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Thesis title: The Shape of Travel Behaviour: The Effects of Street Network on Travel Behaviour among residents along Masaya Highway, Managua city

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Summary

Cities have design features in its urban form that distinguish and define them. Among the urban form aspects that provide structure to cities are street networks, which are fixed in space, providing them with geometry. Several studies explain that the street network was found to have an association with changes in commuting among residents. These changes can be associated with social and economic demographics, as well as culture and the built environment.

In a suburban area of Managua, along the Masaya Highway, housing projects have been following similar designs, and there has not been an upgrade in the existing street network of the area. The lack of adequate infrastructure and accessibility to public transport has led residents to experience difficulties in commuting, which affects their travel behaviour in aspects of modal choices, departure time choices and trip chaining. For example, some residents assure that they have to change their routes because of the street's physical conditions.

The following research aimed to explain the current influence of street networks aspects such as connectivity and physical characteristics of streets, in travel behaviour; like modal choice, trip chaining and departure time choice, among residents of the neighbourhoods along the Masaya Highway.

The methodology consisted in the implementation of a survey strategy that collected qualitative and quantitative data. Through questionnaires, information on people’s travel behaviour influenced by the street networks was gathered. Also, semi-structured interviews with urban experts, architects and engineers were conducted to collect information about the urban development of the delimited study area.

During the data analysis, several inferential statistical analyses were carried to describe the relationship between the dependent and independent variables. Also, descriptive statistical analysis and spatial analysis supported the results obtained from the inferential analyses, to be able to triangulate the information. Besides, four areas were selected for the sampling, so results among them could be compared.

The connectivity and the street’s physical characteristics of the four areas present the features of a suburban region, even though that is not the situation anymore. On the other hand, the results of the inferential analysis showed a significant relationship between connectivity and street’s physical characteristics, with the modal choices residents made.

The influence of the street network variables in trip chaining and departure time choice did not show a significant relation. But, when comparing the four areas of study, the location of residency marked a difference in people’s travel behaviour.

It is crucial to say that the provision of urban public transport is a determinant factor for modal choices, trip chaining and departure time choice. Managua’s municipality should prepared and conduct strategies to improve urban development.

Keywords

Travel behaviour. Street network. Urban Form. Connectivity. Street. Physical characteristics. Modal choice. Departure time choice. Trip Chaining.

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This work is dedicated to my country, Nicaragua. Hopefully, this is a small contribution as an architect and urban manager.

Abbreviations

JICA	Japanese International Cooperation Agency
MTI	Ministry of Transport and Infrastructure
IRTRAMMA	Instituto Regulador del Transporte del Municipio de Managua (Transportation Regulatory Institute of the Municipality of Managua)
INIDE	Instituto Nacional de Información de Desarrollo (National Institute of Development Information)
ALMA	Alcaldía de Managua (City Hall of Managua)
NACTO	National Association of City Transportation Officials
GIS	Geographic Information System

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Chapter 1: Introduction

This chapter introduces the background to the study, describing the problem statement for well understanding of the research's objectives. The main research question and sub-questions are also stated in this chapter. The significance of study on this chapter justifies the meaning of the research, concluding with the scope and limitations.

1.1 Background

Concepts of exchange and movement such as transport are seen as elements of defining a city since they influence the conditions of performances like spatial and economic development (Wright, 2012). Within a city, the demand for transportation is controlled by the spatial administration of residential development gathered around a location, land use and layout (Hamiduddin, 2012). It is in the urban structure of cities that the association between urban transport and the spatial form of residential development is noticed.

Speaking of which, the urban form concept can be viewed from numerous geographical measures and categorised into levels such as a metropolitan area, city and neighbourhood (Tsai, 2005). Also, used to analyse accessibility between origins and destinations as an urban form indicator, are the street networks (Boeing, 2018). According to Boeing, street networks are incorporated in space, providing cities with geometry and topology. The indicators of the street network are noticeable parts of urban structures and forms, and they also provide a significant impact on travel behaviour (Moeinaddini et al., 2016).

Travel behaviour is about how individuals make travel decisions, and its different aspects can be studied and related to the street network of cities. The new researches on travel behaviour are studying the physical movement of persons outside their reference locations (Axhausen, 2007). As Axhausen states, the choices of travel are determined by taste differences, lifestyles, attitudes and socio-demographics. Many studies of travel behaviour contribute to a comprehension of how and why the urban form is associated with travelling (Handy, 1996).

Located in Central America is Nicaragua, a tropical country of 6,3 million habitants that shares coasts with the Pacific and Atlantic ocean (INIDE, 2018). Situated in the Pacific Area is the capital city, Managua, and its metropolitan region comprehends the departments of Managua, Masaya, Carazo and Granada with a total population of 2,2 million habitants. The municipality of Managua is composed of an area of 267.17 square km, and by the year 2017, the population estimated was of 1,045,912 habitats just for the neighbourhoods within the municipality (INIDE, 2016). Managua controls the country economically and politically, and it is the primary symbolic national reference point (Rodgers, 2004).

For some, it is referred to as “the city of chaos”. After the earthquake that devastated the city centre in 1972, the business and services that were in the city centre bounced back in a decentralised mode, building a fragmented city of semi-autonomous districts connected by a disordered and confusing transport network (Rodgers, 2004). The earthquake changed the city completely, and people started to build sparsely in one-story homes.

According to the Ministry of Infrastructure and Transport, the municipality of Managua has 2,106 km of the street network in all its territory (MTI, 2018). The street network of Managua is mainly composed by radial networks that connect the centre of the city with the suburban areas and its surroundings, as well as road rings that border the city in a circumferential direction (JICA, 2017a). The highway from Managua to Masaya, a primary distributor road, is a critical axis of the city and has been attracting commercial and residential development in the last 15 years, due to that is considered one of the sub-centres in the latest master Plan of Urban Development of the city. Moreover, this highway is the main road that leads to other important cities and departments of the country, like Masaya, Granada, Rivas and Carazo.

The first widening of the highway to Masaya from the intersection Jean-Paul Genie to Ticuantepe was made in 1998, leading to an accelerated residential and commercial development alongside the highway. By 2012, alongside the highway from Managua to Masaya, there were already approximately 83 housing developments (Moncada, 2012).

The public urban transportation in Managua is coordinated by the Transportation Regulatory Institute of the Municipality of Managua (IRTRAMMA, in Spanish) and the services provided in the city are the regular routes, the interlocal routes and expressos which travel from Managua to other cities (JICA, 2017c). Other transport services like three-wheelers can travel only inside certain sub-urban regions of the city, avoiding the main roads and transporting people where buses cannot reach.

A study made in 2005 with information from the Japanese International Cooperation Agency compares the travel behaviour characteristics among 13 cities worldwide, including Managua (Hyodo et al., 2005). The study considered the whole area of the city and measured the time departure on generated trips, the modal choices and trip chaining among residents. The trip generation departure showed peak hours starting at 6 a.m., noon and 5 p.m. For the modal choice, the use of large buses where prevalent, as well as walking. The predominant preferences for trip combinations were from School-Home and Work-Home. This study compared essential household characteristics, considering the level of development of transport infrastructure, degree of motorisation, culture and demographics.

Street networks are part of the urban design of the city and vary from dense urban grids of greatly interrelated streets to scarce suburban network forming rings (Ewing and Cervero, 2010). This would be the case for Managua, a city that has been developing following the demands of the housing market (Grun, 2014).

It is in urban planning and transportation research where street networks are taken into account to determine accessibility between origins and destinations, and the calculation of the urban form is introduced (Boeing, 2018). Since urban organisation indicators are shifting fast, future research studies may have to assess these changes by revising their data sources, as well as inspecting the urban structure indicators and residents' commuting tendencies so the different results are covered (Moeinaddini et al., 2016).

1.2 Problem Statement

Residents living along the Masaya highway experience difficulties in commuting because of the characteristics of their neighbourhood's street networks, affecting and influencing their travel behaviour in aspects of modal choices, departure time choices and trip chaining, also known as the combination of trips. In the urban area along the highway, between the Jean-Paul Genie and Ticuantepe roundabouts, residential developments have been following similar design patterns (Suárez and López, 2015), without any upgrade in the existing street network of the area. Even though the highway is a main road that connects to the city centre, there is lack of connectivity and accessibility to the urban transport (JICA, 2017c), affecting their commute in different aspects every day.

After the earthquake in the city centre in 1972, the growth of the city shifted along the highway to Masaya. The history of the city suggests that it is highly disintegrated spatially, socially and administratively (Brown and Bornstein, 2006). An examination of the overall urban form implies that many of the elements that contribute to the re-integration of the city around a new axis and commercial centre are leading to fragmentation and disintegration as specific groups, places and networks operate in distinct detached ways.

Starting in the 1990s, the city showed an increment in the private housing real estate sector with segregated residential developments that create small and closed residential units in the southern area of the city, along the highway to Masaya road axis (Suárez and López, 2015). With time and new developments, came new challenges to the area. Like Zhao, Lu and de Roo explain (2010), one of the significant factors influencing changes in commuting patterns is urban expansion. It means that land-development management could have implications for transportation of residents.

The highway to Masaya, from the roundabouts Jean-Paul Genie to Ticuantepe, is the area of the city with more cars and less accessible urban transportation (JICA, 2017c). Even though there is a high demand for urban transport, there is no much offer of public transport that connects the neighbourhoods along the highway. The rapid expansion of urban areas has been causing imbalances in the spatial form of cities, affecting transport performance and its caused because the supply of transport infrastructure does not keep pace with the housing expansion of cities (Ambarwati et al., 2016). Aspects like street connectivity and intersection density reduce access distances and offer more routing options for residents (Ewing and Cervero, 2010), whereas the availability of public transport and the compactness of the residential environment influences travel behaviour (Dieleman et al., 2000).

The commercial development along the Masaya Highway has increased in the last year (JICA, 2017b), following the residential developments. Unfortunately, only the capacity of the Masaya Highway between the roundabout Jean-Paul Genie and Esquipulas has been upgraded in the last years, while the rest of the street network around the neighbourhoods has remained the same. The neighbourhoods in the southeast of the city create a grand demand for transport that is satisfied by the interdepartmental services of public transportation. Nevertheless, in the area there is a high demand for private vehicles since the urbanisations are highly dependent on them (Consorcio Team Red PROCAD, 2014a).

For the ex-president of the Nicaraguan Association of Architects and Engineers, the problem of the street network of the capital is that it has not been renewed in more than 50 years, creating a deterioration of the roads, traffic saturation and disorder in the public transport (Largaespada, 2013). According to an official from the Road Maintenance Fund, there is no logic in the highway to Masaya that corresponds to the development of residential areas and the road capacity.

The roads and streets have exhausted their design capacity, creating inconvenience for the residents travelling around the area. Sadly, authorities claim that their budget does not allow them to intervene structurally in the street network enough to make noticeable changes (Anon, 2013). Adding to the fact that no significant changes have been done to the network system, streets that access to the main roads get congested (JICA, 2017b).

To get to some neighbourhoods along the highway, residents have to change their routes due to the physical conditions of the streets. They have been asking for years to the municipality for better pavement conditions of the street network, as well as the provision of alternative routes to get to the centre of Managua that will improve connectivity across the city (Barrios and Lara, 2015).

The interurban arterial road of the highway from Managua to Masaya only counts with the interurban transportation services and espressos, and not the ones from the city itself

(Consorcio Team Red PROCAD, 2014a). Due to the type of residential urbanisations in the area of the highway, a high amount of commutes are made by private vehicles (Consorcio Team Red PROCAD, 2014b), as well as taxis and three-wheelers where buses do not reach. It has been proved that the purpose of the trip is a crucial element in modal choice for work and study trips (Larrañaga and Cybis, 2014).

According to a survey made by the Japanese International Cooperation Agency (2017c), 37% of the population in Managua prefers not using public transport and complains about the limitations of mobility. Among the problems of mobility found from Managua's residents, there is the high traffic volume, adverse conditions of sidewalks and streets, lack of parking spaces, insufficient vial signal, problems at the bus terminals, besides the lack of control in the operation of public transport. Moreover, there are certain areas in the outskirts of the city where public transport is barely accessible, and people need to use three-wheelers to get to the nearest stop (JICA, 2017c), as the situation of the area of study.

As for the street network shaping travel behaviour, the urban dispersal and spread out of cities, influence travel and the use of motorised vehicles (Li et al., 2019). Also, Moeinaddini et al. (2016) concluded in their article that the street network characteristics had a positive relationship with private motorised daily trips. This statement could be the case of some residents along the Masaya Highway that might have to share transportation with others or even mix different modal choices to get to their destination.

Among residents of the area, the commute between home and work also involves other activities to avoid tour frequency. According to Badland (2008), people may require motorised transport when combining several trips, like transporting children to school, doing groceries or shopping. In the case of Porto Alegre (Larrañaga and Cybis, 2014), the modal choice of residents depended on the city's topography and the small variability of the average block length. Street connectivity is one of the built environment characteristics that influence the most people's choice for walking.

Some residents of Managua have changed their travel behaviour to avoid possible problems on the road, and it happens more with people that live farther from their workplace (Bejarano, 2017). The location of places where residents want to go and how they get there will depend on their assets, the transportation system in place, their needs and demands or even bus fares, among other factors (Crane, 2000).

1.3 Research Objective

The objective of the research is to explain the influence of the street network (connectivity and physical characteristics of streets) in neighbourhoods along the Masaya Highway on travel behaviour (mode choices, trip chaining and departure time choice) of the residents.

1.4 Research Questions

To address the problem statement explained above, the following main research question is proposed:

- How does street network (connectivity and physical characteristics of streets) influence travel behaviour (modal choice, trip chaining and departure time choice), in neighbourhoods along the highway to Masaya in Managua city?

As a complement to the main research question, the following sub-questions are suggested:

1. How are the connectivity and physical characteristics of streets provided to access the highway to Masaya?
2. How does connectivity and physical characteristics of streets influence modal choice when accessing the highway to Masaya?
3. What types of trip chaining do residents practice based on the connectivity and physical characteristics of streets, when travelling from their homes to work, leisure, school and shopping?
4. How does connectivity and physical characteristics of streets influence the departure time choices when accessing the highway to Masaya?

1.5 Significance of the Study

For urban planning and transportation sectors, the relation between the built environment and travelling needs to be comprehended, so decisions in urban management are adequately justified. For the moment, there are no studies in Nicaragua addressing street network and travel behaviour, which increases the scientific significance of this research. The literature on travel behaviour exists (Crane, 2000), but for every city the results are different due to their socio-economic characteristics, transportation supply and accessibility, urban form and culture, among other reasons.

This study is for well appreciation of the area's urban built environment features, as well as the difficulties of mobility in this sector of Managua. As some scholars mention, the relation between the built environment and travel is a examined subject in urban planning (Ewing and Cervero, 2010), so decisions to make effective interventions can be made (Boeing, 2018). This research could conduct to the development of new local policies that are aware of road users, providing improved street conditions for better urban mobility according to the user's needs.

As for the societal relevance, this research also addresses the needs of public and private transport users, related to the street networks of the areas where they live. Studies on travel behaviour serve as a supply for planning the spatial circulation of residential areas and transport infrastructure, as well as organising public and private transport (Bartosiewicz and Pielesiak, 2019). At the same time, to understand the potential function of land use policies in responding to the motorisation trend happening in our cities (Pan, Shen and Zhang, 2008). With this study, recommendations can be made to the governmental transportation sector according to the behaviour of users. The findings of the study might also influence the decisions of private investors, from housing developers to home buyers.

1.6 Scope and Limitations

The study's location is in Managua, Nicaragua's capital city, along the highway to Masaya, between the kilometre 7 and 13, in the southern area of the city. This area was selected due to the fast urban development, and the notorious problems residents face every day because of the street network of the neighbourhoods.

This research aims to study the travel behaviour of residents in the different residential communities, who also present different socio-economic and demographic characteristics. The attitudes that lead to different mobility strategies among the residents around the area is one of the focuses of study.

The independent variables in this research are the street network variables, whereas the dependent variables are the travel behaviour variables. As mentioned before, the focus is only in the relation between the connectivity and physical characteristics of streets with modal choice, departure time choice and trip chaining.

The information was collected via primary sources from the fieldwork. The collection of data would also depend on the disposition of the people interviewed and surveyed. These could refuse to respond; therefore it is expected that the sample size can cover the margin of error.

Chapter 2: Literature Review / Theory

This chapter introduces the theoretical background of the problem stated in Chapter 1. This chapter explains the urban form concept as a broader concept and street network with its various ways of measurement. Secondly, travel behaviour is explained as well as definitions of it that are going to be assessed in the study which are: modal choice, departure time choice and trip chaining. Lastly, the studies that relate the concepts are explained for better understanding of the theories.

2.1. Urban Form

From the literature, urban form is a concept that can be perceived in different ways. It can be defined as the spatial formation of static foundations within a municipal region, including the spatial form of land uses, density, the spatial design of transport and communication infrastructure (Anderson et al., 1996). Urban form is also a compound of multiple characteristics on an aggregate level since certain elements may vary depending on the neighbourhood (Handy, 1996).

To define urban forms, the authors Sharifi and Yamagata (2018), divide urban form features into categories, namely macro-, meso-, and micro-scales. At the macro-scale the urban form comprehends the complete structure of the city, like scale hierarchy city size, development type, distribution forms of residents and jobs. At the meso-scale, urban form benefits the general structure of neighbourhoods and districts, and these characteristics are a diverse typology of a transportation network, access to services and geometry of open spaces. The micro-scale elements of urban form concern the construction of buildings, their spatial relation with each other, and the position respecting pedestrians and traffic networks. At the micro-scale, they have direct and indirect influences on elements and features such as the amount of clustering, connectivity, and accessibility.

For Crane (2000), urban measures focused on land issues are population density, employment location, mixed land uses and street configuration. According to Chen and Akar (2017) and Badland (2008), some variables to measure the urban form include density, transport network design, street design and land-use mix, which can vary across regions.

For others, the urban form can be described as the physical and spatial demonstration of human activities (Sharifi, 2019), and its research aims to understand the dynamics and difficulties of the physical configuration of cities.

Considering the Nicaraguan context, the aspects of urban form contemplated to be more appropriate for this research come from the built environment and street network characteristics, being the most relevant aspects for the relations among variables of this study. Along with the neighbourhoods considered for the study, aspects like street network connectivity, street length, street width and pavement conditions are different, influencing travel attitudes among residents in several ways.

2.1.1. Street network

Street networks consolidate and assemble human spatial dynamics and movements in a city as they motivate commutes and the locality of homes and companies. Topological characters describe the structure of the network and include measures of connectivity, centrality and clustering, whereas geometric aspects represent the network's distances, areas and densities (Boeing, 2019a).

Considered as the "backbones of cities", street networks are essential for the appearance of cities and guide their growth and evolution (Sharifi, 2019). They are among the most long-lived mechanisms of urban form and can stay for decades. For that, their design and structure can lead to negative or positive pathways. Streets have consequences for the proper functioning of existing infrastructure and future growth, as well as the progression of other types of urban infrastructure.

Street networks are fixed in space, providing areas with geometry like coordinates, lengths, shapes and angles (Boeing, 2018). Additionally, Boeing explains that they can be simplified in two-dimensional models as well as in three-dimensional space, revealing the presence of grade separation, bridges and tunnels. Street network, named from others by street pattern (Leck, 2006), plays a fundamental role in the development plans of cities.

Besides distributing energy, materials and people in an urban area (Samaniego and Moses, 2008), street networks provide the primary structure for an efficient and durable urban form, and its attributes include structure, street integration and intersection design (Donovan and Munro, 2013). They vary from dense and highly interconnected urban grids to scarce suburban networks of curved streets. Measures include average block size, the proportion of four-way intersections and the number of intersections per square mile (Ewing and Cervero, 2010).

2.1.1.1. Connectivity

Categorized as an urban design variable (Badland, 2008), connectivity is considered as a configuration of accessibility (Lamiquiz and Lopez-Dominguez, 2015). It can also be acknowledged as the facility to travel between two points, concerning the features of the street design (Saelens et al., 2003).

The different spatial configuration that street networks present could be orthogonal and non-orthogonal grids, curvilinear, cul-de-sac, radial, organic and hybrid (Sharifi, 2019), which are aspects related to connectivity. For Lee (2017), it is connected with the size of blocks in the dense urban areas of Los Angeles.

The urban connectivity of streets can also depend on their hierarchy. According to the Functional Classification of Urban Road System in Nicaragua (ALMA, 1983), the roads are classified as follows: Primary distributor system, Primary collector System, Secondary collector system, Road System, Cul-de-sac and recreational system.

Connectivity is the scope to which streets interconnect at regular intervals, allowing the connection to desired destinations (Hawkins, 2007). In other studies, street connectivity was measured as the ratio of the number of four-leg intersections in an area (Lee, 2017). As for Boeing (2017), high connectivity of networks provides more routing options choices to residents and are more resistant against failure. For other authors, the concept of connectivity relates to the number of linear kilometres of streets per square kilometre of an area, which is defined as street density (Ball, 2012; Matley et al., 2000).

Connectivity measures assess the concentration of links between street segments and refers to the ease of travel between locations. Well-associated networks have short links, a lot of intersections and minimal dead-ends, providing straight directions to destinations (Sreelekha et al. 2016).

Moreover, grid road configurations offer more direct route choices and are likely to provide higher street connectivity. Four-way intersections should also reduce travel distance per destination since they provide more direct routes (Wang et al. 2014).

2.1.1.2. Physical Characteristics of Streets

Some measures of the physical characteristics of streets are more significant to analyse in this research than others since they have a consistent presence in the delimited area of study. Usually, the physical characteristics are considered as part of the design of a street (Haybatollahi, 2015; Sharifi, 2019), while some studies have appointed that when there are changes in neighbourhood characteristics and streets, travel behaviour also changes (Cao, et al. 2007; Sharifi, 2019). Next, the selected physical characteristics of the street to take into account in this research are briefly explained.

2.1.1.2.1. Street Length

According to Strano, et al. (2018), the street length is one of the geometric properties of the networks in which studies have focused. Line and segment length are considered geometric characteristics of street networks (Lamiquiz and Lopez-Dominguez, 2015), and the street length can be regarded as the sum of edge lengths in undirected demonstration of networks (Boeing, 2017).

Short and long streets have distinctive historical significance in the development of cities, as they tend to reduce with increasing density of the urban configuration. As denser and ‘urban’ the area of the city is, the shorter the street because of rectangular grids(Strano et al., 2013). In their study, the overall average street length of selected networks represent a simple and useful indicator of the diversity of cities.

2.1.1.2.2. Street Width

The NACTO Urban Street Design Guide (2012), considers street width as a container and a public space with context, land use and traffic. The guide uses street width and dimension as a primary point of departure for the street design.

In the case of Nicaragua the urban road network system is classified according to the street’s function, width, length, circulation way, travel demand, elements within the right of way and travel demand (ALMA, 1983).

2.1.1.2.3. Type of Pavement

The type of pavement covering the street can be assessed by structural indicators which relate to the pavement’s adequacy to withstand traffic loads and exposure to visual sufferings (Marcelino, Lurdes Antunes and Fortunato, 2018). Among the pavement physical characteristics, there is surface texture and structural conditions, which mark a relevant difference between streets.

In a study made by the Japanese International Cooperation Agency (1999) as part of a Master Plan for the Transportation System in Managua, the type of pavements identified in most of the streets were either asphalt, block or concrete.

2.1.1.2.4. Pavement Conditions

Road physical infrastructure deteriorates due to poor maintenance, ageing and exposure to the weather and traffic (Marcelino et al., 2018). Even when each road pavement has different forms and materials that help distinguish them, there are certain various defects of deterioration. From the common road pavement defects there are: rupture of the road edge, cracks, potholes and depressions (Thu Huong et al., 2016). Potholes are irregularly shaped holes of various sizes in the pavements, while longitudinal cracks are unconnected flaws crossing longitudinally along the pavement.

Related to the Nicaraguan context, JICA’s study (1999) takes into account three factors characterising the pavement condition, which are potholes, cracks and rutting.

2.2. Travel Behaviour

The knowledge of travel behaviour is decisive for the administration of strategic and spatial planning, necessary to asses in urban, regional and national management. Travel behaviour can be described as a set of human attitudes and choices on executing activities that require moving from one place to another, such as getting to work, school, shopping and leisure places (Bartosiewicz and Pielesiak, 2019). This theory was found to be the most adequate for the present research.

Researches on travel behaviour aim to comprehend how commuting preferences decisions like transport mode to commute to work or using the car, which route to take, are made. Furthermore, several approaches have been used, including the tour based approach, the trip chaining based approach and the tour-based approach (Zhang, 2017).

In her research, Handy (1996) considers socio-demographics as determinants of decisions in travel behaviour. These variables include gender, age, employment status, educational background, household revenue, household size, the number of children, mobility restrictions and residential tenancy.

Several studies have been made to analyse signs related to the impact of the street network on travel behaviour, at different levels of spatial development (Teguh, 2013). In their analysis, Samaniego and Moses (2008), considered road network design influences on the travel behaviour, contemplating population density, the variation of the spatial design and the network geometry affecting residents in different areas.

In Managua, a study made by the Japanese International Cooperation Agency (1999, 2017) analysed some travel behaviour preferences among the residents living in the city, intending to describe the transport situation to propose a Transportation Master Plan for the metropolitan area. Among the travel behaviour preferences, the studies included modal choice, travel time, the combination of trips and purpose, which are going to be considered in this study.

2.2.1. Modal Choice

Among the transportation types in public transit, there are buses, minibuses, microbuses, workplace shuttles and taxis (Guerra, 2018), as well as other choices like metro, bus rapid transit and trains might also be available depending on the city. For some Latin-American cities, the urban spatial structure has a significant role in the user mode choice, as explained by Guerra in his study of Mexico’s largest urban areas.

The relative attractiveness of networks to different modes depends on the design and scale of the roads (Ewing and Cervero, 2010). In Badland's study (2008), the modal choices were divided into three categories: motorised transit and transport-related physical activity, like walking or cycling.

According to Yang, et al. (2018), the factors that influence the mode choice of travel of residents can be classified into five clusters: travel demand characteristics, travel mode characteristics, socio-demographic characteristics, subjective attitudes and environmental characteristics. Also, travel modes have different appearances in terms of travel distances, travel time duration, cost, safety, comfort, flexibility, and convenience.

In his research, Thogersen (2006) traced travel choices by the traveller's evaluation and motives, individual abilities (and constraints), and contextual opportunities (and limitations). Also associated with modal choices is driver's license ownership (Sultana and Lei, 2018) since driver license owners tend to use more private vehicles.

In Santiago de Chile, accessibility and modal choice might be dependent on socioeconomic conditions, notwithstanding the hustle of motorisation of the last two decades (Gainza and Livert, 2013).

2.2.2. Departure Time Choice

In the urban transport context, departure time decisions have received attention from analyst alarmed with decreasing congestion through demand measurement, particularly along significant freeway commuting corridors (Mahmassani and Chang, 1986).

The departure time of trips is the distribution of time between the first departure of the day until the final return to home, considering that the activities of the person might be defined by their schedule (Axhausen, 2007).

According to Noland and Small (1995), most studies have focused on schedule delay, which is defined as the difference between the time of entrance and the work start schedule. They also mention that someone can shift one's schedule to take advantage of lower congestion on the streets.

Departure time choice makes part of this study because according to the background of this study, traffic congestion around the area becomes a determinant of the travel choices among residents. In an effort to avoid traffic congestion, residents adjust their departure time choices to meet their destinies when they need to be (Bejarano, 2017). Therefore, the street network characteristics perform an essential role in the departure time choices of residents along the Masaya highway, since they might influence other traffic-related problems.

2.2.3. Trip Chaining

To explain the concept of trip chaining, the meaning of "trip" is explained first. For Primerano et al. (2008), a trip is considered to be a tour that involves several activities. Even though most people have one primary trip a day, they may also have one or more secondary trips that can variate. A trip is also described as the one-way travel segment between an origin and a destination, by any transport mode (McGuckin and Murakami, 1999).

As for trip chains, they are defined as the combining of secondary activities to a primary activity through travel that is made when the individual leaves home until when they return home (Primerano et al., 2008). So, trip chains are scheduled activities that individuals will follow and can be categorised in two groups: simple trip chains involve a single activity, and complex trip chains involve many activities being visited.

For the trip chaining analysis, the primary anchors that link the trips that are usually considered are home and work (McGuckin and Murakami, 1999; Concas and DeSalvo, 2014). A chain is defined by the anchors, for example: if a person leaves work, stays at a store, stops at their kid's school and goes back home (McGuckin and Murakami, 1999). Concas and DeSalvo mention that a trip chain describes the way travellers link trips between locations within an activity space and occurs to save time between the home-work commute.

Trip chaining allows individuals to combine more activities in a single tour (Sultana and Lei, 2018) and the location of their residences have a significant influence on this behaviour. It has been found that residents living in the urban core and suburban areas make more trips compared to those that live in urban borders and the rural regions.

According to Lee (2017), recent works have assessed travel behaviour through observations of the sequence of trips segments, known as the tour-based approach. He describes that a "tour" the fact of linking individual trips and all the stops made along the way. In a study comparing men and woman's trips chaining behaviour, the findings show that adult women make more trips than men at the same age, but men take longer in each activity they make (McGuckin and Murakami, 1999).

2.3. Relation Between Street Network and Travel Behaviour

Several academics and researches have made an effort explaining the relations between street network and travel behaviour. First, Zhao et al., (2010) state that the urban spatial structure cannot work alone since it affects commuting patterns due to the effects of the urban form at the local level. Their empirical analysis found that the networks of urban development have an impact on commuting arrangements when residents socioeconomic characteristics and transport accessibility are taken into consideration. Given that, Pan et al., (2008) state that the results of studies made in developing countries of the built environment related to travel behaviour do not apply to developing countries since contexts are different. The difference could be due to their contrasting urban policies, economic growth and urban development.

Street networks have the potential to affect travel decisions. For example, depending on the grid, the modal choices may vary (Ewing and Cervero, 2010). The design of transport networks might also have a role in containing the use of private cars when it comes to the accessibility to public transit stops (ECMT, 2007).

For some, the influence of urban form on travel behaviour can be complex because of the expansion of the built environment, which in some cases has led to induce that households choose their house location due to personal preferences for travel and location (Concas and DeSalvo, 2014). Then after accounting for "self-sorting" of the residences, the built environment affects commuting choices.

In Lee's study (2017), the features of the built environment that were suggested to be related to modal choices included residential density, land-use mix, street connectivity, the intensity of local employment and the accessibility to the transport network.

Urban street network indicators are noticeable parts of urban configurations and can develop influences on travel behaviour (Moeinaddini et al., 2016). The results from a Porto Alegre study (Larrañaga and Cybis, 2014) shows that variables from the street network such as four-way intersections, and transit availability were the most influential variables for the decision of walking. Also, the comparison of the estimated models for work trips, study trips, as well as other trips showed that the effect of urban characteristics depends primarily on the reason for the journey.

In their research of the effects of street's structure on transit travellers, Ozbil et al., (2009), found that people residing close to a public transport stop tend to use the transit irrespective of the street connectivity levels of the stop area, concluding the significant predictor street connectivity is of ridership levels. They also mention that in residential neighbourhoods, adequate urban design for pedestrians influences the mode of access to transit.

In another research, the street network was found to have a significant association with changes in walking and driving behaviour, adjusting for current attitudes and changes in socio-demographics, as well as taking multiple interactions into account. The models of the study pointed accessibility to public transport as the most crucial factor in reducing driving, and the enhancement of the quality of the built environment like attractiveness, physical activity options and socialising, increased walking (Cao et al., 2007).

2.4. Conceptual Framework

The following section highlights how street network aspects influence the travel behaviour indicators that are taken into account in the research. From the academic literature, it was identified that research that focuses on street networks might detect relationships with travel behaviour. According to Guerra's study in Mexico (2018), road supply had the second most active relationship to commute choice among seven municipal areas.

With that said, the characteristics of the street network have an impact on the scope of travel and preferences on modal choice (Leck, 2006). However, the empirical evidence of the effects of urban form on travel behaviour is mixed. Moreover, street network attributes like length and width have interlinkages with connectivity and permeability (Sharifi, 2019). For Dill (2004), connectivity measures like street density and intersection density are positively correlated with each other, and as Campoli (2012) mentions, they improve urban walkability conditions.

There are several street network characteristics related to mode choices selection in the academic literature reviewed. Researches often look at the nature of intersections as a way of measuring street network and their effects on travel. For example, superblocks with long distances between intersections promote less walkability among residents (Larrañaga and Cybis, 2014). Excellent street connectivity supplies more routing options, and it is a proved element that encourages walking.

In Lee's findings (2017), the relation between the use of public transport is justified when people's destination is more accessible to services and jobs. He also concludes that street networks with fine grids encourage walking to a destination, while biking is preferred for leisure activities.

Moeinaddini, et al. (2016) considered in his study elements like blocks per area, nodes per block and length of roads and motorways as urban street network variables. These variables were independent, influencing the dependent variables, which were the transportations modes.

Several studies also relate street network conditions to departure time choice. According to Chin (1990), departure time choice will be influenced by the street conditions at the time of travel, by evading periods of congestion and routes to minimise time travel. This also relates to the quality of the service of the selected mode of transport.

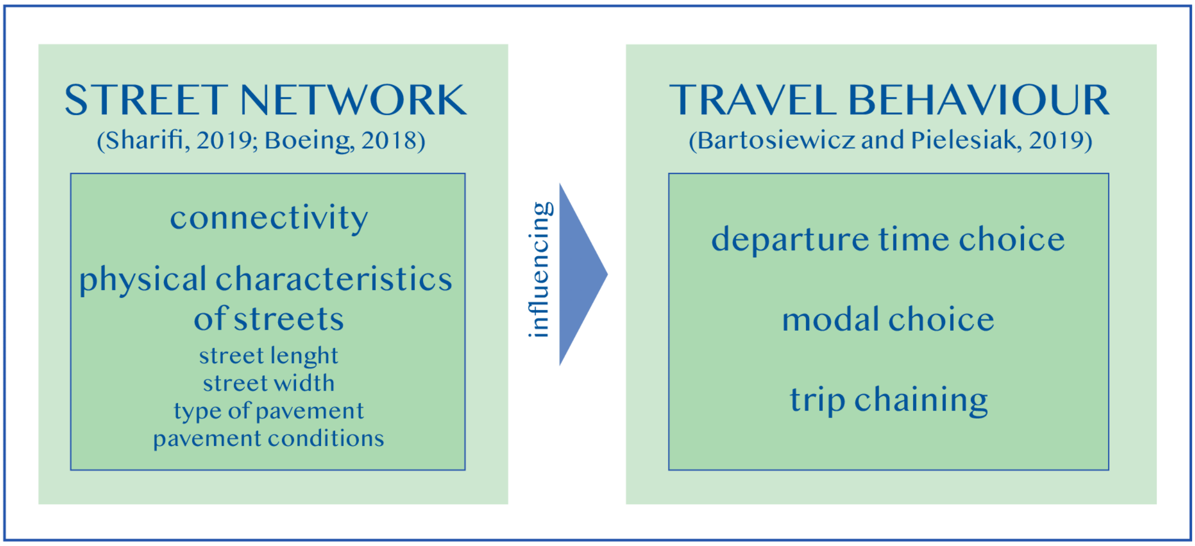
Individuals tend to leave early to the work-place as the distance to the work-place increases. Because of the time spent commuting, residents may have to find time for other activities both before getting to work or after work (Vishnu and Srinivasan, 2013). Residence location has a significant role in deciding the preferred travel time. However, Vishnu and Srinivasan found that congestion on the street network was also discovered to be an influence in departure time choice of workers. The worker was observed to find greater utility when travelling before or after peak hours.

Many studies also compared the influence of street networks on trip chaining behaviour. According to Sultana and Lei (2018) due to the street connectivity and density, residents living in the urban core and suburban areas make more trips in comparison to those living in urban borders, who tend to make more tips chains to reduce their travel distances.

Meanwhile, cities with a radial network show an improved use of nonmotorized transport modes in a number of trips for the home-to-work commute, whereas cities with grid networks tend to have less number of trips per year (Snellen et al., 2002). Fran et al. (2008) also studied the trip combination in their research, where it was found that the degree to which participants chained trips into tours was associated to the land use types near where residents lived and worked.

From the literature review, it can be concluded the presence of an active relation between street network aspects and travel behaviour. For example, it could be determined that street width, length and connectivity influence modal choices. In the same way, departure time choice is influenced by the street network physical conditions, which might also lead to traffic congestion. In addition, trip chaining behaviour can be affected by the connectivity of the road network, which depends on the neighbourhoods' street design. This chapter ends with a conceptual framework that indicates the street network variables of the study, influencing the travel behaviour variables selected.

Figure 1: Conceptual Framework



Source: Author, 2019

Chapter 3: Research Design and Methods

In this chapter, the operationalization and methodology proposed for the resolution of the research questions are explained. The breakdown of the variables and indicators for the street network and travel behaviour concepts are defined for the implementation of the research strategy. In the research strategy section, the methodology for the collection of data and its analysis is presented, so further researchers can use these methods in similar studies in the future.

3.1. Revised Research Question(s)

After examining the literature, the research questions were revised and are reformulated as follows:

- How does street network (connectivity and physical characteristics of streets) influence travel behaviour (modal choice, trip chaining and departure time choice), in neighbourhoods along the highway to Masaya in Managua city?

As a complement to the main research question, the following sub-questions are suggested:

1. How are the connectivity and physical characteristics of streets designed to access the highway to Masaya?
2. How does connectivity and physical characteristics of streets influence modal choice when accessing the highway to Masaya?
3. What types of trip chaining do residents practice based on the connectivity and physical characteristics of streets, when travelling from their homes to work, leisure, school and shopping?
4. How does connectivity and physical characteristics of streets influence the departure time choices when accessing the highway to Masaya?

3.2. Operationalization: Variables, Indicators

The variables described in the following section are considered in the research taking into account Managua's context and the delimited area of study. The indicators and their units of analysis allow the establishment of the bases of this study. They were taken from other studies carried out in Managua and other countries across the globe.

In deductive studies, the theory can be transformed into empirical research by the operationalization of variables (Van Thiel, 2014), what means that the concepts in the conceptual framework are now measures that can be comprehended and recognized by the respondents and readers. Once the indicators of the concepts are categorized and defined, they will be used for formulating questions for the primary data collection instruments.

The explanation of the chosen indicators to measure is argued next, with support from the literature and similar studies mentioned in the Literature Review chapter. These measures have to be understood and recognized by the interviewed residents, and by experts on the subject in a simple way.

The travel behaviour indicators measured in this research are: modal choice, as for the number of modes used to get to their destination; departure time choice, as the preferred time to start the trip; and trip chaining, as for the types of trip combination made in between home and work.

Some travel behaviour indicators that are going to be part of this research were considered by the Transportation Master Plan study in Managua (JICA, 1999). For example, the categorization of transportation modes in the survey to inhabitants remained the following: walk, car, taxi, microbus, bus, motorcycle and bicycle. In the present study, moto-taxis are also going to be included, due to their current popularity to replace public buses in some areas.

Furthermore, trip chaining is measured by the number and type of trips made by residents (Frank et al., 2008). Primerano, et al. (2008), categorized trips into five types: multi or single chain before work, activities practised during work, multi or single chain after work. In the study for the Transportation Plan of Managua (JICA, 1999), the types of trips were measured as follows: to work, to home, to school, personal activity, business activity.

Departure time choice is going to be categorized in three periods: before peak period, peak period and after peak period, during the morning and afternoon routine. In the Transportation Master Plan of Managua (2017), respondents were asked to indicate the timeframe when they travelled, so then it could be categorized according to the peak periods.

In this research, the street network characteristics proposed to be studied are connectivity and street network characteristics. As identified by Frank et al. (2008), Lee (2017) and Larrañaga and Cybis (2014), street connectivity is measured by the four and three-leg intersections per square kilometre known as intersection density. Dill (2012) and Matley et al. (2000) also measured connectivity with street density characteristics by calculating the number of linear kilometres of streets per square kilometre.

Past studies addressed the street physical characteristics of Managua's road network by describing the types of pavement and pavement conditions (JICA, 1999). Among the types of pavement, streets can be covered by asphalt, block or concrete. They considered three factors on the pavement condition, these were potholes, crack and rutting, and then gave them a qualification to describe their situation.

To measure the street's width and length, the functional classification of the urban road system of Nicaragua is going to be referenced for the analysis. From this classification, the rank of the "right of way" measured in meters is considered, as well as the travel length, which is according to the type of road.

In the following table, the concepts of the street network and travel behaviour are subdivided into several variables. For each indicator of measurement, the correspondent units of analysis are listed, which then will be used for the research strategy and data collection methods.

Table 1: Operationalization of Variables

Theory / Concept	Variable	Definition	Indicators	Units of Measurement
Street Network: Embedded in space, providing areas with geometry like coordinates, lengths, areas, shapes and angles (Boeing, 2018). Also, are the most long-lived components of	**Connectivity** (Zhang, 2006; D'Sousa et al., 2006; Boeing, 2017; Larrañaga and Cybis, 2014; Ball, 2012; Matley et al., 2000)	Intersection density	Number of 4-way intersections	Quantity per square kilometre
			Number of 3-way intersections	
		Street density	Number of linear kilometres	Quantity per square kilometre
			Street Width	Meters
			Street Length	Meters

urban form and can stay for decades (Sharifi, 2019)	**Physical characteristics of Streets** (Haybatollahi, 2015; Sharifi, 2019; Cao, Mokhtarian and Handy, 2007).	Features and specifications of streets	Type of pavement	• Asphalt • Blocks • Concrete
			Pavement conditions	• Pothole • Crack • Rutting
Travel Behaviour: Set of human choices on performing activities that require moving from one place to another, such as getting to work, school, shopping and leisure places (Bartosiewicz and Pielesiak, 2019)	**Departure Time Choice** (Chaichannawatik et al. 2019; Mahmassani and Chang, 1986)	Preferred time to start the trip	Time / Peak periods	• Before peak period • Peak period • After peak period
	Modal Choice (Badland, 2008; Guerra, 2018; Yang, et al., 2018; JICA, 1999)	Modes used to get to their destination	Types and Number of modes used to get to their destination	• Walk • Car • Taxi • Bus / Microbus • Motorcycle • Bicycle • Moto taxi
	Trip Chaining (McGuckin and Murakami, 1999; Concas and DeSalvo, 2014; Frank, et al., 2008)	Types of trips made in between home and work	Visited Places	• Home • Work • School • Shopping • Leisure

Source: Author, 2019

3.3. Research Strategy

To address the questions of the present research, a survey methodology was conducted. Subsequently, quantitative and qualitative data was collected on people's travel behaviour influenced by the street network of the neighbourhoods along the Masaya highway.

The survey strategy was considered to be adequate for this research since it is an efficient way to collect new data that can be generalized and statistically analysed, subsequently adding external validity to the results and findings. Another benefit of the survey is that it includes several variables and many units of study, reaching a large number of people. It is also useful when it is necessary to explore or describe residents' attitudes (Van Thiel, 2014).

Different researches mix qualitative and quantitative information applied to travel behaviour (Mars et al., 2016). Qualitative methods applied to travel behaviour focus on the specific understandings of individuals, and then to explain the relation of the findings of quantitative methods, so it is usual to use both methodologies at the same time.

In this empirical research, the quantitative data was collected through questionnaires and open sources of geographic information systems, while the qualitative data was collected through semi-structured interviews. Therefore, the area of study along the Masaya highway was delimited, and each of the neighbourhoods to analyse were identified.

Several steps made part of the design of the survey strategy conducted for this research. First, it was through a spatial analysis that the street network characteristics of the delimited area were recognized and examined. Quantitative data was equally obtained to describe some of the spatial attributes of streets, like the connectivity and physical conditions of streets. With GIS, it was also possible to locate and delimitate the areas of study, the location of bus stops and the approximate location of participants homes of the questionnaire geographically. Since GIS was used in certain aspects, the triangulation of information according to the spatial information of the area and people's travel behaviour information obtained in the questionnaires was expected to be possible.

Secondly, the qualitative characteristics of the street network and how it developed through the years was addressed with semi-structured interviews with selected professionals that have worked in urban development, transport and planning. The interview's questions were based on the variables operationalization, as well as related to the research problem statement. The semi-structured interviews were useful to collect information that has not been found in literature from Managua's street network. Through open-ended questions was expected to get information about the development of the street network, concerning the residential areas and the mobility context in Managua. With this type of questions, the interviewees could develop more on their knowledge that supports the findings from the questionnaire and the spatial analyses.

Additionally, the influence of the street network on travel behaviour among the residents of the area was investigated through a questionnaire, which is the main focus of the research. The responses from the questionnaires were according to the indicators and units of analysis from the operationalization table. With the questionnaire, travel behaviour was measured through a series of questions on trip chaining, preferred departure time choice, and modal choice related. Also, questions on the perception of the street network are included, and with the home's approximate location of respondents, the answers provided could be confirmed according to the spatial analyses carried out.

3.4. Data Collection

Different data collection methods were used to gather the information necessary to undertake the research question. In this case, the methods were built from the operationalization table, contemplating the indicators of study and units of analysis.

With the inclusion of GIS software in the methodology, it could be possible to confirm some trends of travel behaviour could have taken place after the analysis of quantitative and qualitative data. It was possible trough ArcGIS Pro the preparation of the data set for the spatial analysis.

Part of the information necessary to describe how is the street network to access to Masaya Highway was downloaded from an open-source software such as Open Street Maps. In studies addressing street networks, the use of GIS software's was implemented for characterizing the street network on various indicators (Sreelekha et al., 2016). For example, Moeinaddini et al. (2016), used Open Street Maps to convert the street network into polygons and nodes. With the information collected with Open Street Map, a spatial analysis of the street network was possible with the tool ArcGIS Pro. From the GIS open sources consulted were obtained the lines of the streets, the points of the bus stops, the delimitation of the neighbourhoods and the delimitation of Managua's districts.

To explain the influence of street network's indicators on travel behaviour among the residents along the Masaya Highway, quantitative new data was necessary and is collected through the questionnaires, which were planned to be carried out at resident's home and online. The collection of mixed questionnaires methodologies was proposed because online questionnaires save time and effort, whereas face-to-face questionnaires also allow the social connection with respondents and observation of the area. With the information collected, statistical analyses were elaborated to analyse the correlation between dependent and independent variables.

In the questionnaire, personal characteristics of the correspondents such as vehicle ownership, driver's license ownership and occupation were suggested as control variables. These personal characteristics might influence people's behaviour and be used to limit the variable's potential in affecting the results.

At the same time, semi-structured interviews contained a series of open-ended questions that could adapt to different professional profiles, where the respondent have worked in the subjects of study in public and private entities. The people chosen for the interview are urbanists, architects, civil engineers, residential and commercial developers as well as academics, and the selection of various profiles could enrich the responses since coming from different perspectives.

The operationalization of the interview's questions was conceived from the necessity to explain the development in the area and what regulation plans have supported it. Also, some relation between street network concepts and travel behaviour were expected to be associated, and the perception of experts to be further explained. The semi-structured interviews are the leading qualitative approach of this research and are valuable to provide a global and general vision of the characterization of the street network situation in the area. Therefore, they make part of the qualitative data collected necessary to support the quantitative findings of the spatial analysis and the questionnaires.

3.4.1. Delimitation of the Area: Sample Size and Selection

Based on different investigations on the street network and travel behaviour, this research contemplates the selection of four different areas along the highway to Masaya to stratify the sample of the questionnaires, so travel behaviour can be compared later with the spatial information from GIS.

In the study carried by Larragaña and Cybis (2014) in Porto Alegre, four neighbourhoods were selected considering their connectivity, similar characteristics along with pairs, elegance, the income of households and percentages of walking trips. Similarly, Pan et al. (2008) carried their investigation into four representative neighbourhoods in Shanghai with different periods during which they were developed. They also considered other characteristics like residential style, distance to the central business district and density. Another study in the San Francisco Bay Area (Schwanen, 2005), considered three communities with different spatial layout and structure to relate the urban form and travel behaviour. These areas presented characteristics according to their density, street pattern, public transport service, street connectivity and land-use mix.

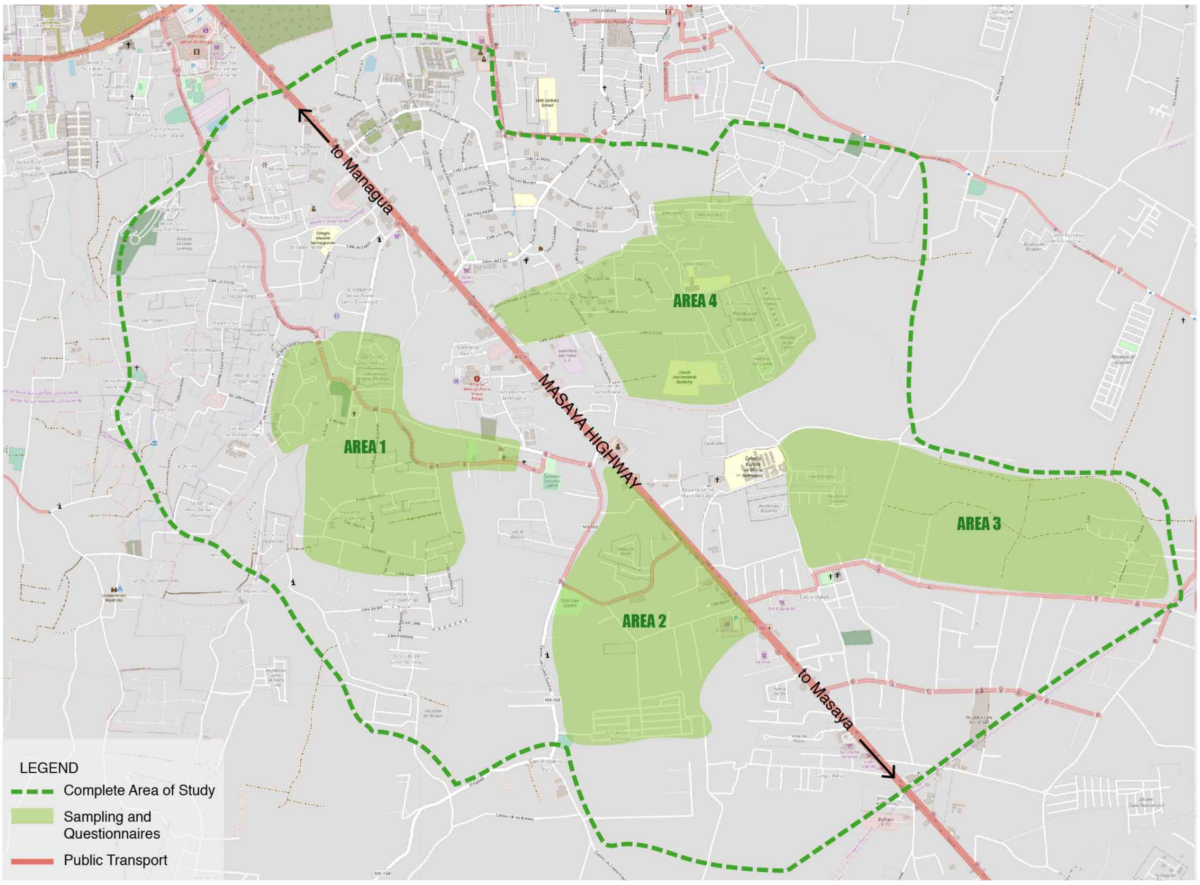
To summarize, the selection of the four areas of the present study contemplates their connectivity, density, access to public transport, neighbourhood design, time period development, closeness to the Masaya highway and household incomes. From the west side of the highway, two areas were selected and are detailed next.

The first area contemplates: Estancia Santo Domingo, Las Sierritas, Altos de Santo Domingo and Universidad Católica. This is a low-density area with high to low-income households, developed during the '80s and '90s, so lots are bigger compared to the other areas. This first area has provision of public urban transport stops, as well as a private university close by and some commercial spaces.

Further south is Area #2, and the residentials selected are Xochitlán, Portales de Coimbra, Paseo del Prado, from PriceSmart to Hotel Contempo. Some of the neighbourhoods selected for this Area #2 have a direct connection to the Masaya highway, as well as provision of public urban transport stops and other types of transport like mototaxis. This is mostly a residential area with gated residential developments of medium and high-income households and also single lots of low income. There are as well commercial and industrial zones within the area that are next to the Masaya Highway.

From the east side of the Masaya highway, other two areas were selected. The third area contemplates the neighbourhood Esquipulas, also considering the residentials Alamedas de Esquipulas and Ermita de Esquipulas. In this selected area, there is no public urban transport provision and less street density. There are also empty lots among the area that are considered as rural areas. This area also contemplates gated residential communities of medium and high-income classes that started to develop in the 2000s. Closer to the urban core of Esquipulas, there are medium and low-income small houses scattered.

Figure 2: Delimitation of areas for sampling



Source: Author, 2019

For Area #4, the southeast area of neighbourhood Las Colinas Sur was selected, from its third entrance from the Masaya Highway, up to the residentials Terracota, Frascati, Portales de las Colinas and Alamedas de las Colinas. This neighbourhood is known for its cul-de-sacs and irregular street grid, developed at the end of the ’90s until the last present years. There is no provision of public urban transport stops within this area. Households are from low to high-medium income, and a part of them are located in residential developments with two-story houses.

In Nicaragua, a population census has not been conducted since 2005; therefore, a satellite calculation of households had to be made to determine the total population of the four areas selected, resulting in 2,010 households. According to the Central Bank of Nicaragua (2017), there are 4.5 habitants per household in the city of Managua, which means that the total population of the four areas selected is 10,405 habitants. For the calculation of the sampling, the confidence level considered was 95% with a margin of error of 8%, using the following statistical formula:

$$\text{Necessary Sample Size} = (\text{Z-score})^2 * \text{StdDev} * (1-\text{StdDev}) / (\text{margin of error})^2$$

The proposed sample size to conduct the questionnaires was of 150 residents total in the four areas, distributed proportionally according to the habitants per area. The following table details the distribution of the questionnaires among the four areas selected: Area 1 is comprised by 23% of the population, for that only 35 questionnaires were planned to be conducted; Area 2 is comprised by 32%, which means 49 questionnaires were expected to be responded; Area 3 is only 15% of the population, so 23 questionnaires were planned to be filled in; and finally, Area 4 is comprised by 29% of the population, meaning that 44 questionnaires were going to be conducted.

Table 2: Sample Size Calculation

	Population Calculation	Population Percentages	Number of Expected Responses	Number of Final Questionnaires
Area 1	2,399	23%	35	36
Area 2	3,366	32%	49	40
Area 3	1,580	15%	23	23
Area 4	3,060	29%	44	52
TOTAL	**10,405**	**100%**	**150**	**151**

Source: Author, 2019

As shown in Table 2, the final number of conducted questionnaires was of 151, and was only in Area 2 that difficulties were presented, so the expected responses were not achieved. This will be further explained in Chapter 4.

3.5. Validity and Reliability

For the methodology, several processes mentioned add value and validity to the research. The triangulation of information was done by using different methods to collect data that will support the mixed findings in the study. Triangulation is possible when the data is collected through different perspectives.

Even though the information gathered with Open Street Map and the semi-structured interviews are not part of the primary research approach, it supports the findings related to travel behaviour from the questionnaires. Because the use of a GIS software helps to identify the different results between the selected areas, it was used for triangulation. For example, different spatial analyses were conducted to confirm the results from the questionnaires.

Before gathering the official data with the questionnaires and the semi-structured interviews, a pilot study was planned to ensure that the instruments were correctly understood to the respondents. For the pilot study, ten residents of the Masaya highway were asked to fill in the questionnaire and share their comments and doubts before doing fieldwork and gather the official data.

Moreover, to elevate the respondence rate of the questionnaire, these were planned to be completed face-to-face at people's homes. Additionally, the same questionnaires were shared online to reach to more residents in a more effective manner.

This research contemplates semi-structured interviews, which are a flexible method and essential information can be obtained through them. The respondents in this study are involved in the research topics in different manners, so it will be possible to receive information from different perspectives to make the findings on the street network more substantial.

3.5.1. Limitations of Research Design

In every research study, some limitations might appear during the data collection process that could interfere in the validity and reliability methods. As for the quantitative information of this research, some of the limitations are non-response from the respondents of the questionnaire. Also, entry restriction in gated communities is possible due to the security rules of these residentials, limiting the data collection.

The structure and type of questions of the questionnaires is also a limitation when performing the statistical analyses. Having more diversity of variables allows more inferential analyses to be performed that would provide different information and relations among the dependents and independent variables in the study.

As for the interviews, limitations are that the selected people to interview would not be able or willing to respond to the questions in place. To the extent possible, attempts were made to resolve the problems presented during the data collection process, which will be explained in Chapter 4.

3.6. Data Analysis Techniques

This section explains how the information collected was manipulated and processed, so the objective of this research could be achieved and answer the questions that demonstrate the influence of the street network in travel behaviour.

The information obtained from Open Street Maps allowed performing spatial analysis with the software ArcGIS Pro. It was expected from this process to gather information about the street network variables, like connectivity, street density, intersection density, proximity to bus stops, so that they could be related to the travel attitudes of residents obtained from the questionnaires.

The following steps were proposed for the use of ArcGIS Pro:

- First, the road network map was obtained from Open Street Maps and converted into an ESRI shapefile format to add it into ArcGIS Pro.
- Then, a layer was created with only the streets of the delimited area. This included the neighbourhoods' administrative delimitation from the municipality.
- Once all the needed elements were collected and organised, the Network Analysis properties were set to perform the required analysis and present the results.

With the layer obtained from Open Street Map containing the street network polylines, the number of 4-way and 3-way intersections per square kilometre was planned to be calculated with the junction tool in ArcMap. Also, a Line Density analysis was carried out with ArcGIS

Pro to calculate the street density per area. In addition, ArcGIS Pro can generate maps presenting the street network's physical characteristics.

During the completion of the questionnaires, it was planned to get the approximate point location of respondents, so a Proximity Analysis to different locations like Masaya Highway and public transport stops is conducted. The proximity analysis could be useful to confirm the information gathered in the questionnaires.

The quantitative data collected from the questionnaires was planned to be evaluated with statistical analyses like descriptive and inferential analysis, and the tool proposed for this type of analysis is SPSS. Since most of the variables of the questionnaire are categorical, nominal and numerical, it could be possible to run Chi-Square test, One-Way ANOVA test and T-Test to determine the relation between street network characteristics and travel behaviour subjects.

For the semi-structured interview, an interview report can synthesise the information for it to be analysed to understand the development trends of the Masaya Highway area. For this, it was expected to transcript all the data obtained, so the codification of the information could be done through a comparative table that categorised the information (Gibbs, 2012). The categorisation and codification of the information were prepared according to the operationalisation variables previously mentioned in this chapter, as well as the research questions pretended to be partially answered with the interviews. The data from the interviews are of high value, and it was expected to be analysed personally carefully.

Chapter 4: Research Findings

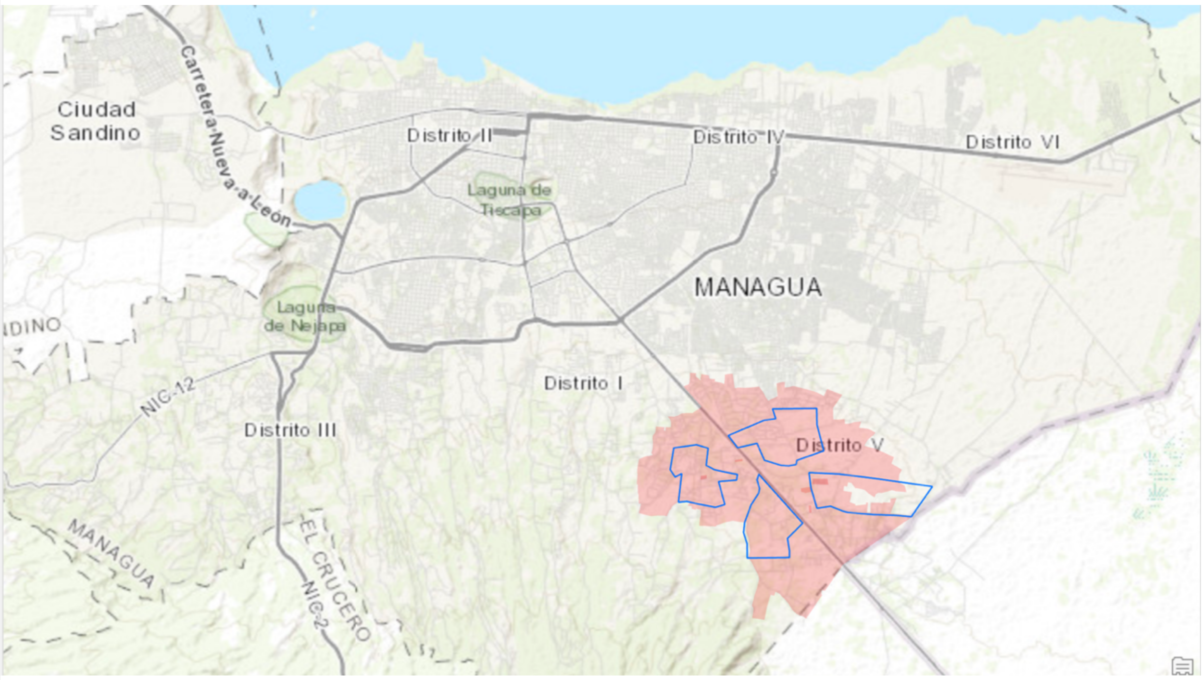
4.1. Data Collection Process

The data collection process was carried out in Managua, where for four weeks, the instruments designed helped performing the necessary interviews with urban experts, and the questionnaires to residents. Also, the collection of the required geographical information was carried out.

As described in the methodology, the qualitative data was collected through interviews and as this advanced, it was noticed the necessity to connect with more urban planners and architects that had studied the urban development of the city in depth. This change occurs because respondents with alike profiles began to provide similar responses. In addition, it was preferred to prioritize interviews with those who had more experience as urban planners, since their responses were more rich in content. Finally, the information was gathered from 3 architects, three urban planners, one housing developer and one transport engineer. Each of them worked in different fields for private companies and public entities, which allowed the interviews and information to be broad enough and provide different perspectives. The meetings were carried in the interviewees' offices, so the logistic was easier, and they could be more comfortable.

During the collection of the quantitative data some difficulties appeared. The process of collecting questionnaires data was more difficult than expected since in two of the four areas, residents were not available or willing to respond. Because of that, 40% of the questionnaires were carried personally, the other 60% of the questionnaires were completed online. The online option made possible to complete the questionnaires on time, besides making the process faster.

Figure 3: City of Managua and Delimitation of the Area of Study



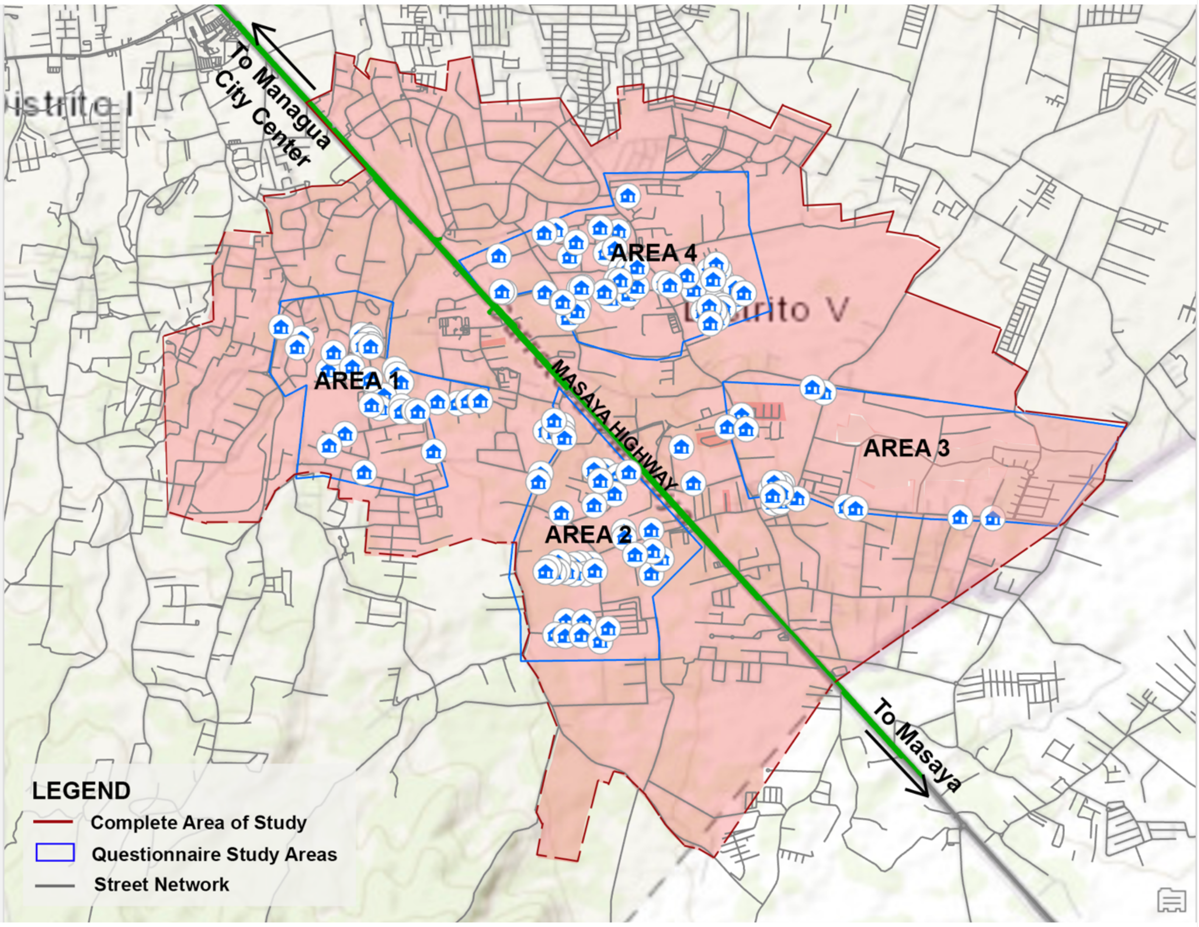
Source: Author, 2019

As for the data collected for the geographical analysis, one part was collected from an open-source Nicaraguan website, which base is Open Street Maps. The information retrieved were the street network lines, location points of public transport stops, and the polygons of the city's districts limits. The rest of the information was given by the Nicaraguan Institute of Territorial Studies, which was the delimitation of the area's neighbourhoods. Moreover, during the process of the surveys, the approximate location of respondents' residencies was tracked and added into the ArcGIS data set.

During the research, the privacy of the respondents of questionnaires was respected. For the online questionnaires, they would give the name of the neighbourhood or gated community where they live, but not the house number, so the location is not precise. An approximate of homes locations was reflected in the maps to protect their identity.

In Figure 3, the delimitation and context of the selected area of study is presented geographically in the city. In Figure 4, the location points of the homes of the respondents of the questionnaires is showed, as well as the street network lines and the Masaya Highway as the main road.

Figure 4: Delimitation of Area of Study and Home Locations of Respondents



Source: Author, 2019

4.2. Data Preparation

A process to organise the information collected was performed to achieve a more comprehensive analysis of all the collected data, as well as the new aspects that were not raised.

Before analysing the qualitative data, the interviews had to be transcribed into a document. When all eight interviews were transcribed, came the identification of passages of text that exemplified the same theoretical or descriptive ideas. The passages were selected according to the research questions that needed to be answered in this research.

A comparative table was prepared to organise the information of the interviews. The comparative table was structured according to the questions of the interviews and the main ideas of each respondent. This practice allowed a more precise analysis for each of the responses and research questions that the study pretends to answer.

For the questionnaires, the online software “Qualtrics” allowed an achievable collection of the data so it could be easily organised and managed before exporting into an SPSS file. In SPSS, new variables were created, since some of the questionnaire’s responses had to be classified into new range categories. It is essential to mention that since 60% of the questionnaires were completed online, some questions were asked twice, but in different ways, to crosscheck during data preparation and adjust according to necessary.

As mentioned before, the data set for the GIS analysis contained the street network lines, the polygons of the four study areas, the polygons of neighbourhoods within the Masaya Highway area of study, and the points of the public transport stops. For the necessary comparison among the four areas of study, some information had to be divided according to the location to analyse.

For further clarification of the triangulation process, the results of the spatial analysis from ArcGIS and the statistical analyses are related and compared through an analytical process with bases from the literature concepts.

4.3. Limitations

One of the difficulties when doing the questionnaires was accessing people’s home. Since most of the new housing developments are gated communities, the entrance was limited, and it made it difficult to carry the questionnaires face to face.

Moreover, during the survey process was noticed the necessity for a more significant sample for each of the areas of study, because having more responses would allow carrying more inferential analysis and better results.

It is also relevant to mention that since April 2018, the country has been going through a socio-economic crisis provoked by confrontations in the Nicaraguan political scene. This has led to thousands of mass dismissals in the public and private sector, inducing to a possible change in people’s travel behaviour compared to before the crisis.

Even when difficulties and limitations appeared, methodological solutions scientifically supported where presented, to achieve the objectives of the study.

4.4. Qualitative Findings from Interviews

In the following section, the qualitative findings collected from the semi-structured interviews are presented. The interviews that form the basis of the findings are mostly those from urban planners and architects that have worked in public entities, since from their knowledge the causes and explanation of Masaya Highway’s problems are justified.

4.3.1. Development of the Street Network along Masaya Highway Area

The following section provides information about the development of the Masaya Highway area in the last decades. When describing the development of the study area, the questions to interviewees looked for descriptions of the area's street network.

Interviewees explained the potential influence of the housing development process of the study area in the street network characteristics of the neighbourhoods. For them, the process is one factor that has shaped the streets, along with the governance actions of the government. This is explained next.

Urban Development along the Masaya Highway Area

For Emma Grun, architect and urban planner, urban planning in Managua started in the 1950s, by following the tendencies of the market and land availability. Since the city developed informally, the plans had to adapt to the rapid urbanization without previous planning.

In the interview with Gerald Pentzke, a former urban planner in the Urbanism Office of the Municipality of Managua, he mentions that the growing development of the Masaya Highway Area was supported by the "Partial Urban Development Plans" (2000) of the Regulator Plan of Managua's Municipality (1982). According to Pentzke, "the plan aimed to answer the urbanization tendency in the southern area of the city, by trying to regulate it in terms of land use", since it was a sub-urban area without the proper infrastructure to support the rapid growth.

Researcher architect and urban planner Néstor López explains that the public investment, as well as the new businesses and services networks that have developed in the area have generated "sub-centres" along the Masaya highway, which allows new residential areas to stock up.

Even if there are plans to regulate rapid urbanization, for another of the interviewees, if there is no political decision, the policies and laws are useless.

It is clear the lack of regulation and guidance from the municipality and governmental institutions, which act only when there is a necessity to solve urgent problems. This might be happening because of the lack of planning and objective prevision.

Connectivity and Physical Characteristics of the Street Network connecting to Masaya Highway

Auxiliadora Reyes, former urban planner and architect that worked at the municipality, clarifies just as Pentzke, that the street network of the area still has the characteristics of a semi-rural network, with irregular streets without pedestrian sidewalks. The current paved roads were trails of a sub-urban area, but now are supporting more traffic in the same structure. For Romer Altamirano, architect and urban planner, the streets have remained the same from decades ago, even if now there is more pressure by individual vehicles. As they explain, the streets are not designed to withstand all the types of vehicles that circulate in them.

Roger Valerio, a developer architect, explains that there is no connectivity in between the predominant gated residentials of the area. For him, the only main artery in the network is the Masaya Highway. Architects and urban planners agree with the idea that the lack of connectivity and the appropriate hierarchy of the roads has pushed the residents to come together on the same road.

Emma Grun, explains that the Masaya Highway has been used as a collector to an urban scale that does not match, generating interruptions in what should be a high-speed road. Also, these residential areas are what was once the perimeter of the city, meaning that still has the infrastructure designated for peripheral areas, like antennas and extensive electrical wiring. Moreover, she mentions the incompatibility of land use as a connectivity problem, making the street network of the area inefficient. She also explains that poor connectivity and design does not allow a proper course of public transport.

For Altamirano, there should be an integral solution to the street network's problems. In addition to that statement, Pentzke believes that "administrative decisions could significantly improve the efficiency of the road network instead of the large capital investment of expanding" the Masaya Highway, which is what the government has done the last two decades.

The street network of the area of study has semi-rural characteristics that have not been changed or improved, where the land use incompatibility also adds to the problem. Since there is no prevision of the city's growth, solving the street's connectivity and physical characteristics is disregarded.

Local Government Responsibilities

There are also co-responsibilities in the regulating entities that, according to several of the interviewees should be addressed more efficiently. The local government does not have the capacity to articulate urban planning with the street network, and there is no response with an adequate technical criterion, Grun states. For her, this is more a problem of governance, because Managua's municipality has tried to make the private sector responsible for the carload generated in the streets of the city. The municipality's efforts have not been enough, and there are no shared responsibilities in the construction of the city.

For Fernando Martínez, former minister of Infrastructure and Transport, there is lack of coordination between the municipality and the entity responsible for the street network. Another urban and housing developer, Gerardo Hernández, stated that the local government is not politically responsible and transparent in their administration.

In conclusion, the local government is responsible for coordinating obligations among developers, architects and urbanists when projects are bid. The lack of regulation and transparency from the governments makes it difficult for the proper development of the area.

4.3.2. Transport and travel preferences among residents from Masaya Highway Area

During the interviews, questions related to travel and transport preferences of the residents in the area were introduced, compared to the accessibility to urban transport. Next, the accessibility to public transportation, the description of residential models and the perception of travel preferences among the residents of the area are explained by the interviewees.

From the interviews, a relation between the residential models of the area with access to public transport and travel preferences of residents was confirmed. Again, how the area has been developing has influenced the preference of using private vehicles, also supported by the lack of accessibility to proper urban public transport. In detail, this is explained in the following section.

Accessibility to Public Transport

As mentioned in the problem statement in Chapter 1, there are several mobility problems in the city that people are facing every day, like high traffic volume, adverse conditions of sidewalks, lack of parking spaces, insufficient vial signal, and issues at the bus stops. Sadly, the delimited area of study is not an exception.

For López, the public transport of the area is of poor quality and with an insufficient connectivity logic. Only those who are from the local communities use it, while the new resident does not use the inter-urban public transport.

Pentzke explains that the inter-urban bus routes have existed for a long time but have not transformed into urban routes even if the characteristics of the area are now urban. Before, the routes of the area used the county trails, which are now paved streets.

"People does not have many choices, there is no sufficient offer of public transport", says Reyes, while Pentzke clarifies that when people chose this area to live, their transportation was going to be solved later. With reduced access to public transport, comes the excessive use of private cars, about which Grun explains the lack of discouraging for the use of private vehicles, that should go along with the improvement of the urban public transport.

As long as there is no public transport adequate to the conditions of the road network, and there is no disincentive to the use of the vehicle, residents of the area will consider the use of a private vehicle to be mobilized as their first option.

Residential Models of the Area

Altamirano says that residential models proposed in the area stimulate the use of private vehicles, first because of the "socio-economic characteristics these are targeting, and secondly because all of the houses offer a garage space".

López thinks it is more about where these residentials are located. Since most of the residential communities are not connected to a continuous urban grid, they behave like some urban islands and residential enclaves homogeneous at the internal but heterogeneous concerning their immediate context. Reyes also comments that the shape of the urbanizations further complicates the public transport routes. As mentioned in the Literature Review, the design on transport networks can contain the use of private cars when there is an accessible and quality public transport service, which in the case of the area the service is miserable and inconvenient.

Grun explains that the residential models are segregating designs that further define the socio-spatial division that already exists in the area. For her, the residential buildings were built to provide a housing solution without any integration with the urban context where they were built.

Hernández, who is an urban housing developer, states that there is no previous planning from the government and municipal entities when new residential areas appear. Local entities should be regulating the developments and providing guidelines to private investors.

The fact that the residential models of the area do not contemplate the context where they are built complicates the connectivity among neighbourhoods and streets for all road users.

Travel Preferences among Residents influenced by the Street Network

When trying to identify the influence of the street network on the travel preferences of residents, interviewees had different perspectives on the issue. First, López explains how he, as a resident of the area, has to adapt to the congestion situation in the Masaya Highway. As he explained, people take advantage of the services provided along the highway to do errands before and after work every day.

For Altamirano, the everyday dynamic is what influences people's travel behaviour. Residents have to organize themselves to confront a scenario where the streets and routes are saturated. However, for Reyes, the streets of the area are designed only for vehicles, without pedestrian sidewalks and an irregular pattern that makes distances longer.

"If the neighbourhood where a person lives is provisioned with pedestrian infrastructure, the mobility habits of the person are influenced and different from where there is no adequate infrastructure for pedestrians", architect Valerio says. This statement can be supported with some studies from Cao et al. (2007) that differences among the neighbourhood's characteristics and streets design influence changes in residents' travel behaviour.

4.5. Quantitative Findings from Questionnaires and GIS

In the following section, analyses from the quantitative findings are presented. First, some general information gathered from the street network and travel behaviour of residents is described using descriptive statistical analysis.

Also, for a more in-depth analysis, statistical inferential analyses are carried out. Since the questionnaire has numerical and categorical variables, a different type of analysis could be performed. For the categorical variables, Chi-Square is performed. When one numerical variable and one nominal variable of 2 categories need to be compared, the T-Test is implemented. Finally, One Way ANOVA and Kruskal Wallis were carried out between a nominal variable of more than three categories, and a numerical variable to compare averages among groups.

At the beginning of the questionnaire, it was asked to residents if in their daily trips they passed by the Masaya Highway every day, and 98% of the respondents answered positively, confirming the importance of the Masaya Highway connection to Managua's city centre and other cities.

According to the questionnaire's sample size calculation per area per population, 151 questionnaires were conducted, divided among the four areas the following way:

Chart 1: Percentages of respondents per area

Source: Author, 2019

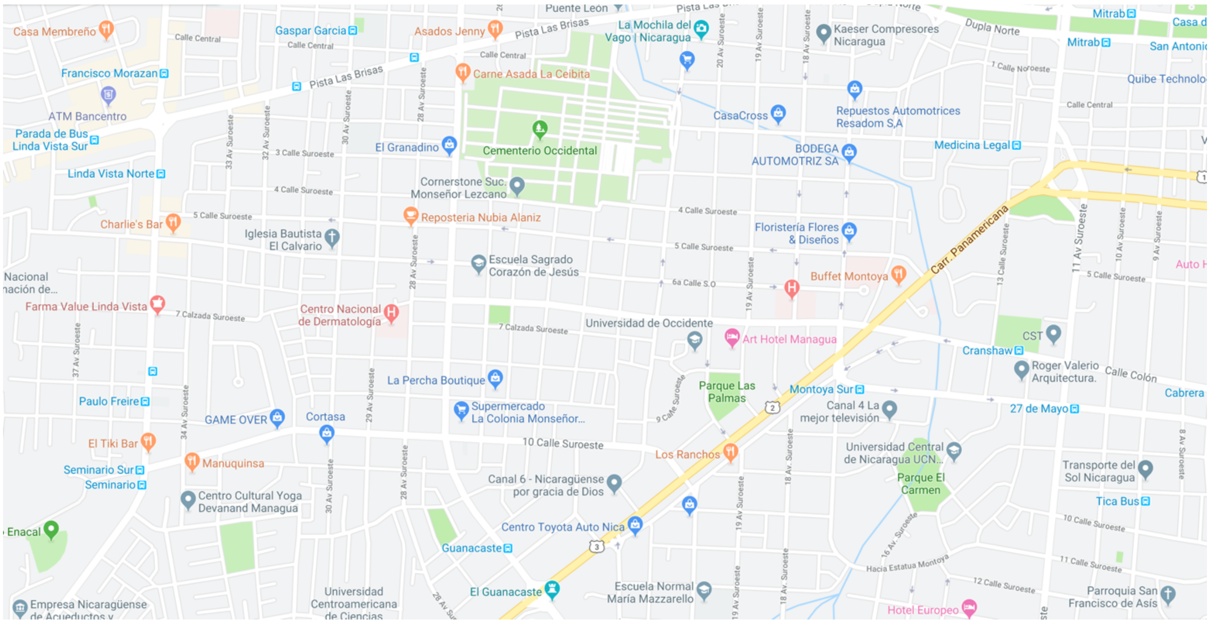
To describe the population, it is essential to mention that 75% of the respondents have some motorized vehicle in their homes. Another 10% have a non-motorized mode of transport, while 15% of the respondents do not own any mode of transport, who rely on the inter-urban public transport, taxis and mototaxis. It is of relevance to mention that 71% own at least one type of driver's license.

4.4.1. Street Network of the Complete Area of Study

With the questionnaire results and ArcGIS analyses, the following section aims to describe the street network characteristics like the street network physical conditions and connectivity. Using descriptive analysis and maps, results are presented next.

Before presenting the findings and maps of the area of study, it is relevant to show some context of the urban form and street network of the city of Managua. In Photograph 1, the old neighbourhood "Monseñor Lezcano" is shown. This neighbourhood has a reticular urban grid, provision of public transport all around, urban infrastructure, decent pavement conditions, sidewalks, good street connectivity and a logical hierarchy of streets. According to the interviewees, Monseñor Lezcano is a good example of how the whole city should be structured.

Photograph 1: Street Map of neighbourhoods near Managua's old city center



Source: Google Maps, 2019

Here are presented satellite photographs of each area of study. As explained before, the Masaya Highway area, between roundabouts Jean Paul Genie and Ticuantepe, is provided by housing developments in a region that was considered as rural several years ago, nonetheless is also equipped with commercial and some industrial developments.

Photograph 2: Satellite photograph Area 1

Source: Google Maps, 2019

Photograph 3: Satellite photograph Area 2

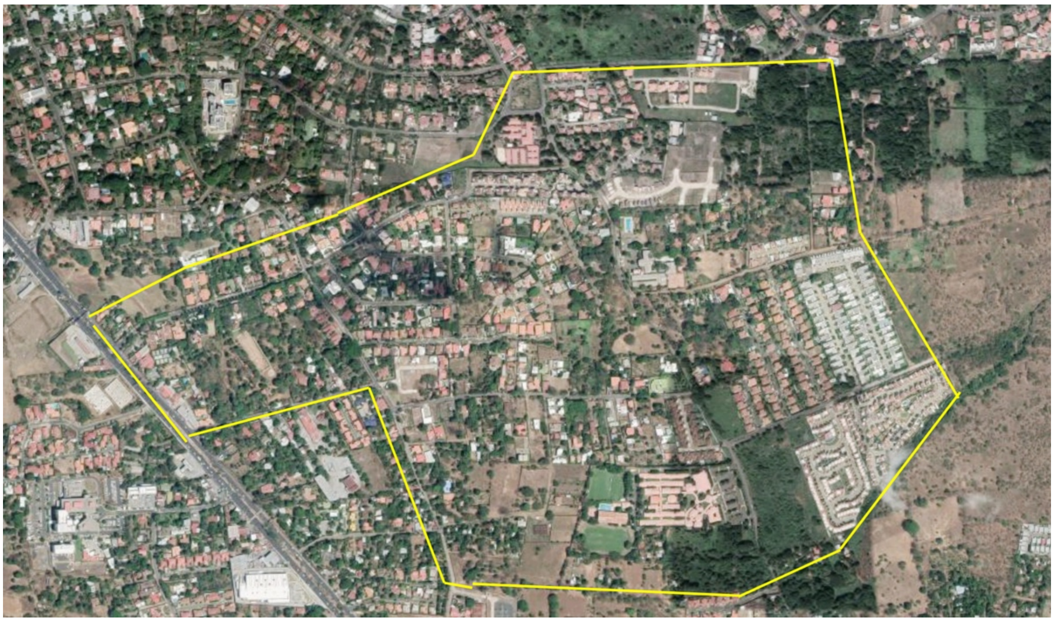
Source: Google Maps, 2019

It can be appreciated in the photographs the new gated communities that have been developed. Some residentials are denser than others, adding to the fact that there are still empty lots remaining in the surroundings. In Area 3, a rural community called Esquipulas, there is still land designated for agriculture, which has been converted into housing developments over the years.

Photograph 4: Satellite photograph Area 3

Source: Google Maps, 2019

Photograph 5: Satellite photograph Area 4



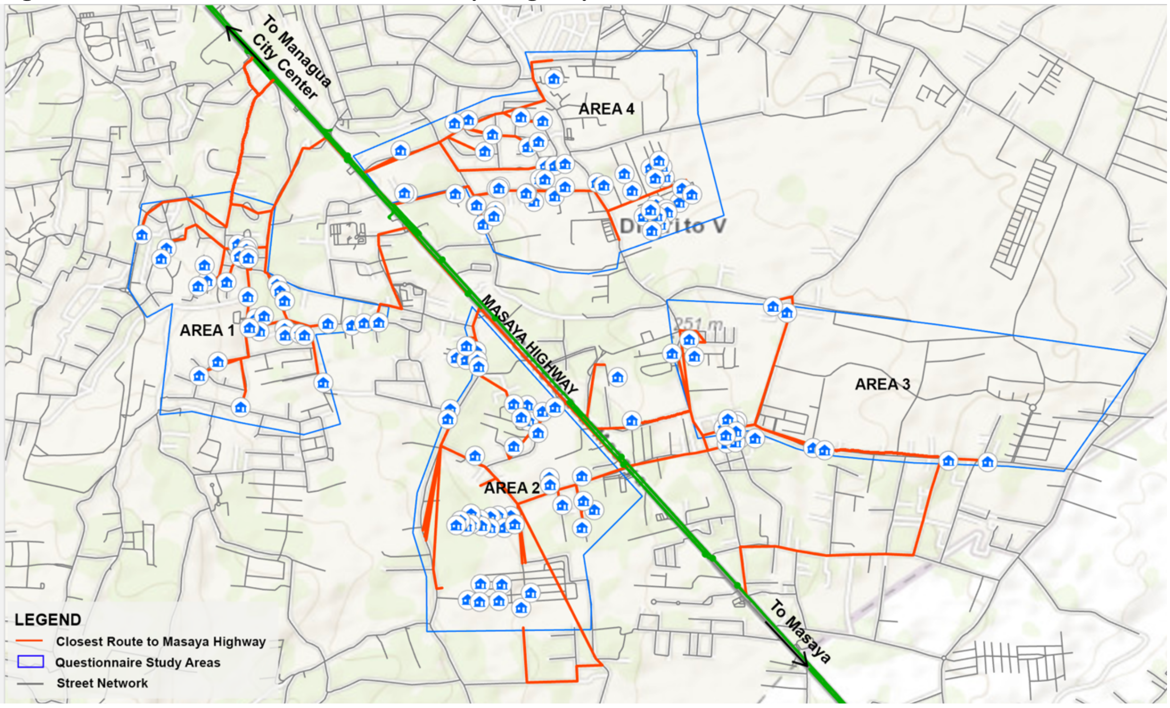
Source: Google Maps, 2019

Area 4, contemplates a part of neighbourhood “Las Colinas”, an area developed for housing in the 1980s with bigger lots in an organic street structure. The southeast region of the area has been developed in the last 15 years with closed gated communities in smaller lots. As architects and urban planners mentioned, this type of residential models do not allow the urban grid to connect, leaving “islands” of housing projects in the surroundings of the city.

Connectivity

In the Literature Review, it was pointed out that aspects like street connectivity and intersection density provide more routing options for users, besides that it shortens distances. In a question related to connectivity, 86% of respondents answered that they could take more than one route from their homes to "Masaya Highway". The following map (Figure 5) shows the shortest routes from their Homes to the Masaya Highway through a Network Analysis in ArcGIS Pro. In Area 1, Area 2 and Area 3, three direct routes lead to the main road. Whereas Area 4 presents only two direct routes to the Masaya Highway, converging all residents in the same streets.

Figure 5: Closest Routes from Homes to Masaya Highway

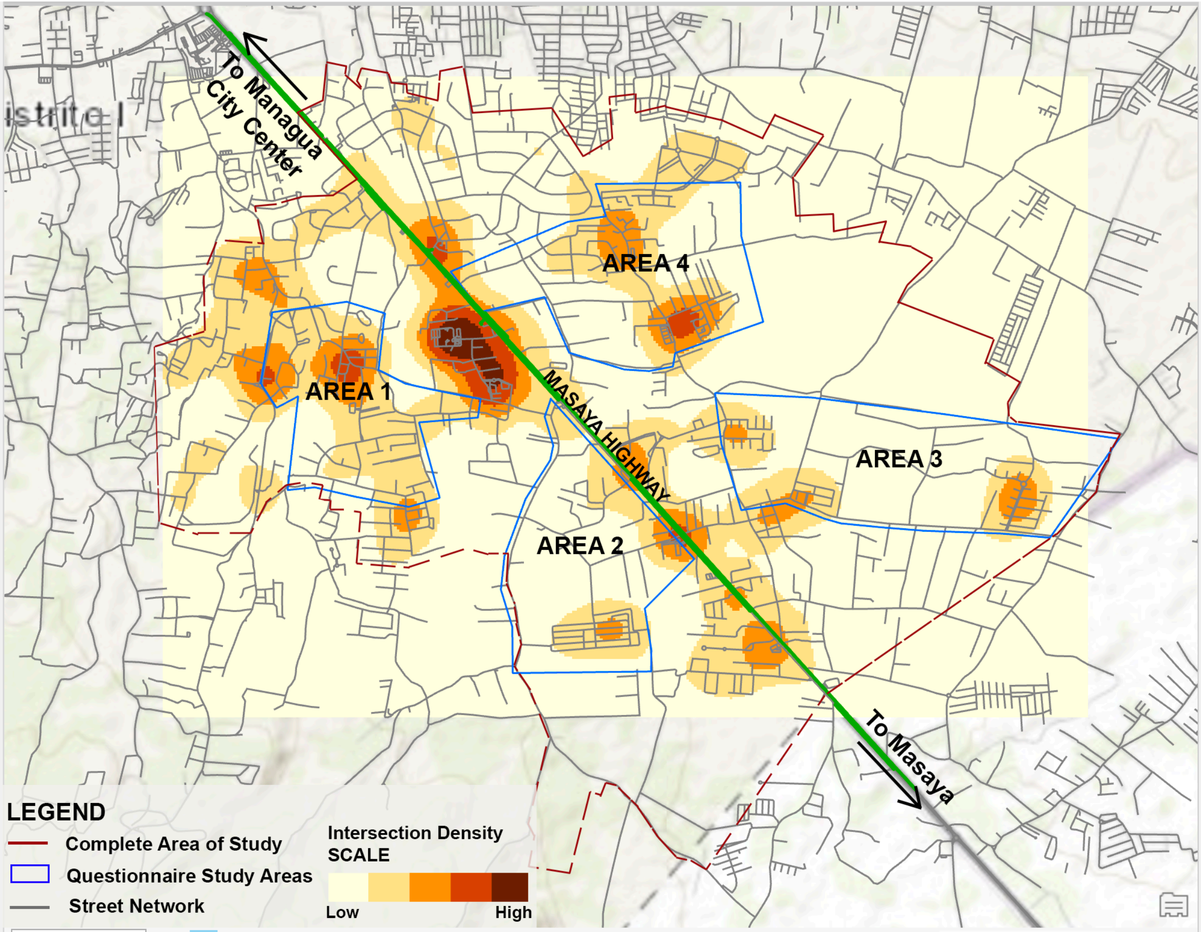


Source: Author, 2019

Using ArcGIS Pro, an intersection analysis in the delimited area of study was processed, so then with Kernel Analysis in Figure 6, an intersection density analysis was obtained. In the map, it can be observed that from the four areas of study, Area 1 and 4 have more intersections in their street network. These areas were one of the first sub-urban locations to developed residential communities many years ago.

Referencing the Literature Review, high connectivity of networks provides more options when moving from one point to another (Boeing, 2017). In Figure 6, it can also be perceived that the structure of the network is not regular, and grid-like road configurations offer more direct route choices and higher connectivity (Wang et al. 2014). The denser areas marked in colour red, are those residential communities with smaller lots, and most of them have cul-de-sacs. Area 3 and Area 2 are the least dense since there are still empty lots that have not been urbanized and developed.

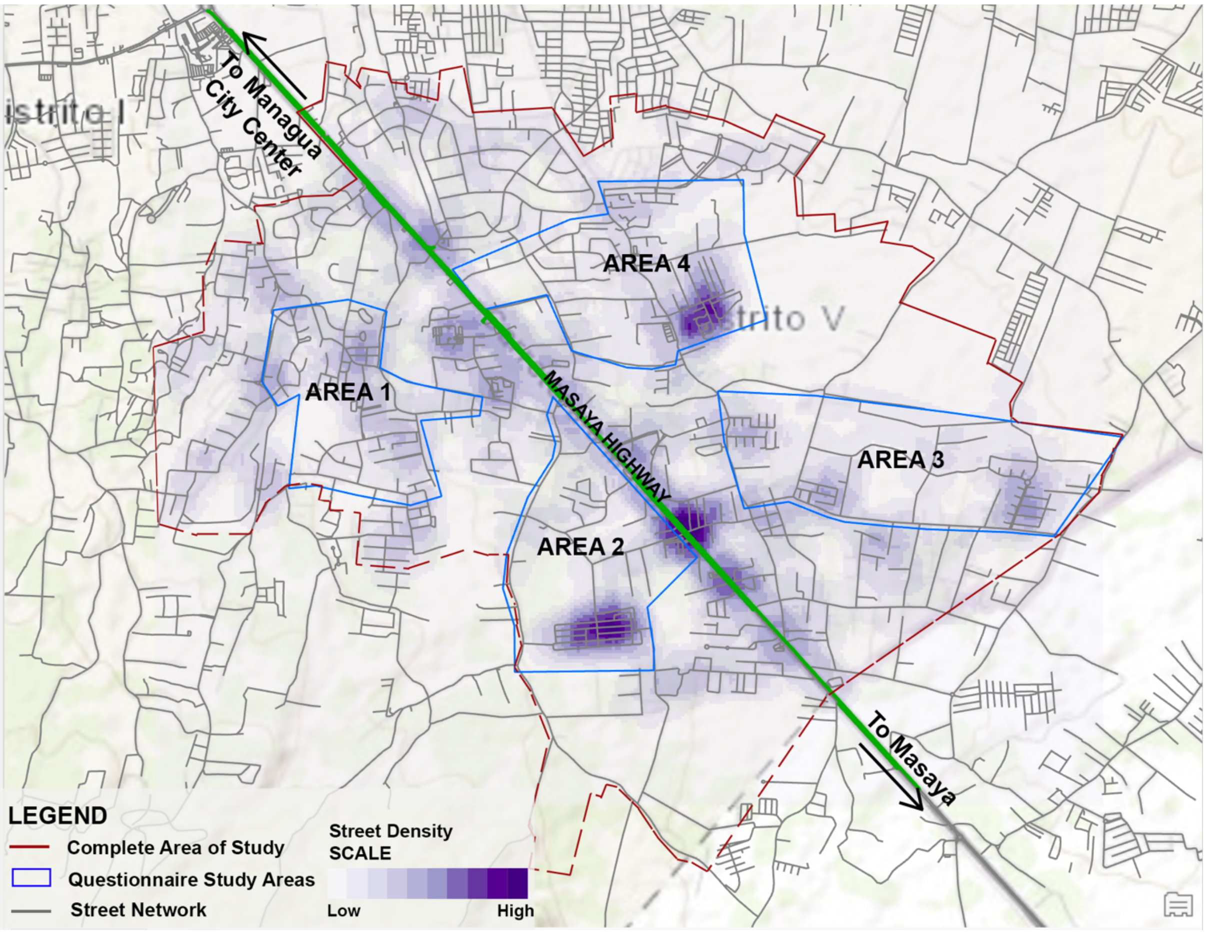
Figure 6: Kernel Analysis of Intersection Points



Source: Author, 2019

In the next Figure 7, the street density analysis carried for the Complete Area of Study shows the concentration of linear kilometres of street per square kilometre of area. Generally, the whole area is equally dense, with more concentration in Area 2, and Area 4. These specific zones of concentration are due to gated residential areas with more than 200 homes in small lots compared to the older residential areas in Area 1 and Area 4. Also, the highlight in Area 4 is due to new residential gated communities.

Figure 7: Street Density Analysis



Source: Author, 2019

In the following satellite photographs, the highest street density points of the Complete Area of Study are selected to show the dense housing developments that might explain the street density. Photograph 1 shows a large housing project of more than 700 one-story homes, whereas in Photograph 2 there is a combination of seven housing projects of one-story and two-story homes, but the residentials are not interconnected.

Photograph 6: Street dense zone in Area 2

Source: Google Maps, 2019

Photograph 7: Street dense zone in Area 4

Source: Google Maps, 2019

Photograph 3 shows the dense zone between Area 2 and Area 3. It can be assumed from the street network grid, that there are several closed residentials of one street which are not interconnected with the adjacent residential developments.

This is the typical case in the Masaya Highway area. For example, the interviewees explained that these residential communities are only solving the housing demand but are not designed to blend in the context of the area where they are built.

Photograph 8: Street dense zone between Area 2 and Area 3

Source: Google Maps, 2019

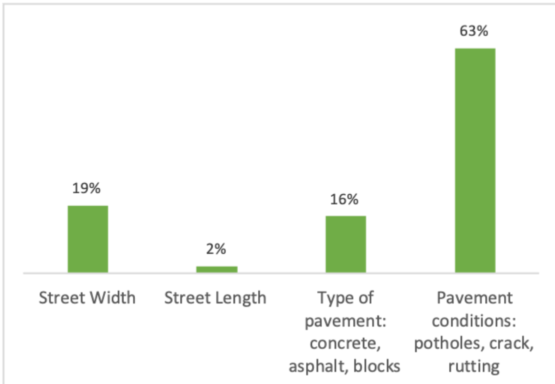
The areas of study better connected to the Masaya Highway are Area 1 and Area 2. Nevertheless, Area 1 and Area 4 have more intersections and street density. This situation can be explained since the neighbourhoods within these areas where what it was before the sub-urban zones of Managua, and as Reyes, Valerio and Pentzke mentioned in their interviews, that the communities of Las Colinas, Las Sierritas and Santo Domingo were the best neighbourhoods along the Masaya Highway.

Physical Characteristics of Streets

From the 66% respondents that confirmed that the street's physical characteristics influence their selection of a route to get to Masaya Highway, for 63% of them the main reason to change their route is the pavement conditions.

As for the street's general physical conditions to get from their Homes from Masaya Highway, 46% of residents responded that the conditions are "Fair" and 28% answered that they are "Good". During the questionnaire process, respondents would mention the lack of sidewalks, no stormwater system and poor conditions of the pavement, like potholes and rutting.

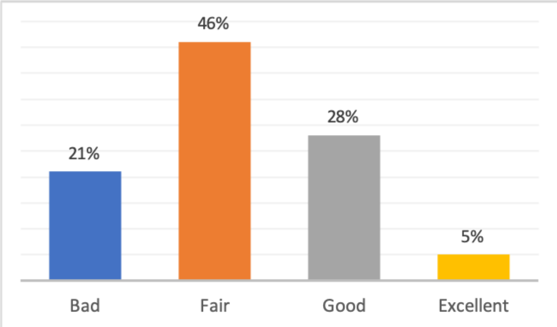
Chart 2: Street's physical conditions that influence route selection to the Masaya Highway



Source: Author, 2019

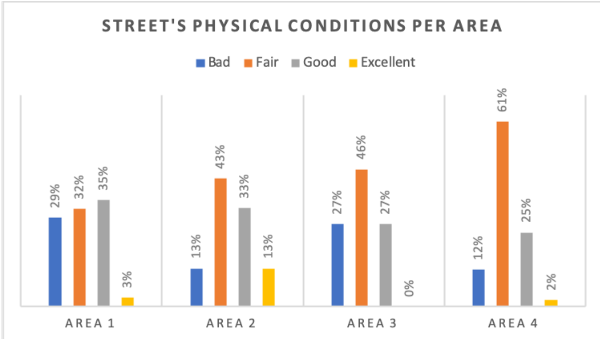
The physical conditions of streets are considered while travelling and depending on the zone where people lives, the relation is stronger. Chart 3 describes the street's physical conditions according to residents to give an overall perspective of the Complete Area of Study.

Chart 3: Physical condition of streets for the Complete area of Study



Source: Author, 2019

Chart 4: Street's physical conditions according to residents of the area



Source: Author, 2019

According to Chart 4, the area with better street's conditions is Area 2, with 46% of respondents considering them as "Good" and "Excellent". During fieldwork, it was observed that Area 2 has one direct route to Masaya Highway with concrete covering, which can be a determinant aspect to consider this as the area with better physical conditions of streets. The majority of people in Area 4 considers that the conditions of the streets are fair. While the perception in Area 1 is undecisive. This was noticed during the realization of the questionnaires, according to the neighbourhood, the street's conditions varied considerably.

The following table summarizes the conditions of the street network of the four areas of study according to their connectivity and physical characteristics, with the information gathered from the questionnaires.

Table 3: Summary of the street network characteristics

Street Network	Connectivity		Physical characteristics of Streets
	Intersection Density	Street Density	
Area 1	Most of the area is medium density. But also a zone with high density of intersections.	The area is mostly medium street density.	Depending on the location of the area, the street's conditions are bad, fair or good. Most people considers the pavement conditions when choosing their route.
Area 2	The area presents some medium and low density of intersections.	The area is mostly low and medium density. There is one zone with high street density that stands out.	Most of the streets are in fair and good conditions. When people chooses their route, they consider the type of pavement and street's width.
Area 3	Mostly low density with some medium intersection density zones.	The area presents from medium to low street density.	Most of the street network is in fair conditions. People equally considers the type and pavement conditions when deciding which route to take.

Area 4	Low to medium density, with a zone of high intersection density.	There is low, medium and one zone with high street density.	Fair conditions in the overall area. Majority of people considers the pavement conditions when choosing their route to Masaya Highway.

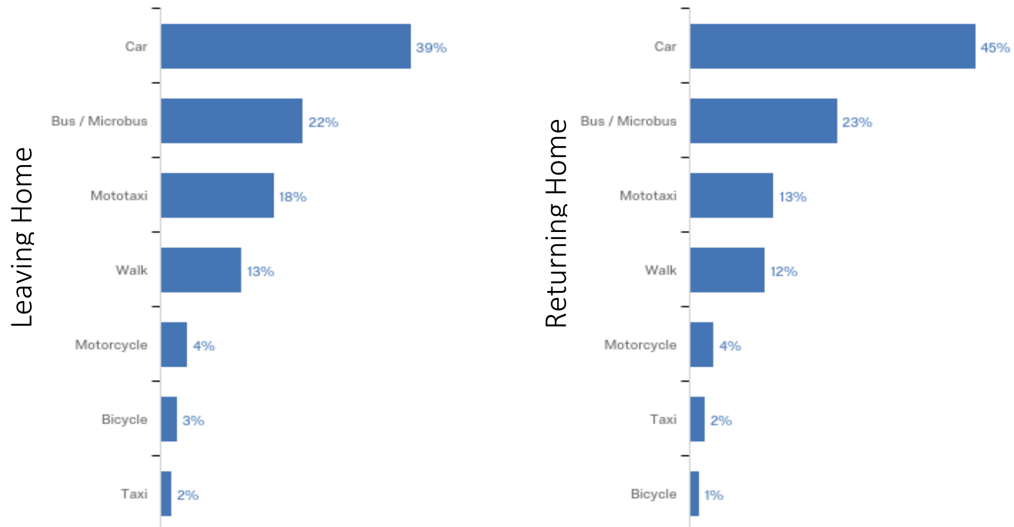
Source: Author, 2019

From Table 3, it can be concluded that Area 1 and Area 4 have a more consolidated street network in terms of connectivity and street density, whereas Area 2 and 3 still present low and medium density areas. As for the physical characteristic of streets, these variate between Bad, Fair and Good among Areas 1, 2 and 3, nevertheless Area 4 is certainly most perceived as Fair.

4.4.2. Street Network influencing Modal Choice

The physical characteristics of streets and connectivity, the independent variables presented in this study as influencers of the modal choices of residents, are analysed in the following section. First, descriptive analysis from the questionnaires is presented, followed by inferential analysis between the independent and dependent variables.

Chart 5: Modes of Transport used



Source: Author, 2019

As seen in the charts, the use of cars as a mode of transport when returning home is higher compared to when people leave home. During the process of the survey, people would mention that when they returned home, another person they know would give them a ride to their homes, so some of those who used the public transport, Mototaxi and walked when leaving would probably use private vehicles when returning. This type of statements of mode variation when leaving home and returning home confirms the statistics' change in modal choices.

However, when asked what mode of transport they used the most, private cars were selected by the majority with 62%, followed by public transport buses with 25%. These results may confirm that the area of study is not planned for pedestrians, supported by the statements of interviewees that this sub-urban area continues to have the street structure of the rural trails.

According to the questionnaire responses, the crucial reason people choose their mode of transport is because "Is their preferred mode of transport" by 66%, and usually vehicle owners agree with this statement, maybe because of the comfort of owning a vehicle, whereas others would agree is due to the proximity to the public transport stops. For the other 34%, their reasons varied from "Is the only mode of transport available leading to the Masaya Highway", is the closest transport to their homes, is the most economical or is the fastest way to get to their destination. In the Literature Review, some factors that influence the modal choice of travel of residents can be the travel demand characteristics as well as the travel mode characteristics (Yang et al. 2018). In the case of the Masaya Highway area, people would use what is more accessible and comfortable for them.

From the control variables, license ownership is a relevant factor when selecting modes of transport. From the 86% of people that have at least one type of license driver, use the car. While 66% of people that do not have a driver's license use public transport buses, and another 16% use Mototaxis to transport or combine transportation modes. It is mentioned by Sultana and Lei (2018) that the possession of a driver's license is associated with the modal choice of residents. So through Chi-Square analysis was confirmed the relation between using a private vehicle or public transport with owning some driver's license, with a significant level of 0.000 for the residents of the area of study.

When comparing through a Chi-Square test, the connectivity variable with the modal choice preferences of respondents, the significance level resulted in being 0.044 as shown in table 4. The results indicate that the fact of having more route options allows people to choose between the different modes of transport available near their homes.

Table 4: SPSS Chi-Square test; variation of route related to types of transport near their Homes

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.054[a]	1	.044		
Continuity Correction[b]	3.036	1	.081		
Likelihood Ratio	3.689	1	.055		
Fisher's Exact Test				.058	.045
Linear-by-Linear Association	4.027	1	.045		
N of Valid Cases	151				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.28.

b. Computed only for a 2x2 table

Source: Author, 2019

Another relation analysis performed with Chi-Square was between the fact of having more than one route option to Masaya Highway, and the mode of transport used when leaving and returning home. The results show a significant relationship when people choose to transport in private cars when they leave home (0.055) and when they return home (0.056), which can be justified because the car is the most used mode of transport and there is also the lack of accessibility to public transportation.

When running the Chi-Square test to analyse the influence of the street's physical conditions and the mode of transport people uses the most, the significance level was 0.000 (see Table 5),

Table 5: SPSS Chi-Square test; street's physical conditions variable related to modal choice used the most

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	19.257[a]	3	.000
Likelihood Ratio	18.210	3	.000
Linear-by-Linear Association	14.648	1	.000
N of Valid Cases	131		

a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 1.98.

Source: Author, 2019

therefore there is a relationship between the classification of the street's physical conditions and the type of transport used most, being cars and public transport buses.

To summarise, the inferential and descriptive analysis showed that the street network variables such as physical characteristics, physical conditions and connectivity of streets do influence the selection of modes of transport among residents of the Complete Area of Study.

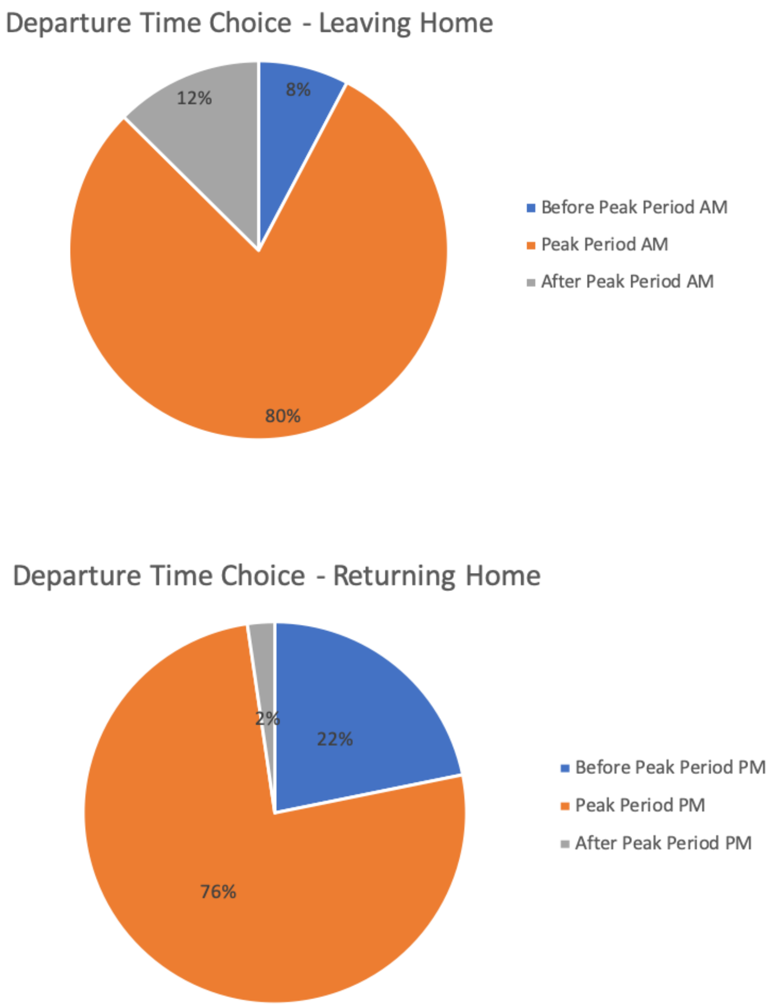
4.4.3. Street Network influencing Departure Time Choice

To support departure time choice variables, questions related to travel time were also asked to respondents. This allows the confirmation of departure time choices among residents. In the following section, street network independent variables are compared with departure time choice and travel time variables through descriptive and inferential analyses.

It was asked to respondents if their selection of a route to get to Masaya Highway depending on the time they travelled to and from home, and 53% confirmed the influence of the street's connectivity and their departure time choice.

The departure times choice of people was consulted to be filled through periods of each hour of the day, and then were categorized as "Before peak Period", "Peak Period" and "After Peak Period" for a better understanding of the results. The results showed that 80% of people choose to leave Home at the peak period. When asked about why they travelled at this hour when leaving home, the respondents preferred selection was "My day schedule starts at this hour" with 56% of responses, most probably representing the peak period AM respondents. While 29% selected "Streets are less congested at this hour" which could represent people leaving before or after peak period AM.

Chart 6: Departure time choices



Source: Author, 2019

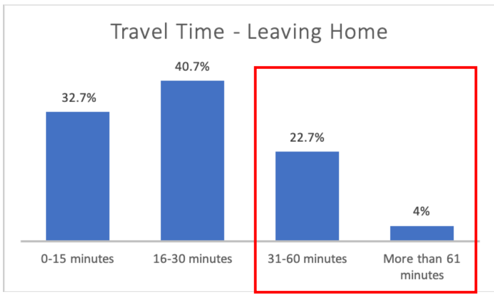
As for when returning home, 76% responded also they returned during peak period. To explain their preferences of departure time, 75% of respondents confirmed they travel at that time because that hour their schedule ends. Whereas 15% prefers to travel when streets are less congested, which could be justified by the 22% respondents that travel "Before peak period PM".

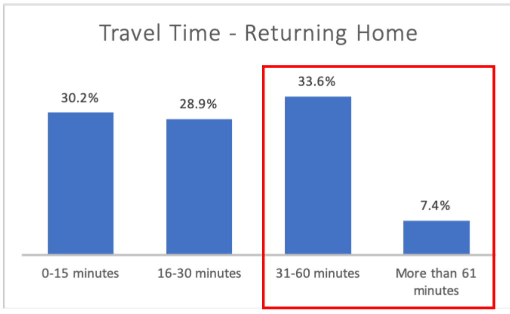
Respondents were also able to explain other reasons for their departure time choices, where they explained that factors like time availability, work demand, the school start time of their children, safety conditions and having flexible hours influenced their choices.

As Bejarano (2017) clarifies, to avoid traffic congestion, some residents adjust their departure time choices to meet their destinies according to their schedule. In the case of the study area, 20% of residents take into account the traffic situation when leaving home in the morning to travel at off-peak periods, as well in the afternoon, that 24% travels at off-peak periods.

In the questionnaire, it was associated departure time choice with the time of travel it takes to people when they leave Home to their primary destination, as well as returned home after their daily trips were finished. Chart 7 compares the time travel of people when leaving and returning home, and it can be noticed that when people return home, their trips take longer than when they leave home in the morning.

Chart 7: Travel time when leaving and returning Home





Source: Author, 2019

Several T-test analyses were carried out to determine the relationship between connectivity and travel time. The average time of travel was compared among the people that have more than one route option to get to Masaya Highway from the ones that do not, but there was no significant relationship between variables. On the other hand, the average of minutes people takes when leaving home was compared to when returning home. It was found a significant difference of 0.000 between the average time of travel when leaving home and returning home, as shown in table 6.

Table 6: SPSS T-Test; average minutes leaving and returning home

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Indicate how many minutes it takes to make this trip (when you leave Home)	28.94	149	21.865	1.791
	Indicate how many minutes it takes to make this trip (when you return Home)	33.72	149	23.329	1.911

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Indicate how many minutes it takes to make this trip (when you leave Home) & Indicate how many minutes it takes to make this trip (when you return Home)	149	.847	.000

Source: Author, 2019

The Chi-Square Analysis to compare connectivity from their homes to Masaya Highway and their departure time choice when leaving and returning home did not show any significant relationship between variables.

When variables questioning the physical conditions of streets were compared to the time of travel when leaving and returning home, there were no significant differences among the areas of study when the Kruskal Wallis' test was carried.

The Chi-Square test also determined a significant relation between connectivity variables and the time of travel it took people when they returned to their homes. This can be justified by the fact that people visit other places after work so that the streets can get more congested.

According to the Chi-Square test, there is no significant relationship between the influence of the streets' physical characteristics when choosing a route between home and Masaya Highway, with their departure time choices. Neither there was between the street's physical conditions of the area where they live and their departure time choice.

The Chi-Square test did show a relation between their general departure time choice and the selected reasons for the departure time choice. According to the descriptive analysis, 53% of respondents would change their route depending on the time they leave home, which could vary their time of travel to their primary destination.

From the analysis presented, it can be determined that street network variables are irrelevant for the departure time choices of residents. There are other variables from the context and dynamic of the area that influence their decisions of departure time like traffic congestion. Nevertheless, there is a significant relationship between the average time of travel between the morning and evening periods.

4.4.4. Street Network influencing Trip Chaining

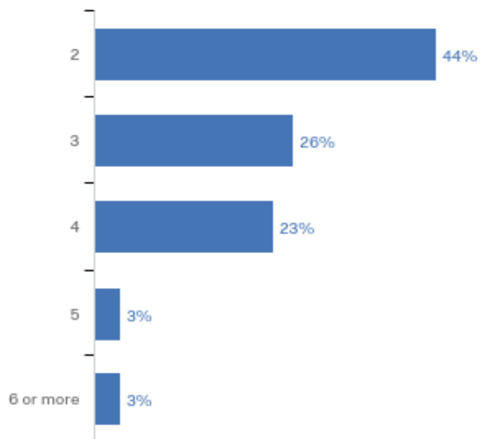
Lastly, the street network variables influencing trip chaining among residents of the Masaya Highway area are presented. Trip chaining has been explained as the combination of trips made since leaving home until returning home. Most people have one primary activity per day, that might combine with secondary activities. As explained in the literature review, trip chaining can be categorized into simple trip chains, involving a single activity, and complex trip chains, involving many activities (Primerano et al. 2008)

Questions about trip chaining were double checked. First, the number of trips made per day was asked so people could understand the concept of trip chaining. According to Chart 8, 44% of people practices only two trips per day.

Related to this, residents were asked if they considered that the street network from the area where they live influenced the number of trips they combined, and the outcomes resulted in being equally distributed with 50% "Yes" and 50% "No".

As defined in the results of the questionnaires, 57% of people prefer to use private cars while doing a combination of trips, whereas 20% of respondents use public transport buses. Barely 11% uses non-motorized ways of transport, like walking and cycling.

Chart 8: Trips frequently made per day

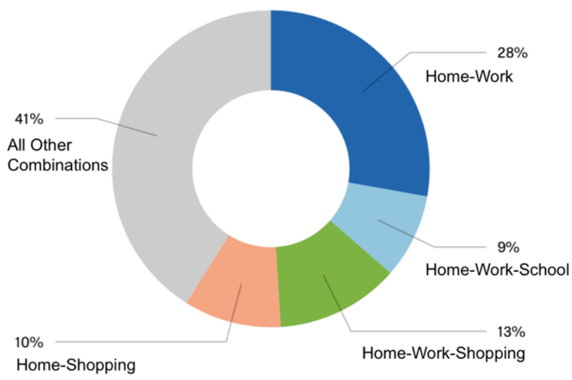


Source: Author, 2019

According to the Chi-Square analysis, there is no significant relationship between the number of trips people perform in one day with the level of connectivity from their homes to Masaya Highway. Neither there is a significant relation between the street's physical characteristics that influence their route to access Masaya Highway and if they consider the street network when trip chaining.

Next, their frequent destinations were consulted. From the answer list they could select: Work, Shopping, School, Leisure Destination, Other. After categorizing their trips combination, the most predominant was Home-Work (28%), Home-Work-Shopping (13%) and Home-Shopping (10%). These can be observed in Chart 9. Other types of combinations also included picking up kids at school, visiting relatives, going to church and other personal diligences.

Chart 9: Trip chaining destinations visited frequently



Source: Author, 2019

When running the Chi-Square analysis, there was no significant relation between the fact of considering the street physical characteristics to get to Masaya Highway and the number of trips made per day. Although, there was found a significant relation between the fact of considering the street physical characteristics to get to Masaya Highway and preferring the bus/microbus (0.017) and car (0.002) as modal choices for trip chaining and making several trips, as shown in tables 7 and 8.

Table 7: SPSS Chi-Square test; consideration of street's physical characteristics influencing selection of car as modal choice

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.469[a]	1	.002		
Continuity Correction[b]	8.333	1	.004		
Likelihood Ratio	9.379	1	.002		
Fisher's Exact Test				.004	.002
Linear-by-Linear Association	9.396	1	.002		
N of Valid Cases	130				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 16.92.
b. Computed only for a 2x2 table

Source: Author, 2019

Table 8: SPSS Chi-Square test; consideration of street's physical characteristics influencing selection of bus/microbus as modal choice

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.739[a]	1	.017		
Continuity Correction[b]	4.744	1	.029		
Likelihood Ratio	5.530	1	.019		
Fisher's Exact Test				.028	.016
Linear-by-Linear Association	5.695	1	.017		
N of Valid Cases	130				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.49.
b. Computed only for a 2x2 table

Source: Author, 2019

Another analysis associated the physical conditions of streets and the number of trips made per day, but no significant relation was found. However, it was found that the physical conditions of streets influence the modal choice preferred when trip chaining, in this case, the use of the car (0.006) and bus (0.005), as shown in tables 9 and 10.

Table 9: SPSS Chi-Square test; physical conditions of streets related to car modal choice when trip chaining

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	10.085[a]	2	.006
Likelihood Ratio	9.993	2	.007
Linear-by-Linear Association	9.125	1	.003
N of Valid Cases	144		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 11.84.

Source: Author, 2019

Table 10: SPSS Chi-Square test; physical conditions of streets related to bus modal choice when trip chaining

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	10.712[a]	2	.005
Likelihood Ratio	9.913	2	.007
Linear-by-Linear Association	8.852	1	.003
N of Valid Cases	144		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.32.

Source: Author, 2019

But, unlike the theory of McGucking and Murakami (1999) which states that women make more trips than men, in this study, there was not found a relationship between gender and number of trips made per day.

Given these points, the relation between street network variables and trip chaining can be summarized by affirming that the only significant association among them is when residents decide which mode of transport to use when trip chaining. This fact sustains the significant relations between street network and modal choices from the previous section.

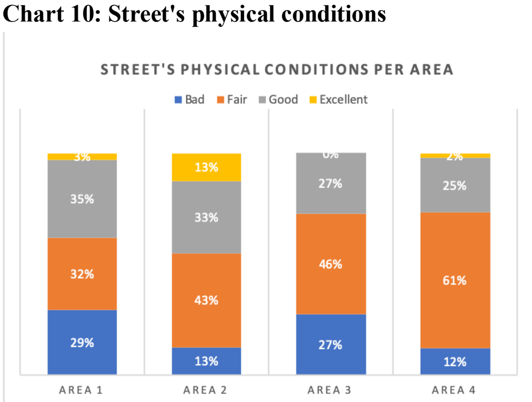
4.4.5. Differences among the four Areas of Study

Considering that the four different areas within the delimited area of study were selected to make comparison among the neighbourhoods, descriptive and inferential analysis were carried to describe people's behaviour in each one of the areas. Besides, to explain the relation and differences presented, the spatial analysis made part of the explanation, by triangulating the information provided.

Street network characteristics per Area

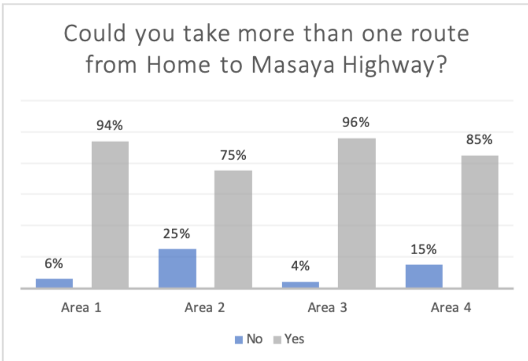
According to the descriptive statistics in Chart 10 of the street's conditions in Area 2, Area 3 and Area 4 the majority of people perceives the street's physical conditions as "Fair", while the majority of respondents in Area 1 consider the conditions as "Good" with 35% of responses.

Chart 10: Street's physical conditions



Source: Author, 2019

Chart 11: Connectivity to Masaya Highway



Source: Author, 2019

In terms of connectivity, the information gathered in the questionnaires describes that when travelling from their homes to Masaya Highway, people living in Areas 1 and 2 have more direct routes to the main road. While Area 2 presents more frequency of people who consider that they have less direct route options to the main road.

For confirmation of the relation of Areas and route options, the Chi-Square analysis showed in table 11, resulted with a significance level of 0.045, affirming a relation between residency location and connectivity.

Table 11: SPSS Chi-Square test; connectivity differences among Areas of Study

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.058^a	3	.045
Likelihood Ratio	8.478	3	.037
Linear-by-Linear Association	.215	1	.643
N of Valid Cases	151		

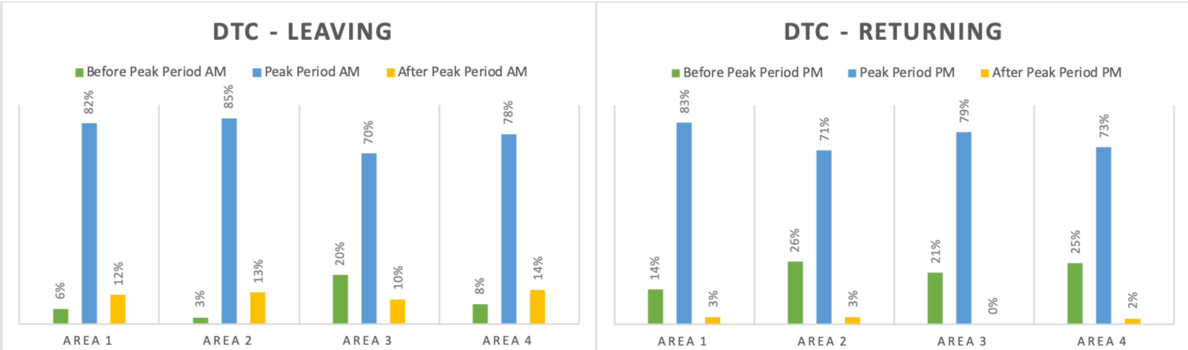
a. 1 cells (12.5%) have expected count less than 5. The minimum expected count is 3.20.

Source: Author, 2019

Departure Time Choice

An analysis was carried to determine the relation of departure time choice and residency location among the respondents, but there was no significant relation found. The following graphic details the preferred departure time of people. In the morning, residents prefer leaving home after peak hours than before peak hours, whereas in the evening, residents prefer traveling before peak hours than after peak hours.

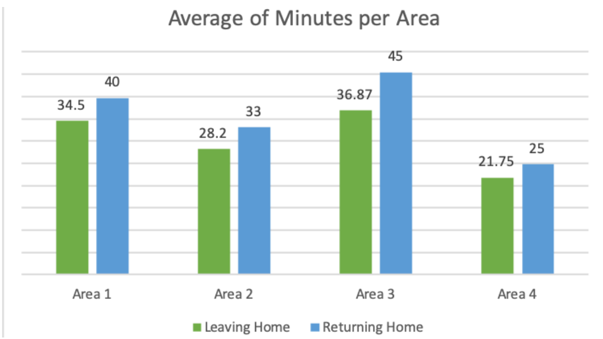
Chart 12: Departure time choice per Area



Source: Author, 2019

When carrying Kruskal Wallis' Test, it was observed that between Areas there is a significant difference in the average time of travel when leaving home. According to Dunnett's T3 Test, there is a difference between Areas 3 and 4, with a significance level of 0.004. As Vishnu and Srinivasan (2013) state, the location of people's residency has a significant role in deciding the preferred departure time choice and time of travel.

Chart 13: Average of minutes Time Travel per Area



Source: Author, 2019

The same analysis was performed for time of travel when returning home. It was observed in the Dunnett's T3 Test a significant difference in the average time of travel between three of the four areas. As demonstrated in table 12, concerning Area 3 and 4, the significance level was 0.002, while between Areas 1 and 4, the significance level was 0.047.

Table 12: Multiple comparisons of travel time among Areas

Multiple Comparisons

Dependent Variable: Indicate how many minutes it takes to make this trip (when you return Home)
Dunnett T3

(I) Area / Location	(J) Area / Location	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Area 1	Area 2	6.590	6.171	.865	-10.14	23.32
	Area 3	-5.768	6.993	.956	-24.82	13.28
	Area 4	14.941*	5.400	.047	.12	29.76
Area 2	Area 1	-6.590	6.171	.865	-23.32	10.14
	Area 3	-12.358	5.999	.236	-28.84	4.12
	Area 4	8.351	4.032	.226	-2.60	19.30
Area 3	Area 1	5.768	6.993	.956	-13.28	24.82
	Area 2	12.358	5.999	.236	-4.12	28.84
	Area 4	20.709*	5.204	.002	6.08	35.33
Area 4	Area 1	-14.941*	5.400	.047	-29.76	-.12
	Area 2	-8.351	4.032	.226	-19.30	2.60
	Area 3	-20.709*	5.204	.002	-35.33	-6.08

*. The mean difference is significant at the 0.05 level.

Source: Author, 2019

Modal Choice

The One-Way ANOVA analysis was also performed to study differences between the average number of modes of transport used when travelling. According to Dunnett's T3 test, there is a significant difference between Areas 3 and 4 of the number of modes of transport used when leaving home (0.008) and a significance level when returning home (0.007) as seen in Tables 13 and 14.

Table 13: Multiple comparisons of types of transport used when leaving Home

Multiple Comparisons

Dependent Variable: Total transport types used when leaving home
Dunnett T3

(I) Area / Location	(J) Area / Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Area 1	Area 2	-.092	.175	.996	-.56	.38
	Area 3	-.373	.197	.323	-.92	.17
	Area 4	.256	.144	.381	-.13	.64
Area 2	Area 1	.092	.175	.996	-.38	.56
	Area 3	-.282	.207	.682	-.85	.28
	Area 4	.348	.157	.161	-.08	.77
Area 3	Area 1	.373	.197	.323	-.17	.92
	Area 2	.282	.207	.682	-.28	.85
	Area 4	.630*	.181	.008	.13	1.13
Area 4	Area 1	-.256	.144	.381	-.64	.13
	Area 2	-.348	.157	.161	-.77	.08
	Area 3	-.630*	.181	.008	-1.13	-.13

*. The mean difference is significant at the 0.05 level.

Source: Author, 2019

Table 14: Multiple comparisons of types of transport used when returning Home

Multiple Comparisons

Dependent Variable: Total transport types used when returning home
Dunnett T3

(I) Area / Location	(J) Area / Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Area 1	Area 2	.044	.132	1.000	-.31	.40
	Area 3	-.338	.168	.261	-.80	.13
	Area 4	.214	.117	.353	-.10	.53
Area 2	Area 1	-.044	.132	1.000	-.40	.31
	Area 3	-.383	.168	.154	-.85	.08
	Area 4	.169	.117	.621	-.15	.48
Area 3	Area 1	.338	.168	.261	-.13	.80
	Area 2	.383	.168	.154	-.08	.85
	Area 4	.552*	.157	.007	.12	.99
Area 4	Area 1	-.214	.117	.353	-.53	.10
	Area 2	-.169	.117	.621	-.48	.15
	Area 3	-.552*	.157	.007	-.99	-.12

*. The mean difference is significant at the 0.05 level.

Source: Author, 2019

The modes of transport used when leaving and returning home that showed a significant relationship with the location of residency were the Car, Bus and Mototaxi. In the Complete Area of Study, walking as a mode of transport is not practised for trip chaining. From the respondent's comments, they would walk only to take public transportation or diligences around the neighbourhood.

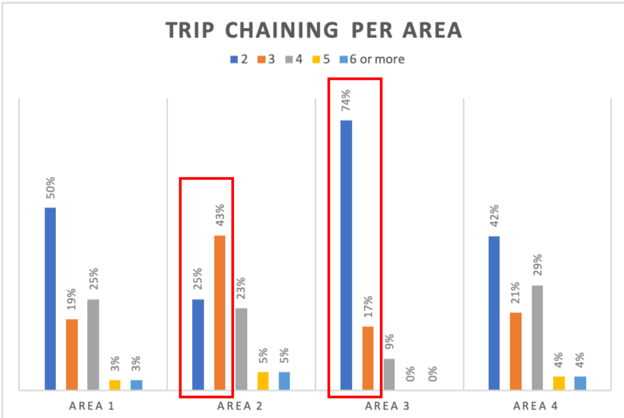
Chart 14: Number of modes of transport used per Area

Source: Author, 2019

Trip Chaining

The following graphic compares the number of trips performed per day by residents of the areas of study. It can be seen that in Area 3 people practice less trip chaining, whereas more than 76% of residents of Area 2 practice three or more trips per day, followed by Area 4 with 58% and Area 1 with 50% of residents performing more than three trips per day.

Chart 15: Trip Chaining per Area



Source: Author, 2019

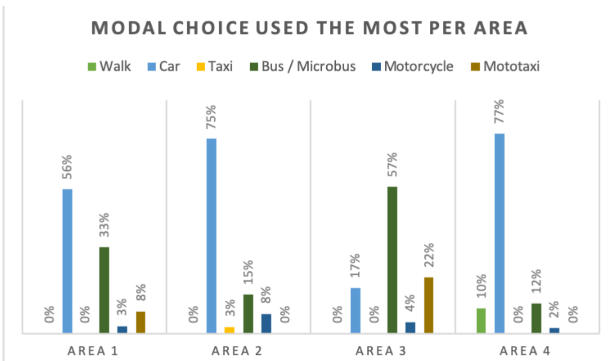
According to the Chi-Square test, there is a significant level of 0.008 that confirms the difference among areas when making 2 or 3 trips a day, confirming the descriptive statistical analysis presented in Chart 15.

This behaviour could be justified because homes in Area 2 are closer and better connected to the Masaya Highway than Area 3. Also, because Area 3 has less intersection density and street density than all the other, and most people use the inter-urban public transport so trip chaining would need more effort for them. As Sultana and Lei (2018) mention, the location of residency has a significant influence in combining trips and visiting different destinations.

Accessibility to Public Transport

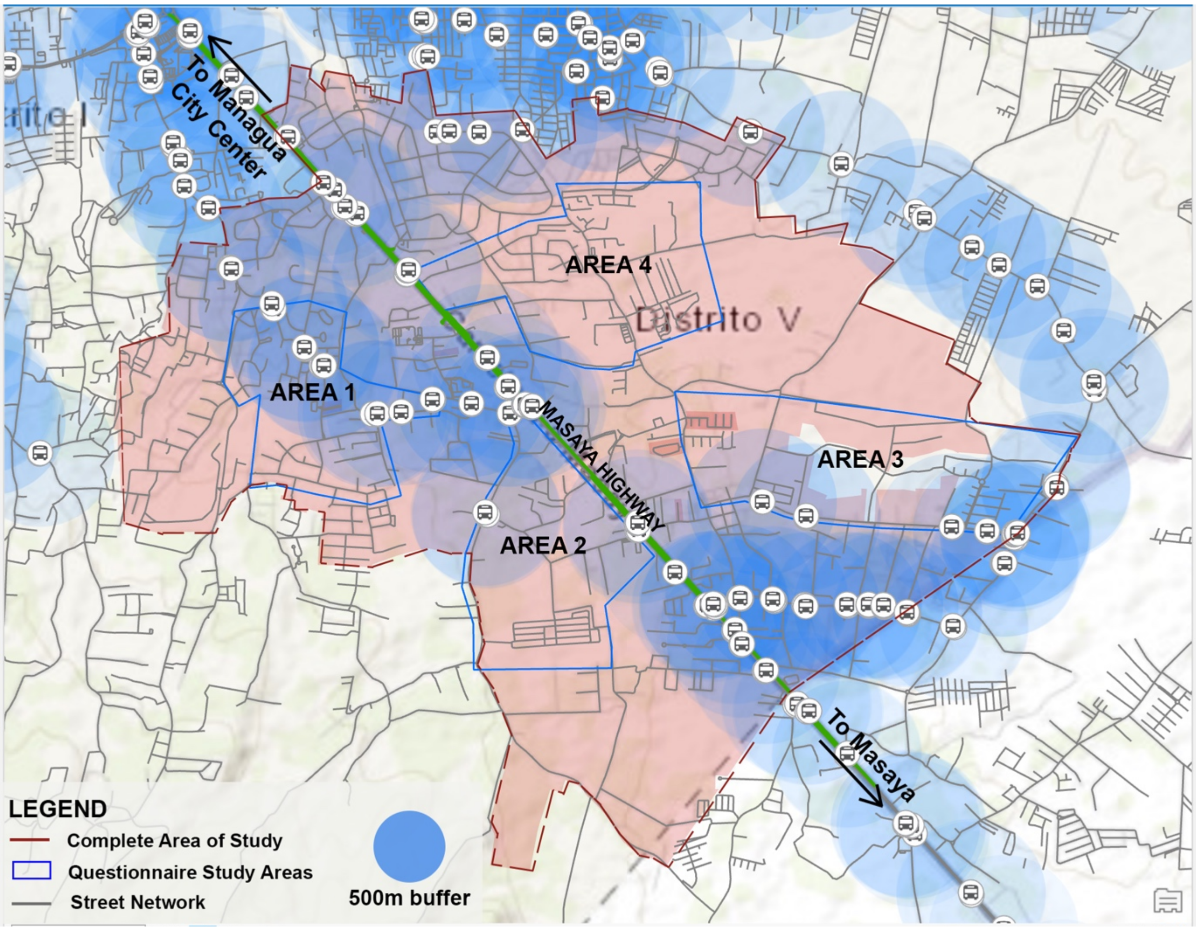
The significance level of the Chi-Square analysis between Areas and preferred mode of transport is 0.000, meaning that there is a significant relationship between the area in which people live and their preference of using a car or bus to transport themselves. The descriptive analysis shows that Areas 2 and 4 use more the private vehicle, whereas in Areas 1 and 3 have a major frequency of people using public transport.

Chart 16: Preferred modal choice per Area



Source: Author, 2019

Figure 8: Coverage of Public Transport Stops in the Delimited Area



Source: Author, 2019

The accessibility to inter-urban public transport was determined by a spatial analysis that gave a buffer zone of 500 meters from each inter-urban bus stop along with the street network. The 500 meters buffer zone is utilized for the analysis since this is a guideline in urban planning for how far a person would walk to a bus stop (Daniels and Mulley, 2013; Wakenshaw and Bunn, 2015). The analysis shows that the areas with better accessibility are Area 1 and Area 3 since bus routes are crossing the areas. While Area 2 is closer to the Masaya Highway, where there are bus stops alongside the road. Lastly, Area 4 is the one that has less access to public transport. This relation could be confirmed with an inferential analysis that quantified a significance level of 0.000 (see Table 15) between the Area variable and accessibility to different types of transport.

Ozbil et al. (2009) stated that when residing closer to public transport stops the chances of using the public transport are higher irrespective of the street connectivity levels of the area, which in this case can be confirmed through an analytical relation between GIS results and questionnaires data. It is relevant to emphasize also that during the interviews, López mentioned that the people that use public transport are those that had lived in the rural communities before the area started to urbanize.

Table 15: SPSS Chi-Square test; relation between area and modal choices

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	27.346[a]	3	.000
Likelihood Ratio	27.844	3	.000
Linear-by-Linear Association	16.936	1	.000
N of Valid Cases	151		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 5.79.

Source: Author, 2019

All things considered, there are significant differences in travel preferences among the four areas of study. The modal choice distinctions are emphasised in access to public transport and owning a private vehicle. On the other hand, departure time choices and trip chaining did not show significant differences between all areas, but there are notable differences that could be due to home location, connectivity and street's characteristics.

4.6. Other Findings

Land Use Compatibility

Grun, an architect and urban planner, states that designing mobility solutions should always be associated with land use planning and densification of areas. However, the fact is that there is no previous urban planning, and regulatory entities should provide guidelines to developers, says Gerardo Hernández, a housing developer in the private sector.

As for the congestion of the road, architect and urban planner Romer Altamirano, mentions that an integrated solution should be delivered. For the moment, the government is only relieving some areas but transferring the saturation to other areas of the city. Given that, priority to specific uses should be provided.

Phenomena that influence Urban Development

Managua's earthquake in 1972, the civil war in the 1980s and economic dynamics of the country have been very influential in the city's development and growth. Also, because of the earthquake, instead of densifying the urban land, people preferred to build one-story houses, which is still a tendency affecting land availability, since all cities have growth limitations.

Because of these aspects, another urban planner explained that the municipality has tried to return and build in the empty lots at the city's centre that was left after the earthquake. The area still has the capacity to absorb more population. Unfortunately, people's beliefs lead them to consider the Masaya Highway area with greater surplus value, even though the area is not sufficiently equipped with urban infrastructure.

Chapter 5: Conclusions and recommendations

5.1. Street Network and Travel Behaviour along Masaya Highway

In the following section, general conclusions are presented before making the final statements for each of the research questions. These general conclusions come from the qualitative and quantitative findings described in Chapter 4.

The Regulation Plan of 1982 and the Partial Plan of Urban Development of 2000, supported the urbanization and development of what was previously a rural and suburban area in Managua. Sadly, the plans where not adequately implemented to achieve an integration with the urban structure of the city, and the area started growing in disorganized matters.

Moreover, the high importance of the Masaya Highway connecting to other important cities of the Pacific Coast made the region attractive for residents. The area was mainly developed due to the private investment of housing projects for medium and high-income groups, while the municipality followed their needs and constructed infrastructure according to their necessities and growth. However, certain physical, social and economic events of the whole city also lead to the rapid urbanization in the area without much control from the government.

From the findings, it can be concluded that there is lack of planning from governmental entities, besides disorganization in terms of co-responsibilities in building infrastructure for the city. The unreliable governance from the municipality leaves gaps in the development of infrastructure in the Masaya Highway area. In addition to that, according to literature and the interviews conducted, closed residential communities have segregated socially and spatially residents even more.

Residents of the area travel around the region following the same roads, since there is no connectivity logic for the actual context in which the city is developing. Also, the type of neighbourhood design shapes the routes where people will travel, and in some cases, it obstructs the connectivity between neighbourhoods. But not only the street network is affected by the uncontrolled urbanization, other systems like garbage, electricity, and water are disturbed as well. With that said, the low density of urbanization in the area has high costs for the municipality.

It is important to highlight that for the residents of the four areas of study, accessibility to public transport is a determinant aspect to take into account when deciding about their modal choices. Differences among the four areas of study are also noted during the analysis. This can be inferred by the different neighbourhood's characteristics, time development and street network aspects in each of them.

In cities, some can decide in which area to live, while others settle where they can afford, no matter how is the accessibility to services and urban transport. In Managua, people look forward to proper urban transport that can easily connect them with all districts within the city. Improving connectivity would encourage the integral development of the city. For example, productivity hours would be more profitable, and people would spend less time in commuting, improving their quality of life as well. In addition to the social and spatial segregation that the residential models of the area have created, urban mobility plays a role in social and economic differences among residents of the area.

It can be noticed from the spatial and network analysis from ArcGIS Pro, that the older residential developments are well connected and with appropriate street's physical characteristics compared to latest urbanized areas, leading to differences in peoples travel behaviour.

5.2. Answering research questions

In the next section, each of the sub-research questions of the study is answered, with final conclusions answering the main research question. Adding to the last chapter, future research questions are proposed, together with the research's contributions and recommendations.

RQ1: How are the connectivity and physical characteristics of streets provided to access the highway to Masaya?

To answer the first research sub-question, the following statements are emphasized. The street network has semi-rural characteristics since there is no upgrading in the streets even though now there is more traffic pressure. There are not many alternatives of collector roads that connect to the sub-centres of the city, so the Masaya Highway, which is a high-speed road, gets obstructed with vehicles during peak periods.

The area of study lacks connectivity between residential areas, and one of the reasons is that the gated community concept does not allow a dense urban pattern with a street design that supports all the transportation modes offered in the region. When trying to provide a future solution for the lack of connectivity between neighbourhood, these segregating residential models in the area could make the task for the municipality more challenging.

Likewise, the streets are designed for cars. There are no sidewalks, proper bus stops, nothing that promotes any other transportation mode rather than cars, adding to the fact that the irregular grid of the area makes distances longer for walking. Besides, other political and administrative problems make the maintenance and upgrading of the street network more difficult, which leaves no hope for connectivity solutions.

The areas with a better connection to the Masaya Highway are Area 1 and Area 2, while Area 1 and Area 3 have the best accessibility to inter-urban public transport routes. The passage of inter-urban routes through these areas is justified because the rural communities in these locations have used them for many years.

It is a fact that the physical conditions of the streets are considered while travelling and depending on the zone where people lives, the relationship is stronger. Overall, the physical conditions of streets in the Complete Area of Study to access Masaya Highway are fair, with certain differences among the areas. Nonetheless, pavement conditions and types of pavement show differences within the areas.

RQ2: How does connectivity and physical characteristics of streets influence modal choice when accessing the highway to Masaya?

The mode of transport that dominates the area is cars, and most people use their vehicles to leave and return home. These results support Moeinaddini et al. (2016) theory, concluding that street network elements have a relation with private motorised daily trips. Nevertheless, it is relevant to mention that in most of the area the gated communities with parking spaces predominate as residential models, and households have one or more private vehicles.

For many, having a car is a necessity, but it is also a representation of social status. In the last years, credit conditions have been striking when people want to get a new vehicle, saturating the street network of the city. This decision of getting their private vehicle could also be supported by the fact that residents of the area do not have many public transport offer, so they feel the necessity to rely on private transport modes. This can be confirmed with the inferential analysis, where license ownership is a relevant factor when selecting the preferred modes of transport.

Along the Masaya Highway axis, there are bus stops of inter-urban routes, and within three of the study areas are also routes that have covered these counties for years. These routes are used more by the native population of the area. Having better connectivity with the Masaya Highway allows people to have more options of transport modes in different locations around their homes.

The physical characteristics and conditions of streets are also an essential factor when choosing their mode of transport. Not all the street network of the area has the same street category, meaning that there is no provision of infrastructure for pedestrians everywhere, discouraging people from walking and having to rely upon the Mototaxis and motorcycles.

Another determinant factor is pavement conditions, which it variates depending on the zone. Where there are dirt roads, potholes and cracking, people are not willing to walk and would prefer taking a Mototaxi to get to the bus stop or the main road.

RQ3: What types of trip chaining do residents practice based on the connectivity and physical characteristics of streets, when travelling from their homes to work, leisure, school and shopping?

Based on the connectivity and physical characteristics of the street network, trip chaining among residents is not significantly influenced. The trip combination most practised is Home-Work, and more than half of the population practices 2 or 3 trips per day. The results show a similarity with JICA's study (2005), where the predominant preferences of trip chaining were Home-Work and Home-School. The results from the present study imply that trip chaining, in general, is not much practised in most of the days of the week. For some of the residents, it is not possible to travel to many different locations in one day because of time availability or their mode of transport, so they prefer doing errands during the weekends.

Although, there is a relation between the physical conditions of the streets and preferring the car and bus when making several trips since in the Complete Area of Study, those are the modal choices used the most. If errands are close to home, people mentioned using the bike, mototaxi or walking to their destinations. But, when trip combination concerns travelling longer distances, they preferred using private vehicles for those that own one, and the public transport for those that are not vehicle owners.

Accessibility to public transport and connectivity was an important factor when comparing which areas of study practised more trip chaining. These results confirm that depending on the location of the residency, people could combine more trips daily.

RQ4: How does connectivity and physical characteristics of streets influence the departure time choices when accessing the highway to Masaya?

As for departure time choices being influenced by connectivity and physical characteristics of streets, there was no significant relationship between variables according to the inferential analyses. Although, people responded in the questionnaires that reasons like their daily schedule, avoiding traffic congestion, time availability, work demand, scheduled start time, safety conditions and having a flexible schedule are deciding aspects for their departure time.

As part of the departure time choice variables, the time of travel was also considered since there was a significant relationship between departure time choice and time travel from the responses. The addition of time of travel allowed to notice other relations with the street network of the study areas. Depending on the area where people lives, time of travel would vary, which could be related to the street network conditions of the specific area.

There was found a significant relation between connectivity variables and time of travel when returning home. Returning home takes people more time, which can be because of traffic congestion or other reasons. Also, depending on the time of travel, most people said they changed their routes, so those who have more route options can variate their route when returning home. Another possible reason can be that the streets are more congested because people visit other places before getting home.

Main RQ: How does street network (connectivity and physical characteristics of streets) influence travel behaviour (modal choice, trip chaining and departure time choice), in neighbourhoods along the highway to Masaya in Managua city?

From the travel behaviour concepts, the modal choice behaviour is the most influenced by street network variables, such as connectivity and physical characteristics of streets. The findings in this study demonstrate a similar situation with Lee's theory (2017) that mentions that the built components of residential areas are relevant for modal choice, including residential density, street connectivity and the accessibility to the transport network.

Unfortunately, walking is not encouraged because of the lack of pedestrian infrastructure. By nature, the county roads do not have sidewalks and storm drains suitable for the mobility of pedestrians around the area. Now, these old county roads have been paved with concrete, asphalt or blocks, but without any adequate pedestrian infrastructure. Also, as Dill (2004) stated, street intersections and street density improve walkability condition. Compared to other neighbourhoods in the city centre of Managua, the area of study lacks an urban grid that would invite people to walk.

Nevertheless, departure time choice and trip chaining do not show to be influenced by connectivity and physical characteristics of streets in the Complete Area of Study. As Altamirano mentioned in his interview, other cultural reasons for people's dynamics could be significantly influencing people's behaviour in these aspects.

To summarize, connectivity and physical characteristics of streets proved a significant relation to modal choices amongst residents of the Masaya Highway area. However, there was not a substantial relation between street network variables and trip chaining. At the same time, departure time choice was not influenced by connectivity or physical characteristics of streets, but time travel showed a relation with connectivity measures.

There were found several differences in travel behaviour among the four areas of study, which are also understood by theories. Some of these theories state that residence location has a significant role in deciding the preferred departure time choice, total time travel to destinations and trip chaining. Like Cao et al. (2007) and Sharifi (2019), that point out that when there are modifications in neighbourhoods characteristics and streets, travel behaviour is also influenced. As Concas and DeSalvo (2014) explained, some households select their home location according to their preferences of travel and commute choices, that are influenced by the built environment of the area.

It is crucial not to ignore the possibility that not only the street network influences people's travel behaviour, but also the dynamics of the residents and the land use incompatibility that makes the street network inefficient.

5.3. Future research questions

In Nicaragua, there are not many academic studies related to urban issues and cities. So, there is a necessity of addressing urban problems with theoretical foundations that can lead to the recognition of possible causes.

Besides urban density, accessibility to urban transport and street network connectivity, land use is another aspect to be studied together with travel behaviour. Land use incompatibility among cities is a factor that adds to traffic congestion and problematic mobility. As described in this study, the urban public transport in Managua is inefficient and insufficient, and the relationship with land use is close, so this could be a possible research to study deeply. In the literature review, the relationship between transport, travel behaviour and land use is mentioned by Hamiduddin (2012) and Lee (2017) in their studies. This topic can be addressed in Managua through a study case methodology that can answer questions such as: "How travel behaviour is influenced by land use?", or "To what extent land use influences travel behaviour?".

Complementary to this, the influence of plans that regulate the construction of the city could also be studied. There are certain co-responsibilities between the public entities and private corporations that need to be examined in detail to provide more urban recommendations. Consequently, the relations between public and private corporation could improve the quality of life of citizens in Managua and other cities. Furthermore, a study relating these concepts can be carried out by answering the following question: "How Managua's regulation urban plans have influenced the development of the city and to what extent these have been fulfilled?". This research question could be answered throughout a mixed methods research design of survey methodology.

Lastly, cultural aspects in Latin American cities are linked to urban problems, and public and private entities are already studying them. Perhaps, the most influential cultural aspects in Nicaragua could be studied in detail and related to the development of cities; these could be the education level of the population, gender issues, and social status perception. This research proposal can be done with survey methodology, that answers a question such as: How cultural aspects influence the development of urban infrastructure in Latin-American cities?

Hopefully, more research questions can be derived from the present study that can contribute to the urban knowledge of cities in Nicaragua or other Latin-American cities.

5.4. Research's contributions

First of all, the new information gathered of people's preferences in the Masaya Highway area, the south area of Managua, is a great achievement from this research study. Until now, travel preferences had not been studied deeply, so this research addressing specific travel behaviour preferences is a major accomplishment for the academic community of Managua.

With the information gathered and relations between street network and travel behaviour explained, urban planning entities and the transportation sector in Managua could propose solutions to the mobility difficulties stated in this study. New urban and transport policies can derive from the research, that could provide better urban mobility according to the needs of residents in the area.

Findings of this research related to street network aspects influencing modal choices among residents have expanded the theories of Larrañaga and Cybis (2014), Ozbil et al., (2009) and Lee (2017). This theories mentioned in the Literature Review chapter, explain a relation between the elements of the built environment, such as street network for travel decisions in residents. Additionally, they also describe a relation of residency location with public transport accessibility and modal choices, which in this study can be justified in the comparison made among the four areas of study.

5.5. Recommendations

With the conclusion of the present investigation, some key recommendations could be proposed for urban planners, architects, contractors and governments of cities around the world.

Several tools can be utilized for urban development processes during the planning of cities. It is necessary to take advantage of all types of contributions from the community, students and civil society to identify urban problems in our cities. In the case of the present research, one of these tools is the new "Master Plan for the Urban Development of the Municipality of Managua" provided by the Japanese International Cooperation Agency in 2017, which consists in several transport and land use projects for the appropriate development of the city. For example, the master plan proposes to extend the road rings of the city, which can give solutions in terms of connectivity among Managua's neighbourhoods and districts.

For this reason, gathering more information about people's travel preferences could serve as guidelines so authorities can improve and follow the development in the area. If possible, increase connectivity among neighbourhoods could improve walkability circumstances or other type of non-motorized transport. With that said, the residential models of the area should allow a proper relationship with the context where they are built.

In the same way, administrative decisions about the dynamics of the city could improve the efficiency of the street network. In many cities across the world, there are being implemented strategical solutions that do not require building new infrastructure. Urban planners of Managua should pay attention to these possibilities, that have been successful in other cities without making major investments and still solving urban problems like traffic congestion, robbery and vandalism.

Equally, the compliance with the implementation of the city's urban regulatory decrees will be decisive for the orderly development of the city. There will have to be a rigid implementation of the city's regulatory plans, as well as responsible technical support from municipal entities. To give an example, the conservation areas of the city in the peripheral areas should be respected, since the water supply of the city comes from these mountains, which also add to the environmental sustainability of the city. In that case, it could be appropriate for urban planners to promote the resettlement of housing projects in the empty lots that remain until now in the city centre, after the devastating earthquake in 1972.

Moreover, this research emphasizes the need to improve the conditions of urban transport in the area, since it could no longer continue with the current inter-urban characteristics that it has had until today. The authorities can no longer ignore these needs, and citizens deserve quality urban transport that provides them with security and comfort. There is a necessity to promote the use of public transport, but with that comes the improvement of the quality and distribution logic of the transport network and the peripheral regions.

To conclude, urban design and mobility can contribute to social inclusion. Proper travel conditions allow residents to integrate and enjoy cities, services and public spaces, besides accessing to culture and other leisure activities. It is important to emphasize that the problems presented in this research, do not fall entirely on public and private entities, but also on all of us citizens who make part of the organism known as the "city".

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Annex 1: Semi-Structured Interview

Semi-Structured Interview Street Network and Travel Behaviour

Managua, Nicaragua

June – July, 2019

Number of Interview: ______________________

Name of Interviewee: _____________________

Location: ____________________

Date: __________________

Objective:

To describe the street network development of the area along the Masaya Highway.

To describe how are the street networks provided to access the highway to Masaya.

Introduction:

Hello, thank you for allowing me to do this interview about the street networks development along the Masaya Highway. The objective of the present interview is to describe how the street networks are provided to access the highway to Masaya, as well as understanding its development.

If it is okay with you, the interview will be recorded, and the information will be used only for academic purposes.

Questions:

1. Do you know if there some Urban Development Plan that supported the construction of new residential areas along the Masaya Highway?
2. How do you think these neighbourhoods are affecting the street network of the area?
3. How do you think that accessibility to Public Transport is influences the selection of homes in the area?
4. How do you think the street networks affect the selection of public transport routes?
5. How do you think neighbourhood design influences travel choices among residents?
6. How do you think the types of neighbourhood design and residential areas influences the use of vehicles (cars, mototaxi, taxi, motorcycle)?
7. How do you think people's awareness and perception of traffic congestion influences their travel behaviour (trip chaining, modal choice, and departure time choice)?
8. How influential do you consider are street networks related to travel behaviour in the Nicaraguan context? Please explain more your answer.

Annex 2: Questionnaire Street Network and Travel Behaviour

Questionnaire Street Network and Travel Behaviour

Managua, Nicaragua

June – July, 2019

Number of Interview: _________

Name of Interviewer: ______________________

Location Area: _________

Date: ________________

Good Morning, I am a Master Student in Urban Management and Development at the Erasmus University of Rotterdam and would like you to help me fill in this questionnaire. This questionnaire aims to understand travel preferences in the area, and the information will be used for academic purposes only.

STREET NETWORK

1. In your daily trips, do you travel along the Masaya Highway?:

a. ___ Yes
b. ___ No

2. Do you choose your route depending on the time you travel?:

a. ___ Yes
b. ___ No

3. Could you take more than one route from your Home to "Masaya Highway"?:

a. ___ Yes
b. ___ No

4. If your previous answer was "yes", Do the street physical characteristics influence your selection of route to get to Masaya Highway?:

a. ___ Yes
b. ___ No

5. If your previous answer was "yes", Select the physical characteristics that would make you change route to get from Home to Masaya Highway and vice versa:

a. ___ Street Width
b. ___ Street Length
c. ___ Type of pavement (Asphalt, Block, Concrete)
d. ___ Pavement conditions (Pothole, Crack, Rutting)

6. How are the street's physical conditions to get to your Home from Masaya Highway?:

a. ___ Excellent
b. ___ Good
c. ___ Fair
d. ___ Poor

TRAVEL BEHAVIOR

7. From your home, do you have different modes of transport located at different routes that connect with Masaya Highway?:

a. ___ Yes
b. ___ No

8. Select the modes of transportation you use when you LEAVE Home to any destination in one trip:

a. ___ Walk
b. ___ Car
c. ___ Taxi
d. ___ Bus / Microbus
e. ___ Motorcycle
f. ___ Bicycle
g. ___ Moto taxi

9. Select the modes of transportation you use when you RETURN Home to any destination in one trip
a. ___ Walk
b. ___ Car
c. ___ Taxi
d. ___ Bus / Microbus
e. ___ Motorcycle
f. ___ Bicycle
g. ___ Moto taxi

10. Why do you choose these modes of transport?:
a. ___ Is the mode of transport closest to my Home
b. ___ Is my preferred mode of transport
c. ___ Is the only one available leading to Masaya Highway
d. ___ Others, please specify:

11. From the previous question, select the type of transport you use the MOST:
a. ___ Car
b. ___ Taxi
c. ___ Bus / Microbus
d. ___ Motorcycle
e. ___ Bicycle
f. ___ Moto taxi

12. What time is your first trip when you leave home?:
a. ___ 12:00 – 12:59 am
b. ___ 1:00 – 1:59 am
c. ___ 2:00 – 2:50 am
d. ___ 3:00 – 3:50 am
e. ___ 4:00 – 4:59 am
f. ___ 5:00 – 5:50 am
g. ___ 6:00 – 6:59 am
h. ___ 7:00 – 7:59 am
i. ___ 8:00 – 8:59 am
j. ___ 9:00 – 9:59 am
k. ___ 10:00 – 10:59 am
l. ___ 11:00 – 11:59 am
m. ___ 12:00 – 12:59 pm
n. ___ 1:00 – 1:59 pm
o. ___ 2:00 – 2:50 pm
p. ___ 3:00 – 3:50 pm
q. ___ 4:00 – 4:59 pm
r. ___ 5:00 – 5:50 pm
s. ___ 6:00 – 6:59 pm
t. ___ 7:00 – 7:59 pm
u. ___ 8:00 – 8:59 pm
v. ___ 9:00 – 9:59 pm
w. ___ 10:00 – 10:59 pm
x. ___ 11:00 – 11:59 pm
y. ___ I have no set schedule / Depends

13. Select the reason why you travel from home at these hours:
a. ___ My day schedule starts at this hour
b. ___ Streets are less congested at this hour
c. ___ The transportation mode I use is not frequent in my area
d. ___ I depend on someone else
e. ___ Other, please specify:

14. Indicate how many minutes it takes to make this trip (when you leave your home):

_______ Minutes

15. What time do you start your trip back home?:
a. ___ 12:00 – 12:59 am
b. ___ 1:00 – 1:59 am
c. ___ 2:00 – 2:50 am
d. ___ 3:00 – 3:50 am
e. ___ 4:00 – 4:59 am
f. ___ 5:00 – 5:50 am
g. ___ 6:00 – 6:59 am
h. ___ 7:00 – 7:59 am
i. ___ 8:00 – 8:59 am
j. ___ 9:00 – 9:59 am
k. ___ 10:00 – 10:59 am
l. ___ 11:00 – 11:59 am
m. ___ 12:00 – 12:59 pm
n. ___ 1:00 – 1:59 pm
o. ___ 2:00 – 2:50 pm
p. ___ 3:00 – 3:50 pm
q. ___ 4:00 – 4:59 pm
r. ___ 5:00 – 5:50 pm
s. ___ 6:00 – 6:59 pm
t. ___ 7:00 – 7:59 pm
u. ___ 8:00 – 8:59 pm
v. ___ 9:00 – 9:59 pm
w. ___ 10:00 – 10:59 pm
x. ___ 11:00 – 11:59 pm
y. ___ I have no set schedule / Depends

16. Select the reason why you travel from home at these hours:
a. ___ My day schedule ends at this hour
b. ___ Streets are less congested at this hour

c. ___ The transportation mode I use is not frequent in my area
d. ___ I depend on someone else
e. ___ Other, please specify:

17. Indicate how many minutes it takes to make this trip (when you return your home):

_______ Minutes

18. Usually, how many trips you do every day?
a. ___ 2
b. ___ 3
c. ___ 4
d. ___ 5
e. ___ 6 or more

19. From the list, select the places that make part of your tour frequently (several days of the week):
a. ___ Work
b. ___ School / University
c. ___ Shopping
d. ___ Leisure destination (e.g.: exercise)
e. ___ Others, please specify:

20. When you make various trips, what mode(s) of transportation do you usually use?
a. ___ Walk
b. ___ Car
c. ___ Taxi
d. ___ Bus / Microbus
e. ___ Motorcycle
f. ___ Bicycle
g. ___ Moto taxi

a. Do you consider that the street network where you live influences the amount of trips you combine?
b. ___ Yes
c. ___ No

GENERAL INFORMATION:

21. Occupation:
a. ___ Student
b. ___ Employed full-time
c. ___ Employed part-time
d. ___ Unemployed
e. ___ Self employed
f. ___ Retired
g. ___ Other

22. Gender
a. ___ Woman
b. ___ Man

23. What type of vehicle do you have in your Home?:
a. ___ Car
b. ___ Bus / Microbus
c. ___ Motorcycle
d. ___ Bicycle
e. ___ Moto taxi
f. ___ None

24. Do you have any type of driver's license?
a. ___ Yes
b. ___ No

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