-0.023	0.667	-0.028	0.653	0.579	0.000	0.583	0.000	0.340	0.004
Rail accessibility	-0.018	0.824	-0.004	0.938	-0.039	0.477	0.112	0.141	0.104	0.239	0.092	0.360
Age	0.111	0.278	-0.100	0.097	-0.121	0.084	0.110	0.249	0.156	0.161	0.106	0.401
Male	-0.231	0.540	0.801	0.000	0.361	0.160	0.201	0.567	0.176	0.667	-0.128	0.783
Female	0.488	0.168	-0.129	0.528	0.068	0.775	-0.256	0.436	-0.372	0.331	-0.156	0.719
Agriculture	-0.006	0.978	-0.164	0.168	-0.147	0.285	-0.020	0.916	0.111	0.614	-0.002	0.994
production	-0.170	0.675	-0.326	0.169	-0.068	0.804	-0.061	0.871	0.267	0.545	0.112	0.823
Sales	-0.422	0.644	-0.587	0.273	0.021	0.973	-0.220	0.796	0.583	0.557	-0.081	0.943
Administration	-0.350	0.608	-0.406	0.307	0.016	0.972	-0.272	0.669	0.297	0.688	-0.106	0.900
Student	-0.405	0.570	-0.487	0.243	-0.049	0.920	-0.429	0.519	0.237	0.759	-0.192	0.828
Others	-0.587	0.468	-0.389	0.409	0.096	0.861	-0.450	0.550	0.193	0.825	-0.473	0.635
p-value		0.000		0.000		0.000		0.000		0.000		0.000
R^2		0.671		0.888		0.849		0.714		0.612		0.498
Freedom F(17,90)		10.783		42.076		29.783		13.200		8.368		5.244

Note: SC means Standardized regression coefficient, ▢ means negative association, ▢ means positive association and Sig. means Significance, ▢ means Sig. < 0.05.

The regression result for work trip (Table 2.7) showed better model fit for motorized travel at origin with 89% of the variance (R^2=0.888, *p*-value<0.000). It meant that urban form and socio-demography variables of origin for work trip are found more influencing factor for motorized travel. D3 (4-way road intersection) is identified as a significant factor for work-related motorized travel. This suggests that road intersection has an important role for the increase of work-related motorized travel at origin which is also supported by the positive sign of SC.

There has been a range of studies shows that better road connectivity resulted in walking and cycling. So the result of this research is different. This is due to the fact that the workplaces in Fukuoka City are further away from the residential location so there is no significant relation to the road design at the origin. The negative sign of SC showed that the urban form variables; D1 (household density), D4 (distance to CBD) and D5 (bus and rail accessibility) are inversely associated with work-related motorized trip at origin; indicating that people living closer to CBD tend to drive more. Poor accessibility to transit has a key role in increasing work-related motorized travel at origin due to a longer travel distance tend to drive or park-and-ride that results in increase of work-related motorized travel.

Similarly, in terms of work-related energy consumption (Table 2.7), the model is found significant at origin with 85% of the variance (R^2=0.849, p-value<0.000). This suggests that reduction in work-related motorized travel and energy consumption is associated with factors at trip origin where D1 (household density), D2 (land use mix) and D3 (road intersection) are identified as the major affecting factors for reducing work-related travel energy consumption at origin. The negative sign to household density showed that people living in a low household dense area tend to consume more travel energy; it is likely due to the unavailability of work opportunities near residential areas. The positive sign of SC to land use mix and road intersection indicates that even the trip origin has a higher mix of land use and a better road connectivity, there has no significant influence on the work-related travel energy consumption. This suggests that whether or not there is a balance of land use types at work trip origin is irrelevant to people's choice of workplace and travel mode and thereby irrelevant to the travel energy consumption. The work-related non-motorized travel showed a better model fit at trip destination with 71% of the variance (Table 2.7). D5 (bus accessibility) is uniquely significant. It suggests that to encourage non-motorized travel, planning implications need to focus on transit accessibility at work destination.

2.6.5.1.3 Analysis of Socio-Demography Variables for Work Trip

The negative sign of SC showed that age has negative relation with work-related motorized travel and energy consumption, indicating that older people tend to travel a short distance (Table 2.7). Male population is significantly associated with motorized travel, suggesting that females tend to travel less than males. This is due to the fact that female often works near home to balance their job and family responsibilities. This is also consistent with our result where female showed negative relation to motorized travel. As for occupation, sales and administrative affairs are found positively associated with travel energy consumption which explains that those with highly educated individuals and office workers tend to use motorized mode.

2.6.5.2 Study Trip

2.6.5.2.1 Empirical Analysis for Study Trip

The trips for study purpose are found generated from most of the residential zones (Figure 2.22). The analysis showed that these zones are also worked as destination for study trip which meant that people are traveling a shorter distance for study (Figure 2.23). It also indicates that the educational institutions mainly primary schools are decentralized throughout in Fukuoka City.

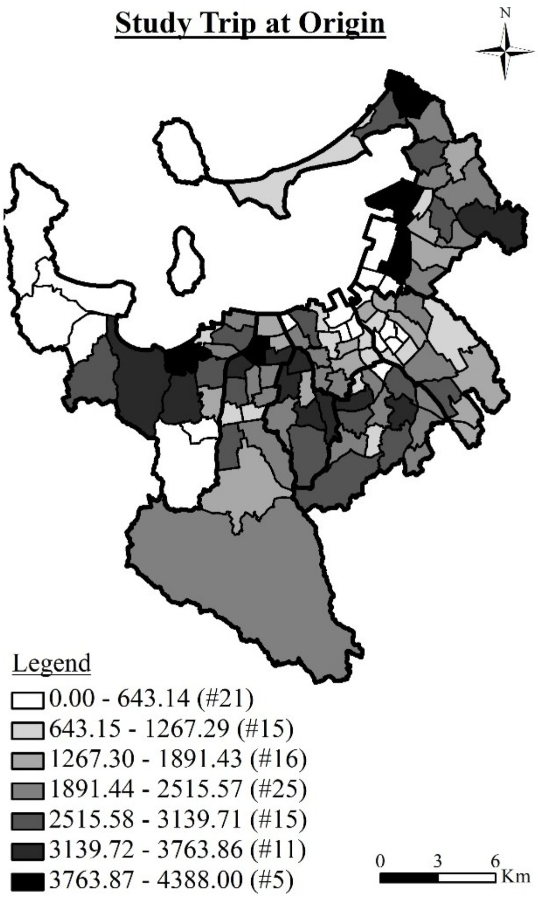

Figure 2.22 Study trip at origin

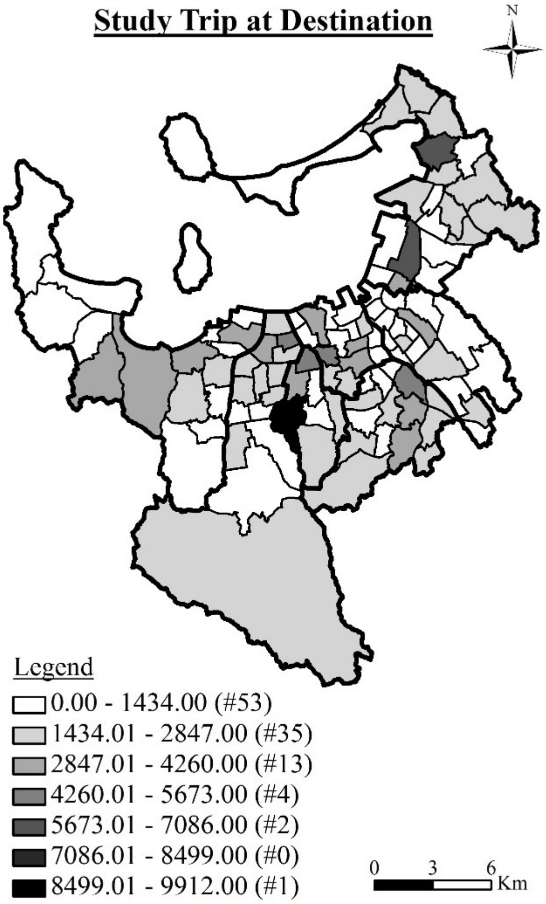

Figure 2.23 Study trip at destination

2.6.5.2.2 Multiple Linear Regression Model Analysis for Study Trip

From the regression result (Table 2.8), it is found that study trip is vital for non-motorized travel with 89% of the variance (R^2=0.885) at origin. D3 (4-way road intersection) and D4 (Distance to CBD) are found significant factors for study-related non-motorized travel which meant that road connectivity, as well as CBD accessibility are key indicators of non-motorized mode use for study trip. In fact, rise in road intersection results rise in a smaller block size. Smaller block size indicates better road connectivity and that is friendly for non-motorized travel. In terms of CBD accessibility, the positive sign of SC showed that closer to the CBD area, people tend to use non-motorized mode. This is likely to the fact that surrounding areas of CBD have comparatively more educational facilities. The positive sign of SC showed that D1 (population density), D3 (4-way road intersection) and D5 (bus accessibility) have a positive relation with study-related non-motorized travel. This indicates that the residential area with higher density, better road connectivity and easy access to bus services are likely to have shorter travel distance which can be traveled by walk, bicycle and park-and-ride. Similarly, the result (Table 2.8) showed that study-related motorized travel at origin has 76% of the variance (R^2=0.761) whereas energy consumption has only 47% (R^2=0.47). This meant people tend to use school bus/ shuttle for a shorter distance.

Table 2.8 MLRM analysis for study trip

Study trip	Origin						Destination					
	Non-motorized		Motorized		EC		Non-motorized		Motorized		EC	
	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.
Population density	0.009	0.900	-0.154	0.144	-0.347	0.028	-0.162	0.250	-0.329	0.068	-1.904	0.060
Household density	-0.084	0.236	-0.116	0.257	0.004	0.977	-0.081	0.553	0.167	0.336	1.154	0.252
Land use mix	-0.026	0.699	0.067	0.485	0.069	0.628	0.137	0.284	0.216	0.185	0.334	0.739
3-way road intersection	-0.093	0.247	0.038	0.740	0.076	0.660	0.151	0.332	0.368	0.064	1.522	0.132
4-way road intersection	0.183	0.009	0.318	0.002	0.258	0.083	0.130	0.327	-0.029	0.862	0.150	0.881
CBD accessibility	-0.197	0.011	-0.097	0.375	0.039	0.811	-0.164	0.264	-0.035	0.849	0.358	0.721
Bus accessibility	0.068	0.213	-0.052	0.507	-0.116	0.324	-0.015	0.890	-0.018	0.895	-0.078	0.938
Rail accessibility	-0.091	0.060	0.110	0.115	0.108	0.297	0.274	0.004	0.479	0.000	3.744	0.000
Age	0.015	0.799	-0.103	0.238	-0.119	0.361	-0.064	0.581	0.056	0.706	0.512	0.610
Male	0.780	0.001	0.633	0.051	0.798	0.098	0.391	0.364	0.215	0.694	0.118	0.906
Female	-0.048	0.817	-0.020	0.948	-0.273	0.541	0.150	0.709	-0.004	0.995	0.383	0.703
Agriculture	-0.241	0.046	-0.154	0.374	0.051	0.844	-0.273	0.239	-0.062	0.834	-0.724	0.471
production	-0.469	0.052	-0.199	0.564	0.208	0.687	-0.547	0.239	0.042	0.943	-0.016	0.987
Sales	-0.857	0.115	-0.259	0.740	0.656	0.572	-1.139	0.276	-0.005	0.997	-0.239	0.811
Administration	-0.763	0.060	-0.219	0.706	0.522	0.546	-0.814	0.296	0.049	0.960	-0.206	0.837
Student	-0.442	0.296	-0.138	0.820	0.421	0.642	-0.741	0.363	0.041	0.969	-0.211	0.833
Others	-0.734	0.126	-0.148	0.829	0.690	0.501	-0.870	0.346	-0.030	0.979	-0.239	0.812
p-value		0.000		0.000		0.000		0.000		0.005		0.014
R^2		0.885		0.761		0.470		0.572		0.309		0.282
Freedom F(17,90)		40.745		16.885		4.686		7.073		2.366		2.084

Note: SC means Standardized regression coefficient, ☐ means negative association, ☐ means positive association and Sig. means Significance, ☐ means Sig. < 0.05.

2.6.5.2.3 Analysis of Socio-Demography Variables for Study Trip

The result showed that as the age of student rise, increase in non-motorized travel whereas a decrease in motorized travel and energy consumption at trip origin (Table 2.8). This might due to the fact that small aged children are usually dropped by their parents or that students are sent to school by school bus/shuttle. However, the result is opposite in the case of destination whereas the age of student rise, non-motorized travel decreases and motorized travel, as well as energy consumption increased. It indicates that primary education is available at a walkable distance from home location but for higher education, one needs to travel a longer distance.

2.6.5.3 Business Trip

2.6.5.3.1 Empirical Analysis for Business Trip

The empirical result for business trip at both origin and destination showed that almost the same travel pattern at both trip ends which meant people are traveling a short distance for business purpose (Figure 2.24, 2.25). Zone 1 of Chuo-ku and 16 of Hakata-ku are identified as highly traveled zones for business purpose. It is due to the fact that these zones are associated with the highest rank of land use mix, bus and rail accessibility.

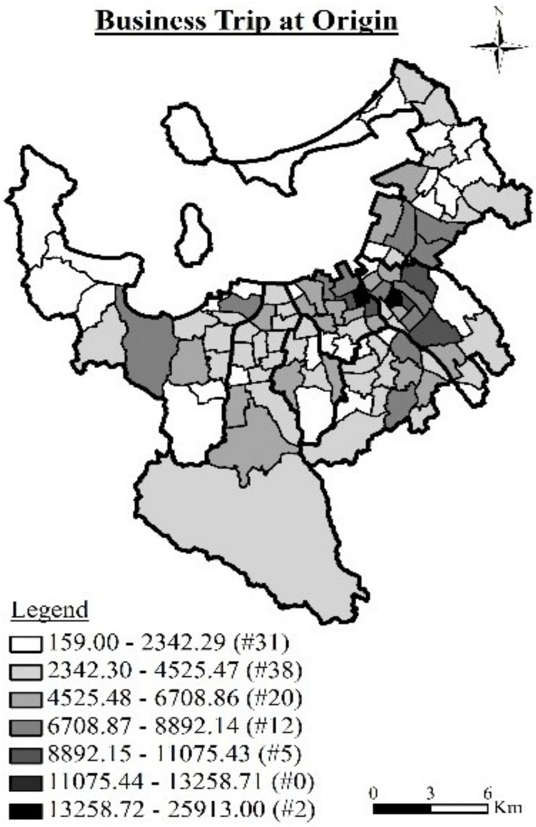

Figure 2.24 Business trip at origin

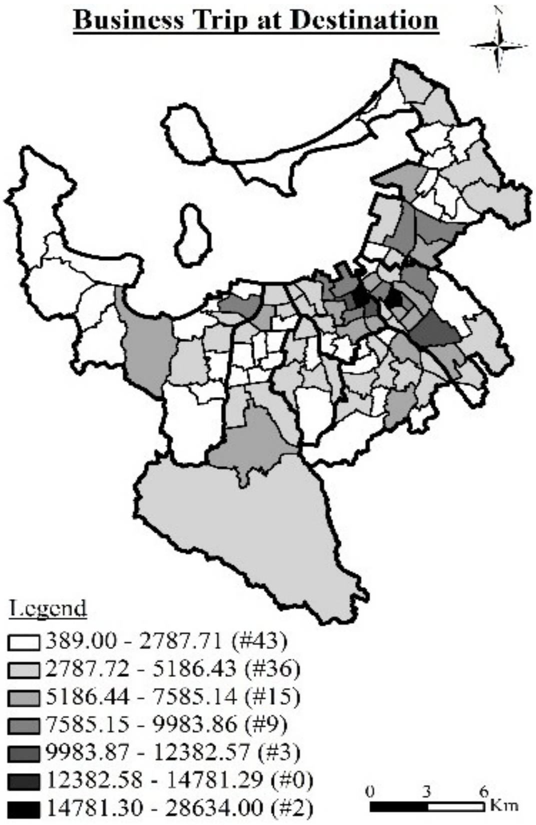

Figure 2.25 Business trip at destination

2.6.5.3.2 Multiple Linear Regression Model Analysis for Business Trip

The regression result for business trip showed better model fit for non-motorized travel at both trip origin and trip destination with 67% of the variance (Table 2.9). That meant people are not traveling a longer distance for business purpose with motorized mode so the effect of urban form and socio-demography are found very low on business-related travel energy consumption. D5 (bus accessibility) was found uniquely significant which meant that access to bus stops acts as the proxy indicator of increase or decrease in business-related non-motorized travel. Similarly, for business-related motorized travel also, D5 (bus accessibility) is found uniquely significant (Table 2.9). Here it is important to note that D5 is an important effect factor of urban form for business-related motorized and non-motorized travel. In terms of energy consumption, the model is significant only at origin with 41% of the variance. D5 (bus accessibility) is found uniquely significant at trip ends. The negative sign of SC showed that D1 (population density) and D4 (distance to CBD) are inversely related to business-related energy consumption. This result suggests that higher population density even though further away from CBD has potential to reduce business-related travel energy consumption if better transit accessibility is available.

Table 2.9 MLRM analysis for business trip

Business trip	Origin						Destination					
	Non-motorized		Motorized		EC		Non-motorized		Motorized		EC	
	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.
Population density	-0.060	0.625	-0.138	0.355	-0.280	0.093	-0.050	0.685	-0.112	0.449	-0.255	0.160
Household density	0.057	0.636	0.069	0.633	0.136	0.396	0.053	0.654	0.029	0.839	0.089	0.611
Land use mix	-0.095	0.399	0.039	0.775	0.004	0.980	-0.090	0.419	0.038	0.777	0.032	0.845
3-way road intersection	0.115	0.399	0.187	0.256	0.413	0.025	0.130	0.335	0.134	0.413	0.213	0.284
4-way road intersection	0.108	0.353	0.255	0.072	0.277	0.078	0.117	0.311	0.180	0.198	0.163	0.336
CBD accessibility	-0.041	0.752	-0.385	0.015	-0.334	0.055	-0.013	0.918	-0.291	0.061	-0.158	0.400
Bus accessibility	0.735	0.000	0.418	0.000	0.216	0.084	0.730	0.000	0.433	0.000	0.272	0.047
Rail accessibility	0.084	0.301	0.060	0.541	0.036	0.738	0.091	0.259	0.130	0.185	0.124	0.296
Age	0.170	0.099	0.182	0.144	0.049	0.722	0.161	0.115	0.105	0.396	0.027	0.855
Male	0.212	0.576	0.483	0.291	0.668	0.189	0.194	0.604	0.305	0.502	0.428	0.438
Female	-0.285	0.419	-0.378	0.376	-0.355	0.453	-0.310	0.375	-0.264	0.534	-0.147	0.775
Agriculture	0.254	0.212	-0.091	0.711	-0.265	0.331	0.258	0.202	-0.000	0.999	-0.259	0.383
production	0.469	0.250	-0.226	0.645	-0.457	0.402	0.473	0.241	-0.023	0.963	-0.355	0.550
Sales	1.096	0.233	-0.648	0.559	-1.241	0.313	1.154	0.205	-0.302	0.784	-1.319	0.325
Administration	0.679	0.320	-0.656	0.427	-0.998	0.276	0.737	0.277	-0.319	0.697	-1.002	0.315
Student	0.603	0.400	-0.739	0.393	-1.186	0.217	0.630	0.374	-0.506	0.555	-1.248	0.233
Others	0.717	0.376	-0.872	0.373	-1.231	0.257	0.783	0.329	-0.506	0.602	-1.339	0.258
p-value		0.000		0.000		0.000		0.000		0.000		0.008
R^2		0.670		0.517		0.407		0.676		0.525		0.297
Freedom F(17,90)		10.745		5.673		3.640		11.060		5.843		2.240

Note: SC means Standardized regression coefficient, ☐ means negative association, ☐ means positive association and Sig. means Significance, ☐ means Sig. < 0.05.

2.6.5.3.3 Analysis of Socio-Demography Variables for Business Trip

The regression analysis result revealed that there is no significant relation with socio-demography variables in all the terms (non-motorized travel, motorized travel and energy consumption) for business trip (Table 2.9). The positive sign of SC explained that male population is positively associated with non-motorized travel, motorized travel and energy consumption indicating that male population tends to travel more for business purpose than females.

2.6.5.4 Private Trip

2.6.5.4.1 Empirical Analysis for Private Trip

The trips for private purpose are found generated almost from every zone where zone 1 of Chuo-ku is identified as the main destination (Figure 2.26, 2.27). It showed that people are traveling a longer distance for private trip where the trip destinations are found CBD surrounding area. This is likely due to the fact that closer to the CBD is relative to the availability of shopping and entertainment facilities.

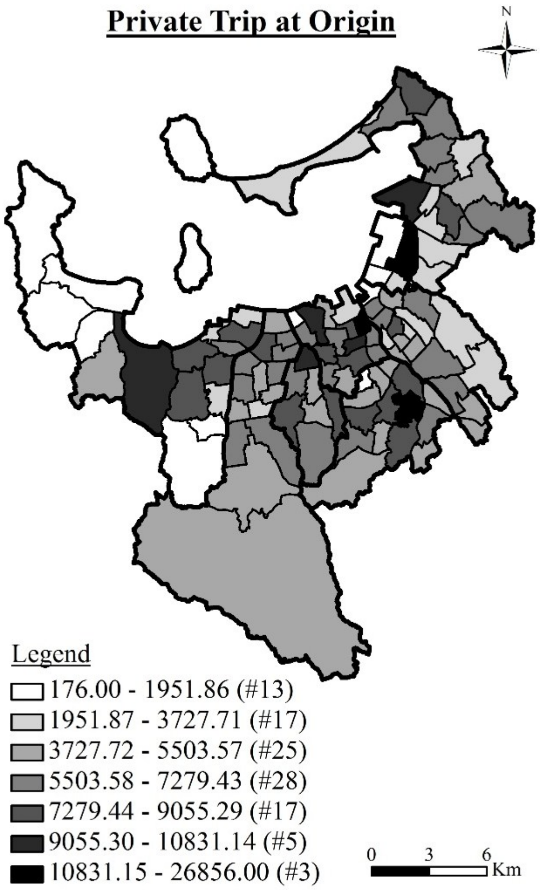

Figure 2.26 Private trip at origin

2.6.5.4.2 Multiple Linear Regression Model Analysis for Private Trip

The result of the regression demonstrated that private trip model (Table 2.10) is a better fit for motorized travel at origin with 73% of the variance (R^2=0.731, *p*-value<0.000). It suggests that reduction in motorized travel is associated with the affecting factors of private trip at origin where D3 (4-way road intersection), D4 (distance to CBD) and D5 (bus accessibility) are found uniquely significant which meant that these variables of urban form are influencing factors for private trip-related motorized travel. D4 (Distance to CBD) is found negatively associated with motorized travel at origin which meant that people living closer to the CBD tend to travel more by motorized mode for private purpose. Energy consumption for private trip is found significant only at origin; however, there is not found any unique significance in relation with independent variables (Table 5). The negative sign of SC to D1 (population density and household density) showed inverse relation with private trip-related motorized travel and energy consumption at trip origin, indicating that less dense area is associated with longer private trip distance, increase of motorized travel and energy consumption. In the case of private trip-related non-motorized travel, somewhat surprisingly, the result showed that as D1 (population density) and D2 (land use mix) increase, non-motorized travel decreased (Table 2.10). This can be explained by the fact that D1 and D2 at both trip ends have no significant influence on the private trip-related non-motorized travel. This is consistent with our intuition, whether or not there is a balance of land use types near the home location is irrelevant to people's choice of travel for private purpose.

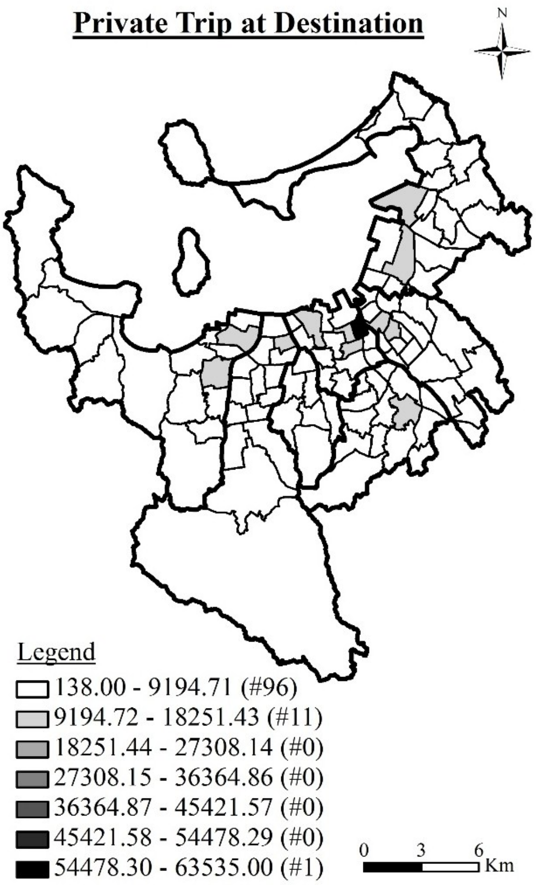

Figure 2.27 Private trip at destination

Table 2.10 MLRM analysis for private trip

Private trip	Origin						Destination					
	Non-motorized		Motorized		EC		Non-motorized		Motorized		EC	
	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.
Population density	-0.075	0.546	-0.131	0.241	-0.312	0.067	-0.079	0.563	-0.099	0.517	-0.281	0.116
Household density	0.125	0.306	-0.182	0.095	-0.063	0.701	0.021	0.872	-0.143	0.334	-0.045	0.794
Land use mix	-0.093	0.412	0.048	0.638	0.053	0.726	-0.089	0.469	-0.087	0.528	-0.028	0.862
3-way road intersection	-0.041	0.766	0.198	0.108	0.015	0.934	0.001	0.992	0.100	0.551	0.081	0.679
4-way road intersection	0.155	0.189	0.246	0.021	0.223	0.161	0.033	0.799	0.085	0.554	0.087	0.602
CBD accessibility	0.072	0.580	-0.233	0.047	0.115	0.511	0.152	0.285	0.065	0.680	0.156	0.397
Bus accessibility	0.670	0.000	0.469	0.000	0.103	0.418	0.764	0.000	0.810	0.000	0.541	0.000
Rail accessibility	0.095	0.249	0.044	0.549	0.090	0.420	0.045	0.618	0.009	0.932	0.108	0.355
Age	0.052	0.618	0.032	0.730	-0.085	0.546	0.030	0.789	-0.010	0.937	-0.114	0.439
Male	0.416	0.278	0.434	0.205	0.225	0.663	0.668	0.111	0.360	0.440	0.316	0.561
Female	0.044	0.902	0.110	0.729	0.313	0.516	-0.246	0.526	-0.179	0.680	0.042	0.934
Agriculture	0.181	0.380	0.105	0.568	0.038	0.892	0.249	0.267	0.180	0.472	0.109	0.709
production	0.300	0.466	0.332	0.366	0.294	0.596	0.483	0.281	0.432	0.389	0.369	0.527
Sales	0.729	0.432	1.072	0.197	0.847	0.499	1.108	0.274	1.033	0.361	0.913	0.488
Administration	0.553	0.423	0.702	0.256	0.603	0.518	0.838	0.266	0.768	0.362	0.645	0.511
Student	0.331	0.648	0.716	0.269	0.495	0.612	0.583	0.459	0.532	0.546	0.421	0.682
Others	0.615	0.452	0.997	0.174	0.855	0.439	0.932	0.296	0.891	0.372	0.860	0.459
p-value		0.000		0.000		0.000		0.000		0.000		0.003
R^2		0.662		0.731		0.385		0.600		0.498		0.319
Freedom F(17,90)		10.359		14.370		3.314		7.933		5.261		2.484

Note: SC means Standardized regression coefficient, ▢ means negative association, ▢ means positive association and Sig. means Significance, ▢ means Sig. < 0.05.

2.6.5.4.3 Analysis of Socio-Demography Variables for Private Trip

Similar to business trip, in the model for private trip also there is no significant relation with socio-demography variables (Table 2.10). The negative sign showed that age has the inverse relation with private trip-related energy consumption at both trip origin and destination. It indicates that old aged people tend to travel less and at a shorter distance.

2.6.5.5 Return Home Trip

2.6.5.5.1 Empirical Analysis for Return Home Trip

It is remarkably found that zone 1 of Chuo-ku and 16 of Hakata-ku are highly indicated as an origin for return home whereas almost all zones are found as the destination (Figure 2.28, 2.29). All the zones which were origin for work trip and private trip are found as the destination for return home.

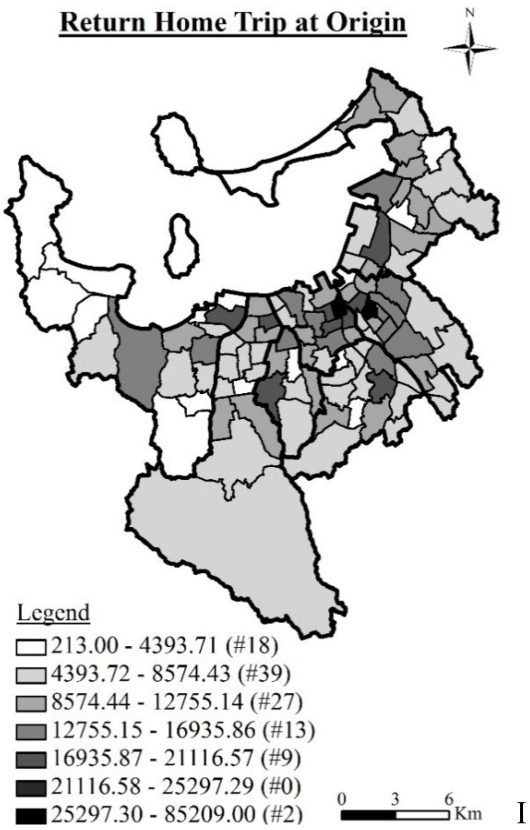

Figure 2.28 Return home trip at origin

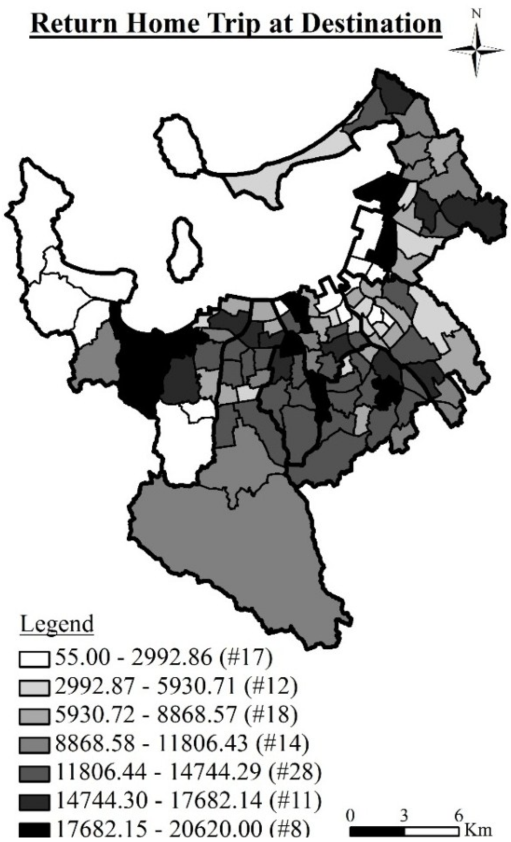

Figure 2.29 Return home trip at destination

2.6.5.5.2 Multiple Linear Regression Model Analysis for Return Home Trip

Table 2.11 MLRM anlysis for return home trip

Return Home trip	Origin						Destination					
	Non-motorized		Motorized		EC		Non-motorized		Motorized		EC	
	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.	SC	Sig.
Population density	-0.106	0.359	-0.109	0.442	-0.222	0.178	0.025	0.763	0.019	0.777	-0.215	0.055
Household density	0.068	0.546	-0.076	0.580	-0.054	0.735	0.206	0.012	-0.149	0.025	-0.124	0.250
Land use mix	0.114	0.281	-0.036	0.779	0.023	0.875	0.046	0.541	0.069	0.265	0.117	0.246
3-way road intersection	0.150	0.240	0.136	0.385	0.168	0.353	-0.103	0.263	0.098	0.191	0.260	0.035
4-way road intersection	0.025	0.819	0.135	0.311	0.158	0.305	0.217	0.007	0.253	0.000	0.213	0.043
CBD accessibility	-0.020	0.870	-0.048	0.744	-0.075	0.658	-0.130	0.137	-0.141	0.048	0.048	0.678
Bus accessibility	0.444	0.000	0.711	0.000	0.528	0.000	0.022	0.732	-0.011	0.835	-0.049	0.553
Rail accessibility	0.145	0.060	0.101	0.277	0.161	0.138	-0.031	0.579	-0.032	0.472	0.013	0.855
Age	0.007	0.944	0.079	0.501	0.024	0.857	0.041	0.556	-0.083	0.143	-0.117	0.206
Male	0.668	0.062	0.254	0.557	0.156	0.755	0.320	0.212	0.528	0.012	0.363	0.286
Female	-0.010	0.977	-0.274	0.497	-0.116	0.804	0.446	0.064	0.142	0.463	0.179	0.572
Agriculture	-0.067	0.723	0.158	0.498	0.086	0.749	-0.125	0.363	-0.098	0.377	-0.014	0.938
production	-0.176	0.643	0.392	0.400	0.336	0.532	-0.347	0.208	-0.144	0.517	0.198	0.587
Sales	-0.377	0.661	0.878	0.404	0.600	0.621	-0.708	0.255	-0.089	0.858	0.663	0.421
Administration	-0.307	0.631	0.588	0.452	0.384	0.671	-0.574	0.215	-0.063	0.865	0.495	0.420
Student	-0.469	0.484	0.429	0.600	0.229	0.809	-0.531	0.273	-0.074	0.849	0.422	0.511
Others	-0.355	0.639	0.578	0.532	0.300	0.779	-0.642	0.242	0.072	0.871	0.703	0.334
p-value		0.000		0.000		0.000		0.000		0.000		0.003
R^2		0.710		0.567		0.419		0.849		0.901		0.734
Freedom F(17,90)		12.944		6.936		3.825		29.741		48.229		14.572

Note: SC means Standardized regression coefficient, [light grey box] means negative association, [white box] means positive association and Sig. means Significance, [dark grey box] means Sig. < 0.05.

Return home trip showed a better fit model for motorized travel at destination location (Table 2.11). It is obvious that trip generated with motorized travel is more likely to end up or return home also by motorized mode. This is satisfied with the regression result from work trip (89% of the variance on motorized travel) and private trip (73% of the variance on motorized travel). D1 (household density), D3 (4-way road intersection) and D4 (distance to CBD) are found uniquely significant for return home trip-related motorized travel at destination whereas D5 (bus accessibility) is found uniquely significant for both motorized travel and energy consumption at origin. This meant that people living in a residential area with better bus accessibility and services are attracted to the destination which has higher household density and a better road connectivity that encourage them to walk, cycling and park-and-ride. This suggests that return home trips are made at longer distance and it also indicates that to encourage public transit and reduce energy consumption, D5 plays a significant role.

2.6.5.5.3 Analysis of Socio-Demography Variables for Return Home Trip

The male population was found uniquely significant for motorized trip at destination/residential location, indicating that males have a higher propensity to effect on motorized travel (Table 2.11). The negative sign of SC to the subject of age at home location showed inverse relation to motorized travel and energy consumption indicating that older people tend to travel less. It might be due to their retired life, they don't have to go to work, or driving may simply more difficult than taking public transport.

2.6.6 Discussion and Conclusion

This research provides additional insights into the linkage among built environment, five different purpose-related non-motorized travel, motorized travel and travel energy consumption by applying Empirical analysis and Multiple Linear Regression Model (MLRM) analysis methods. This research results adequately responded to the objectives that were set out in section 2.6.2.

The empirical analysis used in this research is based on the trip generation to perform activities at diverse locations. It concludes that the work trip and study strip predominantly generate from higher residential areas. Travel destinations for work, business and private purposes are identified closer to central business district (CBD) that are associated with a highly mixed land use, higher bus and rail accessibility. Regarding travel distance, the results suggest that travel for work, private and return home purposes, people travel a longer distance while a shorter distance travel for study and business purpose.

The analysis results presented in section 3 support the second and third objectives of this paper. This research confirms that reduction in motorized travel and energy consumption is possible with higher population and household density (D1) at work trip origin but simultaneously need to improve Transit accessibility (D5). It meant that even work destinations are further away from the CBD, it consumes low travel energy due to the likelihood of taking transit modes rather than private cars. Furthermore, the finding suggests that higher land use mix (D2) does not have a direct effect on reducing work-related travel energy consumption, however; it has a direct effect on the increase in non-motorized travel at work destination which indirectly supports to decrease work-related travel energy consumption at destination.

Similarly, this research confirms that increase in non-motorized travel is associated with study trips. The empirical result showed that most of the study trips are originate and traveled to the same zone which indicates that people prefer shorter travel distance for study purpose. The regression result showed that higher road intersections (D3) significantly affect in non-motorized trip as it provides better road connectivity and that is friendly for non-motorized travel. However, study trip shows an affect on the increase in motorized travel, it does not show significant influence on travel energy consumption which suggests that people tend to use school bus/ shuttle for a shorter distance. Also, the current policy in Fukuoka City that requires pupils to choose schools in their living areas is found effective to reduce study-related travel energy consumption. The result suggests that the effective policies and strategic planning concerning school locations in Fukuoka City would be significant planning implication concerned with the city which is under a rapid urbanization and motorization process.

The empirical result showed that the origin and destination for business trip are mostly to the CBD surrounding areas and it is also found that for business purpose, people use high energy intensity transport mode (private car and taxi). This is one of the reasons for higher energy consumption in CBD areas. Non-motorized travel is found comparatively more significant for business trip. So, business-related energy consumption can be reduced by increasing non-motorized travel where bus accessibility (D5) is identified significant factor.

Private trip showed comparatively low significant on travel energy consumption, suggesting that a research on energy consumption on the basis of private trip is statistically insignificant but it is significant for accounting number of trips of motorized travel and non-motorized travel due to influencing factors of urban form and socio-demography. This empirical result shows that the most of the private trips are generated in the areas where higher bus accessibility (D5) and traveled to CBD surrounding areas, indicating bus system covers most of the Fukuoka area that attracts people to take a bus for private trip.

The empirical analysis of return home showed that most of the origin zones are the zones of destination for work trip and private trip. The result concludes that a reduction in motorized travel and energy consumption is associated with higher density (D1) at trip destination but need to improve transit accessibility (D5) at both trip ends. This result is satisfied with the result of work and private trip model analysis. The result highlights that residential location is an influencing factor for travel mode choice and energy consumption.

2.7 Influencing Mechanism Analysis of Urban Form on Travel Energy Consumption Evidence from Fukuoka Using MLRM Analysis

2.7.1 Introduction

Compared to abundant studies on the connections between urban form and mode choice using socio-economic factors as controlling variables, studies on the influences of travel purpose are rare. Unless it is individual travel to perform any activity, there is apparently no use of mode choice and no travel energy consumption for that individual. In this regard, socio-demography factors do not show much evidence on this matter. Different types of travel purposes are different by nature and generate various travel patterns that further affect mode choice and travel energy consumption. There are considerable differences in the transport mode used for different purposes [54]. To some extent, the types of purpose could represent the types of destination locations. So, the research result by using Multiple linear regression model (MLRM) analysis in section 2.6 did not show much difference in the influencing factor at trip origin and trip destination. Due to these reasons, the research framework established in section 2.6 was realized the need to revise so that the research result sounds better methodology and more conclusive.

Therefore, this study aims to understand the relationships between urban form, mode choice and travel energy consumption in a more logical and systematic way to provide additional insights into how urban form affects travel energy consumption. The analysis method to achieve this aim is threefold: first, this research analyzes the relationship between urban form on travel mode choice (non-motorized mode, motorcycle, car, bus and rail) by using travel purpose (work trip, study trip, business trip and private trip) as the controlling variable. Second, it analyzes the relationship between mode choice on travel energy consumption by using travel distance as the controlling variable. Third, it analyzes the interrelationship between urban form, mode choice and travel energy consumption and further identifies the influencing factors of travel energy consumption.

2.7.2 Database Construction and Analysis Method

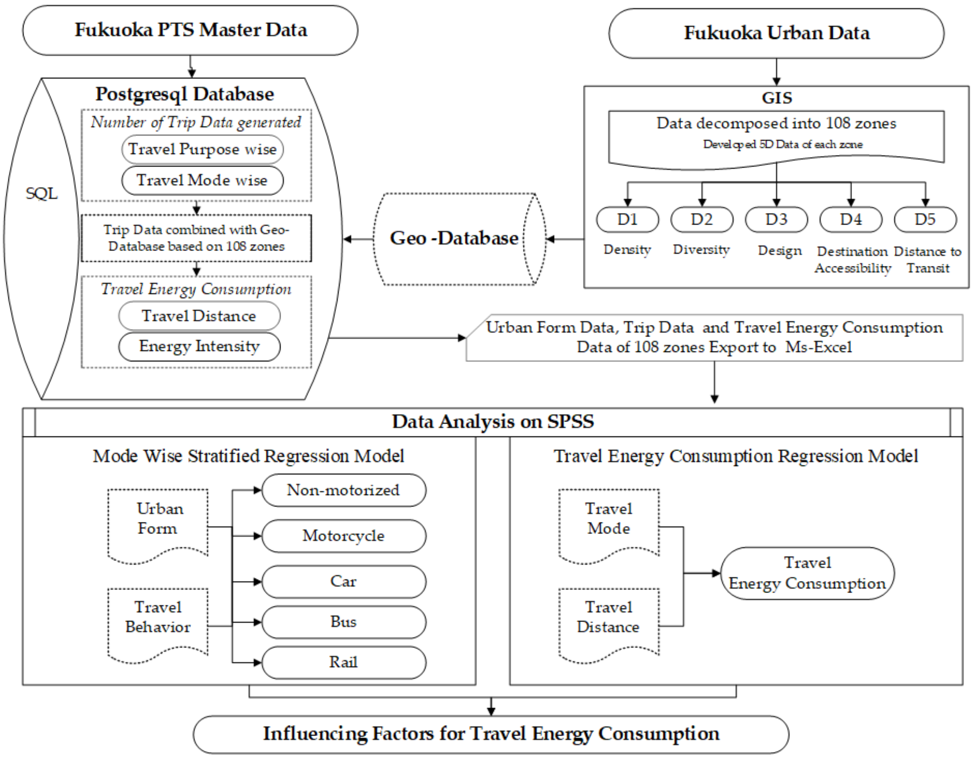

Figure 2.30 Database construction and analysis method

After collecting and simulating the required data as explained in section 2.4, we constructed the database including urban form, travel behavior and travel energy consumption for each of the 108 zones for analysis purposes (Figure 2.30). To create the geo-database including all the 5Ds of each of the 108 zones, we collected various variables of urban form (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit) and processed it in GIS. The created geo-database was utilized to get an overview of the data and management of the data. The database was then inserted into the Postgresql database, version 9.3; to combine with PTS master data (Figure 2.30). The PTS master data was inserted into the same Postgresql database in which urban data (5Ds) of 108 zones were presented. The number of trips (travel purpose wise and travel mode wise) was calculated using SQL (Structural Query Language). The total number of trips included in this research is 3,451,683. The calculated trip data was combined based on 108 zones. Using this trip data of 108 zones and additional variables of travel distance and energy intensity factor for travel mode, travel energy consumption of each zones was estimated.

The constructed information of each of the 108 zones (urban form, travel behavior and travel energy consumption) was exported to MS-Excel in order to make it importable in SPSS and further to apply the Multiple Linear Regression Model (MLRM) analysis. The data analysis was conducted by using the statistical software package SPSS 23.0. In this research, two separate MLRMs were performed. In the first phase of MLRM, urban form variables (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit) and trip behavior variables (trip for work, school, business, private) were chosen as independent variables where travel mode choice is used as a dependent variable. In the second phase of MLRM for energy consumption, the independent variables consist of mode choice for travel (non-motorized, motorcycle, car, bus and rail) and travel distance. The dependent variable is total travel energy consumption. Variable selection is carried out on the basis of literature review and a good understanding of travel behavior so as to develop a regression model that is robust and to explain dependent variables y.

MLRM was applied as an analysis method because it is widely recognized and the most popular model to analyze when many factors may have relationships with dependent variables. In this research, dependent variables 'y' is identified as mode choice variables (Table 2.13) and travel energy consumption (Table 2.14). 'y' involve the effect of large number of factors (independent variables x_i). In MLRM, dependent variable is described as a linear function of independent variables x_i, as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + \varepsilon$$ **Equation 2.6**

where,

y = Dependent variable
x_i = Independent variable (i = 1, 2, … n)
β_0 = Constant (y-intersect)
β_i = Regression coefficient of the variable x_i (i = 1, 2, … n)
ε = Error (in Multiple Linear Equation, error term assumed to be zero)

The slope β of the regression line is called the regression coefficient. It provides a measure of the contribution of the independent variable x towards explaining the dependent variable y. So, this unstandardized coefficient is useful for predicting things in the real world. The coefficient of determination R^2 (Table 2.13, Table 2.14) is a measure of how well the regression model describes the observed data. The general rule of thumb is that the number of samples or observations should be at least 20 times greater than the number of variables under study. So this study satisfies the rule of thumb.

We checked the models of both mode-wise stratified and travel energy consumption for possible multicollinearity between the independent variables using VIFs (variance inflation factor) and found that it was not a problem as VIFs < 10 [55] and also Tolerance > 0.2 [56] is satisfactory. However, for work trips, tolerance was found to be 0.152, which is nearly 0.2 if we consider a round figure. Therefore, we decided not to exclude this variable from the model. The tested result is shown in Table 2.12.

Table 2.12 Multicollinearity test

Stratified Mode Choice Models			Travel Energy Consumption Model		
Independent Variables	Collinearity Statistics		Independent Variables	Collinearity Statistics	
	Tolerance	VIF		Tolerance	VIF
Density (D1)	0.379	2.635	Non-motorized mode	0.345	2.896
Diversity (D2)	0.425	2.356	Motorcycle	0.451	2.215
Design (D3)	0.293	3.418	Car	0.433	2.311
Destination Accessibility (D4)	0.246	4.067	Bus	0.521	1.918
Distance to Transit (D5)	0.838	1.193	Rail	0.577	1.732
Work Trip (WT)	0.152	6.560	Travel Distance	0.757	1.322
School Trip (ST)	0.310	3.229			
Business Trip (BT)	0.362	2.764			
Private Trip (PT)	0.281	3.559			

2.7.3 Results

In this section, the summary of mode-wise regression analysis based on independent variables of urban form and controlling factor of travel variables are described. The results of the mode-wise stratified models by Multiple Linear Regression Models are shown in Table 2.13. Among the models, the model for non-motorized mode showed a better model fit with 90% variance (R^2 = 0.901, p-value < 0.000). All the models showed variation above 60%, which indicates a good model for each dependent variable. Here, we summarized only the significant association ($p < 0.001$, $p < 0.05$) of independent variables with mode choice.

The non-motorized regression model showed that density (D1) indicated significant positive association with non-motorized mode ($p = 0.000$). Design (D3), as measured by road intersection, is inversely predictive of non-motorized mode ($p = 0.035$). Destination accessibility (D4) is positively associated ($p = 0.05$). Among travel variables, work trip (WT), study trip (ST) and private trip (PT) are positively significant on non-motorized mode choice ($p = 0.000$), whereas business trip (BT) is inversely associated but has very low significance.

The regression result for motorcycle was 62% ($R^2 = 0.618$, p-value < 0.000). Among urban form variables, design (D3) and destination accessibility (D4) are significant for motorcycle use ($p < 0.05$). All the travel variables are positively associated with motorcycle use. However, only study trip (ST) and business trip (BT) are significant ($p < 0.05$).

The regression results for car showed 83% ($R^2 = 0.833$, p-value < 0.000). Density (D1) and design (D3) are significant ($p = 0.05$ for D1 and $p = 0.000$ for D3) for car use. Similar to motorcycle use, all the travel variables are positively associated with car use but significant only for study trip (ST) and business trip (BT) ($p < 0.05$).

The regression result for bus was 67% ($R^2 = 0.666$, p-value < 0.000). Only Density (D1) showed a significant effect ($p \leq 0.05$) on bus use among the urban form variables. Among travel variables, business trip (BT) and private trip (PT) are positively significant ($p = 0.004$ for BT and $p = 0.000$ for PT) on bus use.

The regression result for rail was 61% of ($R^2 = 0.612$, p-value < 0.000). Design (D3) showed significant inverse association with rail ($p = 0.000$). Similarly, the positively significant relation ($p < 0.05$) between destination accessibility (D4), which indicates that rail use is increased, as increase in distance from CBD. For rail use, all the trip purposes showed positive association with rail use but only work trip (WT) and business trip (BT) are significant ($p = 0.020$ for WT and $p = 0.000$ for BT).

Table 2.13 Mode wise stratified regression model

Independent Variables	Non-motorized mode			Motorcycle			Car			Bus			Rail		
	B	T	*p*	B	T	*p*	B	T	*p*	B	T	*p*	B	T	*p*
Constant	-2.387	-2.647	0.009	0.465	0.425	0.672	-0.349	-0.342	0.733	-0.525	-0.424	0.673	-2.023	-1.292	0.199*
Urban form variables															
Density (D1)	0.477	4.002	0.000**	-0.160	-1.104	0.272	-0.386	-2.862	0.005*	0.362	2.211	0.029*	0.067	0.324	0.747
Diversity (D2)	0.209	1.679	0.096	0.047	0.311	0.756	0.242	1.717	0.089	0.006	0.034	0.973	0.041	0.191	0.849
Design (D3)	-0.277	-2.135	0.035*	0.469	2.977	0.003**	0.669	4.556	0.000**	−0.215	−1.204	0.231	−0.856	−3.798	0.000**
Destination Accessibility (D4)	0.285	1.910	0.050*	-0.430	-2.379	0.019*	-0.253	-1.498	0.137	0.019	0.095	0.925	0.636	2.458	0.015*
Distance to Transit (D5)	0.147	1.472	0.144	0.089	0.735	0.464	-0.120	-1.058	0.293	0.261	1.905	0.060	0.200	1.155	0.251
Travel variables															
Work Trip (WT)	0.737	5.348	0.000**	0.156	0.931	0.354	0.230	1.474	0.144	−0.080	−0.424	0.673	0.565	2.359	0.020*
Study Trip (ST)	0.237	3.532	0.000**	0.198	2.115	0.036*	0.297	3.389	0.001**	−0.122	−1.146	0.255	0.077	0.572	0.568
Business Trip (BT)	-0.006	-0.086	0.932	0.203	2.290	0.024*	0.690	8.332	0.000**	0.295	2.935	0.004**	0.431	3.393	0.000**
Private Trip (PT)	0.508	4.547	0.000**	0.238	1.755	0.082	0.187	1.475	0.143	0.758	4.934	0.000**	0.260	1.341	0.183
Summary Statistics															
p-value			0.000**			0.000**			0.000**			0.000**			0.000**
R			0.949			0.786			0.913			0.816			0.782
R-square (R^2)			0.901			0.618			0.833			0.666			0.612

Note: B means Unstandardized regression coefficient, T means test coefficient, *p* means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

The regression model for travel energy consumption was 84% variance ($R^2 = 0.835$, p-value < 0.000) as shown in Table 2.14. This indicates a good model fit where car use and travel distance (TD) are positively significant ($p = 0.000$) with increase in travel energy consumption. However, non-motorized mode showed a significant inverse association ($p = 0.012$) with travel energy consumption.

Table 2.14 Travel energy consumption regression model

Independent Variables	Travel Energy Consumption		
	B	T	*p*
Constant	0.041	−2.640	0.010
Non-motorized mode	−0.122	−2.542	0.012 *
Motorcycle	0.107	1.577	0.118
Car	0.747	15.154	0.000 **
Bus	0.052	1.004	0.318
Rail	0.065	1.538	0.127
Travel Distance (TD)	0.424	5.263	0.000 **
Summary Statistics			
p-value			0.000 **
R			0.914
R-square (R^2)			0.835

Note: B means Unstandardized regression coefficient, T means test coefficient, p means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

2.7.4 Discussion

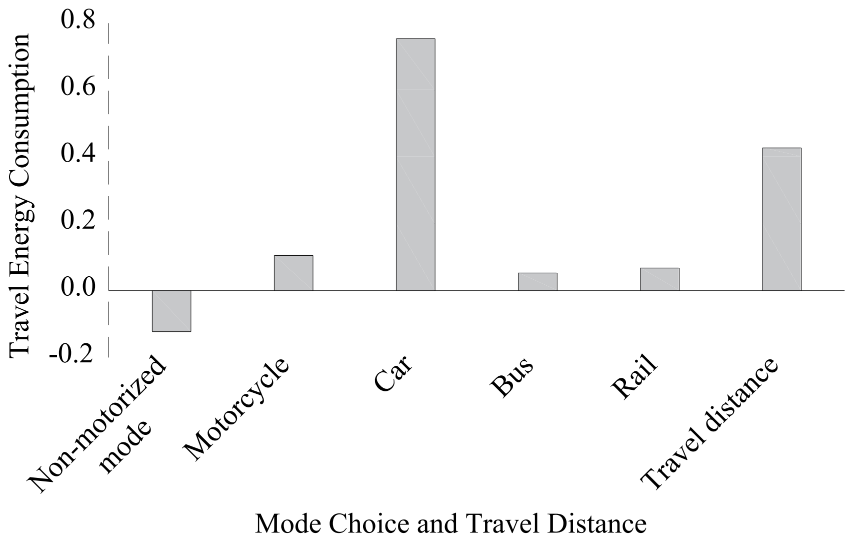

Figure 2.31 Effect of mode choice and travel distance on travel energy consumption

The model results of travel energy consumption indicate that private mode (motorcycle and car) and travel distance are major factors for increasing energy consumption (Table 2.14, Figure 2.31). This result is well known and seems obvious.

However, our research also highlights the influencing factors of travel energy consumption by analyzing the factors that affect mode choice (Table 2.13, Figure 2.32). The model results indicate that the effect of public mode (bus and rail) on energy consumption is very low compared to private mode (Table 2.14), though it is worth highlighting the factors that affect bus and rail use since non-motorized mode is not feasible for long-distance travel. Therefore, public mode is a better alternative to private mode when considering reduction of energy consumption.

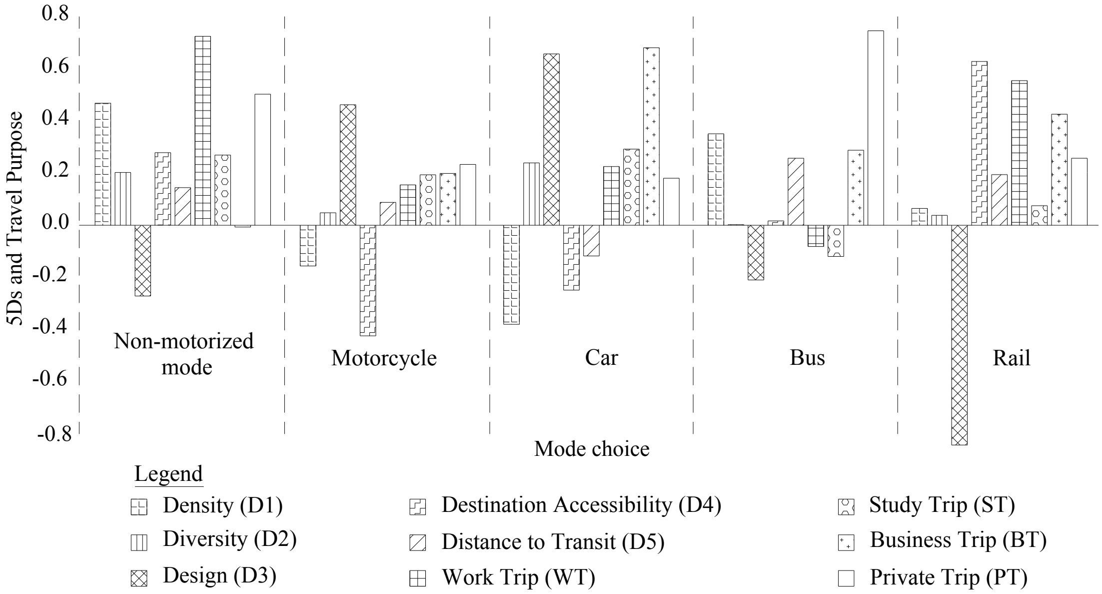

Figure 2.32: Effect of 5Ds and travel purpose on mode choice

Design (D3) is found to be the key factor for increasing private mode use and subsequently increasing energy consumption. More road intersections provide greater road connectivity and more routing options, which, in turn, attract people to use private mode for their convenience. This result is consistent with the research result by Stevens [57] who found that designing streets to make them more walkable is not effective. Also, the research by Marshall and Garrick [58] showed that increasing major road intersection density increases the amount of driving by approximately 1.3 km (0.8 miles) per person per day. However, this result is in contrast to that of Ewing and Cervero [25], who found that D3 had the largest influence on public mode use due to more routing options and short access distances. Therefore, this result highlights that road connectivity is not quite enough to encourage people to use public mode, but need to provide adequate numbers of bus stops and rail stations simultaneously at walking distances along extended routes.

The effect of density (D1) is negative for both car use and motorcycle use as expected: low density areas have a higher probability of using private modes. D1 was the key factor for promoting non-motorized mode. The result suggests that people tend to walk or use a bicycle in dense and higher land use mix areas (D2). High mixed land use areas create shorter distances that contribute to non-motorized mode. However, D2 does not show any supporting role for reducing private mode use. This suggests that whether or not there is a balance of residential, commercial, industrial, utility facilities and public open space, it is irrelevant for people's choice of using private mode. This is likely due to people not necessarily being employed or doing the shopping in the same area where they live. Therefore, only mixed land use planning is not an effective strategy for reducing private mode use but simultaneously need to consider influence of other urban form factors.

As for destination accessibility (D4), the shorter the distance to the CBD, the more use of private mode increased. This meant that private mode use is increased in and near the CBD areas. Conventional wisdom holds that as a distance to the CBD increased, travel distance by car increased. This does not appear to be the case once other variables are controlled.

This result showed that poor transit accessibility (D5) encourages people to drive a car. This is consistent with our intuition that unavailability of bus stops and rail stops at walking distance is likely to encourage use of private mode. D5 is not found significant for non-motorized modes at the individual level. However, when controlling other predictors, it showed the expected and meaningful result. According to Ewing and Cervero [25], in the case of the public mode, it almost always requires a walk at one or both ends of the trip. According to research of Stevens [57], the influence of distance to transit by walking is statistically significant. This result suggests that increasing non-motorized mode use is possible even in the areas further away from the CBD if it has higher density, higher land use mix, and better accessibility to transit. Also, the positive relationship between D5 and public mode use was consistent with the research findings of Ewing and Cervero [25], who found that public mode was the most sensitive mode to the distance to the nearest transit stop. Due to the very meaningful sign associated with D5 in Table 5, results of this research highlight that D5 is the factor that influences all mode choices; non-motorized mode, private mode and public mode.

This study suggests that to promote public mode, it is better to understand the influencing factors of individual public modes so as to make effective countermeasures accordingly. In this study, D1 and D5 are found to be influencing factors for bus use whereas D3 and D4 showed significant effect on rail use. However, most of the studies have combined bus and rail, under a single category: public mode [27].

Among the travel variables, business trip (BT) showed significant positive effect on both private mode and public mode. This means that higher BT increases the likelihood of driving a car and using public mode; however, the magnitude of the influence on bus and rail is significantly smaller than car. Also, the result showed that the car is used for shorter BT whereas public mode is used for longer BT. The reason for using car may be that BT does not follow the same routes every day. The salesman, for example, may be constrained by having to carry samples or by having to visit a number of destinations in a single day. Furthermore, in the case of using a car, it is more likely that the destination has poor transit accessibility. Use of motorcycle is almost same for all the purposes, which indicates that trip purpose does not have an effect on motorcycle use.

Increase in non-motorized mode is strongly related with increase in work trip (WT), study trip (ST) and private trip (PT). This is because of the concentration of various facilities in the dense and transit accessible areas. For reasons mentioned above, non-motorized mode is less used as BT increases.

It is found that people use bus more often for PT. Compared to rail, travel by bus takes more time possibly due to many stop points. Time is not a prime consideration in PT, because people travel for private purposes such as leisure activities when they have free time. This result is consistent with [59], who concludes that shopping and associated activities are linked closely to the use of public transportation. However, increase in rail use is found for WT, indicating that people living further away from CBD use rail to travel a longer distance for work purposes. In summary, trip purposes significantly influence travelers' mode choice behavior towards public mode. This indicated that interventional policy should be developed with respect to different trip purposes.

2.7.5 Conclusions

The rapid urbanizing and motorizing in Fukuoka indicate that travel energy consumption increases rapidly. The growing energy use of urban transport not only increases energy insecurity but also increases environmental pollution and negatively affects public health. Therefore, how to reduce travel energy consumption is becoming an increasingly important question in Fukuoka and also other cities that experience rapid urbanization and motorization. To identify the influencing factors for travel energy consumption, first, it is necessary to understand the interrelationship between urban form, travel behavior and energy consumption. Although past literature has extensively investigated the relationship between urban form and travel energy consumption, the result was less conclusive as the variables of urban form used for analysis were limited. This study included the urban form variables defined by the mostly widely used "5Ds" framework. These are Density (D1), Diversity (D2), Design (D3), Destination accessibility (D4) and Distance to transit (D5). A number of studies have analyzed the relationship between urban form and mode choice, but using travel purpose as a controlling variable is rare. This study attempts to analyze in a holistic manner, purely with the respect to travel behavior.

This study provided additional insights into the relationships between urban form, mode choice and travel energy consumption by applying the multiple linear regression model based on the 108 zones of Fukuoka City, Japan. This study dealt with these methodological challenges for modeling and analyzing the complex relationships between urban form (measured by 5Ds framework), travel purpose, mode choice, travel distance and energy consumption. In the first phase, we developed mode-wise stratified regression model and in the second phase, we developed a regression model of travel energy consumption. This paper analyzed the influencing factors of travel energy consumption, presented quantitative measures for travel energy consumption control in urban areas and also, provided theoretical support. This result is supportive for prediction of travel energy consumption in the case of Fukuoka city and also can be used as a reference for further research on how to reduce travel energy consumption via urban planning.

The study results find that 5Ds affect mode choice and travel energy consumption differently. Density (D1) influences non-motorized mode. The highest influencing factor for the increasing private mode was design (D3). The increase in road intersections provides better connectivity but the lack of bus stops and rail stations at a walking distance might stop people from using public mode and as a result, they tend to use private mode. Therefore, this study highlights that provision of bus stops and rail stations are essential with the increase in road connectivity to promote public mode, reduce private mode use and consequently reduce travel energy consumption. From a policy standpoint, the choice to promote an increase in transit stops might actually have no effect on transit use until and unless a density threshold is met, at which point it becomes necessary to provide transit service in the area.

In addition, the result indicates that the zones with low D1 and poor accessibility to public mode (D5) are found likely to increase car use. The findings suggest that even with long travel distance (TD), reduction of private car and promotion of public mode is observable if transit accessibility is better. The result showed that public mode use is higher as the CBD becomes further away, whereas private mode is highly used in the areas closer to the CBD. Therefore, policy strategies (e.g., parking charge, CBD entry tax) that aim at reducing private mode and travel energy consumption need to focus mainly in and around CBD areas. The findings show that the mixing of land uses (D2) is not effective in reducing private mode use and on travel energy consumption. The findings of this study may have important implications for policymakers and urban and transport planners to make effective countermeasures for reducing private mode use and travel energy consumption.

References

[1] Yang, J.; French, S. The travel-obesity connection: Discerning the impacts of commuting trips with the perspective of individual energy expenditure and time use. Environ. Plan. B 2013, 40, 617–629.

[2] United States Environmental Protection Agency (EPA). Available online: https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation (accessed on 3 November 2017).

[3] Ding, C.; Wang, Y.; Xie, B.; Liu, C. Understanding the Role of Built Environment in Reducing Vehicle Miles Traveled Accounting for Spatial Heterogeneity. Sustainability, 2014, 6(2), 589-601. doi:10.3390/su6020589

[4] Ewing, R.; Bartholomew, K.; Winkelman, S.; Walters, J.; Chen, D. Growing Cooler: The Evidence on Urban Development and Climate Change; Urban Land Institute: Washington, DC, USA, 2008.

[5] Hong, J., Shen, Q., Zhang, L. How do built environment factors affect travel behavior? A spatial analysis at different geographic scales. Transp. J. 2014, 41, 419–440.

[6] Neuman, M. The compact city fallacy. J. Plan. Educ. Res. 2005, 25, 11–26.

[7] De Abreu e Silva, J.; Golob, T.F.; Goulias, K.G. Effects of land use characteristics on residence and employment location and travel behavior of urban adult workers. Transp. Res. Rec. 2006, 1977, 121–131.

[8] Boarnet, M.G.; Crane, R. The influence of land use on travel behavior: specification and estimation strategies. Transp. Res. Part A , 2001, 35(9), 823–845.

[9] Cao, X.; Mokhtarian, P.L.; Handy, S.L. Neighborhood design and vehicle type choice: evidence from Northern California. Transp. Res. Part D 2006,11(2), 133–145.

[10] Cervero, R. Land uses and travel at suburban activity centers. Transp. Q. 1991, 45(4), 479–491.

[11] Ewing, R.; Cervero, R. Travel and the built environment: A synthesis. Transp. Res. Rec. Transp. Res. Board 2001, 1780, 87–114.

[12] Handy, S. Smart growth and the transportation-land use connection: what does the research tell us? Int. Reg. Sci. Rev. 28(2), 146–167 (2005)

[13] Kitamura, R.; Mokhtarian, P.L.; Laudet, L. A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. Transp. J. 1997, 24, 125–158.

[14] Krizek, K.J. Residential relocation and changes in urban travel: does neighborhood-scale urban form matter. J. Am. Plan. Assoc. 2003, 69(3), 265–281.

[15] Frank, L.D., Stone, B., Bachman, W. Linking land use with household vehicle emissions in the central Puget Sound: methodological framework and findings. Transp. Res. Part D 2000, 5(3), 173–196.

[16] Frumkin, H. Urban sprawl and public health. Public Health Rep. 2002,117, 201–217.

[17] Handy, S.; Boarnet, M.; Ewing, R.; Killingsworth, R. How the built environment affects physical activities: Views from urban planning. Am. J. Prev. Med. 2002, 23, 64–73.

[18] Shen, Q. Spatial and social dimensions of commuting. J. Am. Plan. Assoc. 2000, 66(1), 68–82.

[19] Maharjan, S.; Tsurusaki, N.; Divigalpitiya, P. Influencing Mechanism Analysis of Urban Form on Travel Energy Consumption—Evidence from Fukuoka City, Japan. Urban Science, 2018, 2(1), 15. doi:10.3390/urbansci2010015

[20] Pojani, D. and Stead, D. (2015). Sustainable Urban Transport in the Developing World: Beyond Megacities. Sustainability, 7(6), pp.7784-7805.

[21] ICLEI- Local Governments for Sustainability. Sustainable Urban Energy Planning, A hand book for cities and towns in developing countries. UN Habitat and UNEP, 2009.

[22] Cervero, R.; Kockelman, K. Travel demand and the 3Ds: Density, Diversity and Design. Transp. Res. D 1997, 2, 199–219.

[23] Frank, L.D.; Schmid, T.L.; Sallis, J.F.; Chapman, J.; Saelens, B.E. Linking objectively measured physical activity with objectively measured urban form: Findings from Smartraq. Am. J. Prev. Med. 2005, 28, 117–125.
[24] Frank, L.D.; Saelens, B.E.; Powell, K.E.; Chapman, J.E. Stepping towards causation: Do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? Soc. Sci. Med. 2007, 65, 1898–1914.
[25] Ewing, R.; Cervero, R. Travel and the built environment: A meta-analysis. J. Am. Plan. Assoc. 2010, 76, 265–294, doi:10.1080/01944361003766766.
[26] Chatman, D.G. Residential Self-selection, the Built Environment, and Non-work Travel: Evidence Using New Data and Methods. Environ. Plan. A 2009, 41, 1072–1089, doi:10.1068/a4114.
[27] Zhang, M. The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong. J. Am. Plan. Assoc. 2004, 70, 344–360, doi:10.1080/01944360408976383.
[28] Boarnet, M.G.; Michael, G.; Tracy, E.M. Walking, Urban Design, and Health: Toward a Cost-benefit Analysis Framework. JPER 2008, 27, 341–358, doi:10.1177/0739456X07311073.
[29] Comendador, J.; Floridea, D.C.; Maria, E.L.; Juan, C.G.P. Built environment and Social Capital variables influence on travel behavior: the case of two waves panel survey in Madrid. 2015. Available online: https://trid.trb.org/view/1336623 (accessed on 12 February 2018).
[30] Lee, G.; Jeong, Y.; Kim, S. Impact of individual traits, urban form, and urban character on selecting cars as transportation mode using the hierarchical generalized linear model. J. Asian Archit. Build. 2016, 15, 223–230, doi:10.3130/jaabe.15.223.
[31] Jiang, Y.; Zegras, P.C.; He, D.; Mao, Q. Does energy follow form? The case of household travel in Jinan, China. Mitig. Adapt. Strateg. Glob. Chang. 2015, 20, 701–718, doi:10.1007/s11027-014-9618-8.
[32] Choi, H.; Nakagawa, D.; Matsunaka, R.; Oba, T.; Yoon, J. Estimating the efficiency of transportation energy consumption based on railway infrastructure and travel behavior characteristics. Int. J. Railw. 2013, 6, 33–44, doi:10.7782/IJR.2013.6.2.033.
[33] Handy, S.; Cao, X.; Mokhtarian, P. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. Transp. Res. Part D 2005, 10, 427–444.
[34] Banister, D. Viewpoint: Assessing the reality-Transport and land use planning to achieve sustainability. J. Transp. Land Use 2012, 5, 1–14.
[35] Newman,W.G.; Kenworthy, J.R. Gasoline consumption and cities. J. Am. Plan. Assoc. 1989, 55, 24–25.
[36] Banister, D.;Watson, S.;Wood, C. Sustainable Cities: Transport, Energy, and Urban Form. Environ. Plan. B Plan. Des. 1997, 24, 125–143.
[37] Dunphy, R.T.; Fisher, K. Transportation, Congestion, and Density: New Insights. Transp. Res. Rec. J. Transp. Res. Board 1996, 89–96.
[38] Bhat, C.R.; Singh, S.K. A Comprehensive Daily Activity-Travel Generation Model System for Workers. Transp. Res. A 2000, 34, 1–22.
[39] Bhat, C.R.; Pozsgay, M.A. Destination Choice Modeling for Home-Based Recreational Trips: Analysis and Implications for Land-use, Transportation, and Air Quality Planning. Transp. Res. Rec. 2002, 1777, 7–54.
[40] Bhat, C.R.; Zhao, H. The Spatial Analysis of Activity Stop Generation. Transp. Res. B 2002, 36, 593–616.
[41] Frank, L.; Pivo, G. Impacts of Mixed Use and Density on Utilization of ThreeModes of Travel: Single-occupant Vehicle, Transit, and Walking. Transp. Res. Rec. 1994, 1466, 44–52.

[42] Kitamura, R.; Akiyama, T.; Yamamoto, T.; Golob, T. Accessibility in a metropolis: Toward a better understanding of land use and travel. Transp. Res. Rec. 2001, 1780, 64–75.
[43] Boarnet, M.G.; Joh, K.; Siembab,W.; Fulton,W.; Nguyen, M.T. Retrofitting the Suburbs to IncreaseWalking: Evidence from a Land-use-travel Study. Urban Stud. 2011, 48, 129–159.
[44] Lee, J.; Jin, N.; Lee, S. Built Environment impacts on Individual Mode Choice: An Empirical Study of the Houston-Galveston Metropolitan Area. Int. J. Sustain. Transp. 2012, 8, 447–470.
[45] Rogerson, P. Statistical Methods for Geography: A Student's Guide (3 ed.). Thousand Oaks, CA: Sage Publications Ltd, 2010.
[46] Song, Y.; and G. Knaap. Internally Connected, No Commercial, With a Touch of Open Space: The Neighborhoods of New Homes in the Portland Metropolitan Area. College Park, MD: National Center for Smart Growth Research & Education, University of Maryland, 2004.
[47] Fox, M. Transport planning and the human activity approach. J Transp Geogr. 1995, 3,105-116.
[48] Litman, T. Efficient vehicles versus efficient transportation. Comparing transportation energy conservation strategies. Transp. Policy 2005, 12, 121–129.
[49] Handy, S.L.; Clifton, K.J. Local shopping as a strategy for reducing automobile travel. Transportation 2001, 28, 317–346.
[50] Cullinane, S. The relationship between car ownership and public transport provision: A case study of Hong Kong. Transp. Policy 2002, 9, 29–39.
[51] Anable, J.; Gatersleben, B. All work and no play? The role of instrumental and affective factors in work and leisure journeys by different travel modes. Transp. Res. Part A Policy Pract. 2005, 39, 163–181.
[52] Chatman, Daniel G. How the Built Environment Influences Non-work Travel: Theoretical and Empirical Essays. Dissertation submitted in fulfillment of the Ph.D. in Urban Planning, University of California, Los Angeles, 2005. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.632.5209&rep=rep1&type=pdf (accessed on 25 April 2017).
[53] Cao, X.; Mokhtarian, P. L.; Handy, S. L. The impacts of the built environment and residential self-selection on nonwork travel: a seemingly unrelated regression approach. January 2006, Paper 06-1595 presented at the 85th Transportation Research Board Annual Meeting, Washington, DC,
[43] Boarnet, M.G.; Joh, K.; Siembab,W.; Fulton,W.; Nguyen, M.T. Retrofitting the Suburbs to IncreaseWalking: Evidence from a Land-use-travel Study. Urban Stud. 2011, 48, 129–159.
[44] Lee, J.; Jin, N.; Lee, S. Built Environment impacts on Individual Mode Choice: An Empirical Study of the Houston-Galveston Metropolitan Area. Int. J. Sustain. Transp. 2012, 8, 447–470.
[30] Lee, G.; Jeong, Y.; Kim, S. Impact of individual traits, urban form, and urban character on selecting cars as transportation mode using the hierarchical generalized linear model. J. Asian Archit. Build. 2016, 15, 223–230.
[54] Feng, J. The Built Environment and Active Travel: Evidence from Nanjing, China. Int. J. Environ. Res. Publ. Health 2016, 13, 301. [PubMed]
[55] Myers, R.H. Classical and Modern Regression with Applications, 2nd ed.; Duxbury/Thomson Learning: Pacific Grove, CA, USA, 1990; ISBN 978-0534380168.
[56] Menard, S. Applied Logistic Regression Analysis, 2nd ed.; Quantitative Applications in the Social Sciences; Sage University: Thousand Oaks, CA, USA, 2002; p. 106.

[57] Stevens, M.J. Does Compact Development Make People Walk and Use Transit? Available online:https://www.hendrix.edu/uploadedFiles/Departments_and_Programs/Business_and_Economics/AMAES/Stevens%20-%20MAER-Net.pdf (accessed on 2 May 2017).
[58] Marshall, W.E.; Garrick, N.W. Community design and how much we drive. J. Transp. Land Use 2012, 5, 5–21.
[59] Aditjandra, P.T.; Cao, X.; Mulley, C. Exploring changes in public transport use and walking following residential relocation: A British case study. J. Transp. Land Use 2016, 9, 77–95.

CHAPTER 3: INFLUENCE FACTOR OF URBAN FORM ON TRAVEL BEHAVIOR AND TRAVEL ENERGY CONSUMPTION BASED ON DEVELOPING COUNTRY- KATHMANDU CITY

3.1 Introduction

The transport sector, particularly in developing countries, plays a critical role in global energy consumption and greenhouse gas emissions reduction strategies [1]. In Kathmandu, energy consumption and pollutant emissions have increased annually with rapid urbanization and motorization, which has had a great impact on energy security, environment and people's living conditions. According to UN-Habitat report [2], Kathmandu is accounted for the highest share of energy consumption for transport sector. The rapid increase in motorization has negative impact on national economy as transport sector is increasingly reliant on imported petroleum fuel. Further, the total energy consumption in the Kathmandu Valley would grow at an average growth rate of 3.2% during 2005–2050 and a nearly 5 fold increase in CO_2 emissions [3]. Based on the recent trend, motorcycle and car ownership will increase continuously in the long run.

In addition to the threat of gasoline insecurity and financial burden, extensive transportation energy consumption also causes problems in the areas of public health and social equity. The study [4] showed that SO_2, NOx and Pb concentration higher than WHO standard in central part of Kathmandu. One of the major reasons for air pollution in the valley is the growing numbers of vehicles [5]. In the do-nothing scenario until 2020, 80% of roads inside the ring road of Kathmandu will be terribly congested restricting every activity, particularly in central area [6]. Therefore, it is necessary to identify various solutions to reduce the dependency on private modes and consumption of petroleum fuel for the energy security of the country. For this, the foremost important is to identify the influence factor of travel mode and travel energy consumption. Therefore, this chapter attempts to explore the influence factor of urban form on travel behavior and travel energy consumption in the case of Kathmandu by applying two separate analysis methods: Cluster analysis and Multiple Linear Regression Model (MLRM) analysis.

3.2 Rationale of Selection

Nepal is one of the top ten fastest urbanizing countries in the world [7]. Also, Nepal's largest urban conurbation- Kathmandu Valley is growing at 4 percent per year, one of the fastest growing metropolitan in South Asia [8]. It is the first region in Nepal to face the unprecedented challenges of rapid urbanization and modernization at a metropolitan scale [9]. The rapid urbanization, growing population and motorization in Kathmandu are causing the demand for energy to rise sharply. The vehicles registered in the Kathmandu valley comprises 66% of the total vehicles registered in Nepal [10,11] and out of the total registered vehicles, the highest share is covered by motorcycles (80%). Growing motorization has also led to a dramatic increase in financial burden due to over-reliance on the imported petroleum fuel, cause high levels of air pollution, public health degradation and increase in the number of pedestrian accidents.

Kathmandu city has traditionally been the city of walkers and its dwellers rely on walking, cycling and public transport for their daily travel. However, with the increase in motorization, limited attention has been paid to pedestrian and public transport facilities. Poor infrastructure forces most of the people to abandon cycling and public mode and use motorcycles instead. The current state of public transport services in Kathmandu does not serve the mobility needs of the population adequately. The research on Kathmandu [12] showed that the top three reasons behind not using public modes are time save in using private vehicle (26%), not on time (12.4%) and insecure (12.4%).

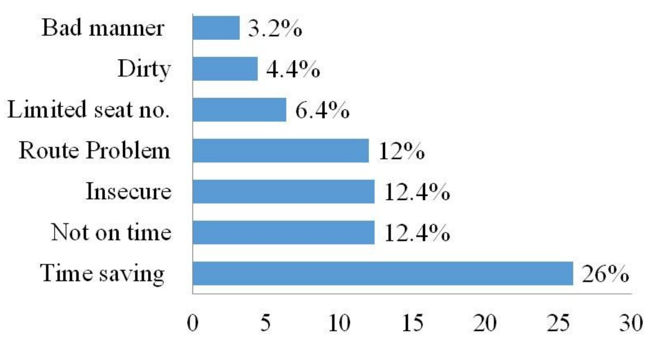

Figure 3.1 Reasons for not using public mode in Kathmandu

Though, we are living in the digital age (more than half of the Nepalese use smartphone today), its use in public transportation is still missing in Nepal. According to the news published in January 2018 [13], recently Nepal has launched a dual-language public transportation app with the aim of contributing to the digitization of Nepal's transportation system but its practical application by passengers is still far away from the reality as the app is still under working process.

Like in many developing countries in Asia, even with high motorcycles rates, Kathmandu still has high walking shares. But, those people who walk are found "captive pedestrians" because they cannot afford or access any other transport mode even if they wanted to [14]. Over the past 10 years, motorization has increased by 12% per year in Kathmandu [15], while the modal share of public transport has remained constant. Studies [16,17] in emission and energy consumption due to transport show an alarming picture of the Kathmandu Valley in the year 2020. The ever-increasing demand for petroleum has led growing concern on how to reduce travel energy consumption. Therefore, it is necessary to identify energy efficient alternative solutions to provide choices for energy decisions and developing energy efficient planning approaches for Kathmandu. So, this research selected Kathmandu as a case study area.

3.3 Introduction: Kathmandu City

Kathmandu City, the capital city of Nepal (Figure 3.2), is the most urbanized and high dense city in Nepal. Kathmandu lies in the Central development region of the country. The city covers the area about 51.94 km^2 with a size of 9.5 km in the east-west direction and 8.3 km in the north-south direction. It is the eldest metropolitan city of Nepal with a population around 1 million (985,000) as of 2011 census. According to The World Bank [18], Kathmandu has the highest population growth rate (4% per year). Kathmandu is the core of the largest urban agglomeration in the Kathmandu Valley, which includes other 4 major cities: Lalitpur, Bhaktapur, Kirtipur and Madhyapur Thimi. As Kathmandu is the central hub for education, employment, business and state administration, it attracts a continuous flow of people from other parts of the country. It is also the main gateway to the country's tourism industry. Kathmandu is divided into five sectors: Central, East, North, West and the City Core.

Administratively, the city is divided into 35 wards. For micro-scale analysis in this research, we analyzed entire Kathmandu via 35 wards.

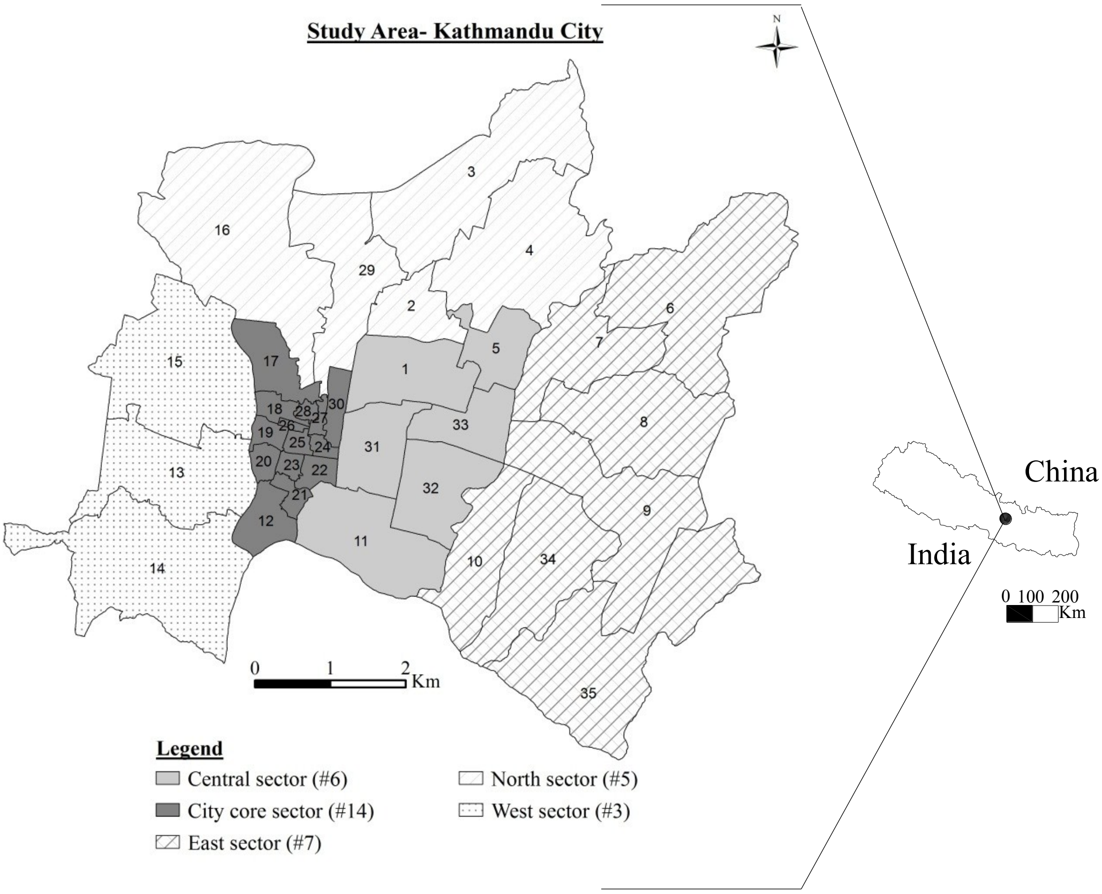

Figure 3.2 Study Area- Kathmandu City

3.4 Research Data Type and Source

The method to collect and simulate the required data is almost in a similar manner as performed in the Fukuoka case. Each dataset of urban form, travel behavior and travel energy consumption is explained below.

3.4.1 Urban Form Data

The urban form related data (population, household numbers, land use allocation, road networks, locations of transit stops and their networks) are collected from various sources and then developed GIS database for interpretation and analysis purpose. Urban form data are presented in terms of "5Ds" (density, diversity, design, destination accessibility and distance to transit). The descriptive results of all urban form related data are shown in Table 3.1.

Table 3.1 Descriptive result summary- urban form variables

	Mean	SD	Minimum	Maximum
	‘5Ds’ Urban form variables			
D1 (Density in terms of central tendency of population density and household density)	22,173.14	17,437.32	2,762.94	66,689.42
D2 (Diversity in terms of land use mix index)	0.41	0.21	0.09	0.86
D3 (Design in terms of central tendency of 3-way and 4-way road intersection)	135.90	84.14	29.00	282.00
D4 (Destination accessibility in km)	2.57	1.31	1.01	5.67
D5 (Distance to transit in terms of transit stops per km^2)	9.21	8.96	0.00	35.68
	Urban form variables used for measuring ‘5Ds’			
Population density (population per km^2)	35,539.54	28,144.75	4,391.74	108,514.72
Household density (household per km^2)	8,806.74	6,748.25	1,134.13	24,864.13
Residential (m^2)	885,362.39	913,775.18	4,547.82	2,644,265.20
Commercial (m^2)	32,508.53	36,262.75	4,490.96	144,103.54
Mixed use (m^2)	44,293.01	33,517.70	4,543.20	131,165.62
Industrial (m^2)	153,477.86	164,702.88	37,015.34	269,940.39
Utility facility (m^2)	138,550.80	196,674.94	755.53	662,813.78
Public open space (m^2)	37,167.66	64,622.59	2,116.34	323,452.89
No. of road intersection 3-way	255.42	157.40	54.00	532.00
No. of road intersection 4-way	16.37	12.95	2.00	49.00
No. of transit stops	14.71	14.05	0.00	52.00

3.4.1.1 Density (D1)

The population density and household density of Kathmandu were calculated based on the data; population number and household number that are published in National Population and Housing Census 2011[19]. National Population and Housing census 2011 is the latest data in Nepal as the census is carried out in every 10 years. To calculate population density, first, the area of each ward was calculated in GIS. Then, number of population in each ward was divided by the area of that ward which gives the population density ward wise. Equation 3.1 is utilized to compute population density. For household density, ward wise residential area was calculated in GIS. Then, using Equation 3.2, household density is calculated. The descriptive result in Table 3.1 shows that population density ranges from 4,391.74 to 108,514.72 person per km^2. The household density ranges from 1,134.13 to 24,864.13 household per km^2. The central tendency of population density and household density showing the mean value is 22,173.14.

Population density = No. of population/ Total area (km^2) **Equation 3.1**

Household density = No. of Household/ Residential area (km^2) **Equation 3.2**

3.4.1.2 Diversity (D2)

The recognized method land use mix index (entropy) is applied to calculate diversity by using Equation 3.3. In the case of Kathmandu, mainly 6 land use types were included. They are: residential, commercial, mix use, industrial, utility facility and public open spaces. The descriptive result in Table 3.1 shows that residential land use covers the highest share (885,362.39) followed by industrial (153,477.86) and utility facilities (138,550.80). In the case of Kathmandu, the entropy varies from minimum 0.09 to maximum 0.86.

$$\text{Land use mix index (Entropy)} = -\left\{\left(\sum_k \left(P_i \times \left(\ln p_i\right)\right)\right)/\ln(k)\right\} \quad \textbf{Equation 3.3}$$

where,

P_i = proportions of each of the land use types (in this research; residential, commercial, mix use, industrial, utility facility and public open spaces) of the total land area

k = number of land use types (in this research; 6)

3.4.1.3 Design (D3)

Design is calculated in terms of road connectivity by measuring number of road intersections as performed in the previous research [20-22]. 3-way and 4-way road intersections were calculated ward wise by using the Spatial Statistics tools in GIS. All the road width was included in the calculation, considering travel by walking and cycling as well. In Kathmandu, 3-way roads are higher than 4-way roads (Table 3.1). The central tendency of 3-way and 4-way road intersection is found 135.90.

3.4.1.4 Destination Accessibility (D4)

D4 is measured in terms of Central business district (CBD) as performed in the previous research [23,24]. In the case of Kathmandu, CBD is identified as the location of Old Bus Park in ward 31. All the transport within and outside the Kathmandu valley starts from Old Bus Park. So, it is a major bus terminal located at the heart of Kathmandu. Due to the transport centric, ward 31 is highly dominated by commerce, entertainment facilities, educational institutions, technical institutions which are engaged in training and equipping students for employment. For calculation of D4, the shortest travel distance to CBD is measured along the road center line by using OD Cost Matrix Analysis in GIS. Table 3.1 shows that the distance to the CBD ranges from 1.01 km to 5.67 km.

3.4.1.5 Distance to Transit (D5)

D5 measures ease of access to the transit or public mode. In Kathmandu, mainly three types of public modes are available. They are bus, micro and tempo (Photo 3.1-3.3). In the questionnaire survey, all these public modes were included. However, in the research part, these modes were combined under the name of public mode (transit) as the energy intensity of these modes does not show much difference.

To estimate transit accessibility (D5) based on various sources, first, we located all types of transit stops (bus, micro and tempo) where people get in and get off the transit in the GIS map of Kathmandu. After having the transit stops in the map (Figure 3.3), the total number of transit stops in each ward was calculated by using Spatial Statistics tools in GIS. Then, transit accessibility as accessibility to bus, micro and tempo was estimated as the total number of transit stops in a ward divided by its land area as shown in Equation 3.4. The descriptive result in Table 3.1 shows that some wards do not have transit facilities in Kathmandu.

Photo 3.1 Bus

Photo 3.2 Micro

Photo 3.3 Tempo

Transit accessibility = No. of transit stops/Total land area (km^2) **Equation 3.4**

The main public transport organization (Sajha Yatayat) for passenger movement was established in 1961 under the Japanese Government grant. With the passage of time, the rapid urbanization and massive rise in Kathmandu's population and modernization has turned the city into motorization, but, the percentage of public vehicles has remained almost the same. Public modes are still far fewer in number to ensure a comfortable [25].

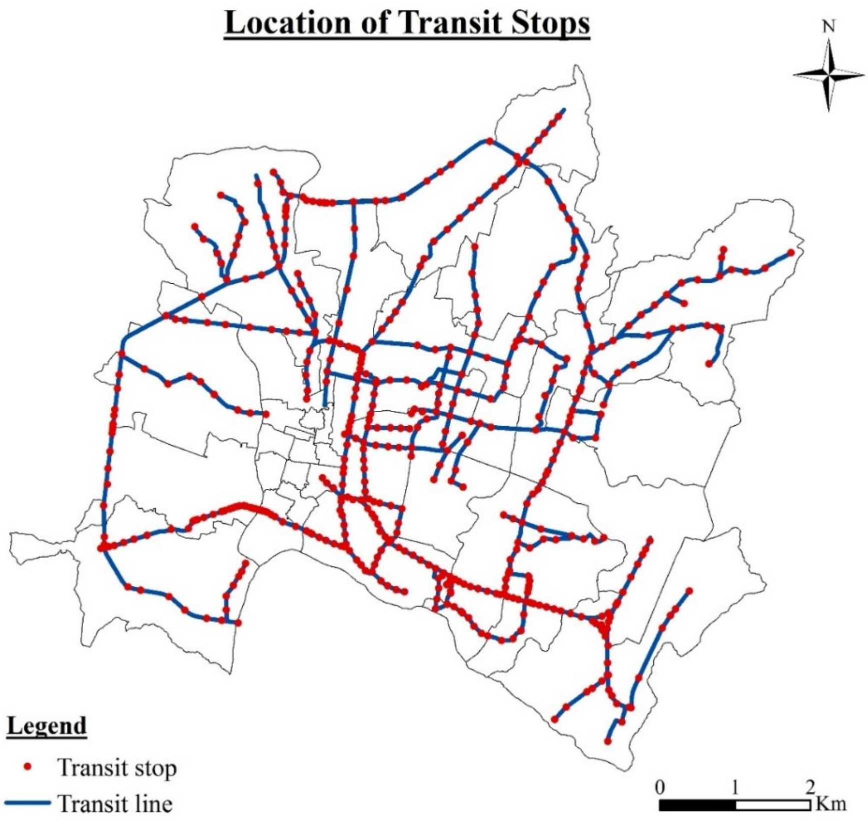

Figure 3.3 Transit stops

Out of the total public transport modes, the share of low occupancy vehicles such as minibus, micro and tempo operating within Kathmandu accounts for 94%; while a share of large buses is only 6% [6]. The maximum passenger capacity of the minibus, micro, tempo and bus is relatively 35, 16, 13 and 50. The public transport service in Kathmandu is fully operated by private sectors and self-financed i.e. without any government subsidies. Because of the absence of a formal public transportation system and lack of proper monitoring and guidance from the government, the quality of public transport service in Kathmandu is poor and inefficient. As the revenue is based on the number of passengers carried by a vehicle, it results in unhealthy competition among operators such as pick up and drop off passengers from undesignated areas to maximize profit. Operators prefer profitable routes and timings which cause longer waiting time and unreliability. Public transportation service is almost not available after 8:00 pm in most of the areas that made inconvenient for the people who do not have private mode. Night bus service in major routes of the capital city from the year 2012 has alleviated the inconvenience to some extent [26]. 14 buses provide the service from 8 pm to 11 pm every day only in major routes.

So, the existing infrastructure and public transportation facilities in Kathmandu do not adequately meet the mobility needs of the urban population, both in quality and quantity.

3.4.2 Travel Data

As this study aims to reduce energy consumption by urban planning, we need to understand the travel behavior of the people in Kathmandu. Most of the countries have a city-wise Person Trip Survey (PTS) data or it is also called National travel survey (NTS) data that provides the information on personal travel behavior like, the information of trip purpose, trip distance, travel time and travel mode. But such data do not exist in Nepal and therefore, we conducted a structured questionnaire survey in all 35 wards of Kathmandu city to obtain one-day travel data with the help of the students of Tribhuvan University, Nepal. The survey was carried out in April 2018 for 20 days. The survey was based on a personal interview as it provides a high response rate. Further, we applied stratified random sampling where each ward has a proportionate stratified random sample of population, which provides a better representation of travel behavior in Kathmandu. According to Richardson et al. [27], a sample of 200 people from a population of 10 million is just as precise as a sample of 200 people from a population of ten thousand. In this regard, this study has performed with a sufficient sample size to represent travel behavior of the population of a Kathmandu.

This research covers 861 respondents (59.70% male and 40.30% female). The minimum, mean and maximum sample age is 6, 33 and 85 years respectively. This research includes total 1,789 trips that were generated only in Kathmandu city. The questionnaire survey included the questions regarding the personal information, the purpose of travel, mode of travel and the travel time to go to the destination. The sample of questionnaire form has been included in the Appendix section. The survey included 4 types of travel purpose. They are: work trip, study trip, business trip and private trip. It included 8 types of travel mode. They are: walk, bicycle, motorcycle, car, bus, micro, tempo and taxi. Where walk and bicycle were combined under non-motorized mode. Bus, micro and tempo were combined under transit/ public mode. Taxi has been excluded in the research part as only a few taxi users were found and the conclusions drawn from small samples is not sufficient for statistical analysis. The research with a few samples of taxi users might not draw realistic conclusion. This result seemed obvious because in the case of Kathmandu people use taxi rarely for daily purpose. Taxis are the most expensive form of transport mode in Kathmandu. On average taxis are seven to ten times more expensive than other modes per passenger km.

Table 3.2 Descriptive result summary- travel variables

	Mean	SD	Minimum	Maximum
Travel mode				
Walk	29.14	23.50	2.00	79.00
Bicycle	0.94	1.73	0.00	8.00
Non-motorized mode	30.08	24.38	2.00	81.00
Motorcycle	12.40	10.56	2.00	44.00
Car	0.94	2.31	0.00	8.00
Bus	5.42	4.59	0.00	14.00
Tempo	0.22	0.64	0.00	2.00
Micro	1.17	1.80	0.00	8.00
Transit	6.82	5.85	0.00	22.00
Taxi	0.11	0.40	0.00	2.00
Travel purpose				
Work Trip (WT)	11.48	8.90	1.00	32.00
Study Trip (ST)	7.28	5.95	0.00	28.00
Business Trip (BT)	0.91	1.42	0.00	7.00
Private Trip (PT)	9.88	8.66	0.00	27.00

The descriptive result in Table 3.2 showed that walk is the highest travel mode in Kathmandu with a mean of 29.14 and standard deviation of 23.50. Among the motorized mode, motorcycle is found highly used with a mean of 12.4 and standard deviation of 10.56, followed by bus and micro. This result is satisfied with the literature review which has indicated that motorcycle use and its fuel consumption is rising sharply in Kathmandu. Except for walk and bicycle, the minimum trip value for all the travel modes were found 0 which meant in some wards, people do not use public mode for travel. This result is supported by the descriptive result of D5 (Table 4) where transit accessibility was found zero in some wards. Regarding the travel purpose, the descriptive result (Table 3.2) showed that people in Kathmandu highly travel for work with the mean value of 11.48 and standard deviation of 8.90, followed by study and private trip. Business trip is found very less.

3.4.3 Energy Intensity Data

We collected the energy intensity data based on Kathmandu [28] to make the research result more consistent. Energy intensity factor of each mode are shown in Table 6. Energy intensity is used for estimating the travel energy consumption of one day by an individual in every 35 wards; using Equation 3.5. The travel distance is calculated by converting the travel time obtained from the questionnaire survey. The ward wise estimated total travel energy consumption ranges from 1563.88 to 764511.38 MJ/person/day.

Table 3.3 Energy intensity factor for travel modes

Travel mode	Motorcycle	Car	Transit
Energy intensity factor (MJ/person-km)	0.5	1.2	0.21

$$EC = \sum_{j=1}^{j=n} \sum_{i=1}^{i=m} T_{ij} \times D_i \times EI_j$$ **Equation 3.5**

where,

EC = Total Travel Energy consumption (MJ/person/day)

n = Total number of travel mode

j = Travel mode type {Motorcycle, Car, Transit}

m = Total number of travel purpose

i = Travel purpose {Work, School, Business, Private}

T_{ij} = Travel for purpose 'i' by mode 'j'

D_i = Travel Distance for travel purpose 'i' (km)

EI_j = Energy Intensity factor for travel mode 'j' (MJ/person-km)

3.5 Micro-Scale Analysis of Urban Form, Travel behavior and Travel Energy Consumption Based on Kathmandu Using Cluster Analysis

3.5.1 Introduction

Planning initiatives in many cities throughout the world have been directed at changing land use in order to reduce travel energy consumption, decrease greenhouse gas emissions and achieve other economic, social and environmental benefits. In Kathmandu, with the growth in private mode use and increase in daily travel distance, the shares of energy consumption and air pollution is getting significant and increasing. So, it is necessary to identify and implement the land use solutions to reduce energy consumption. A substantial body of research has suggested that a shift towards more compact and walkable development patterns could reduce transportation related fuel consumption and emissions [29-32]. However, the impact of urban form on travel behavior has been widely studied [20,30,33] mostly based on western countries. In contrast, only a few studies [29,30,34] have explored the influence of urban form on energy consumption and concluded that urban density is the most important influencing factor for transportation energy consumption. However, the role of density in reducing automobile use still remains unclear [35]. The urban land use-transportation system is such a complex entity that all the components in the system work collaboratively rather than separately [36]. Considering only single or limited measures of urban form in an isolated way do not represent the reality.

Therefore, this study considers a multitude of urban form measures based on "5Ds" framework (density, diversity, design, destination accessibility and distance to transit). This research aims to explore the relationship between urban form, travel behavior and travel energy consumption to identify the influencing factors which affect travel and travel energy consumption by using cluster analysis. Since urban form does not have a direct effect on travel energy consumption, we analyzed the relationship between urban form and travel energy consumption through intermediate variables: mode choice and travel distance.

3.5.2 Analysis Methods

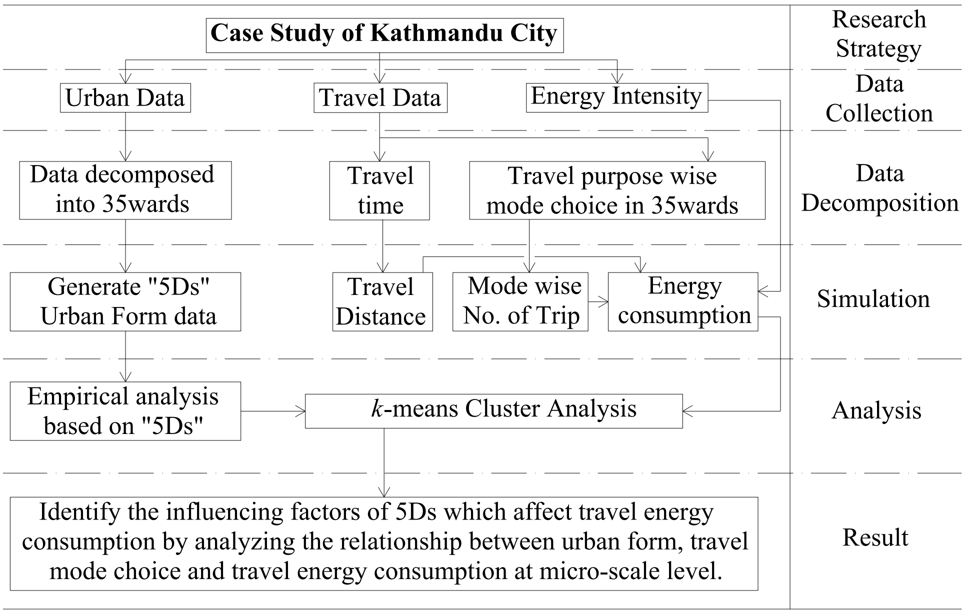

Figure 3.4 Research methodology

First, empirical analysis of urban form characteristics of Kathmandu is performed based on "5Ds" framework at the micro-scale; i.e at ward level. The decomposed urban data into 35 wards were ranked into 7 classes from low to high by using SPSS and processed in GIS for the empirical analysis. Then, a *k*-means Cluster analysis is performed in order to regroup wards into *k*- homogeneous clusters according to the characteristics based on 5Ds and travel energy consumption (Figure 3.4). The goal of using *k*-means statistical cluster analysis technique is to maximize inter-cluster variation while minimizing intra-cluster variation.

3.5.3 Result and Discussion

The research results from empirical analysis and cluster analysis are described below.

3.5.3.1 "5Ds" Empirical Analysis Result

5Ds empirical analysis result based on 35 wards of Kathmandu is described below.

3.5.3.1.1 Density (D1)

D1 is measured as the central tendency of population density and household density. Highest D1 was found in the city core sector which is nearer to CBD areas; specifically, in wards 26 and 27 (Figure 3.5). Similarly, the wards 19,20,21,23 and 28 in the city core sector showed higher density. This result is intuitive since most of the wards in the city core sector include ancient neighborhoods that were developed as compact and walking neighborhoods in the years back. The city core was dominated by residential and mixed land uses. The lowest density was found in the wards (1, 11 and 31) situated in the central sector.

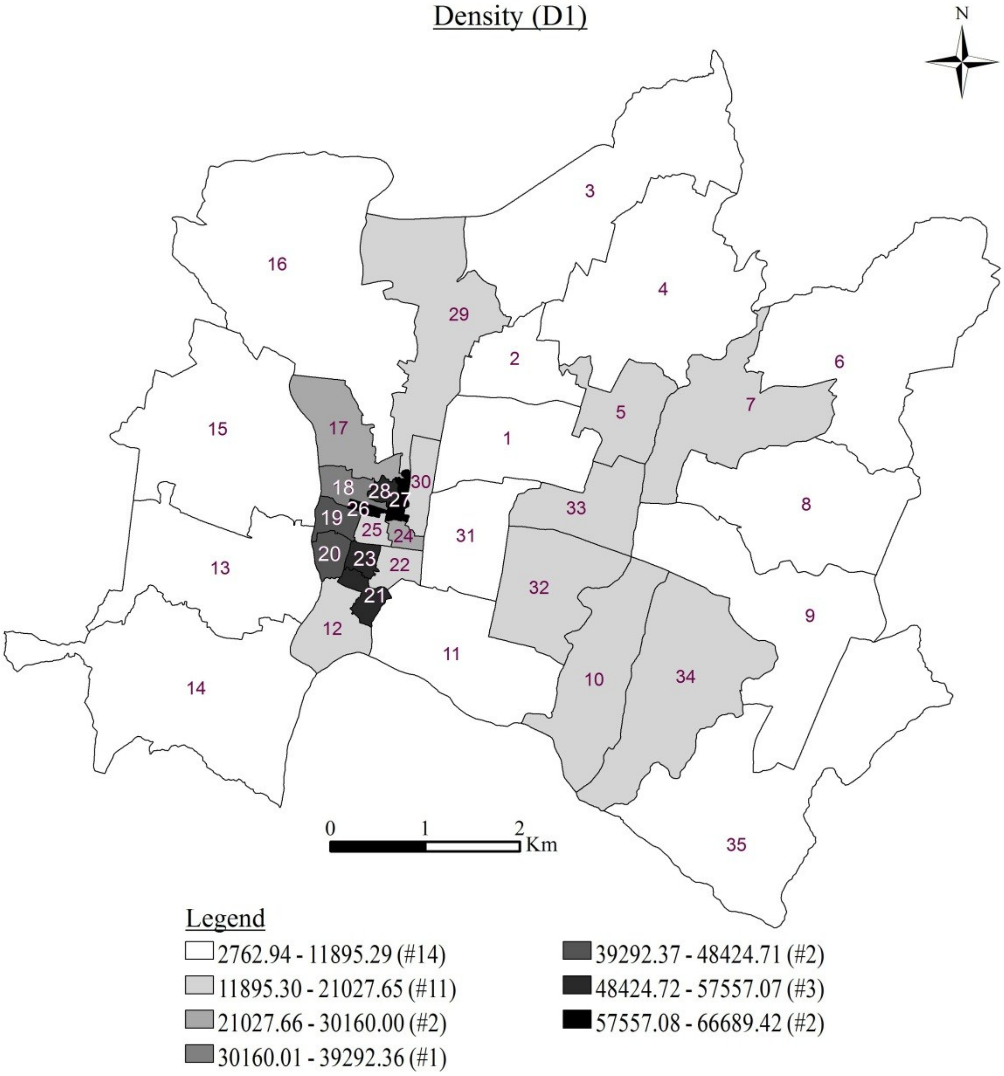

Figure 3.5 D1- Density

3.5.3.1.2 Diversity (D2)

The most balanced land use was found in the city core sector where higher density (D1) and in the central sector where higher transit accessibility (D5). The highest land use mix was found in wards 25 and 31(Figure 3.6). However, these wards showed less density (D1). So, this result suggests that increase in land use mix is not absolutely related to the increase in density or vice versa.

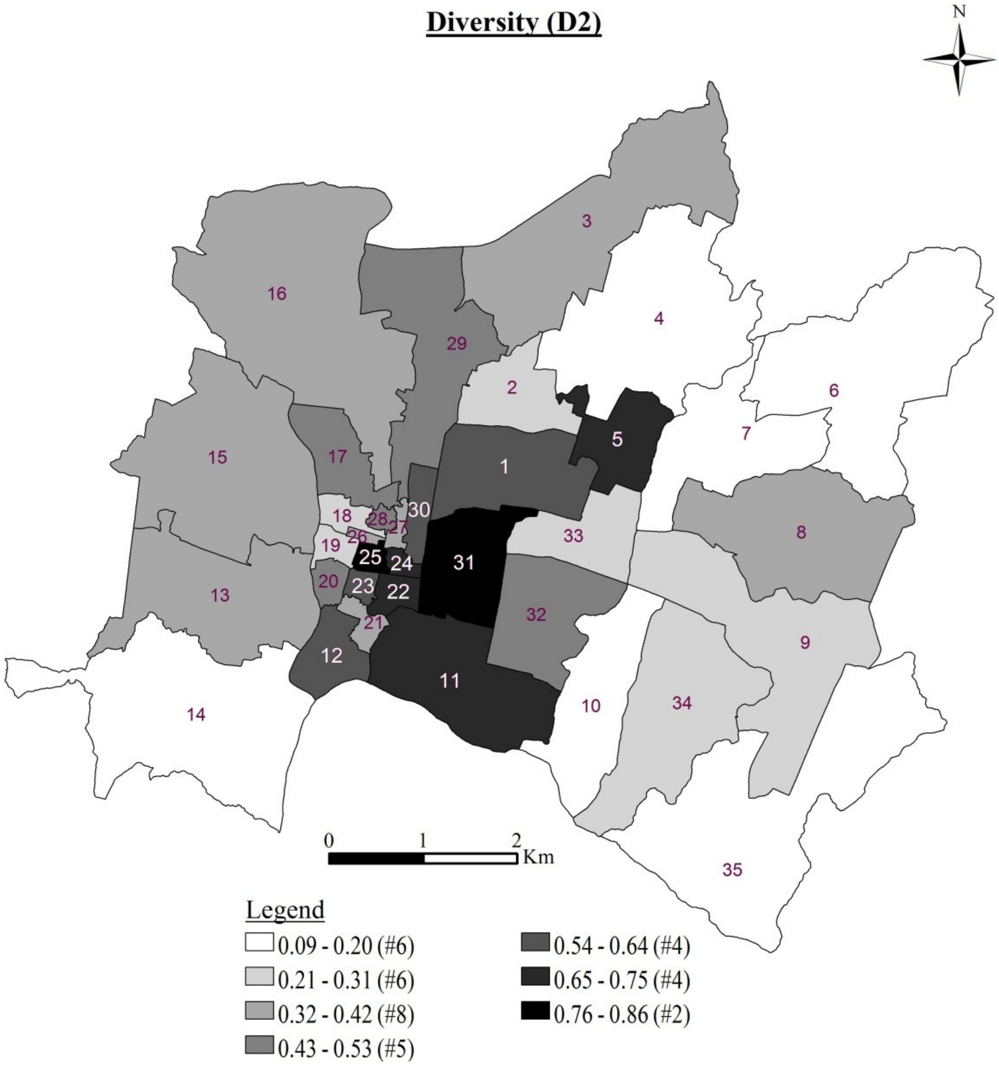

Figure 3.6 D2- Diversity

3.5.3.1.3 Design (D3)

D3 includes the road connectivity and it is calculated as the central tendency of 3-way and 4-way road intersection. The highest road connectivity is found in the wards which are associated with less density and far from the central business district (CBD) (Figure 3.7). Surprisingly, the result showed that even higher the road connectivity, there was poor public transportation. This meant that public transport cannot operate in most wards even there are road networks.

The new settlements (wards 6, 7 and 16) are extended from city core sector showed higher road connectivity and so better facility of public transportation. On the other hand, D3 was found low in the city core sector. The planning of traditional settlement in city core such that highly built with attached-row-residential and road intersections were mainly at start or end of the neighborhood. The residential neighborhood planned with linear alleys and courtyard system so the wards in city core sector have fewer road intersections and so less road connectivity.

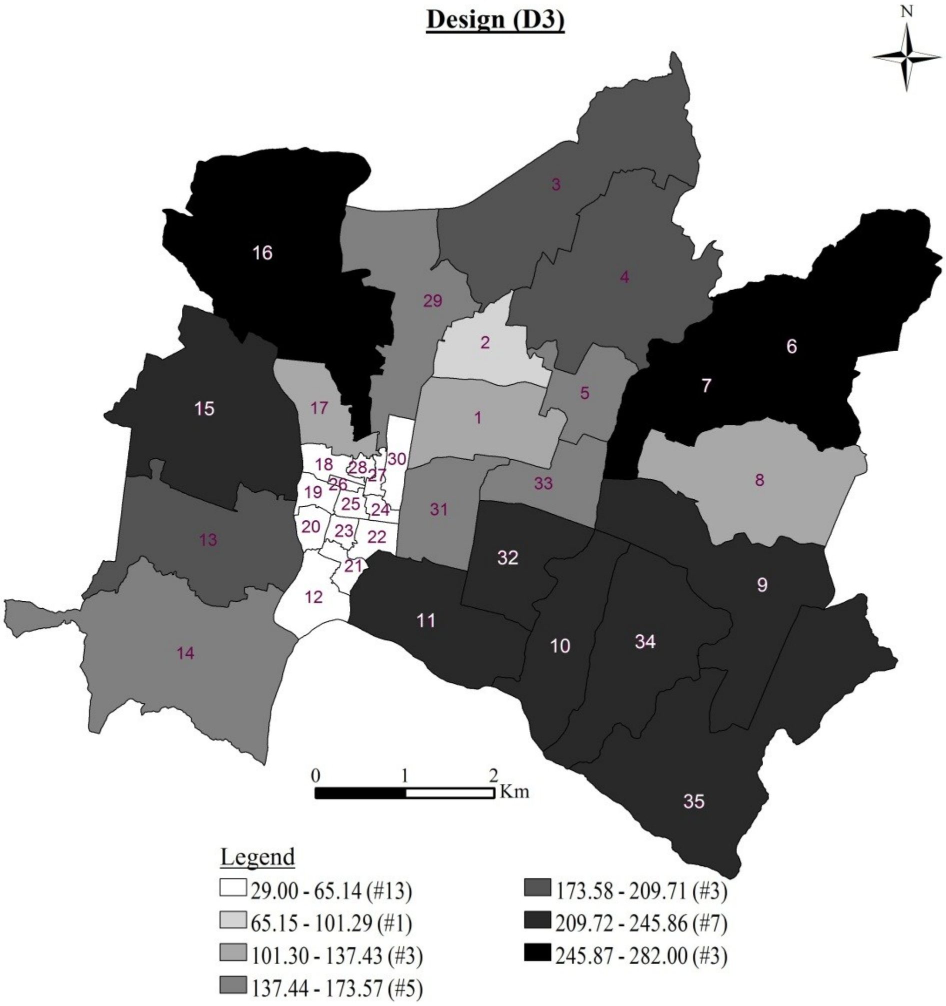

Figure 3.7 D3- Design

3.5.3.1.4 Destination Accessibility (D4)

D4 measures ease of access to trip attractions. In this study, D4 is measured based on CBD and it is considered as the existing place of Old Bus Park which lies in ward 31 of the central sector (Figure 3.8). Most of the wards situated in the city core and central sector were found accessible by walk to CBD. It is found that the ward nearer to CBD has higher land use mix (D2). This result is satisfied because CBD is the location with maximum employment and shopping opportunities. And in the case of Kathmandu, the CBD is near to the ancient neighborhood so there is higher density (D1) in and surround the CBD as well. The study showed that the wards further away from CBD were associated with less density (D1), less land use mix (D2) and higher road connectivity (D3).

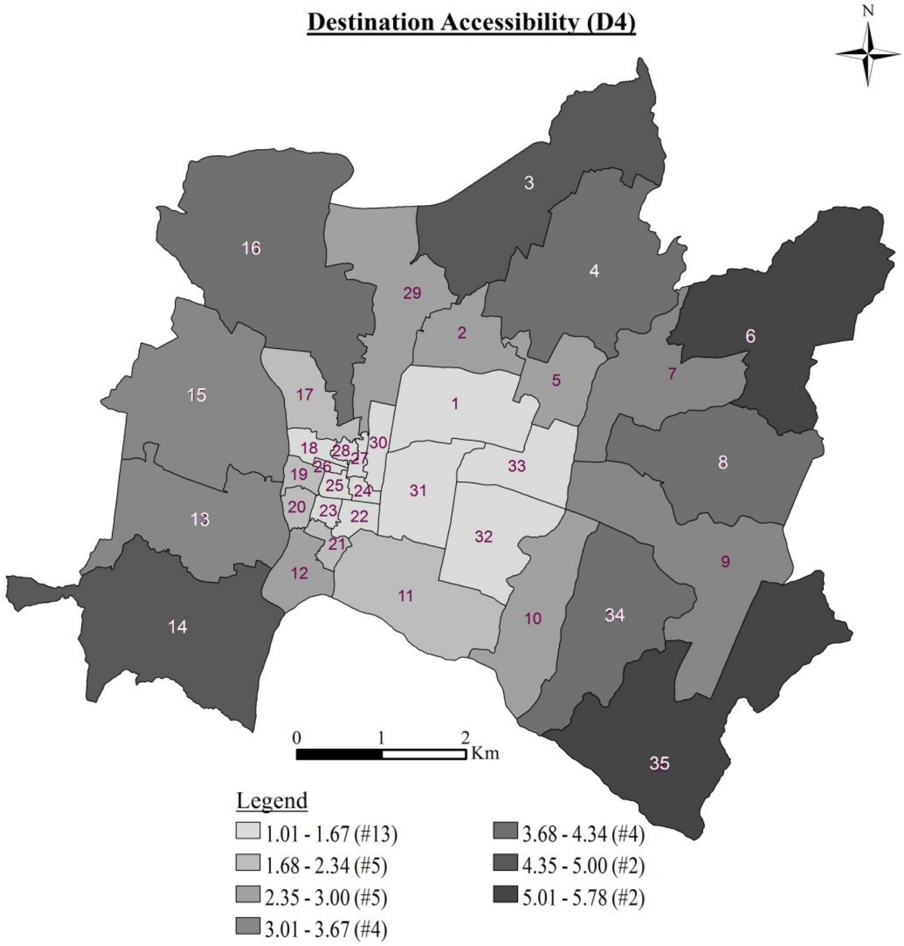

Figure 3.8 D4- Destination accessibility

3.5.3.1.5 Distance to Transit (D5)

D5 measures access to nearest transit or transit stop. The highest transit accessibility was found in ward 31(Figure 3.9) which has the highest land use mix (D2) but less density (D1) and near to CBD. Ward 31 contains Old Bus Park from where transport is available to various places within and outside the valley. Commerce, education, entertainment and employment are the strong points of this centrally located ward. In Kathmandu, 10 of 35 wards (ward 18-21, 23-28) have no transit accessibility which is situated in city core sector. This is due to the fact that city core was developed as a walkable settlement in the ancient period; at that time walk was major means of transport mode for travel. Most of the residences were mix used (shop/work on the first floor and living on upper floors) that had encouraged all urban facility within walking distance.

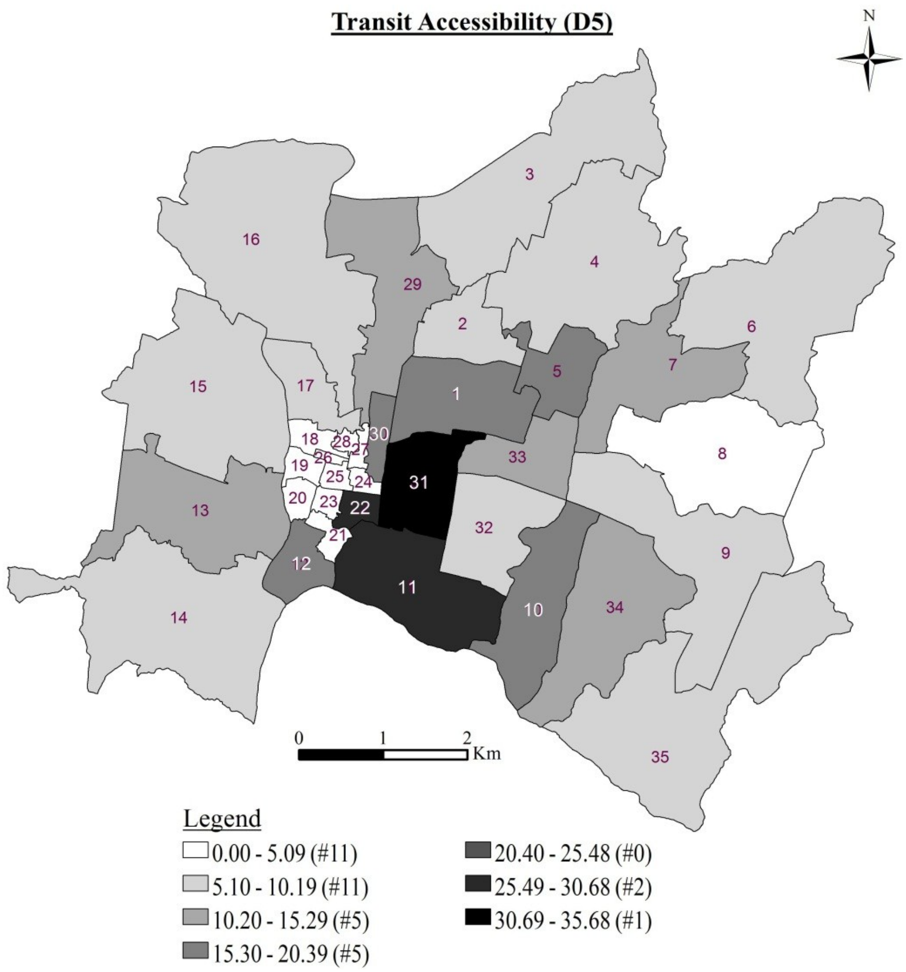

Figure 3.9 D5- Transit accessibility

3.5.3.2 Cluster Analysis Result

After analyzing urban form characteristics of Kathmandu based on 5Ds, we performed cluster analysis by using 5Ds and travel energy consumption to identify homogenous clusters. Several attempts were made with different numbers of clusters and finally, it was found that three clusters were a satisfactory number (three different types of wards), where each one had an acceptable number of wards and sufficient variation between clusters. Each clusters' characteristics are described below on the basis of cluster centroid values (Figure 3.10). Figure 3.11 shows the location of each cluster.

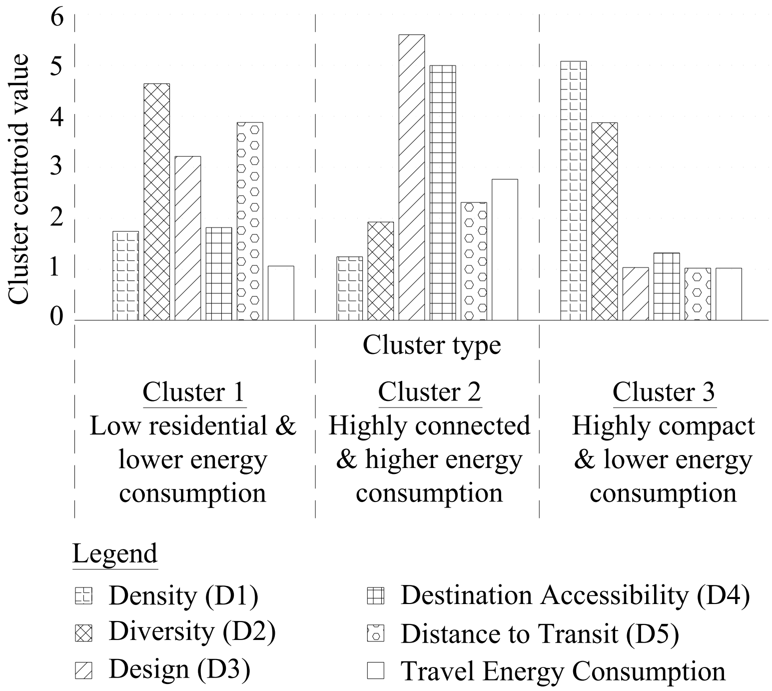

Figure 3.10 Cluster centroid values

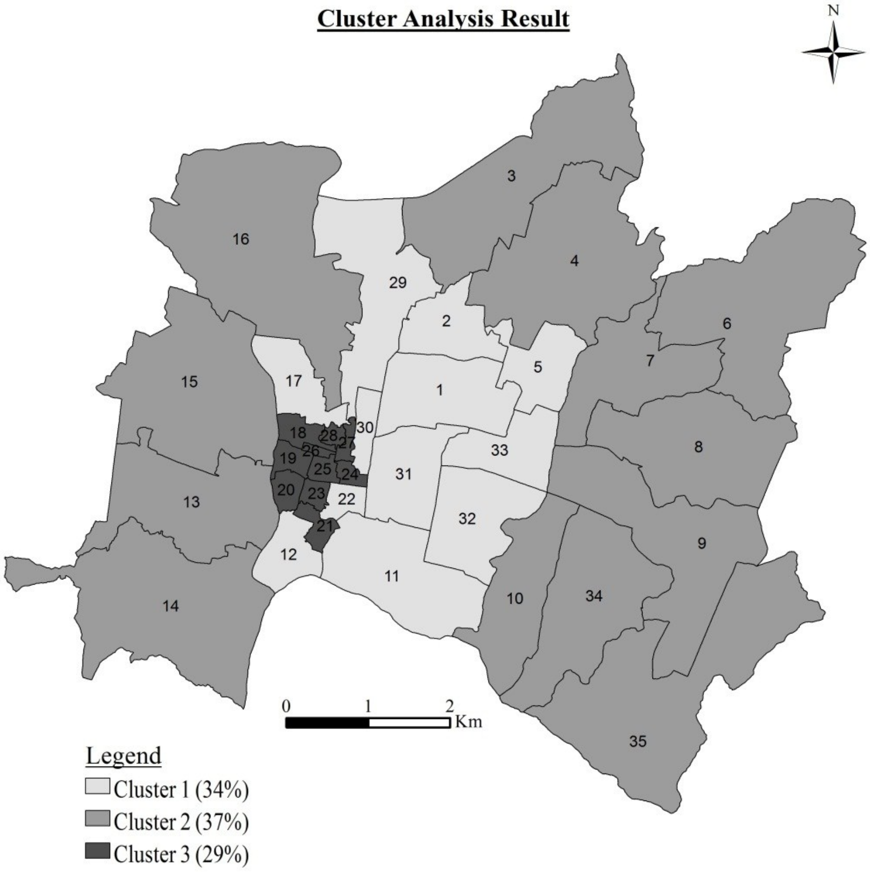

Figure 3.11 Cluster analysis result

3.5.3.2.1 Cluster 1- Low Residential and Lower Energy Consumption

Cluster 1 is characterized by low density (D1; low population density and household density) and lower energy consumption; whereas, this cluster represents higher land use mix (D2) and better public transit accessibility (Figure 3.10). That meant cluster 1 primarily comprises wards situated in the central sector of Kathmandu. From the empirical analysis, it is also found that the wards in the central sector have low density, higher land use mix and better public transit accessibility. This cluster also includes some wards from North sector (2, 29) and core sector (12,17,22,30). The wards in this cluster were highly dominated by employment and entertainment facility, institutions, open space and bus parks. This cluster represents 34 percent of the total number of wards in Kathmandu city (Figure 3.11).

Though the wards in this cluster showed less energy consumption, among energy-intensive mode use, motorcycle was found highly used (26.74%) followed by public mode (14.42%) and car (1.86%) (Table 3.4, Figure 3.12). It is worth noting that increase in the use of motorcycle meant more fuel consumption because motorcycle has energy intensity 0.5MJ/person-km which is more than double of public mode (0.2 MJ/person-km). This meant energy consumed by one passenger to travel 1 km by bicycle is higher than using public mode. As a result, the total energy consumption in this cluster was found highest shared by motorcycle (540,585.47 MJ/person/day), followed by car (1,320) and public mode (3,021.8) (Table 3.5, Figure 3.13). Also, this result highlights that even availability of nearest public transit stops, a public mode is less used. It might be the poor service of public transportation which discourages people to take public mode for travel.

Table 3.4 Cluster wise travel mode share

Travel Mode	Cluster 1		Cluster 2		Cluster 3	
	Used no.	Used %	Used no.	Used %	Used no.	Used %
Walk	233	54.19	692	58.74	95	52.49
Bicycle	12	2.79	21	1.78	0	0.00
Motorcycle	115	26.74	270	22.92	49	27.07
Car	8	1.86	28	2.38	0	0.00
Public	62	14.42	167	14.18	37	20.44

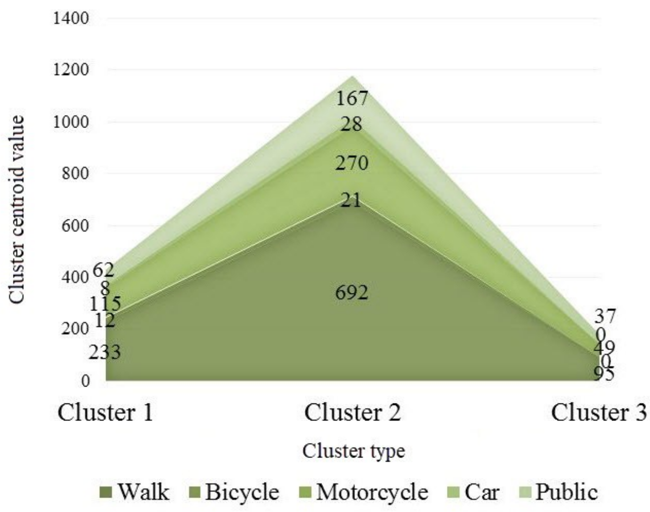

Figure 3.12 Cluster wise travel mode share

3.5.3.2.2 Cluster 2- Highly Connected and Higher Energy Consumption

Cluster 2 represents the wards with higher road connectivity (D3), further away from CBD (D4) and higher energy consumption (Figure 3.10). Also, this cluster indicates wards having less density (D1), low land use mix (D2) and poor transit accessibility (D5). This result also indicates that growth of road network in Kathmandu has taken place without adequate transportation infrastructure. According to report [37], there are many unplanned roads and further, those road conditions are poor caused by its inefficient design, construction, and maintenance. Buses, micros and tempos are the dominant modes of public transport in which the private sector is playing a major role in Kathmandu. So, public transport cannot operate on most of the roads. As the wards in this cluster are situated in the East, North and West sector which represents sprawl residential areas, has led difficulties in operating public transport; specifically large buses. This cluster represents 37 percent of the total number of zones in Kathmandu city (Figure 3.11).

The mode share in this cluster shows highly dominated by walk (58.74%), followed by motorcycle (22.92%), public mode (14.18%) and car (2.38%) (Table 3.4, Figure 3.12). Even, the highest trip by walk, the energy consumption is mainly due to motorcycle use (3,302,326.04MJ/person/day), followed by car (9,299.4) and public mode (15,506.21) (Table 3.5, Figure 3.13).

Table 3.5 Cluster wise travel energy consumption

Travel Mode	Travel Energy Consumption (MJ/person/day)		
	Cluster 1	Cluster 2	Cluster 3
Motorcycle	540,585.47	3,302,326.00	116,416.79
Car	1,320.00	9,299.40	0.00
Public	3,021.80	15,506.21	901.53

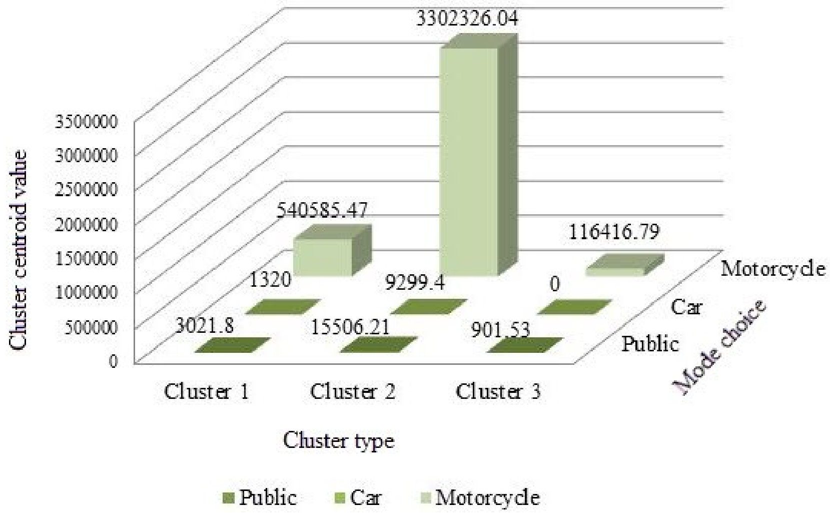

Figure 3.13 Cluster wise travel energy consumption

3.5.3.2.3 Cluster 3- Highly Compact and Lower Energy Consumption

Cluster 3 is characterized by higher density (D1), a relatively better land use mix (D2) and lower energy consumption (Figure 3.10). Also, this cluster represents wards having lowest road connectivity (D3), closer to CBD (D4) and unavailability of public transit accessibilities (D5). This cluster comprises wards situated in the city core (Figure 3.11) and found highly dominated by walk (52.49%.) as shown in Table 3.4. This result is satisfied since the city core was developed as a compact and walking city in the ancient time. In present also, access to urban facilities are at walking distance and walkable distant to CBD from the city core encourages people to walk. Though the transit accessibility is null in the core city, the public mode users are found 20.44% (Figure 3.9, Table 3.4, Figure 3.12). This suggests that if the facilities of public transportation at a walkable distance, people get encourage using it.

However, like in cluster 1 and cluster 2, public mode is not found highly used compare to private mode which indicates the fact that is inadequate and poorly managed public transport. In this cluster also, use of motorcycle occupied the highest share (27.07%) among the motorized mode and the energy consumption by motorcycle is also found higher (116,416.79MJ/person/day) compared to public mode (901.53) (Table 3.5, Figure 3.13). In this cluster, a user of bicycle and car for a daily purpose is zero. In Kathmandu, cycling is mainly done for the recreation purpose rather than as the daily commuting transportation. In fact, the flat terrain in Kathmandu, especially in the core area is very feasible for cycling.

3.5.4 Conclusion

This study applied 5 dimensions of urban form (5Ds: density, diversity, design, destination accessibility and distance to transit) to explore the influence of urban form on travel energy consumption at a micro-scale; studying entire Kathmandu city via 35wards.

This study highlights that compact planning in Kathmandu is still dominated by walking as all the three clusters showed the highest mode share by walk. So, compare to other international cities, Kathmandu is walkable and less energy consumer city but the rapidly urbanizing, increasing private mode specifically motorcycle and increasing rate of fuel import have led growing concern on how to reduce travel energy consumption in Kathmandu.

Cluster wise major findings of this research: First, cluster 1 revealed that residential zone has a direct effect on travel energy consumption. Second, cluster 2 showed that highly connected zone (D3) with less density D1 and diversity D2, poor transit accessibility (D5) and further away from CBD (D4) results in an increase in motorcycle and rise in energy consumption due to high energy intensity of private vehicle and longer travel distance. This study suggests that the provision of transit facilities is essential for the increase in road connectivity to promote public mode, to reduce motorcycle use and consequently reduce travel energy consumption. Simultaneously, this study highlights that providing transit stops is not sufficient, it also needs to improve the service otherwise even there is a better transit accessibility, people use private mode as in case of cluster 1. Third, cluster 3 highlights that only compact planning is not effective to reduce private mode use and travel energy consumption but simultaneously need to improve transit accessibilities (D5) and services.

Overall, this study has several important implications for land use planning and policy-making to reduce travel energy consumption in Kathmandu. The solutions for reducing travel energy consumption can be achieved based on clusters that have been identified in this study. Strategies that promote densification, increase land use mix and improve transit accessibility would positively influence transit use and reduce travel energy consumption.

3.6 Influencing Mechanism Analysis of Urban Form on Travel Energy Consumption Evidence from Kathmandu Using MLRM Analysis

3.6.1 Introduction

In the case of Nepal, a considerable number of studies has concentrated on the growth trend in the evolution of different vehicle types, their energy demand and associated environmental emissions (3,38-40). However, these studies have failed to shed light on the direction of the causality between what kind of land use planning or urban form effect on travel energy consumption. Many studies found that the urban form variables to be associated with the choice of non-motorized modes and transit [22,41-45]. The study by Cao et al.[46] showed urban form plays a modest role in vehicle choice. Also, the research based on Fukuoka in chapter 2 showed that urban form has a significant role in vehicle choice and thus on travel energy consumption. So far, there has been relatively little research on the broader question of how urban form affects energy consumption [47].

Therefore, it is critical to understand the underlying causal relationship between urban form and travel energy consumption in the case of Kathmandu for promoting the reduction in private mode and associated travel energy consumption. This study raises the unexplored research question of how the multiple variables of urban form (5Ds) effect on travel energy consumption in Kathmandu. To tackle this goal, first, this study analyzes the relationship between urban form on travel mode choice (non-motorized mode, motorcycle, car and transit) by using travel purpose (work trip, study trip, business trip and private trip) as the controlling variable. Second, it analyzes the relationship between mode choice on travel energy consumption by using travel distance as the controlling variable. Third, it analyzes the interrelationship between urban form, mode choice and travel energy consumption and assists to identify the influencing factors of travel energy consumption.

3.6.2 Database Construction and Analysis Method

For the clarification of the mechanism underlying the relationship between urban form and travel energy consumption, first, the database was constructed including multiple variables of urban form (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit), travel behavior and travel energy consumption of each 35 wards of Kathmandu, and then, applied Multiple linear regression model as an analysis method (Figure 3.14).

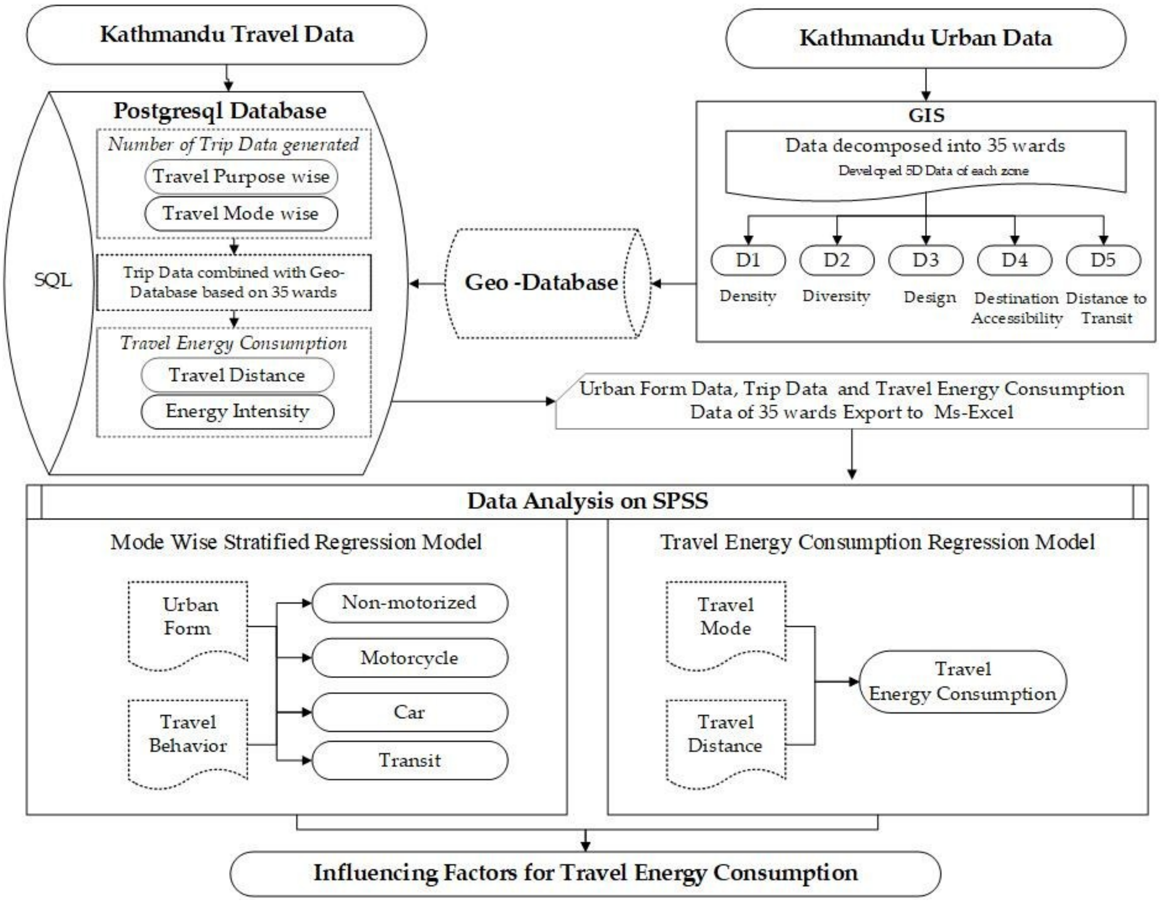

Figure 3.14 Database construction and analysis method

5Ds data of each ward were processed in GIS and created geo-database for observation and management of the data. The 5Ds database was then inserted into the Postgresql database to combine with trip data (travel purpose wise and travel mode wise) and additional variables of travel energy consumption (travel distance and energy intensity) of each 35 wards. The constructed database of each ward was exported to MS-Excel for making it importable in SPSS and then, the analysis was conducted by applying Multiple Linear Regression Model (MLRM).

In this research, two separate MLRMs were performed. In the first phase of MLRM, urban form variables (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit) and trip behavior variables (trip for work, school, business, private) were chosen as independent variables where travel mode choice is used as a dependent variable. In the second phase of MLRM for energy consumption, the independent variables consist of mode choice for travel (non-motorized, motorcycle, car and transit) and travel distance. The dependent variable is total travel energy consumption.

Table 3.6 Multicollinearity test

Stratified mode choice models			Travel energy consumption model		
Independent variables	Collinearity Statistics		Independent variables	Collinearity Statistics	
	Tolerance	VIF		Tolerance	VIF
Density (D1)	0.309	3.239	Non-motorized mode	0.240	4.163
Diversity (D2)	0.397	2.517	Motorcycle	0.281	3.562
Design (D3)	0.211	4.750	Car	0.585	1.711
Destination Accessibility (D4)	0.253	3.950	Transit	0.283	3.534
Distance to Transit (D5)	0.471	2.125	Travel Distance	0.100	10.005
Work Trip (WT)	0.152	6.564			
School Trip (ST)	0.314	3.186			
Business Trip (BT)	0.877	1.140			
Private Trip (PT)	0.293	3.409			

The test for multicollinearity between the independent variables was performed for both models: mode-wise stratified and travel energy consumption, by using VIFs (variance inflation factor).VIFs < 10 [48] and Tolerance > 0.2 [49] is the condition of satisfactory for the model. So, the two models of this research were found satisfies this condition; except the tolerance value for work trip (0.152 in the first model) and for travel distance (0.100 in the second model) as shown in Table 3.6. However, both the work trip and the travel distance satisfy the condition for VIF. Further, for work trip, tolerance was found to be 0.152, which is nearly 0.2 if we consider a round figure. Therefore, we decided to remain these two variables in the model.

3.6.3 Results

Among the mode wise stratified models, the model for non-motorized mode showed a better model fit with 92.4% variance ($R^2 = 0.924$, p-value < 0.000) as shown in Table 3.7. Even the regression model shows the best fit, the influence of urban form variables (5Ds) for non-motorized modes at the individual level is found less significant. However, when controlling other predictors, it showed the expected and meaningful result. Among urban form variables, destination accessibility (D4) is found positively predictive of non-motorized mode ($p = 0.06$). Among travel variables, private trip (PT) is positively significant on non-motorized mode choice ($p = 0.000$).

The regression result for motorcycle was 84.6% ($R^2 = 0.846$, p-value < 0.000). Among urban form variables, density (D1) showed significant inverse association with motorcycle use ($p < 0.05$). For motorcycle use, study trip (ST) and work trip (WT) showed positively significant ($p = 0.000$ for ST and $p < 0.05$ for WT). Whereas, business trip (BT) showed significant inverse association ($p < 0.05$) with motorcycle.

The regression result for car showed 54.5% ($R^2 = 0.545$, p-value < 0.05). Similar to the non-motorized model, the influence of urban form variables on car use was not found significant at individual level. However, design (D3) and destination accessibility (D4) showed relatively more influence while controlling other predictors. Among travel variables, work trip (WT) is positively significant ($p < 0.05$) on car use.

The regression results for public mode use showed 68% ($R^2 = 0.68$, p-value < 0.000). Similar to the models of non-motorized mode and car use, the model of public mode use also showed less significance of 5Ds. Among travel variables, work trip (WT) is found positively significant on public mode choice ($p < 0.05$).

The regression model result for travel energy consumption was 96.5% ($R^2 = 0.965$, p-value < 0.000) as shown in Table 3.8. This indicates a good model fit where non-motorized mode and public mode are found inversely significant ($p = 0.000$ for non-motorized mode and $p < 0.05$ for public mode use). Likewise, motorcycle and travel distance are positively significant ($p = 0.000$) with travel energy consumption. Car use showed positive association with travel energy consumption but with less significant ($p = 0.318$).

3.6.4 Discussion

The regression results for travel energy consumption indicate that motorcycle and travel distance are major factors for increasing energy consumption (Table 3.8, Figure 3.15). The result showed that promoting non-motorized mode and public mode can reduce energy consumption in Kathmandu; which satisfies with the results of international studies. Unlike other studies, this research identifies the influencing factors of urban form variables that affect mode choice (Table 3.7, Figure 3.16).

Density (D1) is found the key factor that affects motorcycle use and simultaneously energy consumption. Higher density promotes higher land use mix which in turns creates shorter distances that contribute to non-motorized mode. The model result for non-motorized mode also showed that increase in D1 and land use mix (D2) effect in increase of non-motorized mode. For the car use, even though less significance the associated sign showed that increase in D1 and D2 are not found effective to reduce car use especially where road connectivity is higher and poor public mode accessibility. Similarly, an increase in D1 and D2 near the CBD areas create less public mode use. This result satisfies the result of empirical analysis in chapter 5 where transit accessibility is found null in the city core since the city core was developed as walkable city in ancient time. But due to modernization, people own private modes and drive on the road which was developed for walking purpose.

After density, design (D3) is found effecting factors for motorcycle use. As lower the road connectivity, motorcycle use is found higher. The literature review and also questionnaire survey result showed that motorcycle use is higher in Kathmandu among other the travel modes. Less connected road meant less option of routes. Higher use of motorcycle on the limited available routes is one of the main reasons of traffic congestion in Kathmandu. Here, the point should be noted that fuel consumption during traffic congestion is unproductive in terms of energy, environment and money. For example; a 1000cc car burns 2 litres of fuel if it is kept in idle for an hour, a heavier vehicle consumes double. A motorcycle engine consumes 0.25 litre per hour if it is just sitting in a traffic jam. This means that if a 1000cc petrol hatchback is got stuck in traffic for an hour a day one lose Rs 194 a day (@ Rs 97/litre), Rs 5,820 a month and Rs 69,840 a year [50]. Conversely, increase in road connectivity shows increase in car use. More road intersections provide greater road connectivity and more routing options, which, in turn, attract people to use private mode for their convenience. So, in the case of Kathmandu, either road connectivity increase or decrease it is found that people use highly private modes. The difference is in the areas where road connectivity is higher people tends to own car and where road connectivity is less, and highly dense areas people tends to own motorcycle. In fact, motorcycle is suitable for any type of road; even in alleys where two people hardly can pass. So, motorcycle is popular in Kathmandu and also becoming riskier to the pedestrian in Kathmandu. As a result increase in road connectivity results decrease in non-motorized mode. The research result by Stevens [51] also found that designing streets to make them more walkable is not effective. It showed that increase in D3 increases public mode use with a very low significance which indicates that greater in road connectivity does not mean higher availability of public mode.

This research result showed that better the destination accessibility (D4), higher the use of private modes (motorcycle and car). This meant private mode is increased in and near the CBD areas. This result highlights that the traffic congestion in city center of Kathmandu is due to the use of private mode especially low occupant mode like motorcycle. Whereas non-motorized use is found higher in the areas further away from CBD even density and land use mix is comparatively low but transit accessibility (D5) is better. It almost always requires a walk at one or both ends of the trip while taking public mode [20].

Table 3.7 Mode wise stratified regression model

Independent Variables	Non-Motorized			Motorcycle			Car			Transit (Public)		
	B	T	*p*	B	T	*p*	B	T	*p*	B	T	*p*
(Constant)	-1.128	-1.178	0.25	2.1	2.077	0.048*	0.662	0.347	0.732	4.050	2.556	0.017*
Urban form variables												
Density (D1)	0.047	0.412	0.684	-0.260	-2.220	0.036*	0.001	0.003	0.997	-0.290	-1.570	0.128
Diversity (D2)	0.006	0.058	0.954	-0.090	-0.800	0.432	0.068	0.321	0.751	-0.250	-1.400	0.174
Design (D3)	-0.010	-0.086	0.932	-0.190	-1.550	0.133	0.336	1.436	0.163	0.030	0.157	0.876
Destination Accessibility (D4)	0.246	1.971	0.060	-0.190	-1.440	0.162	-0.390	-1.540	0.135	-0.170	-0.830	0.416
Distance to Transit (D5)	0.084	0.746	0.462	-0.070	-0.570	0.574	-0.230	-1.020	0.316	-0.210	-1.130	0.268
Travel variables												
Work Trip (WT)	0.272	1.768	0.089	0.420	2.570	0.017*	0.713	2.324	0.029*	0.610	2.396	0.024*
Study Trip (ST)	0.250	1.718	0.098	0.720	4.696	0.000**	0.175	0.602	0.552	0.285	1.181	0.249
Business Trip (BT)	0.226	1.954	0.062	-0.270	-2.190	0.038*	-0.150	-0.630	0.532	-0.120	-0.610	0.550
Private Trip (PT)	0.456	4.287	0.000**	0.010	0.058	0.954	-0.280	-1.330	0.194	-0.320	-1.840	0.078
Summary statistics												
p-value			0.000**			0.000**			0.008*			0.000**
R			0.961			0.920			0.738			0.824
R-square(R^2)			0.924			0.846			0.545			0.680

Note: B means Unstandardized regression coefficient, T means test coefficient, *p* means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

Table 3.8 Travel energy consumption regression model

Independent Variables	Travel Energy Consumption		
	B	T	*p*
(Constant)	-0.157	-1.176	0.249
Non-Motorized mode	-0.305	-4.780	0.000**
Motorcycle	1.022	12.790	0.000**
Car	0.051	1.015	0.318
Transit (Public)	-0.189	-2.585	0.015*
Travel distance	0.485	4.952	0.000**
Summary statistics			
p-value			0.000**
R			0.982
R-square(R^2)			0.965

Note: B means Unstandardized regression coefficient, T means test coefficient, *p* means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

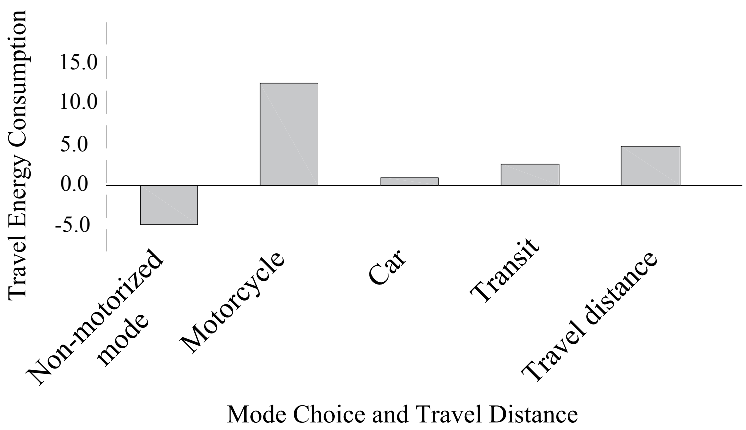

Figure 3.15 Effect of mode choice and travel distance on travel energy consumption

The distance to transit (D5) also shows a meaningful relation with motorcycle use indicating that increase in public mode accessibilities can support in reducing motorcycle use, but surprisingly, the result showed that even rise in transit accessibilities it has an adverse effect on public mode use. It meant even bus, tempo or micro stops are available at the easy access, people are less encouraged to use these public modes likely due to the poor quality in transport service. So, only providing the public mode is not adequate but also requires quality in service.

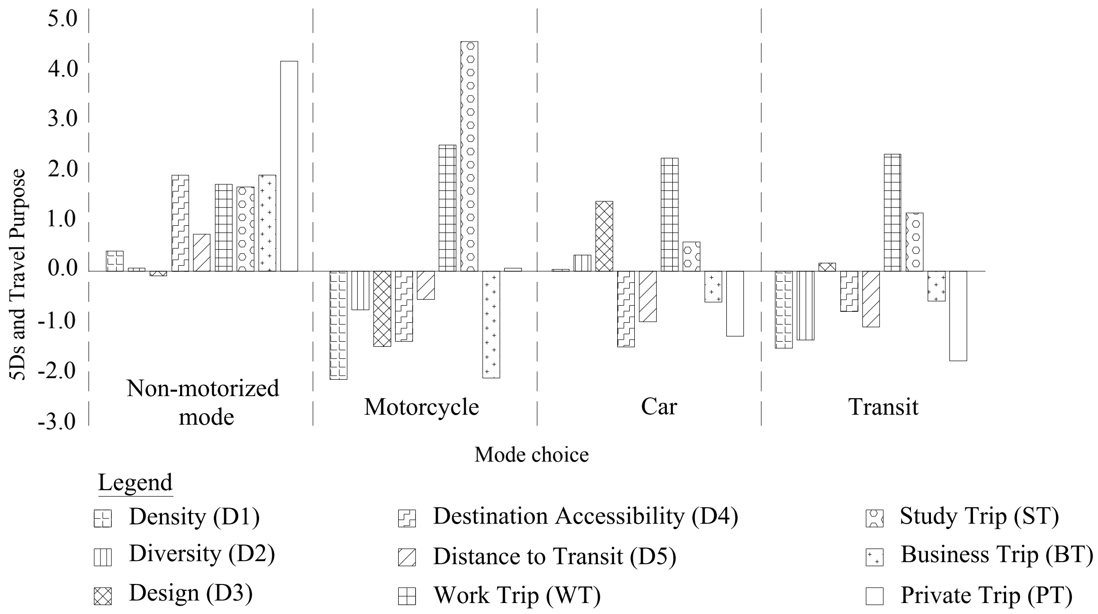

Figure 3.16 Effect of 5Ds and travel purpose on mode choice

All motorized mode is found positively related with increase in work trip which meant people use motorized mode mainly for work purpose. Motorcycle is found highly used for study trip (ST) followed by work trip (WT). In Nepal, people send their children (including kindergarten students) where they like regardless of the travel distance. Most of the families use motorcycle for dropping and picking their children from the school, likely on their way to work or business. As motorcycle is affordable for all economic group and convenient mode especially in the narrow streets like of Kathmandu, it is popular among college students, office workers and housewives.

As the business trip (BT) is increased use of motorized mode (motorcycle, car and public mode) is found reduced which indicates people travel short distance for business purpose that can be traveled by walk or they engage in home based business. Increase in non-motorized mode is strongly related with increase in private trip (PT). It indicates that people in Kathmandu travel short distance for PT. Though the shorter travel distance, people use motorcycle more often for PT.

3.6.5 Conclusions

This study is very important in the present context of Nepal as the country is facing financial burden due to ever increasing fuel import. This study has presented the relationships between urban form, mode choice and travel energy consumption by applying multiple linear regression model based on the entire 35 wards of Kathmandu city. This study dealt with the methodological challenges for modeling and analyzing complex relationships between urban form, travel purpose, mode choice, travel distance and energy consumption.

The result of regression model can be used to take a decision in urban planning that aims to reduce travel energy consumption in Kathmandu. This study has shown that increase in non-motorized mode and public mode has a significant role in reducing travel energy consumption. Likewise, reduction in motorcycle use and travel distance is the found key factor for reducing travel energy consumption in Kathmandu.

This study suggests that increase in non-motorized mode is possible even further away from CBD areas if it is facilitated with public mode services and higher density (D1). Unless a density threshold is met, providing public mode is not effective to reduce travel energy consumption. So, for increased use of public mode also, density has a key role. In contrast, this study showed that increasing transit accessibility has an adverse effect on public use. Therefore, this result suggests that improving transit accessibilities in terms of service quality may result supporting role to reduce travel energy consumption.

The result indicates that increase in density (D1) and design (D3) promotes motorcycle use reduction. Whereas, increase in D3 is influences car use. Therefore, this study suggests that an increase in road connectivity, public mode needs to be provided with better transit accessibilities and quality service to encourage people to use public mode for travel.

Both motorcycle and car are found highly used near to CBD areas. This indicates that the centralized development in city core of Kathmandu has led people to travel to CBD. So, this study suggests that urban decentralization within Kathmandu is effective; in such a case, most of the trips can be travel by walk or bicycle; simultaneously need to provide better service of public mode.

References

[1] Krambeck, H. Transport Energy Consumption Trends - Three Trajectories. Available online: http://blogs.worldbank.org/transport/global-implications-of-transport-sector-energy-consumption-in-the-developing-world-0 (accessed on 15 June 2010)

[2] UN-Habitat. STATE OF THE WORLD'S CITIES 2008-2009: HARMONIOUS CITIES. https://sustainabledevelopment.un.org/content/documents/11192562_alt-1.pdf (accessed on 20 November, 2016)

[3] Shrestha, R. M.,; Rajbhandari S. Energy and Environmental Implications of Carbon Emission Reduction Targets- Case of Kathmandu Valley, Nepal, Energy Policy 2010, 38(9), pp. 4818-4827.

[4] Coll, M.; Vandersmissen, M.; Thériault, M. (2014). Modeling spatio-temporal diffusion of carsharing membership in Québec City. Journal of Transport Geography, 38, 22-37. doi:10.1016/j.jtrangeo.2014.04.017

[5] Chapman, L. Transport and climate change: A review. J. Transp. Geogr. 2007, 15, 354–367.

[6] MoPIT/JICA: Final Report- Data Collection Survey on Traffic Improvement in Kathmandu Valley, Ministry of Physical Infrastructure and Transport. 2012.

[7] UNDESA (United Nations, Department of Economic and Social Affairs), World Urbanization Prospects, The 2014 Revision, UNDESA: New York, USA, 2015.

[8] The World Bank website: http://www.worldbank.org/en/news/feature/2013/04/01/managing-nepals-urban-transition (accessed on 5 May 2018).

[9] Muzzini, E.; Aparicio, G. Urban Growth Spatial Transition in Nepal: An Initial Assessment, World Bank Publications, Washington DC, 2013.

[10] Ministry of Physical Infrastructure and Transport, Department of Transport Management, Government of Nepal, Registration of Transport in Bagmati, Fiscal Year 2046/47-070/71 office wise. https://www.dotm.gov.np/uploads/files/transport_registration_fiscal_year_2046_47_070_71_typewise.pdf (accessed on 2 February 2018)

[11] The Federal Democratic Republic of Nepal Ministry of Physical Planning, Works and Transport Management Department of Roads, Data Collection Survey on Traffic Improvement in Kathmandu Valley, JICA, Nippon Koei Co., Ltd, Eight-Japan Engineering Consultants Inc., 2012.

[12] Maharjan, S.; Tsurusaki, N. A Study on the Energy Consumption Behavior in Kathmandu, Nepal, Journal of Architecture and Urban Design, Kyushu University, 2016, Vol. 30, pp. 33-44.

[13] Karyalaya launches transportation apps http://kathmandupost.ekantipur.com/news/2018-01-16/karyalaya-launches-transportation-apps.html (accessed on 3 November 2018)

[14] Leather, J.; Fabian, H.; Gota, S.; Mejia A. Walkability and Pedestrian Facilities in Asian Cities- Status and Issues. Asian Development Bank 2011.

[15] DoTM. Vehicle registration statistics, Department of Transport Management, Government of Nepal, Kathmandu, 2013, http://www.dotm.gov.np/uploads/files/Details _of_Registration _of_Tr anspor t_Ty peWise -up _to_2070_71.pdf (accessed on 13 October 2016)

[16] Adhikari, DP. Energy and environmental implications of alternative transport options: the case of Kathmandu, Nepal. MSc thesis, School of Environment, Resources and Development, Asian Institute of Technology, Bangkok, Thailand, 1997.

[17] Dhakal, S. Electric vehicles as a transportation option for Kathmandu Valley: economics and implications for electricity planning and the environment. MSc thesis, School of

Environment, Resources and Development, Asian Institute of Technology, Bangkok, Thailand, 1996.
[18] The World Bank Group. Managing Nepal's Urban Transition. Retrieved October 16, 2016. http://www.worldbank.org/en/news/feature/2013/04/01/managing-nepals-urban-transition 3.1.3 Research data type and source, 1 April 2013.
[19] National Population and Housing Census 2011. Government of Nepal, Central Bureau of Statistics, Kathmandu, Nepal, 2012, https://unstats.un.org/unsd/demographic-social/census/documents/Nepal/Nepal-Census-2011-Vol1.pdf (accessed on 6 February 2016).
[20] Ewing, R.; Cervero, R. Travel and the built environment: A meta-analysis. J. Am. Plan. Assoc. 2010, 76, 265–294, doi:10.1080/01944361003766766.
[21] Chatman, D.G. Residential Self-selection, the Built Environment, and Non-work Travel: Evidence Using New Data and Methods. Environ. Plan. A 2009, 41, 1072–1089, doi:10.1068/a4114.
[22] Zhang, M. The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong. J. Am. Plan. Assoc. 2004, 70, 344–360, doi:10.1080/01944360408976383.
[23] Boarnet, M.G.; Michael, G.; Tracy, E.M. Walking, Urban Design, and Health: Toward a Cost-benefit Analysis Framework. JPER 2008, 27, 341–358, doi:10.1177/0739456X07311073.
[24] Comendador, J.; Floridea, D.C.; Maria, E.L.; Juan, C.G.P. Built environment and Social Capital variables influence on travel behavior: the case of two waves panel survey in Madrid. 2015. Available online: https://trid.trb.org/view/1336623 (accessed on 12 February 2018).
[25] The Himalayan Times, Public Transportation: Is it really FOR the public? 27 November 2016. https://thehimalayantimes.com/perspectives/public-transportation-really-public/ (accessed on September 7, 2018)
[26] Nepalnews Mercantile, Night bus service starts in capital. Published on 17 Aug 2012. https://www.youtube.com/watch?v=WPpkoDAi05o (accessed on 25 January 2018)
[27] Richardson, A. J.; Ampt E. S.; Meyburg A. H. Survey Methods for Transport Planning. Parkville, Vic.: Eucalyptus, 1995.
[28] Dhakal, S. Implications of transportation policies on energy and environment in Kathmandu Valley, Nepal, Energy Policy. 2003, 31, 1493-1507.
[29] Newman,W.G.; Kenworthy, J.R. Gasoline consumption and cities. J. Am. Plan. Assoc. 1989, 55, 24–25.
[30] Banister, D.; Watson, S.; Wood, C. Sustainable Cities: Transport, Energy, and Urban Form. Environ. Plan. B Plan. Des. 1997, 24, 125–143.
[31] Cervero, R.; Kockelman, K. Travel demand and the 3Ds: Density, Diversity and Design. Transp. Res. D 1997,2, 199–219.
[32] Cervero, R.; Murakami, J. Effects of Built Environments on Vehicle Miles Traveled: Evidence from 370 US Urbanized Areas. Environ. Plan. A 2010, 42, 400–418.
[20] Ewing, R.; Cervero, R. Travel and the built environment: A meta-analysis, Journal of the American Planning Association, 2010, 76, 265–294.
[33] Handy, S.; Cao, X.; Mokhtarian, P. Correlation or causality between the built environment and travel behavior? Evidence from Northern California, Transp. Res. D. 10 (2005) 427–444.
[34] Brownstone, D.; Golob, T. F. The impact of residential density on vehicle usage and energy consumption, Journal of Urban Economics, 2009, 65, 91–98.
[35] Chen, C.; Gong, H.; Paaswell, R. Role of the Built Environment on Mode Choice Decisions: Additional Evidence on the Impact of Density, Transportation, 2008, 35, 285–299.

[36] Liu, C.; Shen, Q. An Empirical Analysis of the Influence of Urban Form on Household Travel and Energy Consumption, Comput. Environ. Urban Syst, 2011, 35, 347–357.
[37] Sectoral Profile: Kathmandu Metropolitan City, Nepal, 2010.
[38] Pokharel, Shaligram: An Econometric Analysis of Energy Consumption in Nepal, Energy Policy, 2007, 35, No. 1, pp. 350-361.
[39] Bajracharya, I; Bhattarai, N. Road Transportation Energy Demand and Environmental Emission: A Case of Kathmandu Valley, Hydro Nepal- Journal of Water, Energy and Environment, 2016, 18, pp. 30-40
[40] Bastola, U.; Sapkota, P. Relationships among Energy Consumption, Pollution Emission, and Economic Growth in Nepal, Energy 80, pp. 254-262.
[41] Cervero, R. Transit-based housing in California: Evidence on ridership impacts. Transp. Policy 1994, 1, 174–183.
[42] Handy, S. Methodologies for Exploring the Link between Urban Form and Travel Behavior. Transp. Res. Part D Transp. Environ. 1996, 1, 151–165.
[43] Ewing, R.; Cervero, R. Travel and the built environment: A synthesis. Transp. Res. Rec. Transp. Res. Board 2001, 1780, 87–114.
[44] Frank, L.; Pivo, G. Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-occupant Vehicle, Transit, and Walking. Transp. Res. Rec. 1994, 1466, 44–52.
[45] Badoe, D.A.; Miller, E.J. Transportation-Land-use Interaction: Empirical Findings in North America, and their Implications for Modeling. Transp. Res. Part D Transp. Environ. 2000, 5, 235–263.
[46] Cao, X.; Mokhtarian, P. L.; Handy, S. L. Neighborhood design and vehicle type choice: Evidence from Northern California. Transp. Res. D 2006,13 (2), 133-145.
[47] Pisarski, A.E. Overview , in: Transportation, urban form, and the environment. Transportation Research Board Special Report 231, National Research Council, Washington, DC, 1991.
[48] Myers, R.H. Classical and Modern Regression with Applications, 2nd ed.; Duxbury/Thomson Learning:Pacific Grove, CA, USA, 1990; ISBN 978-0534380168.
[49] Menard, S. Applied Logistic Regression Analysis, 2nd ed.; Quantitative Applications in the Social Sciences;Sage University: Thousand Oaks, CA, USA, 2002; p. 106.
[50] Mathema, P. It's an expensive jam. Nepali Times 2011. http://archive.nepalitimes.com/news.php?id=18124.W4BN6s77Rpg (accessed on June 2016)
[51] Stevens, M.J. Does Compact Development Make People Walk and Use Transit? Available online:https://www.hendrix.edu/uploadedFiles/Departments_and_Programs/Business_and_Economics/AMAES/Stevens%20-%20MAER-Net.pdf (accessed on 2 May 2017).

CHAPTER 4: SYNTHESIS

4.1 Identifying Urban Form Driving Factors for Travel Energy Consumption Based on Research Findings

This dissertation dealt with two different analysis methods: Cluster analysis and Multiple Linear Regression Model (MLRM) analysis. The results from the research using these analysis methods contribute to the current literature by gaining additional insights into the relationship among different aspects of urban form (D1 density, D2 diversity, D3 design, D4 destination accessibility and D5 distance to transit), travel behavior (travel purpose, travel mode and travel distance) and travel energy consumption. Cluster result identified the homogeneous groups that show the same characteristics of urban form, travel behavior and energy consumption. Whereas, MLRM provides a powerful analysis framework that made it possible to analyze the complex relationships of urban form, travel behavior and energy consumption. MLRM analysis helps us to understand how much the dependent variable change when we change the independent variables. MLRM allows the degree of correlation between the variables to be determined. In this chapter, first, we compare the results of cluster analysis based on Fukuoka (section 2.5) and Kathmandu (section 3.5) to identify the urban form driving factors of travel energy consumption at a micro-scale. Then, this chapter compares the results of MLRM analysis based on Fukuoka (section 2.7) and Kathmandu (section 3.6), and identifies the urban form driving factors of travel energy consumption at a city level.

4.1.1 Comparative Analysis Based on Cluster Results

The cluster analysis result of both case studies has presented in terms of urban form variables in Table 4.1. The results of cluster describe the characteristics of a homogeneous group with sufficient clarity. The three resulting groups from cluster analysis are found the same types (Figure 4.1) with almost similar characteristics for both Fukuoka and Kathmandu city. In respect to energy reduction in cities at a micro-scale, the interrelationship between urban form, travel behavior and travel energy consumption associated in each cluster group has a significant meaning.

Table 4.1 Identifying influence of urban form (5Ds) on travel energy consumption based on comparative analysis of cluster results

	Cluster 1- Low residential and lower energy consumption					Cluster 2- Highly connected and higher energy consumption					Cluster 3- Highly compact and lower energy consumption				
	D1	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**	**D1**	**D2**	**D3**	**D4**	**D5**
Fukuoka	↓	↓	↓	↑	↓	↓	↓	↑	↑	↓	↑	↑	↓	↓	↑
Kathmandu	↓	↑	↑	↑	↑	↓	↓	↑	↑	↓	↑	↑	↓	↓	↓

Legend

↑ Positive influence of 5Ds on travel energy consumption

↓ Negative influence of 5Ds on travel energy consumption

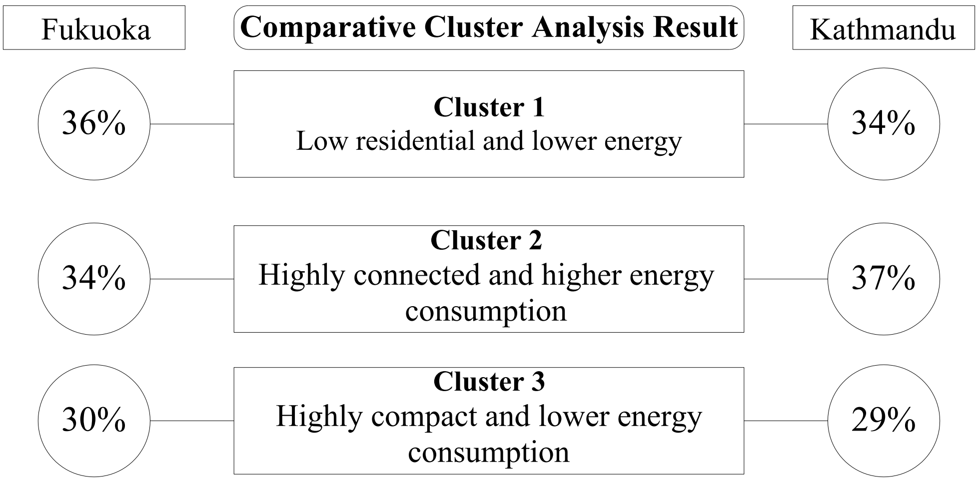

Figure 4.1 Comparative cluster analysis result

The first Cluster group, which contains 36% of the total number of zones in Fukuoka city and 34% of the total number of wards in Kathmandu city, is characterized by Low residential and lower energy consumption. The results of cluster 1 for both cities showed that the areas having low density (D1) and further away from CBD (D4) are associated with low energy consumption. This cluster meant that as the areas with low residential areas i.e. low density is directly related to trip reduction and consequently reduce energy consumption. In the case of Fukuoka, the areas under this cluster have less land use mix (D2), less road connectivity (D3) and poor transit accessibilities (D5). Whereas, the result of Kathmandu showed that D2, D3 and D5 are greater in the areas under this cluster. Likewise, the highest shared motorized mode in this cluster is found private vehicle for both cities. In the case of Fukuoka, it might be poor accessibilities to D5, people use their private modes. But in case of Kathmandu, even the D5 is better, private mode is highly used; which highlights that providing transit facility is not sufficient but also requires to attract and encourage people with its quality in service. Even, cluster 1 showed characteristics of lower energy consumption, it could be more energy efficient in the case of Kathmandu by encouraging people to use more transit. Otherwise, increase in D3 in this cluster groups likely increase the use of private modes in Kathmandu.

Cluster 2 is categorized by highly connected and higher energy consumption which contains 34% of the total number of zones in Fukuoka and 37% of the total number of wards in Kathmandu. The interrelationships between urban form, travel behavior and travel energy consumption associated in this cluster group are found almost the same for both Fukuoka and Kathmandu. Among 5Ds, a strong positive input is found for road connectivity (D3). In the case of Kathmandu, D4 also has a strong positive input for energy consumption. This meant that as further away from CBD, road connectivity is better and so, most of the people tend to use private mode for their convenience. Further, this cluster indicates less density (D1), less land use mix (D2) and poor accessibilities to public mode (D5) in both case studies. To reduce energy consumption, in this cluster group, D1 and D2 need to increase in the areas further away from CBD and also need to provide or improve public mode facilities. Increasing D1 and D2 are long term plans so, to have speedy effect in energy reduction, the short term plans need to be focused. Like, the existing road networks can be facilitated with public vehicles. In the less dense areas, the regular service of minibus/ tempo might be an effective solution to increase public mode and reduce travel energy consumption. Even though, the public mode operated by private sectors, it is felt that it should be managed or monitored by the government. Also, planning policy might be effective to control sprawl urban growth in Kathmandu. It is important to consider that as increase in sprawl development, people tends to own private mode.

Cluster 3 contains 30% of the total number of zones in Fukuoka and 29% of the total number of wards in Kathmandu, identified as Highly compact and lower energy consumption. This cluster is characterized by a strong input for D1 and D2 that meant higher the density and land use mix, lowered the energy consumption. The cluster results for both cities showed that the areas closer to CBD are highly compact (higher D1 and D2) with less road connectivity (D3) and less energy use. Whereas, the sign associated with D5 is found different for Fukuoka than that of Kathmandu. In the case of Fukuoka, it is reflected that as closer to CBD, development of more compact areas with better transit accessibilities that encourage people to walk, bicycling and use public mode. The highest share of mode in this cluster is found rail followed by non-motorized mode. Whereas, in the case of Kathmandu, even closer to CBD with higher compact areas, transit accessibilities are found very poor. Also, some areas under this cluster showed zero transit accessibility. However, this result is satisfied since the city core was developed as compact and walking city in the ancient time and in present also, access to urban facilities and CBD are at walking distance from the city core. Though this cluster is identified as the lower energy consumption, the cluster result of Kathmandu showed that the highest share of motorized mode is private vehicle; especially motorcycle. Kathmandu once a walkable city in the ancient time has turned to motorized city. Even today, the highest share of transport mode is found walk in this cluster whereas among motorized mode motorcycle has the highest share of trips. This highlights that even the walkable distance or cycling distance, people of Kathmandu highly use motorcycle for travel. It is either the problem of self-decision of people or the deficiencies in urban infrastructure like pedestrian road network, cycling environment and public mode services. It is necessary to flow the message among the people that owning a car or motorcycle is not a symbol of richness and walking does not mean poverty.

4.1.2 Comparative Analysis Based on MLRM Results

Both case studies have shown that travel energy consumption mainly depends on non-motorized mode, private mode and travel distance. The MLRM results of both cities showed that even further away to CBD, if density (D1) and land use mix (D2) is higher as well as transit accessibilities is better, it promotes non-motorized mode. Whereas, as higher the road connectivity (D3), it increases private mode use.

However, it is possible to promote public mode in the areas with higher road connectivity, especially for longer travel distance by providing better transit facilities and accessibilities. On one hand, transit share is greater at higher densities and on the other hand, the effect of density is compounded by transit-oriented design. TOD or transit zones are typically located within a radius of one-half mile from a transit station, as this is generally considered a reasonable walking distance for pedestrians. However, geographic proximity alone does not make development transit-oriented. In order to ensure TOD adequately meets the needs of potential residents, it is important to ensure frequent, high-quality transit service, good connections between transit and the community and community amenities.

Table 4.2 Identifying influence of urban form (5Ds) on travel energy consumption based on comparative analysis of MLRM results

Fukuoka	Travel mode		5Ds				
			D1	D2	D3	D4	D5
To reduce travel energy consumption	↑	Non-motorized	↑	↑	↓	↓	↑
	↓	Motorcycle	↑	↓	↓	↑	↓
	↓	Car	↑	↓	↓	↑	↑
	↑	Bus	↑	↑	↓	↓	↑
	↑	Rail	↑	↑	↓	↓	↑

Kathmandu	Travel mode		5Ds				
			D1	D2	D3	D4	D5
To reduce travel energy consumption	↑	Non-motorized	↑	↑	↓	↓	↑
	↓	Motorcycle	↑	↑	↑	↑	↑
	↓	Car	↓	↓	↓	↑	↑
	↑	Transit (Public)	↓	↓	↑	↓	↓

Legend

↑ Positive influence of 5Ds on travel energy consumption

↓ Negative influence of 5Ds on travel energy consumption

In the case of Fukuoka, car is found as the highest energy consumer. Whereas, in the case of Kathmandu, motorcycle is found a major source of energy consumption. Based on these highest shared energy intensive modes, this chapter analyzes the relationship between 5Ds and travel energy consumption and identifies the urban form driving factors of energy consumption.

For both case studies, Density (D1) is found the common key factor for energy consumption (Table 2.13, 3.7, 4.2). Higher density leads to reduce private mode and simultaneously reduce energy consumption. Along with density, it also needs to include other variables as the regression result is the result of all variables after controlled. In both case studies, near the CBD areas, private mode is found highly used for short travel distance. If this scenario continues, then there is no longer to increase in private mode trips and traffic jams in CBD areas even in non-rush hours which in turn directly effects on the increase in energy consumption. So, planning policy needs to be focused on decentralized development. Also, this study suggests that some policies might be effective to discourage people to drive in and near CBD areas by making inner CBD areas private vehicle free zone or applying a higher parking charge.

Increasing transit accessibilities (D5) is found another common influencing factor for reducing private mode use. The MLRM result of both studies showed that road connectivity (D3) has an affecting role in private mode use. In both cities, an increase in D3, use of car is also increased. So this study reveals that extending the road network without transit facilities will adversely affect energy consumption as more cars will be used. Specifically, in the case of Kathmandu, road widening is being touted as an essential intervention to solve the Kathmandu's severe traffic jam. But the result showed that road widening will not solve traffic jam, rather increases numbers of private vehicles and worsen traffic congestion and threaten energy demand-supply. In Kathmandu, motorcycle is found highly used even less in road connectivity. This might be because a motorcycle is suitable to use even in a small width of roads, especially, this is frequently seen in the alleys and even in crowded market places in Kathmandu.

4.2 Identifying Energy Efficient Planning Approaches For Kathmandu Based on Research Findings

Kathmandu has a comparatively less energy consumption compared to other international cities, though, it is necessary to search for energy efficiency in petroleum fuel as the import of fuel tremendously increasing every year. A substantial literature review highlights that long term energy efficiency in transport sector is possible by accompanying land use planning, whereas, technological intervention has a very low and short term impact. Therefore, this section aims to identify the energy efficient planning approaches for Kathmandu.

Revisiting the regression results for travel energy consumption (Figure 4.2, Table 4.3), It was found that motorcycle and travel distance are major factors for increasing energy consumption. The result showed that among the increasing factors for travel energy consumption, motorcycle has the highest effect.

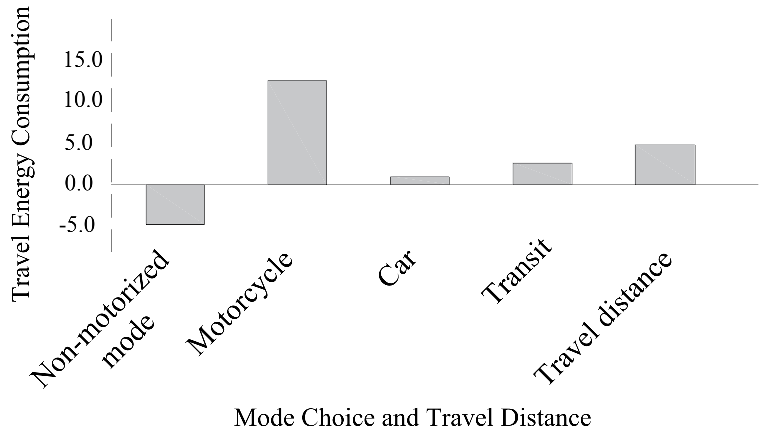

Figure 4.2 Effect of mode choice and travel distance on travel energy consumption

Table 4.3 Travel energy consumption regression model

Independent Variables	Travel Energy Consumption		
	B	T	*p*
(Constant)	-0.157	-1.176	0.249
Non-Motorized mode	-0.305	-4.780	0.000**
Motorcycle	1.022	12.790	0.000**
Car	0.051	1.015	0.318
Public (Transit)	-0.189	-2.585	0.015*
Travel distance	0.485	4.952	0.000**
Summary statistics			
p-value			0.000**
R			0.982
R-square(R^2)			0.965

Note: B means Unstandardized regression coefficient, T means test coefficient, *p* means Significance, ** means $p < 0.001$ and * means $p < 0.05$.

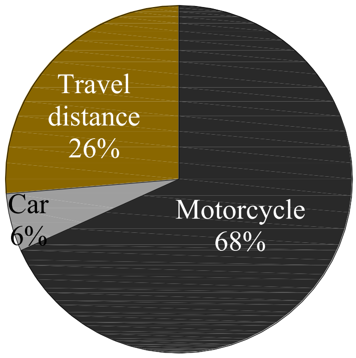

Figure 4.3 % share of effect factors for the increase in travel energy consumption

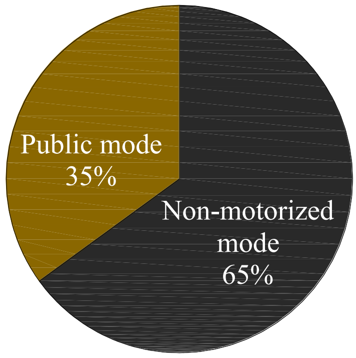

Figure 4.4 % share of effect factors for the reduction in travel energy consumption

The share percentage of each effect factors for the increase in travel energy consumption is shown in Figure 4.3. Similarly, the result showed that increase in non-motorized mode and public mode can reduce energy consumption in Kathmandu. The share percentage of non-motorized mode and public mode for the reduction of travel energy consumption is shown in Figure 4.4.

The regression result for travel energy consumption (Table 4.3) can be more clearly expressed in the form of Multiple Regression Equation as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon$$ **Equation 4.1**

where,

y = Dependent variable
x_i = Independent variable (i = 1, 2, … n)
β_0 = Constant (y-intersect)
β_i = Regression coefficient of the variable x_i (i = 1, 2, … n)
ε = Error (in Multiple Linear Equation, error term assumed to be zero)

Energy consumption= -0.157 + {-0.305 (Non-Motorized)} + {1.022 (Motorcycle)} + {0.051 (Car)} + {-0.189 (Public)} + {0.485 (Travel distance)} + 0

In multiple regressions, each coefficient is interpreted as the estimated change in y corresponding to a one unit change in an independent variable, when all other variables are held constant. So, the Equation 4.1 explains that an increase in one motorcycle user will increase travel energy consumption by 1.022MJ/person/day when other variables are held constant. Similarly, the increase in one car will increase travel energy consumption by 0.051MJ/person/day and increase in one kilometer travel distance will increase energy consumption by 0.485MJ/person/day when other variables are held constant. So, in the case of Kathmandu, the planning strategy and policy need to focused on the reduction of motorcycle to have effective result in the reduction of energy consumption.

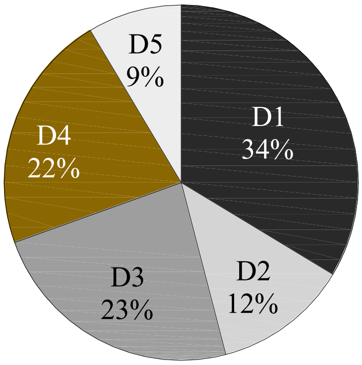

Figure 4.5 % share of 5Ds effect factors for the reduction in motorcycle use

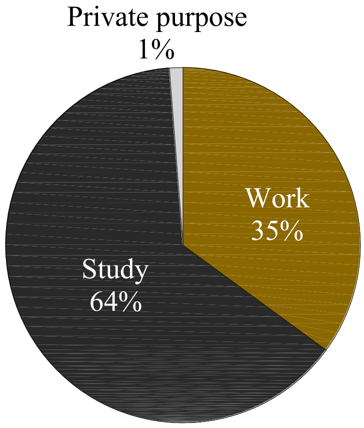

Figure 4.6 % share of travel purpose effect factors for the increase in motorcycle use

Similarly, an increase in one non-motorize mode user and increase in one public mode user will reduce travel energy consumption by 0.305MJ/person/day and 0.189MJ/person/day accordingly when other variables are held constant. This meant promoting walking and cycling is significant to reduce travel energy consumption in Kathmandu. Also, an increase in public mode relatively supports energy reduction.

After understanding that a motorcycle is a highly influencing factor for increasing travel energy consumption in Kathmandu, the regression results for motorcycle use was analyzed from the mode wise stratified regression result in detail to understand the share percentage of the effect factors among 5Ds; urban form variables and travel purpose for the motorcycle use. The result showed that all the variables of urban form have the influencing role in the reduction in motorcycle use. However, the most affecting factor is found density (D1, 34%) followed by design (D3, 23%) and destination accessibility (D4, 22%) as shown in Figure 4.5. This meant as higher the density, energy consumption decreases. Regarding design (D3), as higher the road connectivity, motorcycle use reduces. The result showed that an increase in D3 increases public mode use with a very low significance which indicates that even road connectivity is higher it is less facilitated with public mode in Kathmandu. This research result showed that better the destination accessibility (D4), higher the use of private modes (motorcycle and car). This meant private mode is increased in and near the CBD areas and hence traffic congestion in the city center. Whereas non-motorized mode use is found higher in the areas further away from CBD even density and land use mix is comparatively low but transit accessibility (D5) is better.

The distance to transit (D5) also shows a meaningful relation with motorcycle use indicating that increase in public mode accessibilities can support in reducing motorcycle use, but surprisingly, the result showed that even rise in transit accessibilities it has an adverse effect on public mode use. It meant even public facilities are available at the easy access, people are less encouraged to use it. It is likely due to the poor quality in service.

The share percentage of travel purpose for the increase in motorcycle is shown in Figure 4.6. The result showed that motorcycle is highly used for study (64%) purpose followed by work (35%) and private purpose (1%). In Nepal, people send their children (including kindergarten students) where they like to admit, regardless of the travel distance. Most of the families use motorcycle for dropping and picking their children from the school, likely on their way to work. As motorcycle is affordable for all economic group and convenient mode especially in the narrow streets like of Kathmandu, it is popular among college students, office worker and housewife. Whereas, increase in non-motorized mode is found strongly related with increase in private trip (PT). It indicates that people in Kathmandu travel short distance for PT.

In this way, the findings of the MLRM analysis provides a clear idea on which factors of urban form need to be focused to reduce the most affecting factor (i.e. motorcycle use) for the reduction of travel energy consumption in Kathmandu. But implementing the findings in overall Kathmandu is not logical, for instance, density increase is not required or even not possible in all the wards of Kathmandu. Therefore, to implement the findings and propose the solutions, it is important to represent the entire city into a number of homogenous groups based on the similarities in wards' characteristics. So, cluster analysis was performed in section 3.5. Three cluster groups were identified that represent overall Kathmandu. They are: Cluster 1- Low Residential and Lower Energy

Consumption; Cluster 2- Highly Connected and Higher Energy Consumption and Cluster 3- Highly Compact and Lower Energy Consumption.

Aiming the reduction of travel energy consumption, the wards in cluster 2 are found the most important to be considered based on the characteristics of this cluster. Though the cluster 1 and cluster 3 showed lower energy consumption, the highest share is found by motorcycle among the motorized modes use. So, the reduction of motorcycle users in all the three clusters is necessary to promote transport energy efficiency in the entire Kathmandu city. The recommendations are proposed based on the cluster wise characteristics as described below.

4.2.1 Cluster 1

As this cluster already has higher mix land use and higher transit accessibility, we recommend to increase density by attracting people to live in this cluster by developing mix used high rise apartment based on TOD concept. In such high heterogeneity land use zone, most of the trips can be traveled by walk or bicycle which results in a cut off the trip by motorcycle use. In addition, according to Building bye-laws of Kathmandu city, the Floor area ratio (FAR) for mix used building is 3.0 in most of the wards belongs to cluster 1. This meant high rise building is feasible and implementable in this cluster. Among the wards situated in this cluster, the ward 1, 11 and 31 need to be focused first for implementing the proposal of mix used high rise apartments as these wards showed the lowest density.

As cluster 1 belongs to the CBD area, it attracts many people travel from different areas of the city. So, we recommend promotion of BRT in such a way that it integrates with other public transport modes; which serves as feeder services in the areas of cluster 2. There might be a possibility that even balance of land use mix and higher density, the workplace or study area might be different other than cluster 1. Even in such a case, if transit service facilitated with BRT, people can only choose transit; instead of using motorcycle. In addition, most of the main streets in Kathmandu have been recently widen in cluster 1; so there is room for large buses.

The research findings showed that providing access to the public mode is not sufficient to promote public mode but also require improvement on public transit accessibility (more transit stops at a walkable distance in dense residential areas) and services (favorable service routes, information on the time schedule, punctuality, reasonable charge and safety). In the Kathmandu, the off-peak (early morning and late evening) transit facilities could be one of the attractive strategies to encourage people to use public mode. Also, the policy on public transportation needs to provide better quality services i.e. to create public transport services those are service-oriented rather than profit-oriented.

4.2.2 Cluster 2

For the energy reduction in cluster 2, increase in density is proposed in such a manner that other urban form variables also maintained the percentage share of other urban form variables as shown in Figure 4.5. Due to the limitation of Floor area ratio, FAR (only 1.75) as mentioned in Building bye-laws of Kathmandu, high rise apartment in cluster 2 is not much possible. In such a case, increase in density is possible with the increase in closer integration of residential development with urban facilities (work areas, schools, commercial, civic and recreational uses). Cluster 2 has still a plenty of undeveloped plots. So, we proposed increase in land use mix to support density increase based on TOD concept. It will promote trip reduction by motorcycle for study, work and private purpose. The MLRM showed that along with density (D1), destination accessibility (D4) and road connectivity (D3) has a higher influencing role.

Even land use mix is better and achieve higher density in this cluster 2, people living here will neither necessarily be employed at the workplaces in the same cluster nor primarily use the local shopping. In addition, cluster 2 is found further away from CBD compared to other clusters, indicating that people tend to use motorcycle for longer travel distance as there is poor transit accessibility. Whereas, this cluster has higher road connectivity compared to other clusters which highlight that with the increase in road connectivity, it needs to provide easy access to transit and quality in service to encourage people to use public mode for daily travel. Unless we provide the choice of alternative transport mode, reduction of motorcycle use is not possible. Likewise, unless a density threshold is met, providing public mode is not effective. So, this study recommends the regular service of low passenger public mode in cluster 2 as a solution to reduce motorcycle use and simultaneously energy consumption.

As D4; accessibility to the CBD has no control by urban planning in the existing city, so this study proposes solutions related to policy interventions. Most of the travel originated from cluster 2 end in cluster 1 as cluster 1 has higher land use mix compare to cluster 2. This has led not only higher energy consumption but also one of the main reasons for traffic congestion in the city center of Kathmandu. So, to solve this problem high fixed charges, such as parking charges, vehicle taxes and insurance, can actually affect vehicle use as once the charges have been paid, the private vehicle user generally feels that he/she should get use out of it. The main challenge associated with shifting transport mode is that they are generally unpopular with the public and so require political courage to implement.

To reduce motorcycle use for study, like in Fukuoka, people need to be encouraged to send their children to elementary school within the ward they living. This help to encourage walking. Furthermore, an attractive street design (landscaping, furniture, aligning shade trees along sidewalks, breaking up the horizontal length) with short and direct connections between urban facilities (work areas, schools, market, and parks) need to promote walking.

Among the wards situated in cluster 2, the wards 3, 8 and 9 are required to be focused first as these wards showed lowest density. D2 is mainly required to increase in the wards 4, 6 and 7 whereas D3 needs to increase in the wards 4, 8 and 14. Regarding D4, the wards 3, 6 and 35 showed the farthest from the CBD, so density and land use mix need to increase in these wards. Regarding D5, the lowest transit accessibility is found in the wards 6, 8 and 9. Increasing density and land use mix in these wards will support transit accessibility.

4.2.3 Cluster 3

Unlike cluster 1 and 2, this cluster already has higher density and higher land use mix; representing the city core of Kathmandu. Though this cluster has no transit accessibility, it has proximity to transit stop located in cluster 1 and cluster 2. Therefore, this study recommends to revitalize the city core as Transit-oriented development (TOD) by developing transit accessibilities with quality in service surrounding the cluster 3; to create a vibrant community centered on walking, cycling, transit access and reduced motorcycle dependence. According to LEED for

Neighborhood Development, proximity within ½ mile walking distance promotes TOD.

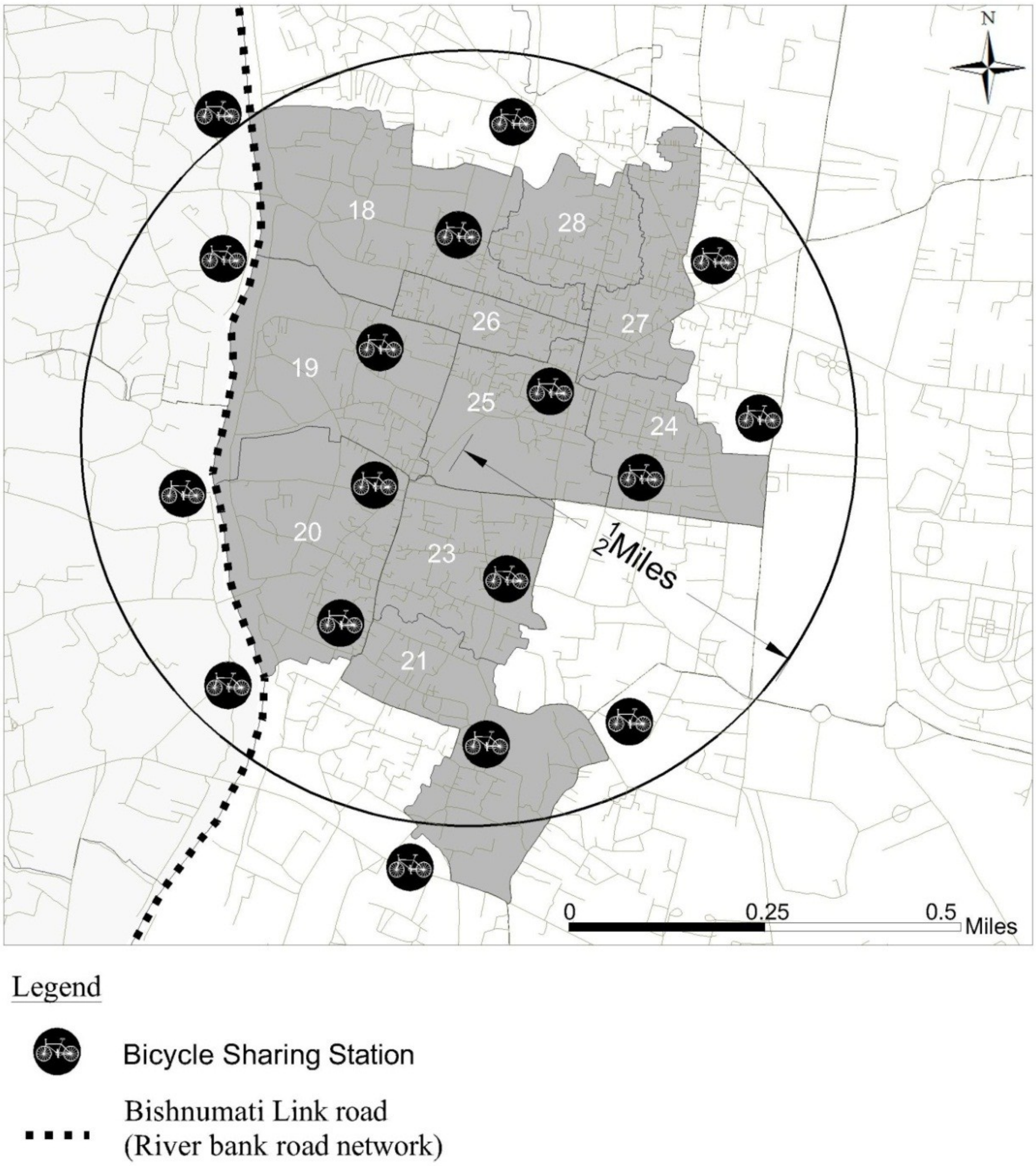

Figure 4.7 Proposed Transit Oriented Development (TOD) and Bicycle Sharing System in cluster 3; the City core sector

With this reference, TOD has been proposed to the city core sector at the radius of ½ mile from the center of the city core as shown in Figure 4.7. The proposed BRT in cluster 1 will enhance TOD. Also, in order to improve the quality of TOD, this study recommends restriction of motorcycle accessibility in the city core area to limit the intrusion of private mode and provide better and safer conditions for pedestrians and cyclist. This will also enhance the preservation of historic streets and places (Photo 4.1) in the city core.

Photo 4.1 Combined street network including traditional streets and market squares in the city core area (Source: doi: 10.5379/urbani-izziv-en-2011-22-02-004)

As this cluster is closer to CBD, most of the trips can be done by using non-motorized mode (walk and bicycle). However, cycle user is found null in this cluster. In fact, the flat terrain in Kathmandu, especially the city core area is very feasible for cycling. The roads of the city core are oriented for non-motorized mode as developed in the years back, so the operation of a bicycle sharing system is feasible in this cluster. So, this study recommends bicycle sharing system in the city core areas and near major transit stations outside the TOD as shown in Figure 4.7. Bicycle sharing can be a substitute for transit, particularly for short distance trips. On the other hand, for the long distance trips, bicycle sharing may complement public mode by connecting origins to transit stops and thus increase transit accessibility and reduce motorcycle use.

The ring of the proposed bicycle sharing system in cluster 3 satisfies the threshold distance for bicycling which is about 2.5 miles. The banks of river networks can serve dual purposes in transportation and recreation. So, Bishnumati Link road is proposed to develop as safe bicycle routes (Figure 4.7).

4.3 Evaluating energy efficiency based on influence of 5Ds on travel energy consumption

The energy performance in transportation is influenced by many factors, such as urban forms and travel variables. This complex situation makes it very difficult to accurately evaluate the energy efficiency in transport. This section reviews the multiple linear regression models (MLRM) developed in chapter 3- section 3.6; for solving this problem, which include elaborate and statistical measures.

In this section, evaluation of energy efficiency has been performed at individual ward level and cluster level by thoroughly analyzing each influencing factor in section 3.5, 3.6, 4.1; and approximately by altering those influencing factors based on the predicted effect of proposed recommendation for Kathmandu in section 4.2. Based on mode wise stratified regression model (Table 3.7), travel energy consumption regression model (Table 3.8) and Multiple Regression Equation (Equation 4.1), we produced regression equations where each regression coefficient (Table 4.4, 4.5) are taken into account for the evaluation purpose.

Table 4.4 Regression coefficient from mode wise stratified MLRM

	Constant	D1	D2	D3	D4	D5	WT	ST	BT	PT
Non-Motorized	-1.128	0.047	0.006	-0.01	0.246	0.084	0.272	0.25	0.226	0.456
Motorcycle	2.1	-0.26	-0.09	-0.19	-0.19	-0.07	0.42	0.72	-0.27	0.01
Car	0.662	0.001	0.068	0.336	-0.39	-0.23	0.713	0.175	-0.15	-0.28
Transit (Public)	4.05	-0.29	-0.25	0.03	-0.17	-0.21	0.61	0.285	-0.12	-0.32

Note: D1- density, D2- diversity, D3- design, D4- distance to CBD, D5- transit accessibility
WT- work trip, ST- study trip, BT- business trip, PT- private trip

Non-motorized mode= -1.128+ {0.047 D1} + {0.006 D2} + {-0.01 D3} + {0.246 D4} + {0.084 D5} + {0.272 WT} + {0.25 ST} + {0.226 BT} + {0.456 PT}+ 0

Motorcycle= 2.1+ {-0.26 D1} + {-0.09 D2} + {-0.19 D3} + {-0.19 D4} + {-0.07 D5} + {0.42 WT} + {0.72 ST} + {-0.27 BT} + {0.01 PT} + 0

Car= 0.662 + {0.001 D1} + {0.068 D2} + {0.336 D3} + {-0.39 D4} + {-0.23 D5} + {0.713 WT} + {0.175 ST} + {-0.15 BT} + {-0.28 PT} + 0

Transit= 4.05+ {-0.29 D1} + {-0.25 D2} + {0.03 D3} + {-0.17 D4} + {-0.21 D5} + {0.61 WT} + {0.285 ST} + {-0.12 BT} + {-0.32 PT} + 0

Table 4.5. Regression coefficient from travel energy consumption model

	Constant	Non-Motorized	Motorcycle	Car	Public	Travel distance (TD)
Energy Consumption	-0.157	-0.305	1.022	0.051	-0.189	0.485

Energy consumption= -0.157 + {-0.305 (Non-Motorized)} + {1.022 (Motorcycle)} + {0.051 (Car)} + {-0.189 (Public)} + {0.485 (Travel distance)} + 0

Summarizing the major proposed recommendation in each cluster:

Cluster 1 : Mix used high rise apartment based on Transit oriented development (TOD) and bus rapid transit: This meant increase in density (D1), land use mix (D2) and transit accessibility (D5).

Cluster 2: Increase in land use mix to increase density and regular service of low passenger public mode: This meant increase in density (D1), land use mix (D2) and transit accessibility (D5).

Cluster 3: Transit oriented development and bicycle sharing system. This meant increase in transit accessibility (D5).

Among the wards in cluster 1, the prioritized wards (1, 11 and 31) which have the lowest density are predicted to increase density and transit accessibility by 50% (Table 4.6) as the impact of mix used high rise apartment based on TOD and bus rapid transit. With the increase in density, higher mix land use and being close to public transit services, it has been assumed that travel distance will be reduced by 50% (Table 4.6). As a result, the energy efficiency in ward 1, 11 and 31 are found 86%, 36% and 6% (Figure 4.8) respectively. Simultaneously in other wards, increase in density and transit accessibility by 25% and increase land use mix where low degree has shown significant energy reduction as in Figure 4.8.

Table 4.6. Influencing factors for energy efficiency- Cluster 1

Ward No	D1	Std.	D2	Std.	D3	Std.	D4	Std.	D5	Std.	WT	ST	BT	PT	TD	Predicted D1	Predicted D2	Predicted D5	Predicted TD
1	3584.62	1	0.62	6	112	3	1.63	3	15.89	3	1	1	0	5	47.35	6576.93	0.70	23.84	23.68
2	10413.23	3	0.25	1	73	2	2.60	6	8.55	1	8	4	3	12	186.83	10413.23	0.25	10.00	186.83
5	14622.27	4	0.67	6	144	4	2.70	6	17.73	3	7	5	2	7	178.21	14622.27	0.67	17.73	178.21
11	6031.80	1	0.69	6	242	7	1.77	3	28.28	6	4	5	0	6	129.31	9047.70	0.69	42.42	64.66
12	16104.79	5	0.57	5	58.5	1	2.56	6	17.64	3	8	3	0	5	166.46	20130.98	0.57	22.05	124.84
17	24394.51	7	0.48	4	127.5	4	2.15	4	7.55	1	14	5	1	12	302.06	30493.14	0.48	3.00	226.55
22	18525.63	6	0.75	7	29	1	1.34	1	26.66	5	4	3	0	1	49.81	23157.03	0.75	33.32	37.35
29	14306.60	4	0.43	3	159	5	2.98	7	12.48	2	20	9	2	24	616.96	17883.25	0.64	15.60	462.72
30	20395.65	6	0.60	5	55.5	1	1.09	1	19.47	3	3	4	0	0	137.23	25494.56	0.60	24.33	102.92
31	9798.57	3	0.77	7	150	4	1.26	1	35.68	7	7	7	1	4	182.33	14697.86	0.77	53.52	136.75
32	16650.31	5	0.53	4	212	7	1.27	1	8.60	1	15	4	0	8	487.98	20812.89	0.79	10.74	365.99
33	19009.79	6	0.23	1	161	5	1.54	2	10.51	1	12	7	0	5	373.07	23762.23	0.34	13.13	279.80

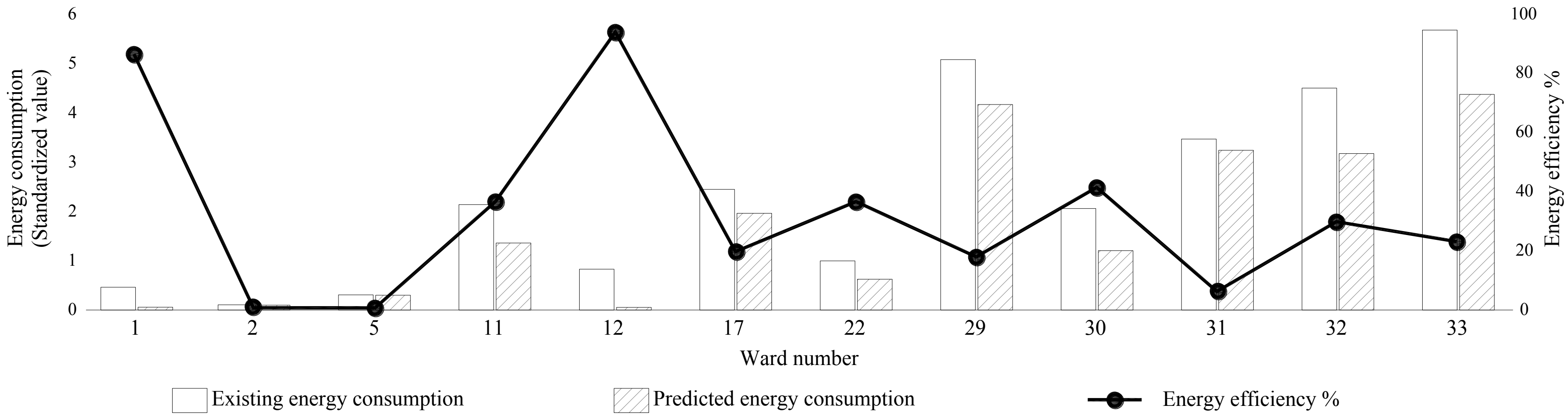

Figure 4.8 Ward wise existing and predicted energy consumption and its energy efficiency % - Cluster 1

Likewise, among the wards in cluster 2, the prioritized wards (3, 8 and 9) which have the lowest density are supposed to increase density by 50% (Table 4.7). To support density increase, land use mix also supposed to be increased by 50% and, transit accessibility increased by 50%. With the compact land use pattern and easy access to public transit services, it has been assumed that travel distance will be reduced by 50% (Table 4.7). As a result, the energy efficiency in ward 3, 8 and 9 are found 62%, 48% and 82% (Figure 4.9) respectively. The wards 4, 6 and 7 that showing low land use mix are supposed to increase D2 by 50% (Table 4.7). The wards having low road connectivity (4, 8 and 14) are assumed to be increased connectivity by 50%. Also, the ward further away to CBD (3, 6, 35) are considered to be increased density and land use mix by 50%. As a result the estimated energy efficiency in ward 4, 6,7 and 35 are found 88%, 96%, 26% and 34% (Figure 4.9) respectively.

In the case of cluster 3, it is supposed that the proposed transit oriented development and bicycle sharing system in this cluster will increase transit accessibilities. The roads in this cluster are oriented for non-motorized mode as developed in the years back, so it is not possible to provide transit facilities within the cluster 3. But, the implementation of bicycle sharing system can be a substitute for transit, particularly for short distance trips. On the other hand, for the long distance trips, integration of transit oriented development and bicycle sharing system will complement public mode by connecting origins (cluster 3) to transit stops (cluster 1 and cluster 3) and thus increase transit accessibility and reduce motorcycle use. The predicted value of transit accessibility (Table 4.9) is based on the number of bicycle sharing stations proposed as shown in Figure 4.7. The highest energy efficiency in cluster 3 are found in the ward 26 (90%) followed by ward 25 (83%) and ward 18 (53%) as shown in Figure 4.10.

Table 4.7 Influencing factors for energy efficiency- Cluster 2

Ward No	D1	Std.	D2	Std.	D3	Std.	D4	Std.	D5	Std.	Work	Study	Business	Private	TD	Predicted D1	Predicted D2	Predicted D3	Predicted D5	Predicted TD
3	6926.20	2	0.35	6	198	4	4.83	6	7.55	2	15	8	1	18	428.30	10389.30	0.52	198	11.33	300.30
4	9244.47	3	0.13	1	187.5	4	3.97	4	6.23	2	13	10	2	24	473.68	13866.71	0.19	281.25	7.78	355.26
6	10645.75	4	0.13	1	269	7	5.67	7	5.90	2	21	10	0	27	447.22	15968.62	0.19	269	7.38	335.41
7	18757.98	7	0.09	1	282	7	3.64	3	10.94	4	24	9	1	24	543.32	23447.47	0.14	282	13.68	407.49
8	2762.94	1	0.42	7	106	1	4.27	4	3.68	1	3	4	0	6	136.43	4144.40	0.63	159	5.52	68.21
9	8871.95	3	0.29	5	236.5	6	3.50	3	5.94	2	20	4	0	10	575.07	13307.92	0.44	236.5	8.91	287.53
10	16064.88	6	0.16	2	224	5	2.64	1	18.49	7	15	11	2	23	589.06	20081.10	0.20	224	23.11	441.79
13	11364.37	4	0.35	6	195.5	4	3.22	2	11.22	4	14	12	0	17	458.12	14205.46	0.44	195.5	14.02	343.59
14	10151.60	4	0.17	2	145.5	2	4.45	5	6.04	2	25	21	2	14	709.74	15227.40	0.21	218.25	7.55	532.30
15	10833.65	4	0.34	6	239	6	3.02	1	6.00	2	23	12	1	22	474.00	13542.06	0.43	239	7.50	355.50
16	11749.16	4	0.42	7	246	6	3.98	4	9.65	3	32	28	2	19	709.74	14686.45	0.52	246	12.06	532.30
34	18071.62	7	0.26	4	218.5	5	3.69	3	14.22	5	24	15	7	15	440.95	22589.53	0.33	218.5	17.77	330.72
35	11820.93	4	0.14	1	243	6	5.33	7	7.79	2	30	18	1	19	709.74	17731.39	0.21	243	9.74	532.30

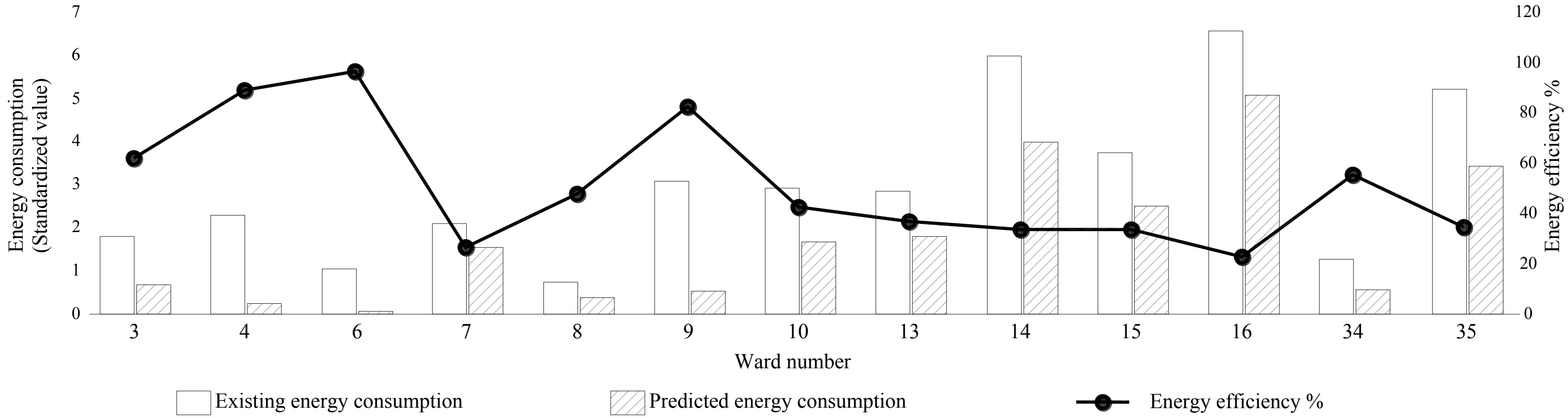

Figure 4.9 Ward wise existing and predicted energy consumption and its energy efficiency % - Cluster 2

Table 4.8 Influencing factors for energy efficiency- Cluster 3

Ward No	D1	Std.	D2	Std.	D3	Std.	D4	Std.	D5	Std.	Work	Study	Business	Private	TD	Predicted D2	Predicted D5	Predicted TD
18	36649.70	3	0.23	1	49	5	1.57	5	0	0	4	4	1	0	168.10	0.23	4.00	84.05
19	43009.47	4	0.21	1	42.5	3	1.86	7	0	0	7	4	0	0	45.00	0.42	4.00	22.50
20	43999.87	4	0.50	4	60	7	1.93	7	0	0	4	3	0	1	64.57	0.50	4.00	32.28
21	55535.73	6	0.36	2	47	4	1.95	7	0	0	5	7	0	0	208.09	0.36	4.00	104.04
23	50288.18	5	0.53	4	45.5	4	1.63	5	0	0	1	6	0	2	79.28	0.53	3.00	39.64
24	24619.36	1	0.75	6	38	2	1.01	1	0	0	2	2	0	0	48.88	0.75	3.00	24.44
25	20622.24	1	0.86	7	42.5	3	1.36	3	0	0	4	2	3	7	213.29	0.86	3.00	106.65
26	66689.42	7	0.33	2	32.5	1	1.48	4	0	0	4	1	0	3	99.87	0.33	3.00	49.93
27	62127.27	7	0.36	2	54.5	6	1.01	1	0	0	4	7	0	2	151.10	0.36	2.00	75.55
28	51415.57	5	0.52	4	31	1	1.26	2	0	0	5	0	0	4	78.06	0.52	2.00	39.03

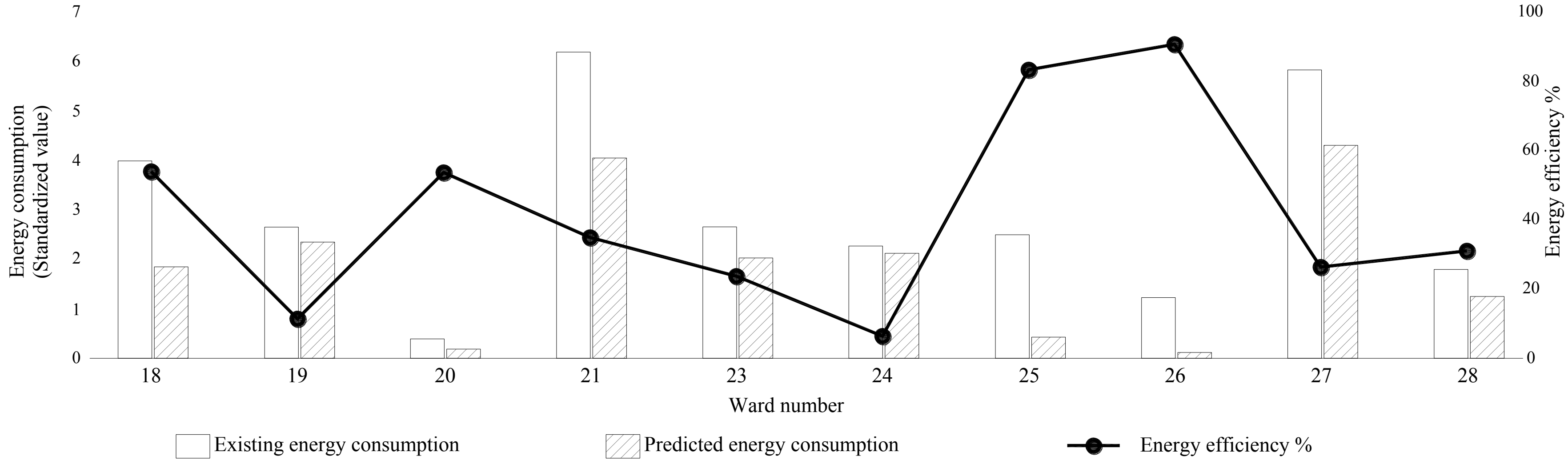

Figure 4.10 Ward wise existing and predicted energy consumption and its energy efficiency % - Cluster 3

In this way, we showed the evaluation of energy efficiency as an example by approximately altering the influencing urban form factors. Based on above example, we can summarized as controlling the urban form factors as shown in Figure 4.11, motorcycle use can be reduced (Figure 4.12) and accordingly reduced in energy consumption (Figure 4.13).

In cluster 1, increase in density by 18%, land use mix by 15% and transit accessibility increase by 28% (Figure 4.11) reduces motorcycle use by 53% (Figure 4.12) and reduction in energy consumption per person per day by 72% (Figure 4.13). Likewise, in the case of cluster 2, increase in density by 32%, land use mix by 68%, road connectivity by 13%, and transit accessibility increase by 18% (Figure 4.11) reduces motorcycle use by 98% (Figure 4.12) and reduction in energy consumption per person per day by 81% (Figure 4.13). In the case of cluster 3, increase in land use mix by 6% and transit accessibility by 32% (Figure 4.11) reduces motorcycle use by 15% (Figure 4.12) and reduces energy consumption per person per day by 71% as shown in Figure 4.13.

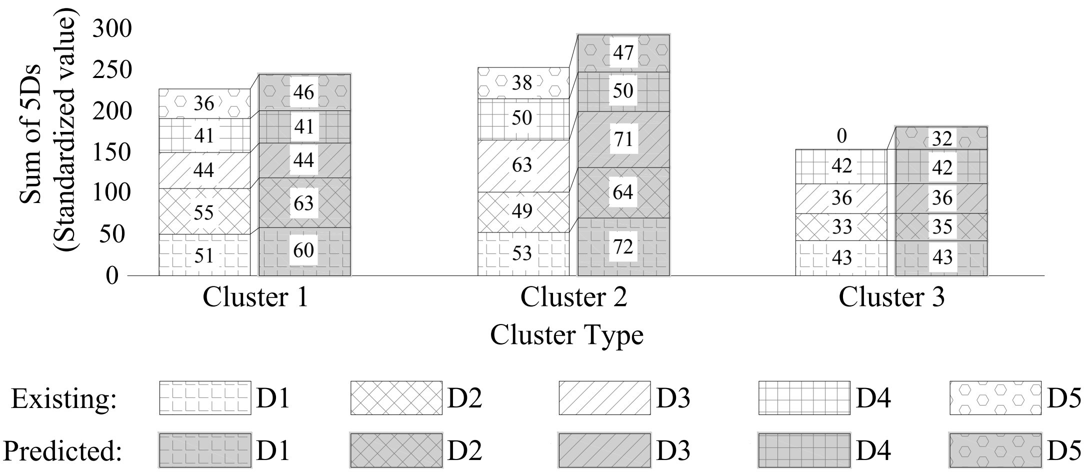

Figure 4.11 Cluster wise existing and predicted 5Ds

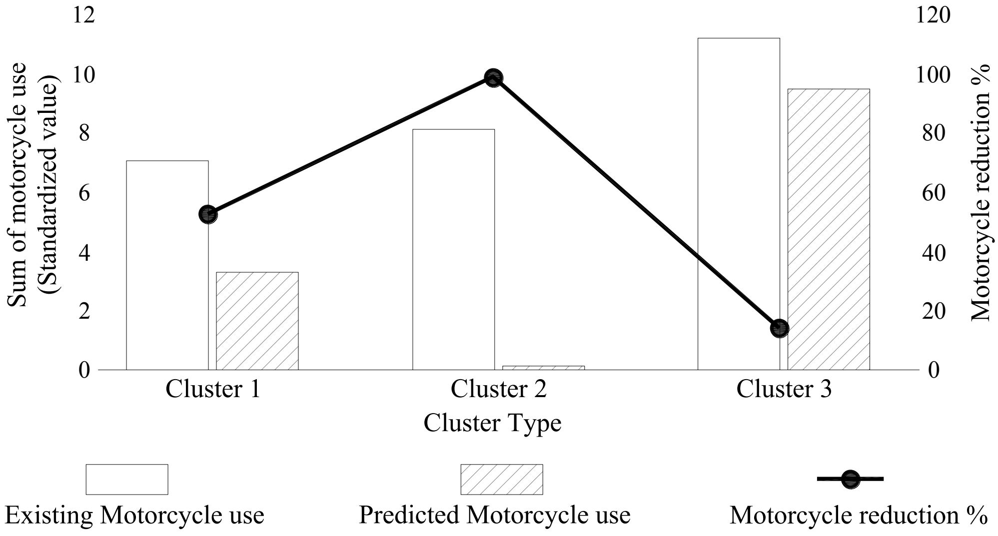

Figure 4.12 Cluster wise existing and predicted motorcycle use and its reduction %

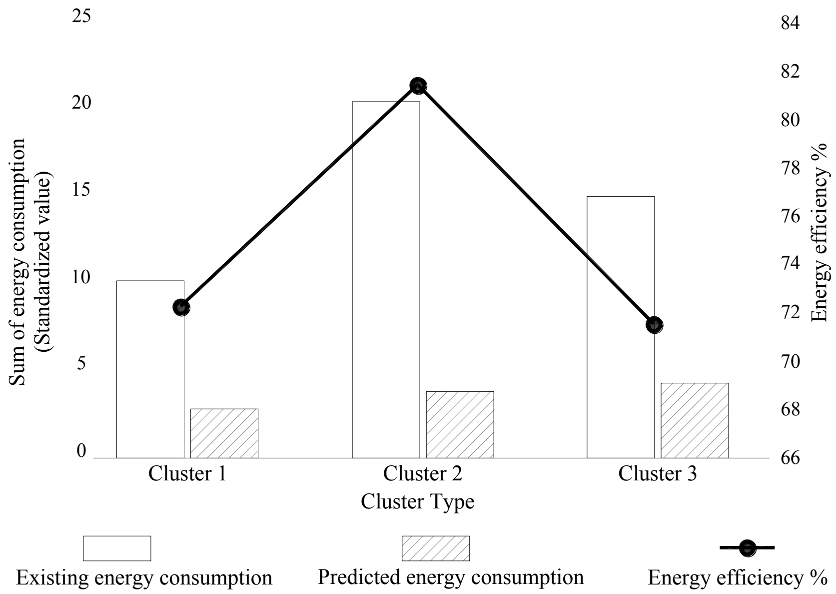

Figure 4.13 Cluster wise existing and predicted energy consumption and its energy efficiency %

Therefore, we conclude that there are significant relations between urban form and energy consumption. Also, it is proved that the proposed energy efficient planning approaches for Kathmandu in section 4.2 reduces motorcycle use and energy consumption significantly.

CHAPTER 5: CONCLUSION

5.1 Conclusion

This dissertation dealt with the two case studies, Fukuoka as the case study of a developed country and Kathmandu as the case study of developing country. The research based on Fukuoka city includes all the 7 wards of Fukuoka divided into 108 zones. Similarly, the entire Kathmandu city was analyzed based on all the 35 wards of the city. This research mainly includes three types of research variables: urban form variables, travel behavior related variables and travel energy consumption. "5Ds" framework (density, diversity, design, destination accessibility and distance to transit) has been applied to include multiple variables of urban form. The travel behavior related variables include travel purpose, travel mode and travel distance. Travel energy consumption variable is obtained by estimation, using travel behavior variables and energy intensity of transport mode. This dissertation dealt with two research methods: Cluster analysis and MLRM analysis.

The conclusions of the research findings are presented in this section as a summary of results and revisited research objectives (introduced in section 1.3).

5.1.1 Objective 1

The first objective was to explore micro-scale analysis of urban form, travel behavior and travel energy consumption. Micro-scale analysis was performed based on the two case studies: Fukuoka City, from a developed country and Kathmandu City, from a developing country. In section 2.5, and section 3.5, the clusters (homogeneous groups) were used to understand the interrelationship between urban form, travel behavior and travel energy consumption. The clusters were found almost the same for both cities, Fukuoka and Kathmandu. So, at some degree, this study concludes that any city if analyzed at micro-scale considering the variables of urban form, travel behavior and travel energy consumption, then a city can be analyzed in terms of three main clusters. These identified clusters are: Cluster 1- Low residential and lower energy consumption, Cluster 2- Highly connected and higher energy consumption, and Cluster 3- Highly compact and lower energy consumption. However, the research suggests that the interrelationship among various variables and the number of zones within the clusters might be different depending on the urban setting of a city.

The results of Cluster 1 from both case studies showed that the areas with low density (D1; low population density and low household density) and further away from CBD (D4) are linked with low travel energy consumption. In the case of Fukuoka, less land use mix (D2), less road connectivity (D3) and poor transit accessibilities (D5) are found influencing for lower energy consumption. In contrast, Kathmandu showed that lower energy consumption is related to higher D2, D3 and D5. Further, in both cases, this cluster indicates that higher use of private mode is associated with low density.

The results of Cluster 2 showed almost the same interrelationship between urban form, travel behavior and travel energy consumption for Fukuoka and Kathmandu. Increase in road connectivity (D3) is found strongly interrelated with the increase in travel energy consumption. Also, higher travel energy consumption is found interlinked with less density (D1; less population density and less household density), less land use mix (D2) and poor transit accessibilities (D5), especially associated with the areas further away to CBD (D4). This type of characteristic associated with higher use of private mode. Higher road connectivity with poor transit accessibilities intentioned people to use private mode.

The results of Cluster 3 from both cities showed that higher density (D1) and higher land use mix (D2) with less road connectivity (D3) is interrelated with less travel energy consumption. The interrelationship between destination accessibility (D4), transit accessibility (D5) and travel mode choice is found different in Fukuoka than of Kathmandu. In Fukuoka, closer to CBD (D4) is associated with better D5 and higher use of public mode followed by walk. So, providing priority to public transportation is viewed as one way to supply an alternative form of mobility to the private car and therefore reduce energy consumption. Whereas, in Kathmandu, closer to CBD (D4) is associated with poor D5 and higher use of walk followed by private mode (motorcycle). This indicates that developing country like Kathmandu, even higher density and close to CBD, use of private mode (motorcycle) is higher due to poor public transportation service. The shift of passengers from private mode to public mode is supposed to be achieved by creating an attractive and competitive public transportation system.

5.1.2 Objective 2

The second objective was to identify influencing mechanism of urban form on travel energy consumption. Influencing mechanism analysis was performed based on the two case studies: Fukuoka City, from a developed country and Kathmandu City, from a developing country. Multiple linear regression model (MLRM) was applied to fulfill this objective. MLRM quantifies the degree of correlation between multiple independent variables on a dependent variable. Also, based on MLRM, it is possible to determine the major influencing factors for travel energy consumption with relationships established among all the variables involved.

Firstly, in section 2.6 based on Fukuoka, MLRM analysis was used to understand the effect of urban form on travel energy consumption and identify the influencing factors for energy consumption. Based on five different travel purposes at both trip origin and trip destination, the research framework was established including urban form (5Ds) and socio-demography as independent variables to predict the effect on three dependent variables- non-motorized mode, motorized mode (public and private) and energy consumption. However, the MLRM result at both trip origin and trip destination has a little difference. It is likely that the zone for trip origin also acts as trip destination depending on the travel purpose. To some extent, the types of purpose could represent the types of destination locations. Moreover, the inclusion of return home purpose likely violates the result as it can be seen, almost all return home trips and other trips that start from home use the same mode. So, the research framework established in section 2.6 was realized the need to be improved and thus, in section 2.7 (case of Fukuoka) and section 3.6 (case of Kathmandu), we modified the research framework and came up with two phases of performing MLRMs. In the first phase of MLRM, urban form variables (5Ds) and travel behavior variables (trip for work, school, business, private) were chosen as independent variables where travel mode choice is used as a dependent variable. In the second phase of MLRM for energy consumption, the independent variables consist of mode choice for travel and travel distance where the dependent variable is total travel energy consumption.

In the first phase of MLRM, non-motorized mode (walk and bicycle) showed better model fit for both cities. In the mode-wise stratified models, the model for non-motorized mode showed a better model fit with 90% variance ($R^2 = 0.901$, p-value <

0.000) in the case of Fukuoka and in the case of Kathmandu 92.4% variance (R^2 = 0.924, *p*-value < 0.000). Non-motorized mode is found positively associated with density (D1), land use mix (D2), distance to CBD (D4), transit accessibilities (D5) and inversely associated with road connectivity (D3). The use of walking and cycling has a potential role in replacing motorized mode use, especially in dense areas. Non-motorized travel is best viewed not as a substitute for private mode but as a complementary mode of travel together with public transportation specifically in the case of longer travel distance. In the case of Fukuoka, D1, D3 and D4 are identified as the most influencing factor for promoting non-motorized mode and reducing travel energy consumption. Whereas, D4 is found influencing factor for non-motorized mode in Kathmandu but with less significance.

After non-motorized mode, among the models in the mode-wise stratified models presented in the first phase of MLRM, private mode showed a better model fit for both cities. In the case of Fukuoka, the model showed 83% variance for car (R^2 = 0.833, *p*-value < 0.000) and in the case of Kathmandu 84.6% variance for motorcycle (R^2 = 0.846, *p*-value < 0.000). This result suggests that the purpose of giving priority to reduce private mode should be dealt with differently. In a developed country, it should be dealt with car use whereas, in the case of a developing country, it should be dealt with motorcycle use. For both case studies, density (D1) is found the most influencing factor for reducing private mode. In addition, distance to CBD (D4) is found positively associated with private mode use. In the case of Fukuoka, car is found positively associated with road connectivity (D3). Contrast to this, in case of Kathmandu motorcycle is found inversely associated with D3.

The second phase of MLRM results of both cities showed that travel energy consumption mainly depends on private mode (car in Fukuoka, motorcycle in Kathmandu), non-motorized mode and travel distance. In the regression model for travel energy consumption, private mode use and travel distance are found positively significant (p = 0.000 for both cities) with an increase in travel energy consumption. Whereas, non-motorized mode showed a significant inverse association (p = 0.012 in Fukuoka, p = 0.000 in Kathmandu) with travel energy consumption. So, the result suggests that the reduction of travel energy consumption can be achieved by reducing private mode use and travel distance as well as increasing non-motorized mode. The requisite of achieving the mode shift and lessen the travel distance is achieved through realizing and implementing the results in the first phase of MLRM. The first phase of MLRM for both cities provide many recommendations regarding urban designs to support the land use and mode choice as the models showed the effects of urban form on mode choice.

5.1.3 Objective 3

The third objective was to identify and evaluate energy efficient urban planning approaches for Kathmandu based on micro-scale analysis and influencing mechanism analysis of urban form on travel energy consumption. Recommendations have been proposed based on the results from objectives 1 and 2. Also, evaluation of energy efficiency has been performed at individual ward level and cluster level by thoroughly analyzing influencing factor to identify how much energy efficiency can be achieved by the implication of those proposed recommendations. The evaluation proved that the proposed recommendations for Kathmandu city reduce motorcycle use and energy consumption significantly. All these recommendations need to be integrated for promoting travel energy efficiency in Kathmandu. Overall, the proposed recommendations are summarized in three categories: Integrated land use-transport planning, policy intervention and inspiration.

Integrated Land Use-Transport Planning

- Revitalize the city core sector of Kathmandu city based on transit-oriented development (TOD).
- Develop mix used high rise apartments in low residential areas in CBD, i.e. where greater land use mix with better transit accessibility.
- Decentralize the daily traveled facilities and services like institutional, and work facilities market areas.
- Provide safe bicycle networks, bicycle parking facilities in strategic places (major road cross-section, near a major transit station, CBD area) to encourage people to cycle.
- Provide safe (installation of street light, traffic light and speed breaker) and attractive street design (landscaping, furniture, aligning shade trees along

sidewalks, breaking up the horizontal length) with short and direct connections between urban facilities (work areas, schools, market, and parks) to promote walking and cycling.

Policy Intervention

- Providing access to the public mode is not sufficient but also requires improvement on public transit accessibility (dedicated bus lanes in rush hours, more transit stops at a walkable distance in dense residential areas) and services (favorable service routes, punctuality, reasonable charge, safety and security).
- promotion of large buses like Bus rapid transit (BRT) in such a way that it integrates with other public transport modes; which serve as feeder services in the areas of sprawl urban development and less connectivity of roads.
- Promote bicycle sharing system; short-term bicycle rental service in the city core areas and near major transit stations outside the TOD
- Restrict motorcycle accessibility in the city core area to limit the intrusion of private mode and provide better and safer conditions for pedestrians and reduce their negative impacts on pollution, safety and aesthetics of neighborhoods.
- Implement Information Technology (IT) in public transportation of Kathmandu as in Fukuoka. Introducing IC card, providing information on the time schedule, fare and nearest transit stations has a significant role to connect people with public transportation.
- Fix high charges, such as parking charges in CBD areas, vehicle taxes and insurance.
- Like in Fukuoka, people need to encourage send their children to elementary school within the ward they living.
- Regional location policy with other cities to develop clustering of commercial activities or land use mixes nearby public transport nodes and corridors.

Inspiration

- Sufficient inspirational programme needs to change the consolidated habits of the population and encourage people to use transit.

- The course related to behavior driven interventions need to include from schooling, to raise awareness among school-children and their parents. It also increases road safety and thus makes walking and cycling a safety option for daily commuting.
- Development of a comprehensive marketing campaign to influence cycling by inspiring them how much cycle has health benefits, environmental and financial benefits.
- Offer transit incentives to get people out of their private mode in exchange for public transportation and also to make them feel that public transportation is a valuable transport option.

5.2 Research Contribution

This research contributes to the current literature by gaining additional insights into both research implications and policy implications. From research implication perspectives, this study provides valuable information that urban form can play a pivotal role in the reduction of private mode and energy consumption. This information can help planners and policy makers develop a more thorough understanding of how urban form influence travel behavior and so, on travel energy. This research has identified the influence of multiple variables of urban form (5Ds) on travel energy consumption. The research results highlighted that the motorcycle use is the most influencing factor for the increase in travel energy consumption in Kathmandu. Likewise, this study highlighted that density has a key role in the motorcycle use reduction. This research has identified that Kathmandu city can be divided into three cluster groups based on the heterogeneity characteristics. Also, this research has identified the target area (specific ward) and measures for Kathmandu city for reducing travel energy consumption that has different condition and limitation compared with a city in developed country.

The result highlights that residential area has direct effects on travel behavior and further on travel energy consumption. Higher densities with higher land use mix promote non-motorized mode. Increase in road connectivity had an adverse effect on the use of non-motorized mode and transit use. The highly connected zone with less density, diversity, poor transit accessibility and further away from CBD results in an increase of motorcycle use and rise in energy consumption as high energy intensity of private vehicle and longer travel distance as well. Even some of the areas in Kathmandu with compact planning was not found effective to reduce private mode use and travel energy consumption as it has poor transit accessibilities and services. Further, in the case of Kathmandu roads have been widening, homes and public buildings mowed down to solve the traffic problem. The research result highlights that it will not support to decrease traffic jam rather continue to increase trip by private mode in Kathmandu. The reason is likely that widening the available road space initially increases speed and comfort and thereby encourages more people to travel in private motor vehicles. More and more users take to the route until the wider road returns to its original level of congestion. So, public modes especially large buses need to promote on wider roads. Further, the research result showed that in Kathmandu, people tend to use private mode not only in the case of poor transit accessibilities but even also in better accessibilities cases. This result highlights that the quantity of transit stops is not the prime attention but simultaneously need to provide quality service.

Unlike previous studies, this research investigates the interrelationship between urban form, travel behavior and travel energy consumption in an integrated way considering multiple variables of urban form (density, diversity, design, destination accessibility and distance to transit), travel variables (travel purpose, travel mode, travel distance) and energy consumption. Also, this research dealt with methodological challenges to tackle the complex interrelationship among research variables by applying two different analysis methods: Cluster analysis and Multiple Linear Regression Model (MLRM). The cluster result provides three homogeneous groups that can be implemented to analyze any city in terms of urban form and energy consumption. Whereas, MLRM provides the relationship with various factors of urban form on travel mode choice and its effect on travel energy consumption and identifies the key factor for travel energy consumption. The result outcomes of the research using both methods are same which shows the validity of the methods in such type of research. So, the research framework used in this study could be applied to understanding the relationship between urban form, travel variables and travel energy consumption. This research serves as a reference to identify the similarities and differences between the case of developed and developing country.

This evaluation method of energy efficiency can be applied to analyze, optimize and predict energy efficiency in any ward or any cluster or city level. The prediction is more accurate as it consists both direct (direct effect of urban form on travel variables, direct effect of travel variables on travel energy consumption) and indirect effect of urban form on travel energy consumption. Using this evaluation method, we can control urban form variables which directly effect on travel variables data and so it can be clearly observed how much energy efficiency can be achieved in energy consumption.

From policy implication perspectives, this study highlights that no single transportation technology or land use policy action can offer a complete checklist of achieving reductions of travel and energy consumption. Instead, a mix of different technologies, policies, and strategies is necessary. This study highlights that integrated land use-transport planning decisions, policy interventions and inspiration among the people, need to prioritize for promoting energy efficiency in Kathmandu.

5.3 Limitation and Future Research

It should be noted that this study has several limitations and some highlights for future research. First, this study uses objective measures of the urban form. Scholars have emphasized subjective measures such as perceptions of street environment and sensitiveness on using public mode also have direct effects on travel behavior. So, both objective and subjective measures need to be considered in future research.

Second, a person's residential self-selection has not included in this research. People who prefer to drive less may selectively live in more compact, mixed land use, and more connected neighborhoods and thus walk more and drive less. In this case, urban form does not have a direct relationship with travel behavior. It is the residential choice which determines the travel behavior. To include a person's residential self-selection, more attitude data or other techniques like panel data are needed.

Third, travel behavior data is collected based on a one-day travel survey and accordingly energy consumption is estimated in this research. Day-to-day variability of user behavior cannot be captured by a snapshot with a one-day survey. Therefore, sophisticated and robust one-week survey data must be considered in future research to provide a detailed travel diary of each family member during the last full week (including weekends).

Fourth, this study only used travel purpose, travel mode and travel distance as travel behavior related variables. In future, more detailed travel data can be used to reflect the energy consumption in the study area. The multiple ways in which urban form influences travel energy consumption should be done with much more information on each trip, including travel mode, distance, vehicle fuel type, vehicle occupancy and speed.

APPENDIX

Fukuoka City - Socio-demography data

Ku	Zone	Total Respondence	Age			Gender		Occupation						
			Average	Min.	Max.	Male	Female	Agriculture	Production	Sales Service	Administrative Affairs	Student	Housewife & Others	Maximum Occupation
Chuo-ku	1	222	45	18	93	116	106	0	3	35	44	1	18	Administrative affairs
	2	478	42	5	94	223	255	0	8	26	34	12	20	Administrative affairs
	3	1,043	40	6	89	492	551	0	4	30	33	8	25	Administrative affairs
	4	2,048	42	5	96	944	1,104	0	3	18	42	13	25	Administrative affairs
	5	1,685	43	5	91	685	1,000	0	2	24	36	12	26	Administrative affairs
	6	959	46	7	94	428	531	0	1	13	45	10	31	Administrative affairs
	7	499	44	7	92	208	291	0	5	24	39	5	27	Administrative affairs
	8	97	44	18	85	36	61	0	11	22	37	5	25	Administrative affairs
	9	789	40	5	97	337	452	1	2	21	40	15	21	Administrative affairs
	10	2,911	40	5	92	1,338	1,573	1	4	13	36	22	25	Administrative affairs
	11	1,475	41	5	93	697	778	0	1	12	39	18	29	Administrative affairs
	12	1,558	42	5	95	731	827	0	1	12	35	22	30	Administrative affairs
	13	1,243	45	5	89	606	637	0	2	9	32	20	37	Housewife / other
	14	1,420	39	5	92	653	767	0	2	13	32	25	28	Administrative affairs
	15	34	46	16	70	13	21	0	24	0	12	6	59	Housewife / other
Hakata-ku	16	152	49	14	81	67	85	0	3	47	15	1	34	Sales / service relations
	17	424	40	5	92	213	211	0	6	23	39	9	23	Administrative affairs
	18	100	45	19	80	43	57	0	4	35	34	8	19	Sales / service relations
	19	614	40	5	98	302	312	0	2	29	38	13	17	Administrative affairs
	20	810	41	5	90	354	456	0	4	21	35	16	25	Administrative affairs
	21	347	44	5	84	136	211	0	3	21	37	10	29	Administrative affairs
	22	584	43	5	91	285	299	1	5	28	28	17	21	Sales / service relations
	23	915	42	5	94	453	462	0	3	18	32	23	24	Administrative affairs
	24	249	40	5	88	127	122	1	4	29	31	16	19	Administrative affairs
	25	833	40	5	92	394	439	0	4	19	25	28	23	Student / Student
	26	1,501	42	5	99	733	768	0	8	16	34	16	26	Administrative affairs
	27	932	45	5	92	442	490	0	9	18	36	13	24	Administrative affairs
	28	514	35	5	92	240	274	0	5	16	31	23	24	Administrative affairs
	29	1,250	44	5	93	630	620	1	13	16	26	16	29	Housewife / other
	30	1,354	41	5	97	668	686	0	7	20	30	19	23	Administrative affairs
	31	2,279	42	5	97	1,040	1,239	0	7	19	30	15	28	Administrative affairs
	32	847	41	5	88	439	408	0	7	18	33	17	25	Administrative affairs
	33	2,081	41	5	96	1,006	1,075	0	7	20	32	16	25	Administrative affairs
	34	812	41	5	92	362	450	0	2	19	40	11	27	Administrative affairs
	35	1,467	41	5	101	757	710	0	3	12	39	20	26	Administrative affairs

Minami-ku	36	468	41	5	99	198	270	0	0	9	37	21	32	Administrative affairs
	37	1,283	40	5	96	663	620	0	2	17	33	25	22	Administrative affairs
	38	1,308	46	5	94	604	704	0	4	13	30	17	36	Housewife / other
	39	1,152	42	5	96	543	609	0	6	14	28	20	32	Housewife / other
	40	1,463	44	5	99	734	729	1	5	14	34	18	28	Administrative affairs
	41	951	47	5	94	385	566	0	3	9	28	19	41	Housewife / other
	42	1,443	46	5	87	607	836	0	4	18	34	12	32	Administrative affairs
	43	1,576	40	5	96	781	795	0	8	18	36	17	21	Administrative affairs
	44	2,621	43	5	94	1,234	1,387	0	3	17	32	17	31	Administrative affairs
	45	2,203	44	5	102	996	1,207	0	6	13	30	17	34	Housewife / other
	46	1,693	43	5	94	745	948	0	10	17	26	19	28	Housewife / other
	47	1,366	41	5	91	667	699	0	6	18	32	19	26	Administrative affairs
	48	1,284	40	5	93	615	669	0	7	14	31	18	29	Administrative affairs
Higasi-ku	49	2,011	41	5	90	1,026	985	0	5	12	30	24	28	Administrative affairs
	50	32	43	10	72	20	12	0	6	6	50	25	13	Administrative affairs
	51	5	27	21	30		5	0	0	60	40	0	0	Sales / service relations
	52	308	45	6	93	127	181	0	5	12	29	20	34	Housewife / other
	53	843	38	5	93	421	422	0	11	11	31	23	24	Administrative affairs
	54	520	38	5	84	238	282	3	8	22	26	22	19	Administrative affairs
	55	1,415	44	5	91	586	829	0	9	15	28	15	32	Housewife / other
	56	1,679	42	5	94	817	862	0	6	12	33	21	28	Administrative affairs
	57	1,893	45	5	98	844	1,049	0	7	14	30	18	32	Housewife / other
	58	839	44	5	94	394	445	0	5	13	33	18	31	Administrative affairs
	59	2,344	41	5	92	1,068	1,276	0	6	13	25	25	32	Housewife / other
	60	1,362	42	5	92	687	675	0	4	11	31	22	31	Housewife / other
	61	1,350	44	5	94	625	725	0	4	18	29	16	32	Housewife / other
	62	1,709	43	5	97	789	920	0	7	12	29	21	30	Housewife / other
	63	2,318	43	5	96	1,061	1,257	0	6	15	25	22	33	Housewife / other
	64	2,658	43	5	93	1,219	1,439	0	7	11	26	19	37	Housewife / other
	65	1,317	45	5	98	665	652	0	6	13	28	19	34	Housewife / other
	66	665	46	6	89	287	378	0	2	16	37	16	29	Administrative affairs
	67	963	45	5	96	465	498	1	6	13	31	16	33	Housewife / other
	68	512	45	5	100	247	265	0	7	12	25	20	36	Housewife / other
	69	77	39	7	80	29	48	5	8	5	14	34	34	Student / Student
Johnan-ku	70	2,793	40	5	89	1,242	1,551	0	4	12	33	23	29	Administrative affairs
	71	2,569	44	5	96	1,117	1,452	0	2	13	34	19	31	Administrative affairs
	72	1,559	43	5	92	759	800	0	4	13	36	17	31	Administrative affairs
	73	2,740	42	5	97	1,240	1,500	0	4	16	29	21	29	Administrative affairs
	74	1,662	39	5	91	849	813	0	3	13	30	31	22	Student / Student

	75	2,320	39	5	95	1,055	1,265	0	4	9	33	27	27	Administrative affairs
	76	1,625	44	5	92	761	864	0	2	19	30	18	31	Housewife / other
Sawara-ku	77	2,921	37	5	95	1,340	1,581	1	2	11	34	27	25	Administrative affairs
	78	1,354	37	5	91	658	696	0	1	15	39	21	24	Administrative affairs
	79	2,573	38	5	93	1,161	1,412	0	4	13	39	23	21	Administrative affairs
	80	1,586	42	5	97	679	907	0	2	11	31	21	34	Housewife / other
	81	1,680	39	5	91	837	843	0	5	14	29	24	27	Administrative affairs
	82	2,347	38	5	89	1,200	1,147	0	3	15	33	27	22	Administrative affairs
	83	1,673	40	5	95	749	924	0	7	15	28	24	26	Administrative affairs
	84	1,440	42	5	89	726	714	0	7	13	33	20	28	Administrative affairs
	85	821	43	5	89	441	380	1	5	9	33	18	33	Administrative affairs
	86	1,809	44	5	103	804	1,005	1	7	18	31	16	27	Administrative affairs
	87	1,033	42	5	98	447	586	0	5	14	31	15	35	Housewife / other
	88	2,009	39	5	93	953	1,056	2	7	17	25	21	28	Housewife / other
	89	1,220	38	5	90	603	617	0	1	8	40	28	23	Administrative affairs
	90	1,713	47	5	94	836	877	2	6	11	33	15	33	Administrative affairs
	91	1,903	42	5	89	908	995	6	6	14	30	22	23	Administrative affairs
Nishi-ku	92	2,037	42	5	95	949	1,088	0	3	12	35	17	32	Administrative affairs
	93	650	42	5	92	310	340	0	6	20	23	18	33	Housewife / other
	94	1,280	40	5	97	643	637	0	3	10	33	19	34	Housewife / other
	95	1,919	41	5	91	908	1,011	1	7	13	27	21	31	Housewife / other
	96	1,829	41	5	94	828	1,001	0	6	15	28	19	32	Housewife / other
	97	806	45	5	97	370	436	2	9	15	24	20	31	Housewife / other
	98	1,809	43	5	102	845	964	1	5	11	30	20	33	Housewife / other
	99	59	50	7	87	28	31	3	0	0	27	14	56	Housewife / other
	100	35	55	30	73	15	20	0	0	34	40	0	26	Administrative affairs
	101	806	37	5	89	377	429	0	2	10	31	31	26	Student / Student
	102	285	45	5	89	138	147	13	6	9	29	20	24	Administrative affairs
	103	2,326	44	5	96	1,052	1,274	1	6	14	29	20	31	Housewife / other
	104	1,221	39	5	98	565	656	2	5	12	27	24	30	Housewife / other
	105	41	53	11	87	15	26	0	27	0	17	12	44	Housewife / other
	106	320	53	5	100	143	177	5	4	9	29	10	43	Housewife / other
	107	98	48	7	87	43	55	10	2	27	13	18	30	Housewife / other
	108	274	43	7	89	119	155	1	9	12	28	18	31	Housewife / other

Fukuoka City - Urban form variables used for measuring ‘5Ds’

Ku	Zone	Total Area (km^2)	Population density (population per km^2)	Household density (household per km^2)	No. of road intersection 3-way	No. of road intersection 4-way	Bus accessibility (bus stops per km^2)	Rail accessibility (influence of rail station per km^2)
Chuo-ku	1	714,915.47	2,853.80	101.81	124	53	22.38	0.90
	2	703,631.10	3,312.90	148.03	106	40	8.53	0.98
	3	832,688.40	6,355.30	197.86	117	106	6.00	0.71
	4	1,588,748.53	6,133.60	101.93	210	93	8.81	0.61
	5	761,648.84	4,435.90	145.69	93	54	9.19	0.90
	6	1,148,899.84	5,364.70	145.91	225	55	7.83	0.67
	7	596,520.98	3,539.90	140.08	47	34	16.76	0.96
	8	1,713,901.95	2,618.60	76.15	69	20	2.40	0.05
	9	983,927.38	3,460.60	204.53	82	36	8.19	0.35
	10	1,797,418.61	4,197.40	151.51	262	60	5.90	0.45
	11	1,026,923.60	5,273.70	138.43	185	81	8.77	0.49
	12	968,492.06	4,232.20	114.86	199	40	11.36	0.88
	13	1,114,522.07	4,123.40	83.55	222	31	8.97	0.10
	14	1,448,295.67	2,907.40	68.68	313	83	6.21	0.00
	15	579,223.83	1,091.70	108.44	24	4	7.53	0.05
Hakata-ku	16	690,133.66	3,298.50	144.28	89	34	7.24	0.89
	17	508,975.24	1,998.60	153.60	61	37	9.82	0.33
	18	427,285.92	1,518.80	25.08	46	29	9.36	0.95
	19	959,077.73	1,943.50	112.51	114	76	6.26	0.13
	20	600,009.08	3,175.80	168.47	137	37	8.33	0.00
	21	548,391.63	3,384.80	195.66	97	36	5.47	0.11
	22	918,428.76	3,363.10	107.69	96	53	11.98	0.98
	23	772,681.61	3,857.10	138.65	78	76	10.37	0.60
	24	942,511.28	526.00	33.63	55	12	10.51	0.00
	25	1,064,283.72	3,758.80	128.21	210	37	8.50	0.83
	26	2,426,967.78	3,299.20	65.20	264	97	5.07	0.21
	27	1,602,181.56	4,183.40	76.56	208	130	5.57	0.46
	28	5,767,972.52	1,048.10	17.58	390	55	11.90	0.66
	29	5,579,256.35	1,773.90	15.91	734	132	5.39	0.00
	30	3,595,045.36	3,598.10	49.36	393	114	6.28	0.18
	31	2,337,582.73	4,220.70	69.88	421	130	6.61	0.23
	32	1,739,630.16	4,015.50	56.93	315	118	3.80	0.30
	33	1,240,416.44	8,827.70	103.65	191	46	5.65	0.63
Minami-ku	34	732,481.95	4,371.30	188.45	88	71	5.46	0.49
	35	1,044,403.52	3,702.10	99.77	176	82	2.87	0.57
	36	728,563.88	2,116.20	68.19	144	32	4.12	0.04
	37	1,587,950.82	4,076.20	66.72	283	127	5.67	0.00
	38	1,874,792.57	3,685.60	53.17	424	136	6.93	0.00
	39	2,384,908.40	3,187.30	21.32	512	88	7.71	0.00
	40	7,779,320.41	2,111.90	6.41	710	135	4.59	0.00
	41	1,255,436.28	2,298.90	46.03	382	67	6.37	0.00
	42	1,676,862.71	4,726.40	73.64	417	92	5.96	0.05
	43	2,024,827.81	4,392.90	131.06	322	138	6.91	0.54
	44	2,010,020.62	5,018.70	89.24	488	93	4.98	0.23
	45	2,874,534.15	3,285.60	49.65	604	95	6.96	0.00
	46	1,575,690.35	2,342.90	60.01	354	149	4.45	0.00
	47	1,947,016.32	3,778.80	79.35	449	131	7.20	0.24
	48	1,340,733.46	2,438.70	90.89	284	84	5.22	0.43
	49	2,933,966.63	3,541.70	79.54	420	141	6.26	0.78
	50	3,476,529.70	1,127.00	35.16	73	17	2.60	0.05
	51	1,235,361.58	1,182.50	62.62	44	12	4.12	0.06
	52	1,077,423.48	3,147.10	105.65	187	51	5.57	0.87
	53	2,299,467.37	2,415.70	55.36	268	93	2.18	0.11
	54	3,056,388.06	1,690.60	44.26	278	96	3.93	0.02

Higasi-ku	55	1,641,016.02	1,823.60	42.35	335	64	6.09	0.22
	56	6,000,800.90	2,257.20	11.78	803	188	9.61	0.17
	57	2,070,994.27	3,037.60	46.82	422	127	3.86	0.35
	58	1,596,201.19	1,840.70	47.38	292	59	1.88	0.39
	59	3,358,908.17	3,495.40	27.34	522	83	5.42	0.06
	60	5,033,311.03	2,785.60	19.77	506	93	4.79	0.44
	61	1,673,484.33	2,487.10	63.76	306	57	4.96	0.60
	62	2,822,157.71	2,213.10	36.48	505	107	4.05	0.80
	63	3,293,558.38	2,573.20	34.70	549	151	5.65	0.49
	64	3,156,519.99	2,555.80	42.25	622	157	2.81	0.44
	65	2,993,544.36	1,899.10	21.19	549	134	4.00	0.70
	66	1,022,917.80	2,461.20	71.49	154	37	8.80	0.86
	67	2,686,090.58	1,163.50	14.70	317	61	2.70	0.00
	68	8,694,844.51	715.20	4.65	737	154	11.51	0.00
	69	5,786,244.99	13.10	1.31	672	56	0.00	0.00
Johnan-ku	70	1,203,938.32	7,031.80	132.82	228	85	6.64	0.69
	71	1,729,903.64	5,473.60	80.75	514	100	5.78	0.70
	72	1,308,849.38	4,286.20	85.01	471	65	1.53	0.21
	73	2,001,124.16	5,249.30	64.35	589	145	3.50	0.00
	74	1,666,722.51	4,038.00	78.96	433	82	8.40	0.08
	75	5,256,324.65	3,536.60	13.56	554	112	6.22	0.07
	76	2,926,797.94	3,393.00	54.54	749	116	6.81	0.86
Sawara-ku	77	1,363,291.57	6,137.70	110.29	229	113	7.69	0.78
	78	787,974.69	3,441.60	137.21	127	27	11.44	0.84
	79	1,134,457.64	7,157.50	142.46	210	118	0.06	0.00
	80	1,150,063.06	3,214.80	86.22	253	56	4.35	0.00
	81	1,167,794.24	3,538.40	75.74	255	74	4.28	0.00
	82	1,287,551.19	4,452.10	79.30	250	102	6.21	0.06
	83	1,619,316.87	2,735.40	53.40	394	113	7.41	0.07
	84	1,056,508.74	2,540.90	64.27	369	68	3.79	0.01
	85	991,675.67	2,197.00	53.41	301	59	7.06	0.77
	86	4,677,404.88	2,591.20	9.51	785	158	4.92	0.27
	87	1,131,430.06	1,468.70	36.11	307	55	8.03	0.83
	88	2,619,629.03	1,641.80	7.96	483	138	8.74	0.00
	89	1,547,172.88	2,570.80	95.78	138	27	11.79	0.00
	90	10,788,058.44	2,423.70	2.21	991	167	9.57	0.00
	91	64,962,157.29	1,037.00	0.57	1,746	180	24.99	0.00
Nishi-ku	92	2,156,874.68	2,943.60	88.32	396	95	7.41	0.40
	93	865,821.71	1,286.20	43.91	179	58	5.15	0.15
	94	1,051,783.17	4,007.20	102.65	199	67	6.66	0.45
	95	2,719,351.85	3,383.10	33.03	557	161	7.85	0.38
	96	2,271,172.95	4,654.50	64.60	464	102	8.97	0.00
	97	1,908,305.65	1,118.50	18.41	401	81	13.64	1.46
	98	4,581,289.37	2,691.60	7.52	835	182	8.49	0.00
	99	1,860,605.72	379.00	2.32	190	38	4,824.11	1.00
	100	3,896,199.26	2.20	0.74	323	30	0.00	0.00
	101	1,396,523.60	1,997.40	83.06	141	32	12.61	0.00
	102	11,357,479.58	393.30	0.62	591	94	28.95	0.00
	103	11,393,647.54	1,521.60	3.97	1,044	218	1.62	0.36
	104	6,600,377.16	1,153.70	6.53	758	161	4.50	1.00
	105	8,443,756.32	40.30	1.33	486	147	0.00	0.00
	106	6,715,564.44	28.40	1.41	645	105	0.00	0.00
	107	12,470,753.67	19.60	0.98	852	93	0.00	0.00
	108	3,676,631.70	801.80	9.49	404	133	6.00	0.04

Fukuoka City - Urban form related variables used to estimate Land use mix index (D2)

Ku	Zone	Total Area (km^2)	Residential (km^2)	Commercial (km^2)	Industrial (km^2)	Utility Faciltiy (km^2)	Public Open Space (km^2)
Chuo-ku	1	714,915.47	24,535.54	278,778.07	1,174.48	83,569.52	55,377.53
	2	703,631.10	187,634.63	192,662.20	3,614.95	38,668.40	6,556.05
	3	832,688.40	338,224.23	163,936.43	14,820.47	38,569.44	7,536.53
	4	1,588,748.53	671,557.83	133,506.81	9,064.52	174,213.91	221,978.60
	5	761,648.84	328,681.62	117,660.74	9,140.78	101,034.67	6,991.43
	6	1,148,899.84	288,388.96	93,280.37	2,908.18	99,697.44	397,917.19
	7	596,520.98	132,109.15	183,934.71	5,321.72	95,282.30	12,506.43
	8	1,713,901.95	46,036.97	251,092.07	157,408.32	69,857.95	0.00
	9	983,927.38	144,461.40	89,778.20	281,924.32	99,545.59	11,481.71
	10	1,797,418.61	510,739.11	43,161.93	3,615.36	240,666.64	371,449.01
	11	1,026,923.60	600,957.92	35,988.52	4,601.67	98,260.69	14,863.07
	12	968,492.06	450,148.46	61,497.11	1,218.16	192,190.50	12,219.59
	13	1,114,522.07	551,608.06	71,008.38	3,033.90	145,036.26	48,755.56
	14	1,448,295.67	654,602.30	46,886.61	3,716.99	126,937.72	252,875.23
	15	579,223.83	18,493.94	168,177.99	0.00	55,924.77	44,371.41
Hakata-ku	16	690,133.66	53,174.16	227,951.76	2,172.97	54,175.94	6,483.27
	17	508,975.24	121,715.31	100,321.91	3,807.07	47,568.94	23,647.08
	18	427,285.92	48,076.33	163,677.01	1,711.34	48,129.02	14,301.22
	19	959,077.73	269,547.56	218,134.80	28,772.07	52,333.93	66,510.56
	20	600,009.08	203,242.40	74,668.35	54,207.17	29,153.78	31,848.26
	21	548,391.63	176,577.57	91,601.84	4,759.11	47,320.81	33,232.90
	22	918,428.76	110,786.44	264,869.16	3,981.63	160,065.01	17,635.05
	23	772,681.61	157,608.12	167,382.28	8,965.54	70,490.87	3,666.44
	24	942,511.28	55,430.85	125,247.15	6,740.17	70,261.88	6,897.39
	25	1,064,283.72	208,511.01	183,632.63	11,128.24	228,169.79	80,257.46
	26	2,426,967.78	606,668.20	469,291.34	161,824.43	143,264.94	64,655.71
	27	1,602,181.56	341,046.08	366,027.40	125,275.86	147,741.57	28,626.91
	28	5,767,972.52	378,836.01	145,739.38	53,116.41	50,545.65	890,416.07
	29	5,579,256.35	1,028,711.85	436,375.60	141,351.48	255,600.75	371,313.15
	30	3,595,045.36	781,297.13	701,403.56	323,985.83	299,911.36	29,172.63
	31	2,337,582.73	872,052.77	311,666.52	39,355.58	246,674.74	55,823.87
	32	1,739,630.16	684,206.59	240,701.54	77,480.69	122,429.75	24,002.94
	33	1,240,416.44	521,601.94	117,580.17	15,257.58	71,879.89	25,017.82
Minami-ku	34	732,481.95	280,935.87	92,588.91	9,009.51	120,666.24	14,804.80
	35	1,044,403.52	665,038.25	29,830.31	2,672.62	46,964.48	39,409.66
	36	728,563.88	288,391.98	10,996.62	1,867.79	22,171.22	275,670.67
	37	1,587,950.82	821,236.86	106,419.83	4,253.15	146,887.78	79,185.55
	38	1,874,792.57	1,153,834.36	115,152.92	7,311.00	74,491.74	80,765.32
	39	2,384,908.40	977,077.42	136,417.56	18,317.62	252,401.09	178,581.59
	40	7,779,320.41	1,239,233.97	102,286.64	33,918.09	179,437.46	1,701,268.74
	41	1,255,436.28	706,207.21	45,748.75	5,207.13	104,791.08	12,623.34
	42	1,676,862.71	931,694.87	94,966.23	6,003.80	170,895.43	24,457.48
	43	2,024,827.81	687,111.08	177,601.67	86,477.08	318,017.73	80,557.39
	44	2,010,020.62	1,082,529.53	76,368.59	12,316.37	206,134.69	60,626.15
	45	2,874,534.15	1,189,785.83	77,137.06	18,658.69	413,606.39	54,577.32
	46	1,575,690.35	725,991.11	75,965.71	11,590.28	200,665.73	28,137.24
	47	1,947,016.32	849,617.22	148,156.18	19,473.44	134,813.92	51,489.95
	48	1,340,733.46	670,325.16	56,001.36	55,333.94	91,342.96	17,670.43
	49	2,933,966.63	876,302.99	232,574.88	62,506.00	596,110.10	96,875.38
	50	3,476,529.70	3,960.74	233,533.33	414,676.16	100,566.74	40,455.95
	51	1,235,361.58	15,150.43	99,128.75	360,284.96	65,900.26	13,080.16
	52	1,077,423.48	305,336.67	92,336.91	21,788.69	401,739.24	27,313.58
	53	2,299,467.37	480,338.17	408,713.37	196,027.12	123,336.08	32,839.50
	54	3,056,388.06	402,247.44	618,601.62	176,293.95	167,128.49	55,436.44
	55	1,641,016.02	760,775.01	150,087.51	8,167.65	102,342.56	36,860.02
	56	6,000,800.90	1,277,188.11	166,696.10	104,364.22	469,384.12	182,182.69
	57	2,070,994.27	1,149,357.23	77,606.38	4,950.96	190,020.49	89,782.90

Higasi-ku	58	1,596,201.19	636,374.20	61,128.05	1,915.90	92,460.41	94,166.25
	59	3,358,908.17	791,217.35	330,342.80	24,473.72	205,836.62	403,833.58
	60	5,033,311.03	987,857.51	21,000.38	596.04	132,440.63	592,036.03
	61	1,673,484.33	685,392.07	100,723.33	3,959.66	154,894.88	53,980.60
	62	2,822,157.71	1,048,600.63	194,015.74	11,871.20	438,727.69	74,193.21
	63	3,293,558.38	1,129,125.89	94,373.30	30,781.40	164,358.43	49,403.18
	64	3,156,519.99	1,410,164.47	171,161.86	25,471.23	161,579.93	62,899.19
	65	2,993,544.36	1,010,747.91	85,213.64	22,413.17	293,161.14	50,388.32
	66	1,022,917.80	294,621.30	128,399.40	3,154.92	134,131.62	16,022.45
	67	2,686,090.58	633,979.77	50,971.74	5,965.70	174,818.16	18,938.94
	68	8,694,844.51	468,032.67	87,102.42	217,656.10	539,503.87	3,123,214.52
	69	5,786,244.99	198,904.62	95,528.52	8,246.02	56,762.03	91,199.10
Johnan-ku	70	1,203,938.32	655,392.69	73,112.47	6,207.24	175,021.74	12,650.22
	71	1,729,903.64	1,074,400.90	77,588.05	6,747.53	136,776.39	37,239.98
	72	1,308,849.38	884,264.95	38,643.24	2,218.18	76,340.83	18,979.16
	73	2,001,124.16	1,081,465.50	141,639.87	18,973.84	119,975.50	51,135.53
	74	1,666,722.51	777,746.14	108,181.51	5,743.31	226,281.77	28,512.64
	75	5,256,324.65	1,015,549.59	150,980.71	10,268.14	321,643.94	525,300.35
	76	2,926,797.94	1,013,161.80	123,155.79	9,013.72	557,086.29	41,548.86
Sawara-ku	77	1,363,291.57	673,452.16	40,500.20	3,192.73	197,679.71	18,221.01
	78	787,974.69	318,982.35	64,326.68	3,149.90	216,302.45	3,510.56
	79	1,134,457.64	646,219.42	89,503.84	6,036.68	71,468.38	44,979.98
	80	1,150,063.06	610,420.73	84,569.69	7,928.35	167,079.13	8,394.32
	81	1,167,794.24	605,001.34	109,996.54	7,443.09	104,762.30	11,851.60
	82	1,287,551.19	582,743.32	86,482.79	8,017.68	87,250.60	85,869.55
	83	1,619,316.87	779,578.84	124,791.16	20,868.37	138,065.55	53,704.03
	84	1,056,508.74	704,163.08	44,249.35	1,807.43	58,711.60	11,125.19
	85	991,675.67	516,778.67	55,515.70	8,986.18	44,013.10	8,130.31
	86	4,677,404.88	1,227,926.70	122,486.71	15,505.96	118,946.02	86,257.69
	87	1,131,430.06	524,156.37	79,610.64	9,088.79	51,153.78	39,564.38
	88	2,619,629.03	893,503.10	121,367.22	36,808.96	243,140.86	57,809.34
	89	1,547,172.88	213,040.13	193,476.41	0.00	254,248.45	33,635.13
	90	10,788,058.44	1,290,517.19	143,549.13	70,890.46	183,249.46	72,791.73
	91	64,962,157.29	1,256,696.48	138,743.20	64,396.26	382,325.42	90,556.95
Nishi-ku	92	2,156,874.68	925,893.28	246,096.73	9,160.60	174,626.76	74,216.26
	93	865,821.71	357,985.16	88,610.57	19,615.88	22,143.02	51,242.98
	94	1,051,783.17	440,943.66	105,549.01	4,662.52	75,667.53	31,144.59
	95	2,719,351.85	1,059,127.29	83,934.04	61,213.70	192,971.50	37,933.06
	96	2,271,172.95	813,519.35	342,018.10	44,268.19	145,049.87	45,341.31
	97	1,908,305.65	517,161.62	106,496.41	15,655.55	136,777.68	104,663.32
	98	4,581,289.37	1,593,349.49	114,067.29	13,999.87	273,372.18	116,101.77
	99	1,860,605.72	160,239.02	57,101.08	48,772.72	50,785.70	142,362.79
	100	3,896,199.26	173,591.68	29,590.07	1,282.39	50,987.79	112,689.34
	101	1,396,523.60	338,728.04	27,241.49	4,302.96	111,080.65	55,228.19
	102	11,357,479.58	422,838.29	25,005.92	80,218.04	36,068.36	207,292.55
	103	11,393,647.54	1,414,035.48	226,901.76	249,090.36	361,230.69	484,413.26
	104	6,600,377.16	1,067,664.21	257,408.79	74,242.02	254,544.38	78,980.07
	105	8,443,756.32	454,034.76	22,504.80	28,459.69	116,843.64	339,069.70
	106	6,715,564.44	428,502.51	69,315.76	38,216.75	373,150.57	214,902.06
	107	12,470,753.67	409,595.65	37,665.12	30,314.46	86,056.47	3,809.98
	108	3,676,631.70	681,497.19	51,079.24	36,547.40	157,642.31	11,416.82

Fukuoka City - '5Ds' Urban form variables

Ku	Zone	D1 (Density) (central tendency of population density and household density)	D2 (Diversity) (land use mix index)	D3 (Design) (central tendency of 3-way and 4-way road intersection)	D4 (Destination accessibility) km	D5 (Distance to transit) (central tendency of bus accessibility and rail accessibility)
Chuo-ku	1	1,477.81	0.59	88.50	0.54	11.64
	2	1,730.47	0.58	73.00	0.62	4.76
	3	3,276.58	0.59	111.50	1.67	3.36
	4	3,117.77	0.70	151.50	2.15	4.71
	5	2,290.80	0.63	73.50	1.44	5.05
	6	2,755.31	0.71	140.00	2.25	4.25
	7	1,839.99	0.69	40.50	1.23	8.86
	8	1,347.38	0.45	44.50	1.93	1.23
	9	1,832.57	0.71	59.00	3.06	4.27
	10	2,174.46	0.66	161.00	3.27	3.18
	11	2,706.07	0.46	133.00	3.79	4.63
	12	2,173.53	0.57	119.50	2.92	6.12
	13	2,103.48	0.59	126.50	3.99	4.54
	14	1,488.04	0.62	198.00	3.63	3.11
	15	600.07	0.55	14.00	4.47	3.79
Hakata-ku	16	1,721.39	0.50	61.50	1.91	4.07
	17	1,076.10	0.64	49.00	2.46	5.08
	18	771.94	0.60	37.50	2.91	5.16
	19	1,028.01	0.64	95.00	3.32	3.20
	20	1,672.14	0.58	87.00	2.38	4.17
	21	1,790.23	0.65	66.50	1.37	2.79
	22	1,735.40	0.62	74.50	1.23	6.48
	23	1,997.88	0.56	77.00	1.43	5.49
	24	279.82	0.41	33.50	2.44	5.26
	25	1,943.51	0.71	123.50	2.41	4.67
	26	1,682.20	0.58	180.50	3.74	2.64
	27	2,129.98	0.60	169.00	3.41	3.02
	28	532.84	0.37	222.50	7.30	6.28
	29	894.91	0.52	433.00	8.52	2.70
	30	1,823.73	0.56	253.50	4.90	3.23
	31	2,145.29	0.60	275.50	6.32	3.42
	32	2,036.22	0.55	216.50	8.05	2.05
	33	4,465.68	0.52	118.50	9.07	3.14
Minami-ku	34	2,279.88	0.62	79.50	2.67	2.98
	35	1,900.94	0.41	129.00	3.28	1.72
	36	1,092.20	0.56	88.00	3.38	2.08
	37	2,071.46	0.55	205.00	4.50	2.84
	38	1,869.39	0.46	280.00	5.43	3.47
	39	1,604.31	0.60	300.00	8.74	3.86
	40	1,059.16	0.48	422.50	10.26	2.30
	41	1,172.47	0.43	224.50	7.43	3.19
	42	2,400.02	0.49	254.50	4.73	3.01
	43	2,261.98	0.62	230.00	4.04	3.73
	44	2,553.97	0.50	290.50	5.24	2.61
	45	1,667.63	0.51	349.50	7.83	3.48
	46	1,201.46	0.52	251.50	8.29	2.23
	47	1,929.08	0.52	290.00	6.53	3.72
	48	1,264.80	0.45	184.00	5.86	2.83
	49	1,810.62	0.62	280.50	5.10	3.52
	50	581.08	0.21	45.00	5.75	1.33
	51	622.56	0.29	28.00	3.46	2.09
	52	1,626.38	0.64	119.00	3.39	3.22
	53	1,235.53	0.53	180.50	5.18	1.15
	54	867.43	0.51	187.00	6.33	1.98
	55	932.98	0.52	199.50	8.32	3.16

Higasi-ku	56	1,134.49	0.46	495.50	11.01	4.89
	57	1,542.21	0.50	274.50	8.63	2.11
	58	944.04	0.51	175.50	7.86	1.14
	59	1,761.37	0.62	302.50	8.46	2.74
	60	1,402.69	0.43	299.50	11.75	2.62
	61	1,275.43	0.54	181.50	10.28	2.78
	62	1,124.79	0.58	306.00	11.49	2.43
	63	1,303.95	0.42	350.00	13.80	3.07
	64	1,299.03	0.46	389.50	15.14	1.63
	65	960.15	0.47	341.50	15.13	2.35
	66	1,266.35	0.59	95.50	8.72	4.83
	67	589.10	0.39	189.00	12.40	1.35
	68	359.93	0.46	445.50	21.96	5.76
	69	7.21	0.18	364.00	33.28	0.00
Johnan-ku	70	3,582.31	0.52	156.50	5.12	3.67
	71	2,777.18	0.45	307.00	6.57	3.24
	72	2,185.61	0.37	268.00	6.11	0.87
	73	2,656.83	0.49	367.00	6.10	1.75
	74	2,058.48	0.54	257.50	6.35	4.24
	75	1,775.08	0.51	333.00	11.08	3.15
	76	1,723.77	0.54	432.50	7.86	3.84
Sawara-ku	77	3,124.00	0.49	171.00	7.11	4.24
	78	1,789.41	0.59	77.00	5.06	6.14
	79	3,649.98	0.51	164.00	5.33	0.03
	80	1,650.51	0.52	154.50	6.61	2.18
	81	1,807.07	0.51	164.50	7.53	2.14
	82	2,265.70	0.56	176.00	7.63	3.14
	83	1,394.40	0.54	253.50	8.79	3.74
	84	1,302.59	0.38	218.50	7.83	1.90
	85	1,125.21	0.42	180.00	9.09	3.92
	86	1,300.36	0.38	471.50	10.95	2.60
	87	752.41	0.50	181.00	9.98	4.43
	88	824.88	0.51	310.50	11.76	4.37
	89	1,333.29	0.57	82.50	5.55	5.90
	90	1,212.96	0.26	579.00	13.25	4.79
	91	518.79	0.08	963.00	18.48	12.50
Nishi-ku	92	1,515.96	0.58	245.50	7.58	3.91
	93	665.06	0.53	118.50	9.41	2.65
	94	2,054.93	0.55	133.00	8.57	3.56
	95	1,708.07	0.45	359.00	10.61	4.12
	96	2,359.55	0.56	283.00	9.43	4.49
	97	568.46	0.54	241.00	10.43	7.55
	98	1,349.56	0.45	508.50	11.60	4.25
	99	190.66	0.38	114.00	12.29	14.98
	100	1.47	0.21	176.50	14.03	0.00
	101	1,040.23	0.47	86.50	8.57	6.31
	102	196.96	0.14	342.50	14.67	14.48
	103	762.79	0.36	631.00	14.10	0.99
	104	580.12	0.37	459.50	16.83	2.75
	105	20.82	0.22	316.50	19.35	0.00
	106	14.91	0.31	375.00	18.55	0.00
	107	10.29	0.10	472.50	24.51	0.00
	108	405.65	0.33	268.50	17.01	3.02

Fukuoka City - Travel mode and travel distance variables

Ku	Zone	Walk	Bicycle	Motorcycle	Taxi	Car	Bus	Rail	Travel Distance (km)
Chuo-ku	1	26,685	10,145	2,320	3,633	29,290	32,216	35,805	864.59
	2	7,191	4,277	1,452	1,477	11,198	5,526	4,901	879.28
	3	7,023	5,341	1,041	553	9,792	3,241	2,074	896.55
	4	9,215	5,571	759	955	12,223	4,618	3,587	894.44
	5	12,154	7,376	979	1,288	10,834	6,318	3,881	869.24
	6	7,083	4,371	559	690	7,878	5,078	3,710	911.90
	7	9,215	5,719	943	1,012	12,226	5,784	5,823	865.26
	8	1,975	1,941	666	322	12,205	1,956	1,805	957.54
	9	4,421	3,372	754	182	11,039	2,563	2,079	949.45
	10	11,884	7,351	708	453	9,991	4,333	4,881	914.21
	11	4,626	5,198	424	500	8,617	2,317	3,510	908.38
	12	6,846	7,678	768	662	7,576	4,530	2,156	903.64
	13	6,475	4,486	950	214	8,563	2,466	773	959.82
	14	7,245	2,356	1,055	68	6,750	2,326	531	924.32
	15	886	955	202	170	4,724	1,052	173	974.14
Hakata-ku	16	8,720	4,448	1,500	1,288	17,415	8,800	12,913	919.42
	17	4,943	3,216	542	259	7,483	2,440	3,940	932.68
	18	3,210	1,984	720	527	10,018	3,495	6,429	961.46
	19	4,713	4,840	826	333	12,895	2,919	4,233	986.55
	20	4,252	3,601	939	466	6,727	1,453	1,412	934.33
	21	3,769	2,967	1,007	620	4,989	2,012	1,371	894.43
	22	7,355	5,209	1,030	2,788	10,083	4,811	5,742	899.58
	23	7,084	3,863	908	370	8,694	4,173	4,267	906.00
	24	1,138	1,336	133	127	4,023	972	468	957.54
	25	3,983	3,895	733	521	9,875	2,497	3,483	955.21
	26	7,189	5,931	1,115	458	20,768	1,776	3,281	1,032.92
	27	3,895	5,305	970	56	12,464	1,393	4,863	1,010.26
	28	2,826	1,074	197	180	7,046	412	2,867	1,315.46
	29	3,905	997	1,071	116	9,003	879	1,015	1,423.12
	30	7,399	5,761	1,506	325	22,433	1,718	2,222	1,097.38
	31	8,473	6,168	1,087	137	16,134	1,792	2,223	1,206.38
	32	5,469	1,908	352	145	8,491	350	2,934	1,379.12
	33	7,848	2,523	571	89	4,808	177	4,362	1,496.39
Minami-ku	34	5,078	3,244	554	507	4,988	2,091	1,469	941.05
	35	6,009	2,665	773	178	6,932	1,257	3,519	966.69
	36	2,915	521	198	146	2,762	544	502	942.43
	37	5,948	2,295	1,122	83	9,476	2,656	837	1,020.45
	38	5,675	3,746	700	261	12,411	3,835	560	1,045.93
	39	7,785	3,240	1,179	123	10,651	2,136	332	1,244.67
	40	5,264	2,305	1,214	21	10,499	2,100	205	1,440.96
	41	3,319	1,588	789	86	7,047	1,766	220	1,210.77
	42	6,873	5,349	890	419	11,571	2,565	1,299	1,047.77
	43	9,146	7,660	1,700	623	15,181	3,132	5,005	1,033.54
	44	14,478	8,236	1,543	491	14,904	3,098	6,298	1,109.25
	45	6,703	4,882	1,124	166	16,567	2,828	1,420	1,247.96
	46	5,961	3,694	640	76	6,742	1,031	1,355	1,366.04
	47	5,806	3,970	931	72	11,361	745	3,024	1,204.60
	48	7,866	3,723	587	32	8,677	295	3,399	1,165.68
	49	10,169	11,755	2,999	341	18,925	3,938	5,833	1,126.17
	50	211	588	504	212	8,532	212	352	1,203.44
	51	232	835	110	0	4,371	680	272	1,023.27
	52	1,711	3,777	1,039	190	7,963	1,434	2,785	1,012.68
	53	2,868	3,070	894	230	14,801	577	1,265	1,118.33
	54	2,764	2,684	916	48	16,290	830	580	1,202.70
	55	7,080	3,022	765	195	13,693	1,703	633	1,385.65
	56	5,216	1,627	977	147	15,859	2,835	1,030	1,662.25
	57	9,268	2,490	1,030	139	12,254	1,740	2,636	1,401.27
	58	2,502	948	319	61	5,655	804	1,118	1,322.85

Higasi-ku	59	9,565	5,514	1,226	421	18,588	4,354	1,533	1,405.06
	60	4,384	2,412	565	21	8,999	1,576	2,651	1,688.01
	61	6,899	2,964	864	228	8,797	2,119	3,636	1,531.38
	62	5,895	2,598	1,117	97	8,740	1,983	4,061	1,651.45
	63	5,283	2,188	1,365	177	12,471	1,630	2,370	1,896.28
	64	9,441	2,290	822	257	15,722	918	4,710	2,071.80
	65	8,132	2,703	432	149	10,616	1,115	2,823	2,031.21
	66	4,494	2,215	707	233	7,193	1,816	1,331	1,411.99
	67	3,171	476	412	104	6,635	1,072	528	1,751.36
	68	2,459	1,032	141	50	6,430	508	1,030	2,784.04
	69	244	32	0	0	601	237	18	4,027.52
Johnan-ku	70	9,888	8,493	850	389	9,605	5,358	2,423	967.82
	71	7,699	5,725	726	360	10,537	3,570	2,604	1,003.33
	72	3,246	3,192	1,181	336	5,621	2,214	857	996.08
	73	7,779	5,346	1,514	223	16,273	3,939	160	1,038.32
	74	6,207	3,788	1,178	21	11,588	2,988	516	1,030.87
	75	5,222	2,526	1,055	79	9,997	2,557	363	1,334.40
	76	8,205	6,637	3,713	474	14,687	3,218	4,219	1,082.18
Sawara-ku	77	8,969	7,080	624	169	12,192	2,343	6,124	1,075.85
	78	6,803	8,814	1,011	540	7,770	4,375	5,470	958.42
	79	8,236	6,936	1,225	162	8,616	2,017	5,143	959.44
	80	5,879	5,101	1,463	153	7,284	2,415	1,758	1,010.47
	81	6,581	4,665	808	151	8,717	2,538	1,747	1,060.57
	82	6,142	4,490	634	0	8,270	1,853	2,900	1,085.06
	83	5,838	4,028	954	44	12,005	2,028	1,300	1,153.71
	84	5,454	3,464	770	17	6,729	1,460	791	1,058.60
	85	2,343	1,788	329	0	6,326	637	596	1,129.45
	86	6,101	4,452	1,335	40	14,979	2,302	1,538	1,322.24
	87	3,017	2,796	560	0	6,429	627	1,067	1,204.86
	88	5,792	3,289	1,205	97	16,242	1,532	649	1,350.80
	89	4,096	4,473	519	239	7,232	4,644	2,181	1,023.35
	90	3,704	1,851	1,598	0	15,544	1,502	666	1,538.99
	91	5,305	1,962	1,037	0	11,227	1,573	228	2,112.47
Nishi-ku	92	10,385	6,282	1,273	198	19,419	1,663	4,747	1,131.83
	93	1,777	1,537	298	32	4,518	42	1,012	1,253.78
	94	5,685	4,255	535	202	10,452	735	4,853	1,166.56
	95	9,962	5,805	1,001	121	13,722	1,188	3,918	1,329.61
	96	7,387	5,742	949	63	15,730	1,683	2,244	1,209.69
	97	2,821	2,374	604	28	8,318	769	1,049	1,263.99
	98	5,120	3,807	826	122	17,054	2,385	1,330	1,391.42
	99	608	234	101	0	3,689	26	11	1,408.19
	100	178	137	0	0	874	123	0	1,766.28
	101	2,690	2,236	283	15	3,251	1,538	780	1,249.29
	102	639	205	77	18	2,798	292	74	1,646.93
	103	8,450	6,462	1,022	63	20,606	672	3,951	1,657.75
	104	3,873	3,498	735	45	10,409	115	3,211	1,941.88
	105	269	138	234	0	1,623	276	305	2,210.03
	106	563	700	88	132	4,492	262	361	2,127.43
	107	417	202	114	0	1,453	58	83	2,778.79
	108	1,126	1,001	90	0	2,293	78	724	1,958.87

Fukuoka City - Travel purpose variables

Ku	Zone	Work Trip	School Trip	Business Trip	Private Trip	Return Home Trip
Chuo-ku	1	2,011	105	25,913	26,856	85,209
	2	2,843	669	9,420	5,662	17,428
	3	6,949	1,029	6,444	5,710	8,933
	4	8,056	1,856	4,388	8,869	13,759
	5	6,925	1,871	6,304	9,700	18,030
	6	3,589	825	5,555	6,609	12,823
	7	2,149	344	9,375	8,134	20,720
	8	1,122	98	8,248	2,218	9,224
	9	3,423	1,185	7,933	3,938	7,931
	10	8,000	2,640	5,158	9,937	13,894
	11	5,652	2,374	4,569	6,443	6,154
	12	4,530	2,035	4,552	8,019	11,080
	13	3,142	2,078	1,977	6,496	10,234
	14	5,095	2,448	1,312	5,444	6,032
	15	83	19	2,306	1,080	4,674
Hakata-ku	16	1,366	83	15,442	8,765	29,478
	17	2,959	337	5,431	3,801	10,295
	18	805	136	9,152	2,681	13,631
	19	3,982	869	6,942	4,397	14,569
	20	4,136	1,090	3,423	3,975	6,226
	21	2,225	392	3,317	3,625	7,176
	22	2,346	802	7,594	6,753	19,523
	23	3,484	1,358	5,915	6,099	12,503
	24	1,218	330	1,557	1,622	3,470
	25	2,978	1,543	6,145	4,330	9,991
	26	6,968	2,363	10,917	7,034	13,338
	27	3,694	1,377	7,162	3,596	13,167
	28	2,470	1,040	1,442	2,544	7,106
	29	4,097	1,439	3,443	2,756	5,280
	30	6,276	2,346	10,438	5,871	16,433
	31	8,151	2,729	5,270	7,262	12,714
	32	4,700	1,485	3,859	3,801	5,804
	33	5,136	1,780	1,875	4,356	7,231
Minami-ku	34	3,575	583	1,870	4,720	7,283
	35	5,677	2,375	3,223	5,031	5,064
	36	1,570	805	1,017	1,838	2,358
	37	6,096	3,405	2,996	3,790	6,130
	38	5,967	2,636	3,404	7,455	7,726
	39	5,360	2,307	2,027	6,211	9,541
	40	5,407	2,663	2,839	4,510	6,189
	41	2,721	1,166	2,635	4,017	4,276
	42	6,102	2,200	4,407	7,767	8,511
	43	8,085	2,622	7,847	8,418	15,512
	44	8,799	3,716	5,848	11,399	19,286
	45	5,654	2,962	7,285	7,303	10,558
	46	3,932	2,187	2,815	4,220	6,345
	47	6,298	2,495	5,219	5,764	6,154
	48	5,218	2,399	3,737	5,330	7,895
	49	8,460	4,388	8,443	12,607	20,098
	50	203	109	4,647	758	4,916
	51	98	0	1,384	507	4,511
	52	1,649	605	3,459	3,445	9,741
	53	3,793	2,023	7,575	2,787	7,527
	54	1,990	1,290	7,146	3,285	10,425
	55	4,224	2,393	3,821	7,211	9,442
	56	6,433	3,447	4,309	6,013	7,489
	57	6,495	3,124	1,799	8,480	9,659
	58	3,537	1,585	840	2,779	2,666

Higasi-ku	59	6,870	3,827	5,517	10,475	14,512
	60	3,784	2,039	1,990	5,455	7,340
	61	4,399	2,279	2,453	6,863	9,513
	62	5,122	2,723	1,358	6,003	9,313
	63	4,227	2,451	3,914	6,439	8,479
	64	6,382	3,955	4,178	8,724	10,968
	65	5,197	2,692	1,588	7,121	9,372
	66	2,793	1,011	1,661	3,682	8,842
	67	2,874	1,434	1,594	3,325	3,171
	68	2,024	731	2,284	2,459	4,152
	69	137	135	159	313	388
Johnan-ku	70	7,557	3,709	3,176	9,797	12,767
	71	7,211	3,300	4,226	6,967	9,517
	72	5,115	1,885	1,253	5,342	3,052
	73	7,967	3,599	5,657	8,319	9,692
	74	5,329	3,613	4,164	5,163	8,017
	75	4,538	2,822	2,291	5,512	6,701
	76	6,439	2,401	5,446	7,707	19,160
Sawara-ku	77	7,126	3,916	5,585	8,252	12,701
	78	3,609	1,491	2,981	6,818	19,943
	79	8,419	3,551	3,466	6,809	10,090
	80	5,198	2,422	2,855	5,914	7,664
	81	6,123	2,442	2,638	5,457	8,547
	82	6,295	3,579	2,436	5,512	6,467
	83	5,933	2,607	3,520	6,214	7,923
	84	4,593	2,216	2,377	4,458	5,041
	85	2,216	1,120	2,955	2,719	3,009
	86	6,759	1,932	4,429	7,103	10,589
	87	3,685	1,119	578	4,031	5,083
	88	4,688	2,707	6,356	6,448	8,607
	89	2,280	1,656	2,521	5,010	11,917
	90	4,418	1,471	5,418	5,093	8,465
	91	4,497	2,224	4,447	3,799	6,449
Nishi-ku	92	7,095	2,684	8,461	7,877	17,876
	93	1,927	930	1,367	2,581	2,433
	94	5,280	2,100	3,996	6,835	8,554
	95	8,664	3,866	3,971	8,853	10,363
	96	6,051	2,999	3,644	7,605	13,599
	97	2,712	1,554	2,927	3,317	5,483
	98	6,017	3,460	5,450	7,439	8,319
	99	48	87	2,159	504	1,871
	100	78	0	845	176	213
	101	2,545	2,154	180	2,725	3,189
	102	789	457	978	955	970
	103	7,235	3,363	6,885	9,147	14,698
	104	4,283	2,578	2,600	4,421	8,086
	105	45	55	628	462	1,655
	106	1,472	258	1,586	1,359	1,923
	107	209	219	863	209	827
	108	1,209	532	732	841	1,998

Kathmandu City - Socio-demography data

			Age	Gender		Occupation					
Sector	Ward No.	Total Respondence	Average	Male	Female	Agriculture	Production	Sales Service	Administrative Affairs	Student	Housewife & Other
Central sector	1	7	50	5	2			2	3	1	1
North sector	2	15	37	8	7		3		4	4	4
North sector	3	33	36	20	13			3	13	9	7
North sector	4	41	43	24	17	1		4	11	9	15
Central sector	5	17	37	9	8		2	1	5	5	4
East sector	6	49	33	24	25		5	13	8	11	11
East sector	7	42	34	23	19		3	5	15	9	10
East sector	8	9	26	2	7			2	1	5	1
East sector	9	33	36	20	13			2	16	7	8
East sector	10	37	31	22	15		2	5	9	13	8
Central sector	11	15	30	9	6		1	3	1	7	3
City core sector	12	12	33	6	6		1	1	5	3	2
West sector	13	35	35	23	12			9	5	13	8
West sector	14	56	32	35	21		2	18	8	25	3
West sector	15	50	28	34	16		1	20	8	15	6
North sector	16	70	28	43	27		2	9	19	28	10
City core sector	17	21	34	15	6		1	3	6	5	5
City core sector	18	9	28	7	2		1	1	2	5	
City core sector	19	11	32	5	6			7		4	
City core sector	20	9	33	7	2			3	1	4	1
City core sector	21	11	27	9	2			2	3	6	
City core sector	22	8	30	6	2			3	3	1	1
City core sector	23	7	23	5	2		1			6	
City core sector	24	3	25	2	1			1		2	
City core sector	25	7	37	4	3			1	3	2	1
City core sector	26	6	33	3	3		1		2	2	1
City core sector	27	11	26	6	5		1	1	2	6	1
City core sector	28	7	31	4	3			3	2		2
North sector	29	41	32	21	20			9	10	13	9
City core sector	30	7	31	6	1				3	4	
Central sector	31	16	26	6	10			4	2	8	2
Central sector	32	27	41	13	14		1	2	12	5	7
Central sector	33	21	31	14	7			2	7	8	4
East sector	34	54	31	35	19		3	15	11	17	7
East sector	35	64	33	39	25			7	21	23	13

Kathmandu City - Urban form variables used for measuring '5Ds'

Sector	Ward No.	Total Area (m^2)	Population density (population per km^2)	Household density (household per km^2)	No. of road intersection 3-way	No. of road intersection 4-way
Central sector	1	1,384,386	5,784.51	1,384.73	213	11
North sector	2	818,526	16,429.53	4,396.93	142	4
North sector	3	3,177,139	10,974.02	2,878.38	379	17
North sector	4	3,212,298	14,743.96	3,744.98	358	17
Central sector	5	789,686	23,199.09	6,045.44	279	9
East sector	6	3,559,074	16,954.97	4,336.52	509	29
East sector	7	1,736,328	29,706.94	7,809.01	532	32
East sector	8	2,445,044	4,391.74	1,134.13	193	19
East sector	9	2,862,280	14,104.49	3,639.41	436	37
East sector	10	1,568,359	25,389.60	6,740.17	426	22
Central sector	11	1,838,671	9,661.87	2,401.73	467	17
City core sector	12	510,252	25,991.08	6,218.50	110	7
West sector	13	2,229,029	18,149.61	4,579.12	359	32
West sector	14	3,643,120	16,056.29	4,246.91	273	18
West sector	15	3,164,630	17,214.02	4,453.29	437	41
North sector	16	4,560,156	18,517.13	4,981.19	453	39
City core sector	17	662,444	39,136.89	9,652.14	241	14
City core sector	18	184,067	58,380.92	14,918.48	95	3
City core sector	19	155,117	69,051.10	16,967.84	81	4
City core sector	20	156,955	69,879.90	18,119.84	114	6
City core sector	21	154,099	89,079.10	21,992.36	92	2
City core sector	22	187,551	30,386.40	6,664.85	54	4
City core sector	23	102,887	81,225.03	19,351.33	86	5
City core sector	24	85,908	40,601.57	8,637.15	71	5
City core sector	25	103,626	33,640.21	7,604.27	80	5
City core sector	26	38,087	108,514.72	24,864.13	61	4
City core sector	27	76,295	99,508.49	24,746.05	98	11
City core sector	28	67,888	82,650.84	20,180.30	58	4
North sector	29	2,002,712	22,495.50	6,117.70	291	27
City core sector	30	256,844	33,339.30	7,451.99	107	4
Central sector	31	1,037,039	15,632.01	3,965.14	274	26
Central sector	32	1,279,676	26,034.72	7,265.90	404	20
Central sector	33	856,664	29,993.09	8,026.48	317	5
East sector	34	2,321,125	28,486.62	7,656.63	413	24
East sector	35	4,106,742	18,578.96	5,062.89	437	49

Kathmandu City - Urban form related variables used to estimate Land use mix index (D2)

Sector	Ward No.	Total Area (m^2)	Residential (m^2)	Commercial (m^2)	Mixed use (m^2)	Industrial (m^2)	Utility Faciltiy (m^2)	Public Open Space (m^2)
Central sector	1	1,384,386	454,940.87	144,103.54	42,013.01		662,813.78	14,015.22
North sector	2	818,526	724,259.26	27,891.44	45,583.70		14,632.57	
North sector	3	3,177,139	2,218,066.17		19,067.18		557,786.08	50,516.40
North sector	4	3,212,298	2,579,294.06		6,887.77		115,755.97	16,602.02
Central sector	5	789,686	4,547.82	4,547.82	13,040.97		51,167.62	14,840.10
East sector	6	3,559,074	2,644,265.20		60,828.96		18,548.96	46,552.18
East sector	7	1,736,328	1,558,378.51		47,040.99		1,822.98	5,754.80
East sector	8	2,445,044	547,367.46				139,166.58	64,618.99
East sector	9	2,862,280	1,150,338.08	6,786.54	131,165.62		34,920.40	13,773.86
East sector	10	1,568,359	1,386,392.18	24,572.58	38,276.27		9,494.16	11,646.38
Central sector	11	1,838,671	623,825.45	85,299.56	47,147.27		622,440.32	154,194.19
City core sector	12	510,252	268,209.50	15,855.67	4,543.20		94,903.89	40,108.23
West sector	13	2,229,029	1,746,968.77	92,762.27	87,959.81		130,781.82	13,319.08
West sector	14	3,643,120	2,446,537.06		107,119.41		89,855.72	71,433.14
West sector	15	3,164,630	1,992,366.90		35,172.80		471,089.39	30,100.68
North sector	16	4,560,156	2,359,000.36	12,096.05	115,001.06	269,940.39	133,378.35	47,437.53
City core sector	17	662,444	189,840.16		59,215.75		11,459.87	11,809.97
City core sector	18	184,067	159,890.76		14,915.25		1,509.73	2,741.67
City core sector	19	155,117	131,148.21		7,785.90		755.53	3,961.31
City core sector	20	156,955	100,491.61		24,117.67		14,823.63	4,893.46
City core sector	21	154,099	119,930.74	4,490.96	23,782.68			2,116.34
City core sector	22	187,551	76,680.41	34,493.41	23,889.69		32,129.87	2,548.84
City core sector	23	102,887	56,798.37	7,561.70	29,790.62		2,074.04	
City core sector	24	85,908	26,925.92	17,807.58	22,764.34		10,655.41	
City core sector	25	103,626	25,985.60	24,491.21	11,339.45		10,013.20	20,860.33
City core sector	26	38,087	26,728.14		10,293.94			
City core sector	27	76,295	47,420.68		24,917.28			
City core sector	28	67,888	36,707.20		21,940.62		6,996.67	
North sector	29	2,002,712	1,349,408.35	51,619.50	99,996.03		245,727.08	7,686.44
City core sector	30	256,844	128,891.55	7,084.18	35,642.52		67,922.39	
Central sector	31	1,037,039	329,073.52	45,297.61	68,899.38		189,200.77	323,452.89
Central sector	32	1,279,676	643,441.96	20,147.59	62,593.04		476,955.98	3,462.72
Central sector	33	856,664	742,561.56		75,438.48		14,679.43	2,606.05
East sector	34	2,321,125	1,795,867.48	11,002.30	43,498.73		184,280.08	13,132.43
East sector	35	4,106,742	2,295,133.98	12,259.10		37,015.34	15,883.40	46,509.23

Kathmandu City - '5Ds' Urban form variables

Sector	Ward No.	D1 (Density) (central tendency of population density and household density)	D2 (Diversity) (land use mix index)	D3 (Design) (central tendency of 3-way and 4-way road intersection)	D4 (Destination accessibility) km	D5 (Distance to transit) (transit stops per km^2)
Central sector	1	3,584.62	0.62	112.00	1.63	15.89
North sector	2	10,413.23	0.25	73.00	2.60	8.55
North sector	3	6,926.20	0.35	198.00	4.83	7.55
North sector	4	9,244.47	0.13	187.50	3.97	6.23
Central sector	5	14,622.27	0.67	144.00	2.70	17.73
East sector	6	10,645.75	0.13	269.00	5.67	5.90
East sector	7	18,757.98	0.09	282.00	3.64	10.94
East sector	8	2,762.94	0.42	106.00	4.27	3.68
East sector	9	8,871.95	0.29	236.50	3.50	5.94
East sector	10	16,064.88	0.16	224.00	2.64	18.49
Central sector	11	6,031.80	0.69	242.00	1.77	28.28
City core sector	12	16,104.79	0.57	58.50	2.56	17.64
West sector	13	11,364.37	0.35	195.50	3.22	11.22
West sector	14	10,151.60	0.17	145.50	4.45	6.04
West sector	15	10,833.65	0.34	239.00	3.02	6.00
North sector	16	11,749.16	0.42	246.00	3.98	9.65
City core sector	17	24,394.51	0.48	127.50	2.15	7.55
City core sector	18	36,649.70	0.23	49.00	1.57	0.00
City core sector	19	43,009.47	0.21	42.50	1.86	0.00
City core sector	20	43,999.87	0.50	60.00	1.93	0.00
City core sector	21	55,535.73	0.36	47.00	1.95	0.00
City core sector	22	18,525.63	0.75	29.00	1.34	26.66
City core sector	23	50,288.18	0.53	45.50	1.63	0.00
City core sector	24	24,619.36	0.75	38.00	1.01	0.00
City core sector	25	20,622.24	0.86	42.50	1.36	0.00
City core sector	26	66,689.42	0.33	32.50	1.48	0.00
City core sector	27	62,127.27	0.36	54.50	1.01	0.00
City core sector	28	51,415.57	0.52	31.00	1.26	0.00
North sector	29	14,306.60	0.43	159.00	2.98	12.48
City core sector	30	20,395.65	0.60	55.50	1.09	19.47
Central sector	31	9,798.57	0.77	150.00	1.26	35.68
Central sector	32	16,650.31	0.53	212.00	1.27	8.60
Central sector	33	19,009.79	0.23	161.00	1.54	10.51
East sector	34	18,071.62	0.26	218.50	3.69	14.22
East sector	35	11,820.93	0.14	243.00	5.33	7.79

Kathmandu City - Travel mode and travel distance variables

Sector	Ward No.	Walk	Walk Distance (km)	Cycle	Cycle Distance (km)	Motorcycle	Motorcycle Distance (km)	Car	Car Distance (km)	Bus	Bus Distance (km)	Micro	Micro Distance (km)	Temp o	Tempo Distance (km)	Taxi	Taxi Distance (km)
Central sector	1	8	15.69	0	0.00	4	31.67	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
North sector	2	25	45.16	0	0.00	11	88.67	0	0.00	0	0.00	4	53.00	0	0.00	0	0.00
North sector	3	52	50.05	0	0.00	18	292.00	0	0.00	2	26.50	0	0.00	2	39.75	1	20.00
North sector	4	49	104.76	0	0.00	10	145.67	0	0.00	11	163.25	3	60.00	0	0.00	0	0.00
Central sector	5	21	37.51	3	20.00	4	73.20	0	0.00	0	0.00	0	0.00	0	0.00	2	47.50
East sector	6	79	105.72	2	1.00	9	183.00	0	0.00	8	109.50	2	28.00	0	0.00	1	20.00
East sector	7	64	77.99	2	6.67	14	247.33	8	80.33	6	76.50	2	28.00	2	26.50	0	0.00
East sector	8	11	14.59	0	0.00	6	75.33	0	0.00	4	46.50	0	0.00	0	0.00	0	0.00
East sector	9	27	25.90	2	5.00	20	328.67	0	0.00	14	159.00	2	30.00	2	26.50	0	0.00
East sector	10	42	28.89	3	15.00	31	478.67	0	0.00	5	66.50	0	0.00	0	0.00	0	0.00
Central sector	11	20	20.06	0	0.00	8	96.00	0	0.00	2	13.25	0	0.00	0	0.00	0	0.00
City core sector	12	15	15.54	0	0.00	6	107.67	0	0.00	4	43.25	0	0.00	0	0.00	0	0.00
West sector	13	49	56.25	0	0.00	15	301.87	0	0.00	6	70.00	1	30.00	0	0.00	0	0.00
West sector	14	71	34.66	0	0.00	38	527.00	0	0.00	14	148.08	0	0.00	0	0.00	0	0.00
West sector	15	69	104.91	8	6.67	16	340.33	0	0.00	2	22.08	0	0.00	0	0.00	0	0.00
North sector	16	59	52.53	1	10.00	44	647.20	11	107.50	24	250.42	8	65.33	0	0.00	0	0.00
City core sector	17	33	33.56	2	5.00	13	222.00	0	0.00	1	15.00	2	26.50	0	0.00	0	0.00
City core sector	18	8	6.93	0	0.00	4	81.67	0	0.00	6	79.50	0	0.00	0	0.00	0	0.00
City core sector	19	12	5.84	0	0.00	4	12.67	0	0.00	6	26.50	0	0.00	0	0.00	0	0.00
City core sector	20	10	6.57	0	0.00	6	58.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
City core sector	21	8	2.92	0	0.00	8	126.00	0	0.00	6	64.17	2	15.00	0	0.00	0	0.00
City core sector	22	12	5.47	0	0.00	4	44.33	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
City core sector	23	12	8.03	0	0.00	2	38.00	0	0.00	4	33.25	0	0.00	0	0.00	0	0.00
City core sector	24	4	1.46	0	0.00	2	25.33	0	0.00	2	22.08	0	0.00	0	0.00	0	0.00
City core sector	25	13	14.96	0	0.00	6	170.67	0	0.00	5	27.67	0	0.00	0	0.00	0	0.00
City core sector	26	6	6.20	0	0.00	5	76.00	0	0.00	0	0.00	2	17.67	0	0.00	0	0.00
City core sector	27	12	16.56	0	0.00	8	96.87	0	0.00	4	37.67	0	0.00	0	0.00	0	0.00
City core sector	28	10	8.39	0	0.00	4	69.67	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
North sector	29	51	83.36	3	12.00	23	393.27	0	0.00	8	73.83	3	54.50	0	0.00	0	0.00
City core sector	30	2	0.73	0	0.00	4	57.00	0	0.00	8	79.50	0	0.00	0	0.00	0	0.00
Central sector	31	16	27.00	0	0.00	10	107.67	0	0.00	4	47.67	0	0.00	0	0.00	0	0.00
Central sector	32	14	27.06	4	10.00	14	209.00	6	60.00	14	181.92	0	0.00	0	0.00	0	0.00
Central sector	33	16	15.32	0	0.00	14	197.33	2	20.00	8	83.92	4	56.50	0	0.00	0	0.00
East sector	34	72	89.75	3	10.00	13	190.53	3	40.00	8	97.42	2	13.25	0	0.00	0	0.00
East sector	35	48	75.00	0	0.00	36	527.33	6	58.33	31	349.08	4	44.17	2	39.75	0	0.00

Kathmandu City - Travel purpose variables

Sector	Ward No.	Work Trip	Work Distance (km)	Study Trip	Study Distance (km)	Business Trip	Business Distance (km)	Private Trip	Private Distance (km)
Central sector	1	1	6.33	1	25.33	0	0.00	5	15.69
North sector	2	8	97.11	4	45.06	3	38.00	12	34.66
North sector	3	15	316.67	8	59.86	1	12.67	18	92.11
North sector	4	13	237.82	10	65.55	2	2.19	24	168.12
Central sector	5	7	126.73	5	5.84	2	22.00	7	23.64
East sector	6	21	358.21	10	70.21	0	0.00	27	78.80
East sector	7	24	412.07	9	101.13	1	6.67	24	76.71
East sector	8	3	57.43	4	67.96	0	0.00	6	31.04
East sector	9	20	453.24	4	116.29	0	0.00	10	49.70
East sector	10	15	281.84	11	123.51	2	20.73	23	235.99
Central sector	11	4	53.59	5	61.14	0	0.00	6	14.59
City core sector	12	8	144.82	3	13.40	0	0.00	5	8.24
West sector	13	14	232.73	12	72.04	0	0.00	17	153.35
West sector	14	25	448.81	21	355.33	2	26.06	14	12.04
West sector	15	23	302.68	12	123.22	1	2.19	22	123.33
North sector	16	32	592.59	28	334.30	2	32.67	19	252.92
City core sector	17	14	144.21	5	28.62	1	20.00	12	109.24
City core sector	18	4	86.77	4	80.96	1	0.36	0	0.00
City core sector	19	7	39.90	4	5.11	0	0.00	0	0.00
City core sector	20	4	39.82	3	40.22	0	0.00	1	2.19
City core sector	21	5	126.36	7	108.22	0	0.00	0	0.00
City core sector	22	4	22.28	3	44.09	0	0.00	1	1.09
City core sector	23	1	38.00	6	39.82	0	0.00	2	1.46
City core sector	24	2	26.43	2	22.45	0	0.00	0	0.00
City core sector	25	4	113.40	2	19.13	3	32.19	7	48.58
City core sector	26	4	47.01	1	34.17	0	0.00	3	27.52
City core sector	27	4	88.73	7	80.15	0	0.00	2	13.13
City core sector	28	5	71.86	0	0.00	0	0.00	4	6.20
North sector	29	20	363.72	9	84.05	2	19.36	24	187.49
City core sector	30	3	74.67	4	89.06	0	0.00	0	0.00
Central sector	31	7	81.03	7	114.94	1	19.00	4	13.86
Central sector	32	15	367.58	4	127.28	0	0.00	8	41.70
Central sector	33	12	260.29	7	122.78	0	0.00	5	34.16
East sector	34	24	267.10	15	37.13	7	74.92	15	79.47
East sector	35	30	719.49	18	393.90	1	20.00	19	81.03

<u>One Day Travel Survey Data in Kathmandu City</u>

Sheet No.			Ward No.		Name				Date		
Family member				**Walk**	**Cycle**	**Motorcycle**	**Car**	**Bus**	**Micro**	**Tempo**	**Taxi**
1	**Gender**	☐Male	**Work**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
		☐Female	**Study**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Age		**Business**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Occupation		**Private**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
2	**Gender**	☐Male	**work**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
		☐Female	**Study**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Age		**Business**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Occupation		**Private**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
3	**Gender**	☐Male	**Work**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
		☐Female	**Study**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Age		**Business**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Occupation		**Private**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
4	**Gender**	☐Male	**Work**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
		☐Female	**Study**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Age		**Business**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :
	Occupation		**Private**	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :	☐ :

Occupation type : ①Agriculture ②Production ③Sales ④Administration ⑤Student ⑥Housewife & Other

One Day Travel Survey Data in Kathmandu City

Occupation type

①	Agriculture	Agriculture, forestry and fishing worker	कृषि, वनस्पति र माछा पालन मार्ने व्यक्ति
②	Production	Mining quarrying practitioner	खनन् उत्खनन् चिकित्सक
		Transportation and communication worker	यातायात र संचार कर्मचारी
		Production process / labor worker	उत्पादन प्रक्रिया / श्रम कार्यकर्ता/ ज्यालामजदुर
③	Sales	Salesperson	बिक्रेता
		Sanitation services for individuals (barbers, beauty, and cleaning)	स्वच्छता सेवाको काममा संलग्न (सौन्दर्य र सरसफाई)
④	Administration	Professional / technical worker	व्यावसायिक / प्राविधिक कार्यकर्ता
		Administrative worker	प्रशासकीय व्यावसायिक कार्यकर्ता
		Office worker	कार्यालय कर्मचारी
		Security worker	सुरक्षा कार्यकर्ता
⑤	Student	Kindergarten, school student	बाल सदन, स्कूल विद्यार्थी
		College student	क्याम्पस विद्यार्थी
⑥	Other	Housewife (excluding occupation worker)	गृहिणी (व्यवसाय/पेशा भएका बाहेक)
		Unemployed, Retired, Other	बेरोजगार, अवकाश प्राप्त, अन्य