The Role of Carsharing in Urban Mobility: Relationship with Human, Spatial, and Modal Features in Metro Vancouver

by

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Abstract

Carsharing systems, by providing the opportunity to access a vehicle without having to own it, can be considered as a desirable component of sustainable transportation strategies. They represent the missing link in the multi-modal options of transport and a complement to public and active modes of transportation.

Previous research demonstrated that carsharing systems can be successfully implemented only in certain urban contexts, with specific characteristics referred to the built environment and the people living in it. The objective of this research is to understand which of these features have an influence on the success of two-way and one-way carsharing in Metro Vancouver.

The findings of this research showed that the usage of both two-way and one-way carsharing is strongly influenced by contextual features, including population density, car ownership, household size, and commuting modal choice. Also, availability and quality of public transit represents the most pivotal variable to ensure carsharing success. The research also provides deeper examination of the specific relationship between two-way carsharing and public transit.

Keywords: Carsharing; Sustainable mobility; Public transit; Transportation planning; Metro Vancouver;

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Chapter 1.

Introduction

1.1. Preface

Between 2010 and 2050, the number of people living in the world's urban areas is expected to grow by 80 percent, from 3.5 billion to 6.3 billion (United Nations, 2014). This growth will pose significant challenges for urban mobility and for the networks of transportation facilities and services that maintain the flow of people into, out of and within the world's cities. Addressing the challenge of urban mobility is essential for maintaining cities' historic role as the world's principal sources of innovation and economic growth, for improving the quality of life in urban areas and for mitigating the impact of climate change (United Nations, 2014). This will require creative applications of new technologies, changes in the way transportation services are organized and delivered, and innovations in urban planning and design (United Nations Habitat, 2013).

Until the last few years, automobile-based travel has been pivotal to the planning of cities in North America allowing people who were able, or chose, to drive to get from anywhere to anywhere in relative comfort. However, this kind of development has also led to many negative consequences such as urban sprawl, traffic congestion, enhanced social division, environmental damage, health degradation, economic difficulties and deprivation of individual freedom. In this context, the concept of sustainable transportation has been developed in city planning and design in order to tackle these problems, to improve the long-term sustainability of cities and to offer greater transportation choices to a broader range of people. The key strategy of sustainable transport is to develop highly accessible cities that reduce the need to travel by private car without limiting individual mobility (Givoni & Baninster, 2013).

In this context, carsharing can be regarded as a desirable component of a sustainable transportation system, representing a missing link in the multi-modal options of transport and a complement to public and active modes (Britton, 2000). Public transit alone cannot completely substitute for private cars. Neither can carsharing.
Even if people live near a reliable and frequent transit network, many still require a

private car to satisfy specific mobility needs. Transit service can be adequate at the origin of the trip, but this could not be the case for the destination or vice versa. It is the integration of the different modes of transportation that creates an opportunity for cities to reduce auto dependency (Newman & Kenworthy, 2000). The key to sustainable transportation is to allow people to satisfy these mobility needs without having to own, and therefore to rely on, a personal car.

That being said, this research seeks to explain what relationship does exist between carsharing, public transit and socio-demographic and geographic characteristics of the Metro Vancouver area. This objective has been pursued using GIS graphic elaborations and statistical analysis that have tested the influence that different variables associated with public transit and with socio-demographic and geographic features have on the usage of two different carsharing schemes, two-way and one-way carsharing (whose peculiarities are described in the next chapter). The research analysis provides a detailed understanding of the current usage patterns of carsharing in the Metro Vancouver region, showing which variables have a direct correlation and thus influence the service.

This research complements the vast body of study that has already been produced and, undoubtedly, will continue to be produced around carsharing. However, in the existing literature, research that analyzes the correlation between carsharing, public transit and geographic, socio-demographic variables, on a small scale, such as the one presented in this thesis, is absent. Also, no other research has undertaken a comparative analysis in the same geographic context of both one-way and two-way schemes of carsharing service.

Understanding carsharing and its patterns in an urban environment is fundamental. The service provides citizens with an additional transportation option that is complementary with other sustainable modes and that will allow people to reduce their dependence on private cars. By considering both two-way and one-way carsharing, we gain the opportunity to compare the two schemes and to obtain useful findings to better comprehend the potential impact of carsharing on sustainable transportation strategies.

The thesis proceeds in the following order:

This Chapter 1 provides a background for the research topic: it illustrates the concept of carsharing, its history and trends and the current situation in the Metro Vancouver region. It also introduces the research question and the expected outcomes that this research foresees.

Chapter 2 contains a literature review that is crucial to fully understand the research context. Three themes of literature describe the benefits of carsharing, the relationship between carsharing and other modes of transportation and the necessary requisites that allow carsharing to succeed in urban environments.

Chapter 3 explains the data collection used for the research and discusses the methodology adopted in the data analysis to respond to the research question.

Chapter 4 thoroughly discusses the correlation analysis between the dependent and independent variables. It also focuses and deepens the relationship between carsharing and public transit.

Finally, Chapter 5 provides some conclusions that can be made considering the research findings and presents and a series of recommendations for future researches on the topic.

1.2. Background

1.2.1. What is carsharing?

Carsharing represents an innovative transportation service that allows people to use a car when needed, without having to bear the costs and responsibilities of ownership. In other words, it converts automobile use from a product into a service, providing people with the use of a car instead of its property (Sullivan & Magid, 2007).

Among the different definitions, carsharing can be defined as “a membership program intended to offer an alternative to car ownership under which persons or entities that become members are permitted to use vehicles from a fleet on an hourly basis” (Millard-Ball et al., 2005).

Carsharing differs from ride sharing or carpooling for the fact that it is not designed to transport a group of individuals to a common destination at the same time. Instead, it represents an alternative to private vehicle ownership that provides access to a car when walking, cycling or public transit is not possible or convenient (Katzev, 2003).

Carsharing also differs from automobile renting because, if needed, it gives an individual access to a car for short and brief trips, charging only for the duration and the distance of each trip. On the other hand, rental agencies are less flexible, usually charging the full daily rate regardless of the length of travel. In addition, renters must purchase the gasoline required to fill the vehicle's tank before it is returned, while carsharing cost already includes fuel, insurance, vehicle maintenance, service, and repairs. Rental cars are usually located only in central city areas or major transportation hubs, like airports, while carsharing vehicles are spread within some regions of the city. Renting requires the completion of time-consuming papers before a vehicle can be accessed, while access to carsharing is immediate and can be done simply through the provider's website or mobile app (Katzev, 2003).

Nowadays, there are two different carsharing service models: two-way and one-way (also known as free-flow systems). Two-way systems, which were the first to appear on the market, restrict vehicles to be picked up from and returned to the same designated location. On the other hand, one-way carsharing systems introduced more flexibility by allowing members to walk up to and take any available vehicle, at any time, without indicating a specific return time or station, as long as it is inside a designated operational area (Feigon & Murphy, 2016).

In addition, there is a more recent scheme called peer-to-peer (p2p), which allows private car owners to earn money at times when they are not using their vehicles by making them available for rental to other carshare members (Feigon & Murphy, 2016). The fundamental idea of this "personal vehicle sharing" is to allow short-term access to privately owned vehicles, offering a lower operating cost and a wider vehicle distribution. This type of system can be valuable in improving the shared-use market as private vehicles enable the potential to expand the range of geographic environment (i.e., suburbs) and to overcome some financial issues that can be among the constraints of more traditional carsharing schemes (Shaheen et al., 2012). However, a range of barriers such as insurance and liability, technology, vehicle availability and trust still need to be addressed.

The field of personal vehicle sharing is still pretty much unexplored, and more research is needed in order to assess market potential and its social, economic and environmental impacts (Shaheen et al., 2012).

1.2.2. A brief history of carsharing

Carsharing has a relatively short history, and it is only during the recent years that it is increasing its popularity and emerging as an alternative mode of transportation. The first carsharing experience can be traced to an early cooperative, called “Sefage”, which initiated its service in Zurich, Switzerland, in 1948. The primary goal was to attract individuals who could not afford to purchase a car but who found the sharing option appealing (Shaheen et al., 1999).

After this launch, no other experiences were reported until the 1970s, when some public carsharing experiments were undertaken, but soon failed, in Europe. The main reasons for these failures were generally inadequate planning, poor marketing and lack of support from local governments (Shaheen et al., 1999).

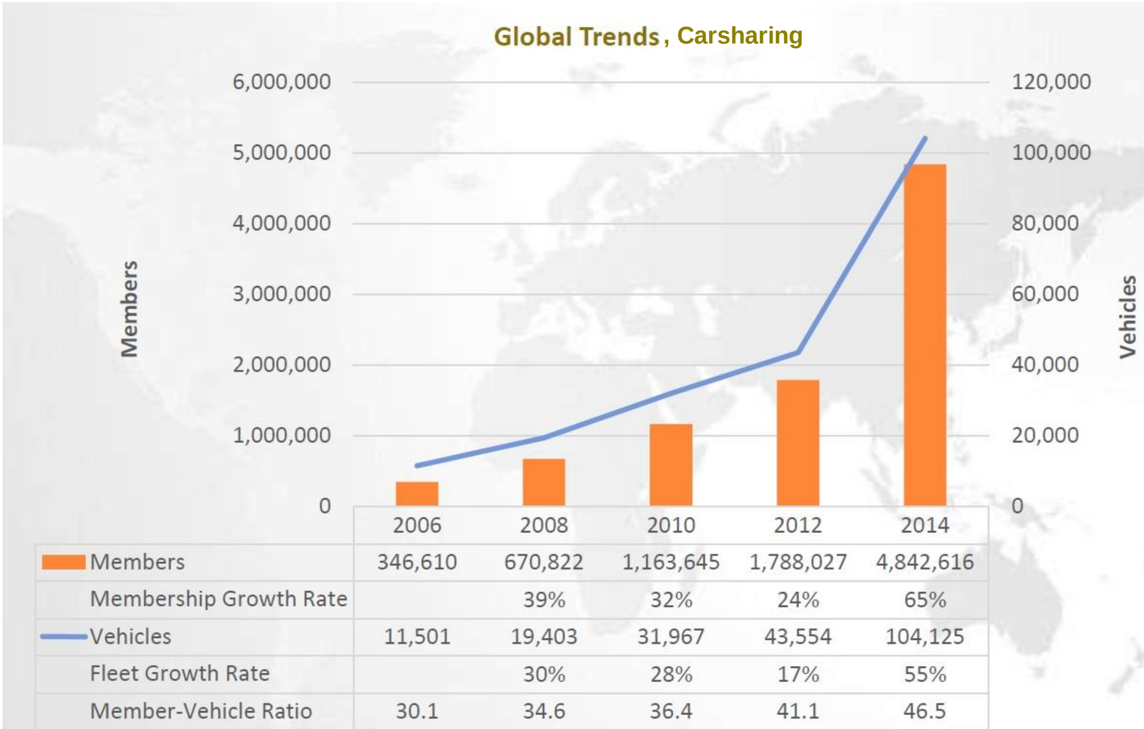
More successful examples began in Europe in the late 1980s, when approximately 200 carsharing operators were active in 450 cities through Switzerland, Germany, Austria, the Netherlands, Denmark, Sweden, Norway, UK and Italy (Shaheen et al., 1999).

The service eventually expanded to North America in 1994, when the predecessor of the current “Communauto” launched the service in Quebec City. In 1998, carsharing also arrived in the United States, specifically in Portland. Since then, carsharing numbers started to proliferate.

In 2008, one-way carsharing was introduced in Germany by Car2Go, allowing members to pick up vehicles without a reservation, and drop them off in different locations. As said, this model allowed for greater spontaneity and flexibility in the trip making, and exponentially enlarged the carsharing user basin because of its greater attractiveness compared to the more traditional scheme.

As of October 2014, carsharing was operating in 33 different countries, five continents, and more than 1,500 cities where approximately 5 million people were sharing more than 100,000 vehicles. Europe, the largest carsharing region, accounted for 46% of worldwide membership and 56% of the global fleet deployed. On the other hand, North America accounted for 34% of worldwide members and 23% of the vehicle fleet (Shaheen et al., 2016).

Figure 1.1 clearly illustrates the global growth trends of carsharing in recent years.



	2006	2008	2010	2012	2014
Members	346,610	670,822	1,163,645	1,788,027	4,842,616
Membership Growth Rate		39%	32%	24%	65%
Vehicles	11,501	19,403	31,967	43,554	104,125
Fleet Growth Rate		30%	28%	17%	55%
Member-Vehicle Ratio	30.1	34.6	36.4	41.1	46.5

Figure 1-1: Carsharing global trends 2006-2014
Source: Adapted from Innovative Mobility Carsharing Outlook, Shaheen & Cohen, 2016

1.2.3. Carsharing in Metro Vancouver

Carsharing arrived in the Metro Vancouver region in 1996, when Cooperative Auto Network (which later changed its name to Modo) was founded. C.A.N began as a sustainable community development research project at Simon Fraser University, and it aimed to promote carsharing as an environmentally responsible alternative to personal vehicle ownership. This was the very first successful carsharing co-op example in an English-speaking region and the second oldest carsharing service in North America (Government of Canada, New Economy Development Group, 2006).

Along with the launch of the service, the city of Vancouver also modified regulations to specifically allow carsharing services to operate in its neighborhoods. One of these regulations was the reduction of parking requirements for buildings that introduced carsharing services. This incentivized developers to substitute multiple parking spaces in buildings with a significantly reduced number of areas designated for carsharing vehicles (Government of Canada, New Economy Development Group, 2006).

A decade after Modo, precisely in 2007, Zipcar entered the Metro Vancouver market. Then, the one-way car sharing scheme arrived in 2011 with Car2go, and soon after with Evo Carshare that has been the latest provider to join the Lower Mainland market. With four different carsharing providers serving the region, Metro Vancouver is one the jurisdictions with the most extensive variety of carsharing offered in the world.

As of 2016, the region had 450 vehicles from Modo, 600 vehicles from Evo, 1,275 vehicles from Car2go and 225 vehicles from Zipcar, for a total number of 2,550 shared vehicles (Durning, 2016). These numbers made Vancouver the second city in North America for the total number of shared vehicles (after New York City) but the one with the highest number of shared vehicles per citizen (Namazu, 2017).

Figure 1-2: Examples of Modo, ZipCar, Evo and Car2Go vehicles

Regarding the geographic distribution of shared vehicle parking spots (two-way carsharing) and operating areas (one-way carsharing), the higher concentration of vehicles is apparently within the Downtown Core of Vancouver and the surrounding neighborhoods. However, in recent years, car share providers have started to expand and to enter the market in North Vancouver City, Richmond, Burnaby, New Westminster, and Surrey. In most of these new locations, vehicles have been placed near SkyTrain stations or on university campuses.

The following figures show the shared cars parking locations (for the two-way scheme) and the extension of the operational area and distribution of satellite parking (for the one-way scheme) in Metro Vancouver. These maps are updated as of December 2017, and each one refers to one of the four different carsharing providers active in the region.

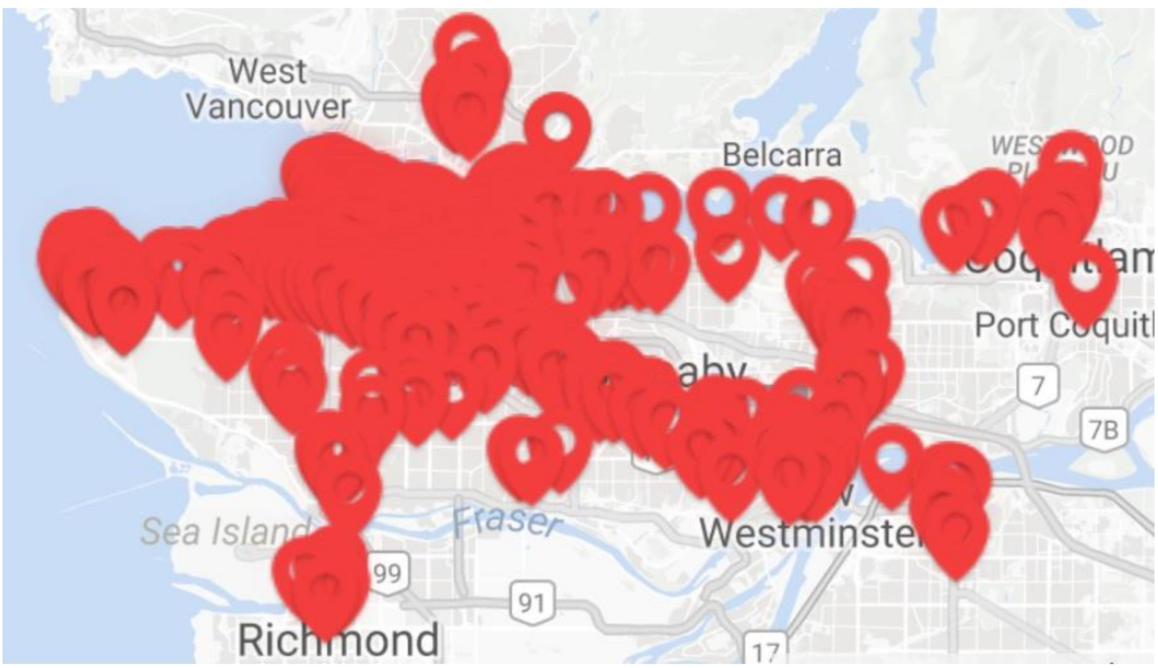


Figure 1-3: Modo carsharing locations distribution in Metro Vancouver
Source: Adapted from Modo website, December 2017(http://www.modo.coop/map/)

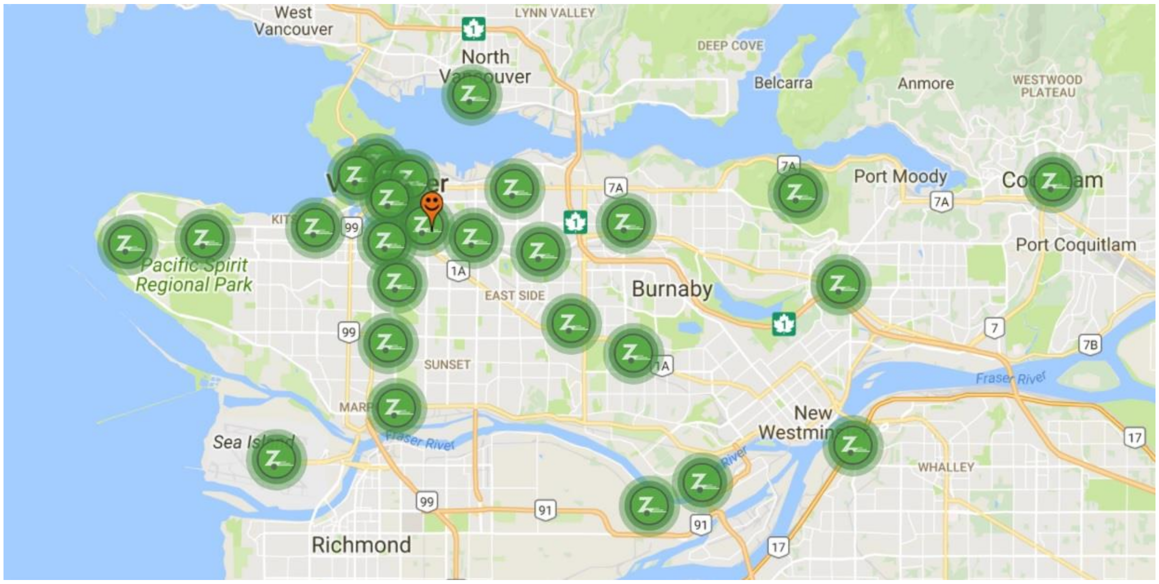


Figure 1-4: Zipcar carsharing locations distribution in Metro Vancouver
Source: Adapted from Zipcar website, December 2017 (http://www.Zipcar.ca/vancouver)

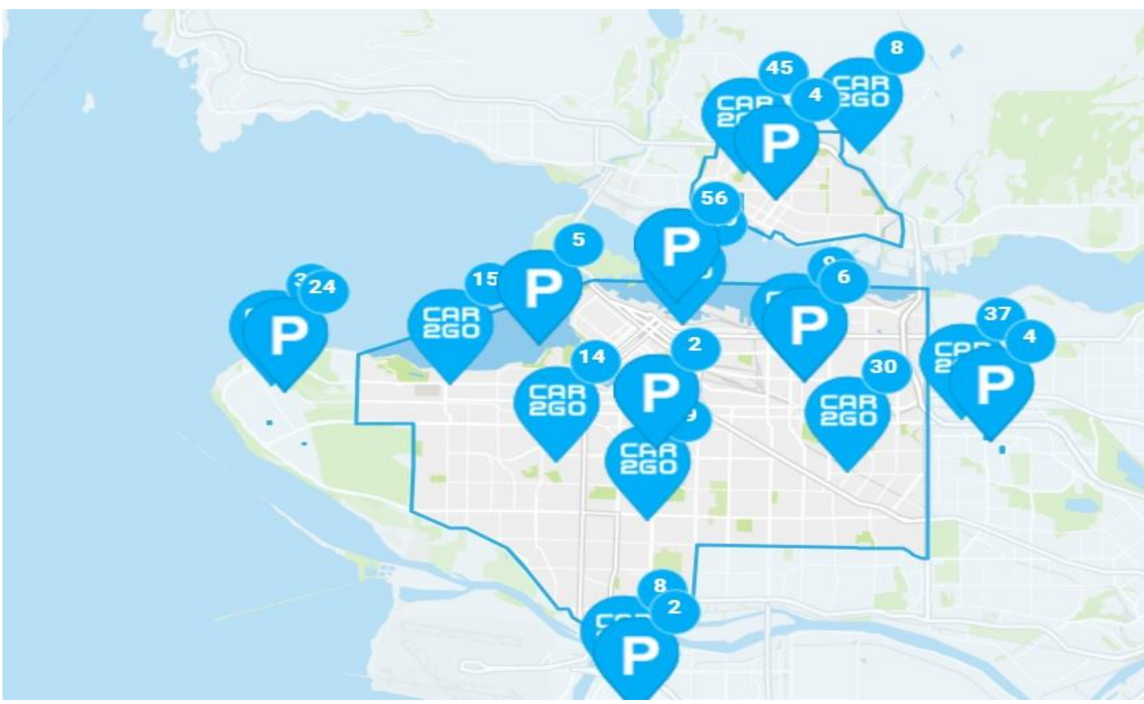


Figure 1-5: Car2Go operational area in Metro Vancouver
Source: Adapted from Car2Go website, December 2017
(https://www.car2go.com/CA/en/vancouver/where/)

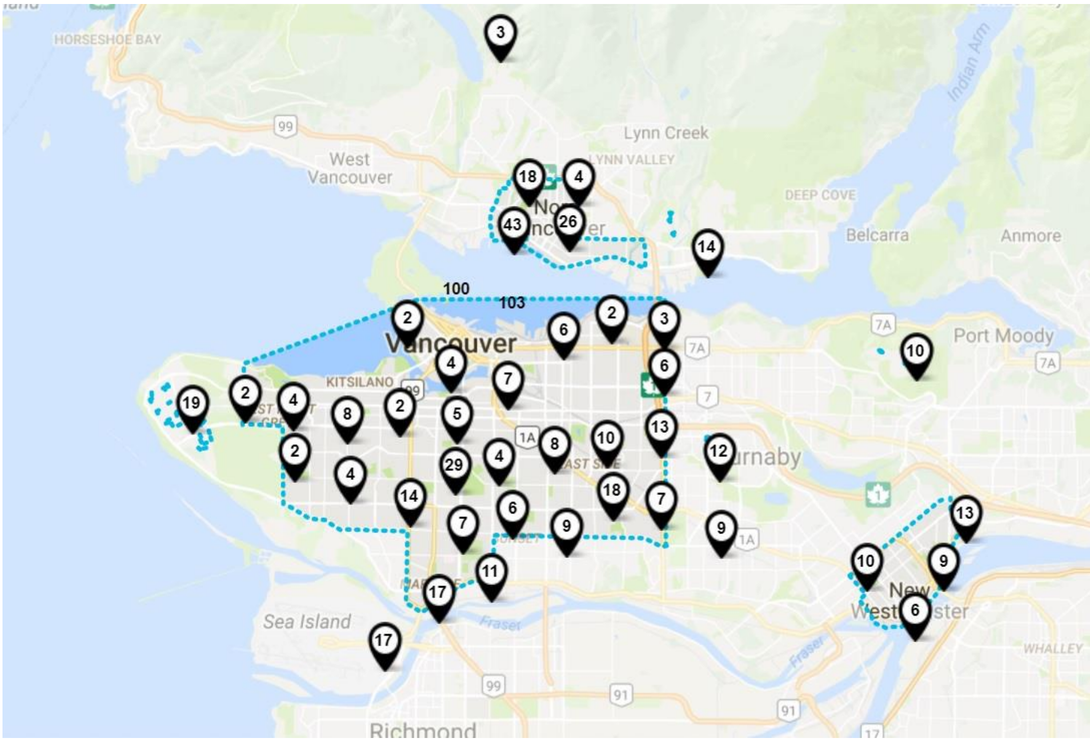


Figure 1-6: Evo Carshare operational area in Metro Vancouver
Source: Adapted from Evo Carshare website, December 2017 (https://www.evo.ca/)

The numbers presented in this section demonstrate that Vancouver is one of the most advanced carsharing cities in the world, and can serve as a model for its implementation. The market can be considered mature enough in to understand the dynamics and analyze the carsharing distribution, usage, and patterns, which is the primary purpose of this research, as explained in detail in the following section. Given these considerations, Vancouver can be considered an excellent case study to pursue research on carsharing.

1.3. Research Question

The specific research question that my thesis addresses is the following:

What type of influence do a location's geographic, socio-demographic characteristics and public transit availability have on the usage of two-way and one-way carsharing in Metro Vancouver?

As the question says, the purpose of the thesis is to understand specific aspects of the existing relationship between carsharing and the characteristics of Metro Vancouver locations where two-way and one-way carsharing services are being used. These characteristics include public transit availability and a series of geographic, socio-demographic features. Specially, the geographic and socio-demographic variables have been chosen after an extensive literature review that showed the influence, either positive or negative, that these variables had on carsharing usage in other urban contexts. Among the others, these variables incorporate population density, dwelling typology, household size, income, education, car ownership and the preferred mode of transportation of their residents.

The relationship between these variables and the usage of carsharing is described in Chapter 4. Even if the analysis extensively illustrates the correlation between various geographic, socio-demographic features and carsharing, the primary focus of the research is on the correlation that the shared car service has with public transit. The reason for that is because, among all the factors and variables that influence carsharing success, different studies showed that the availability of an efficient public transit infrastructure that allows people to rely on public transit is mandatory in order to implement a successful carsharing system in an urban environment (Communauto, 2004; Communauto 2006; Huwer, 2004; Millard-Ball, 2005; Feigon & Murphy, 2016). Carsharing alone is not meant to be a substitute for private cars. It is the integration of carsharing and public transit that can provide an opportunity to reduce car dependence.

The final goal of the correlation analysis is to show how each variable interacts with carsharing and to illustrate how the usage of two-way and one-way services varies under different variables that are proper to Metro Vancouver' locations.

1.4. Expected outcomes

It is expected that the results of this research will be helpful for different stakeholders.

First, it can help carsharing providers' understanding of their business case by showing how the use of shared cars is correlated with the proximity, level of service of public transit and to geographic, socio-demographic variables. This can accelerate the viability testing process in order to bring additional cars in current locations or new locations (for two-way carsharing providers) or to expand the operational service area (for one-way carsharing providers).

Second, it can help TransLink to increase its collaboration and relationships with carsharing providers. This especially concerns the concession of reserved parking spots in proximity with transit stations and within "mobility hubs", i.e., places where different modes of transportation come together seamlessly, especially in providing customers the flexibility of combining driving with transit (TransLink, 2017)

Finally, it can help municipalities reduce their parking requirement policy in favor of the provision of reserved parking for carsharing, especially for those buildings that are part of transit-oriented developments.

Also, it is possible that the findings from this thesis, that uses Metro Vancouver as the area of study, and the methodology that has been used in the analysis, could also be applicable to other cities and their private and public stakeholders. Many cities in other parts of the world are showing a very similar carsharing adoption path to that of Metro Vancouver, and being able to better understand the phenomenon through similar analyses would definitely be helpful for the future of the service and a more sustainable destiny for the cities. However, it is worth noting that, contrary to many other cities in the world where carsharing exists alongside by ride-hailing services (for example Uber or Lyft), in Metro Vancouver, these innovative services are not part of the market at the time of this research. It is impossible to accurately predict how their presence might affect the carsharing usage and, more generally the whole transportation landscape of the region. This is not part of this thesis, but it might be fascinating to include them in future research once ridesharing has entered the Lower Mainland mobility market.

Chapter 2.

Literature Review

The main goals of this literature review are to establish the foundation of the research question, contextualizing the topic and providing the necessary background. In addition, it underlines the thesis' relevance and validity in the broader context of urban studies and specifies the elements that will be taken into account in the research analysis. In order to do that, the following themes have been identified to categorize the literature:

1. Literature identifying the potential social, economic, and environmental effects that carsharing brings to both the cities and its users.

2. Literature analyzing the role of carsharing in the transportation landscape and its relationship with public transit and other modes of transport.

3. Literature identifying the different socio-demographic and geographic variables that ensure carsharing success in urban environments.

The first theme is fundamental in order to introduce the research as it highlights the importance and relevance of carsharing in the broader context of sustainability in urban environments. This will help explain why people should care about this research and how carsharing can directly contribute to a more sustainable future in cities.

The second theme sets the role that carsharing should have in the transportation environment and explains the relationship with other transportation modes, especially with public transit.

The third theme serves the methodology that will be used in order to respond to the research question. Specifically, the theme identifies which geographic and socio-demographic variables have the most considerable influence on carsharing success. Therefore, these variables will be considered in the analysis in order to describe the relationship between carsharing usage and the characteristics of the locations where the service is being utilized in Metro Vancouver.

2.1. Potential social, economic, and environmental effects of carsharing

As illustrated in the previous chapter, this research aims to produce a series of findings that could be useful for carsharing providers, transit operators, and municipalities. The ultimate goal that should be addressed by these stakeholders is to improve and expand carsharing systems in order to offer citizens a valid alternative to private car dependency and to support sustainable transportation strategies. This first literature review theme presents the principal reasons why carsharing should be considered an essential element for sustainable transportation strategies and, more in general, a crucial topic to be studied and researched.

The different reasons to consider carsharing as a key element towards a more sustainable future in cities and to justify the importance of studying this topic are shown in this first literature review theme.

So far, a considerable number of studies has attempted to evaluate the positive effects that carsharing can bring to both the cities where the system is implemented and to its users. The typical benefits found by these different studies are illustrated in the following paragraphs.

Reduction in vehicle ownership

The first positive and most notable impact that is usually linked to carsharing is its ability to reduce vehicle ownership, both in terms of vehicles sold after joining carsharing and in terms of avoided car purchasing. In 2008, Martin & Shaheen conducted a survey where they collected 6,281 responses from members of major North American carsharing organizations. The goal of the survey was to establish a “before and after” analytical design to focus on different impacts of carsharing. Results showed that the average vehicle per household dropped from 0.47 to 0.24, with most of this shift constituted by one-car families becoming carless (Martin & Shaheen, 2010). The aggregated analysis showed that each carsharing vehicle in North America has been able to take from 9 to 13 private cars off the road (Martin & Shaheen, 2010).

Other studies and member surveys released by U.S. and Canadian carsharing organizations showed that 15% to 32% of carsharing members sold their vehicles, and between 25% and 71% of members avoided an auto purchase because of carsharing. In other words, carsharing is capable of removing between 4.6 to 20 cars per shared-use vehicle from the transportation network, with variance due to methodological differences between the studies (Shaheen et al., 2008; Cervero & Tsai, 2003; Lane, 2005; Millard-Ball et al., 2005; Communauto, 2006; Cervero et al. 2007).

That being said, it is worthy to note that the vast majority of carsharing members usually belongs to households with significantly lower car ownership rates than the average. Members also rely on public transit and active transportation modes much more frequently than non-members (Communauto, 2006).

In Metro Vancouver, a study that involved 3,405 car share households in the region, found that each carshare vehicle removed between 5 and 11 private personal cars (Metro Vancouver, 2014).

Savings on transportation costs

Reduced car ownership also means economic advantages for households. In owing a vehicle, it is common that most of the people tend to underestimate its real costs, especially those that are not encountered daily such as insurance, license fees, and maintenance. In this sense, carsharing makes the complete cost of driving more transparent. This allows people to choose the appropriate mode of transport, as they can compare the marginal costs for all modes for each journey.

Different studies have found that, because of carsharing, the average monthly transportation costs also decreased, ranging from $154 to $435 for U.S. members and CAD392 to CAD492 for Canadian members (Shaheen et al., 2008; Cervero & Tsai, 2003; Lane, 2005; Millard-Ball et al., 2005; Communauto, 2006; Cervero et al. 2007; Cohen et al., 2008).

Comparing the cost per trip done by carsharing and by private car, it was found that for people who drive less than 5,000 miles per year, carsharing is the most cost-effective solution (Millard-Ball et al., 2005).

Impact on vehicle kilometers traveled

Carsharing has an essential effect on the kilometers traveled by cars. Martin & Shaheen found that the average observed vehicle kilometers traveled (VKT) per year declined by 27% (Martin & Shaheen, 2011). Considering other members' surveys, Shaheen et al. calculated a 44% average VKT reduction per carsharing user (Shaheen et al., 2008; Cervero & Tsai, 2003; Lane, 2005; Millard-Ball et al., 2005; Communauto, 2006; Cervero et al. 2007).

In Metro Vancouver, about 50% of households with no vehicles before joining carsharing reported driving more after joining. In contrast, about 30% of households with cars before joining carsharing reported a decline in driving after joining (Metro Vancouver, 2014). That said, the overall net effect is a decline in kilometers travelled. The total reduction in kilometers travelled is greater than the total increase, even if there is a higher percentage of people that increased their driving. In other words, more people increased driving by a little, and fewer people decreased driving by a lot. However, the overall decrease is more significant than the overall increase.

Reduction in Greenhouse Gas Emissions and other pollutants

Along with reduced vehicle kilometers traveled and vehicle ownership, carsharing contributes to lower greenhouse gas (GHG) emissions. Martin & Shaheen found a negative balance in GHG emissions (-0.84 t GHG/year) considering the difference between households which reduced emissions by shedding vehicles and driving less and households who increased their emissions by gaining access to a car (Martin & Shaheen, 2011). A study on carsharing in Lisbon found that carsharing can bring reductions of 35-47% in terms of energy consumption and 35-65% in terms of CO_2 emissions (Baptista et al., 2014). In Dublin, it has been calculated that carsharing introduction saved around 86 kT of CO_2 emissions per annum (Rabbit & Ghosh, 2016). In addition, the carsharing fleet can employ smaller than average or alternative-fuel vehicles, such as battery-powered electric cars that can bring additional emissions reductions (Litman, 2000; Ryden & Morin, 2005).

Reduction in parking space requirements

The reduced number of cars circulating due to carsharing means less congestion on the streets but also reduced need for parking. This is particularly important in many urban areas where parking is scarce, and its provision could be costly. Another benefit is represented by potentially reduced parking requirements for new developments: the incorporation of carsharing service allows the opportunity to take the parking demand into account at the time that governmental documents determine parking ratios (Shaheen et al, 2008; Glotz-Richter, 2012).

Increased mobility for users

Carsharing provides people who cannot own a private car the ability to use a vehicle occasionally. This is particularly important since non-drivers' mobility is often constrained. Giving people who currently have no access to an automobile the ability to drive when it is essential, is likely to serve relatively high-value trips that are presently foregone or performed inefficiently by other modes (Litman, 2000). Increased accessibility also means more social equity by improving the mobility options of people who are transportation disadvantaged, as they cannot afford a personal vehicle, and for example, they cannot equally compete with others when a car is needed for job searching and employment (Litman, 2000). Studies have demonstrated that low-income households without access to a car exhibit more dimensions of social exclusion, specifically income and unemployment, than low-income families with higher rates of car ownership (Currie et al., 2010).

All these results showed in this literature review theme support the fact that carsharing introduction brings positive effects to the cities and its users. However, one of the most critical effects has not been discussed yet. It is the impact that carsharing can have on other transportation modes, and especially on public transit. Understanding the role of carsharing in the transportation landscape and why it can form a strong alliance with public transit represents the core of the next literature theme and the central element around which this research question has been built.

2.2. The relationship between carsharing, public transit, and other transportation modes

This research attempts to understand the relationship between the usage of carsharing and the characteristics of the urban locations in which the service is successful. Among these characteristics, great importance is given to public transit availability and its level of service. The decision to focus on this aspect has been taken because different studies have shown that carsharing is suitable as a supplement to public transport and not as its competitor (Communauto, 2004; Communauto 2006; Huwer, 2004; Millard-Ball, 2005; Feigon & Murphy, 2016). However, even if carsharing and transit are considered good complements, none of the previous studies have focused on how the availability of transit, its level of service and its usage influence the usage of two-way and one-way carsharing. This is the main gap that this research seeks to fill. That being said, this theme provides the necessary background to understand what the role of carsharing should be in the transportation landscape and what its relationship is with other modes of transport, including public transit.

In order to address the different challenges of urban mobility and the strong dependence on private cars, creative applications of new technologies and innovative changes in the way transportation services are organized and delivered are required. In particular, one of the goals for sustainable transportation is the development of inter-modality (i.e., the use of different means of transport for the same trip) and multi-modality (i.e., the use of different means of transport during separate trips by the same user) strategies (Vivre en Ville, 2013). The idea is that only a good combination of different modes of transport represents a satisfying transportation offer that can be an alternative to the possession and usage of private cars. A single mode of transport, taken individually, cannot adequately serve the entirety of the travel needs of people which depends on many factors, including travel distance and desired flexibility (Communauto, 2006).

In such strategies, carsharing is regarded as being a desirable component of a sustainable transportation system, representing the “missing link” between different modes of transportation and a key to combined mobility (Communauto, 2006). In other words, transit, cycling, walking, and taxis can often meet most mobility needs, but there will still be other trips for which a private car is required. Carsharing, under this hypothesis, can fulfill these needs and allow users to do without a private car (Millard-Ball et al., 2005). The integration of carsharing into transport strategies gives the opportunity to fill the gap of a quick, capillary, and flexible mobility that other modes cannot satisfy (Communauto, 2006).

The relationship between carsharing, public transport, active transport and other modes (taxis and rental cars) is also effectively represented in Figure 2.1 below.

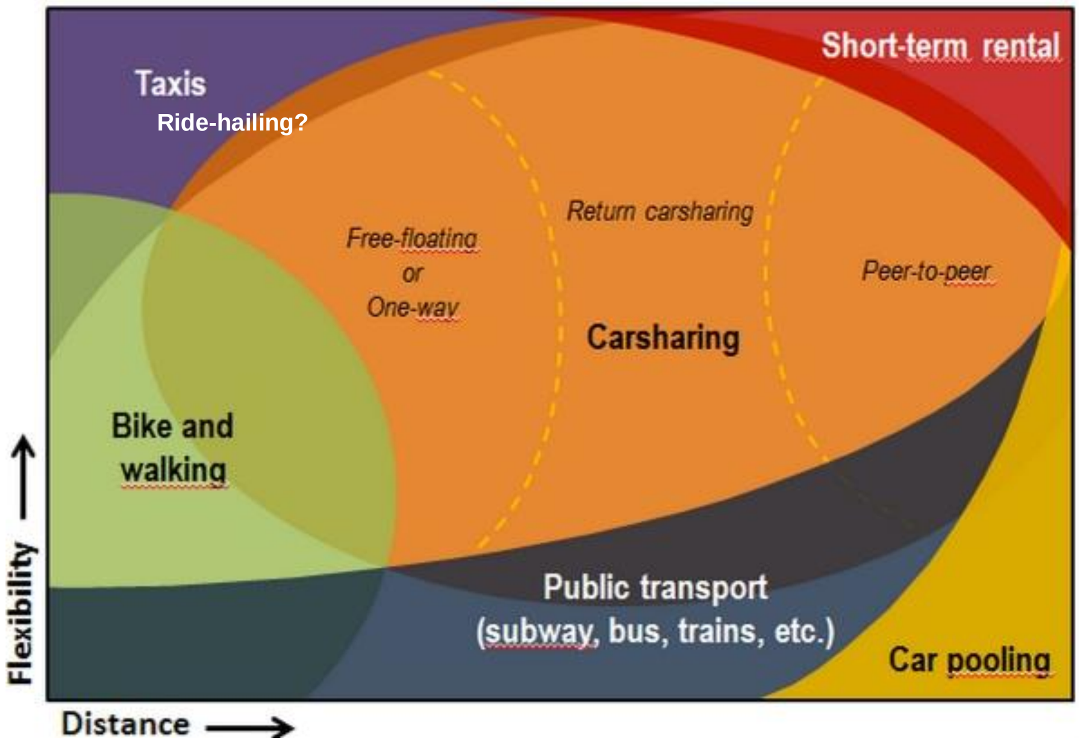


Figure 2-1: Relationship of carsharing with other transportation modes
Source: Adapted from Pilloy, 2014

This figure shows that the integration of carsharing into transport strategies gives the opportunity to offer people the whole range of mobility, including car use (Huwer, 2004). Public transport can be used for short (bus, subway) and longer (train) trips, but it does not offer enough flexibility for all purposes. Taxis and bicycles provide great flexibility, but distance limits them due to costs, effort and time. Car rental serves other needs as it is generally used for trips over a few days when flexibility is required.
The gap between these usual modes of transport is for those journeys with particular purposes when traveling by car is required, such as visiting a special place, transporting something or traveling at an unusual time. Carsharing is capable of bridging this gap

sustainably (Huwer, 2004). What the graph does not include are the recently-launched ride-hailing services (such as Uber, Lyft, etc.), i.e., services that connect travelers with drivers offering to transport them in exchange for payment. Their specific role in the transportation landscape has yet to be defined, however, it is generally believed that in conjunction with other modes, including public transit, they can provide a cost-effective alternative to personal car ownership (Mowat Centre, 2016).

Recent research examined the specific relationship between carsharing and public transit by surveying shared mobility users and interviewing transit officials in seven American cities (Austin, Boston, Chicago, Los Angeles, San Francisco, Seattle, and Washington). As foreseen, the findings showed that greater use of shared modes is associated with higher likelihood to use transit frequently, own fewer cars, and have reduced transportation spending. Shared modes mostly complement public transit, enhancing urban mobility (Feigon & Murphy, 2016).

In addition, combined results from other surveys previously made in North America found that 12% to 54% of carsharing participants walked more often, around 10% bicycled more often and 13.5% to 54% took public transit more frequently than before they joined the service (Shaheen et al., 2008; Cervero & Tsai, 2003; Lane, 2005; Millard-Ball et al., 2005; Communauto, 2006; Cervero et al. 2007; Sioui et al., 2012). In Europe, surveys made in Germany and Belgium proved that respectively 32% and 22% of carsharing users increased their public transportation usage (Koch, 2001; Glotz-Richter, 2012).

More contrasting results come from a 2015 Transportation Sustainability Research Center (TRSC) report which studied the modal shifts of student and business users of the two-way carsharing service ZipCar. The study found that, among the students, only 9% respondents used public transit more but 31% used it less; 7% biked more, 8% less; 12% walked more, 12% less. On the other hand, the business users showed more positive findings, showing that the 41% members who eliminated car ownership entirely used public transport more often and 41% walked more. Just 13% confirmed they took public transport less and 7% walking less (Bondorova & Archer, 2017).

In conclusion, it can be said that the great majorities of studies do collectively show consistent benefits from carsharing schemes and that these do largely encourage beneficial behaviors which complement and support the use of public transport operations more than directly competing with them (Bondorova & Archer, 2017). Specifically, most carsharing approaches have positive benefits both reducing car ownership (and therefore all the impacts associated with that) and lowering the vehicle kilometers driven (and hence environmental impacts of car use). Furthermore, a small reduction in car ownership is estimated to significantly increase demand for public transport. In the long term, if there is a notable shift from ownership to accessing cars, there could be substantial environmental and health benefits (Bondorova & Archer, 2017).

Even if there has been some public debate on whether shared mobility create a positive environmental impact and complements traditional transport services by providing an alternative to individual car ownership, or worsen existing car dominance, it is believed that more transportation options can reduce car ownership and trips and, in some cases, create more transit riders by easing access to public transit. These "new" models can be complementary to transit because, by encouraging an alternative to cars, they tend to increase the proportion of trips for which users take transit (Mowat Centre, 2016). Greater integration between shared mobility and public transit is a key next step in harnessing the complementary value of shared mobility.

These findings, and what has been presented in this literature theme, are part of the rationale that stands behind my research. That being said, even if carsharing and public transit might be considered a strong alliance, my research wants to demonstrate what is the correlation between availability, level of service, and usage of transit, and the usage of two-way and one-way carsharing in Metro Vancouver.

2.3. Socio-demographic and geographic variables that ensure carsharing success

The previous theme showed that several studies agreed that public transit and carsharing can be complementary modes and that a good and efficient infrastructure that allows people to rely on public transit is mandatory in order to implement a successful carsharing system. However, public transit availability is not the only variable that influences the usage and adoption of carsharing. Many studies have identified a series of geographic and socio-demographic variables that play a critical role to ensure carsharing success in an urban environment.

That being said, the goal of this research is not only to test the relationship between carsharing and public transit in Metro Vancouver, but to expand this analysis to include other the variables that have been found to be influencing carsharing usage in different urban contexts. These variables are related to specific characteristics of a location, and this third theme identifies them based on what has been found in previous studies and research.

Since its first implementation in the late 1940s, carsharing has long been a niche service, unable to attract a substantial share of the urban population. In recent years, the game has changed because modern information technology has allowed the schemes to be more user-friendly and social trends favoring sharing over ownership support their adoption (Becker et al., 2017; Shaheen & Cohen, 2013). That being said, the full potential of carsharing can only be realized by understanding the market niches where the service is most attractive.
Millard-Ball et al. found that these niches can be characterized in two broad ways: Demographic, i.e., the groups that are most likely to join a carsharing program, and Geographic, i.e., the neighborhoods where carsharing vehicles can be placed to best effect (Millard-Ball, 2005). In other words, the socio-demographic variables refer to the characteristics of the individuals, while the geographic variables refer to the features of the built environment.

Considering the socio-demographic aspects, different studies have found that the typical carsharing users show some common characteristics worldwide. The following has been found:

-Carsharing appears to be more attractive to men rather than women (Millard-Ball et al., 2005; Harmer & Cairns, 2011; Loose, 2010)

-The majority of members are singles or live in small sized households (Millard-Balll et al., 2005; Cervero & Tsai, 2003; Harmer & Cairns, 2011; Loose, 2010)

-Users are in general well-educated people with median or higher than average income, usually cost-sensitive and with an environmental consciousness (Millard-Ball et al., 2005; Andrew & Douma, 2006; Cervero et al., 2007; Muhr, 2009)

-Most of the users live in households without cars, and public transport represents the most common mode of transportation for daily commuting (Millard-Ball et al., 2005; Synovate, 2007)

Different studies have also described the geographic factors (Cohen et al., 2008; Millard-Ball et al., 2005; Sullivan & Magid, 2007). In particular, Millard-Ball et al. showed that there are four common characteristics necessary for carsharing to succeed:

-High density. Density has two significant impacts on the viability of carsharing. The first one is that there is a broader customer base within walking distance of each shared vehicle. The second one is that dense neighborhoods have lower rates of car ownership and travel (Millard-Ball et al., 2005).

-Ability to live without a car. As explained in the previous literature theme, carsharing is not designed to meet people's entire mobility needs, but to work in concert with other modes such as transit. The availability of good public transportation is therefore key, along with a good pedestrian and bicycle network (Millard-Ball et al., 2005).

-Mix of uses. This factor is also important for two different reasons. The first one is that mixed neighborhoods offer more local opportunities to allow people to be less car-dependent. The second one is that in such areas there could be two types of potential uses: business uses with higher rates during the day, and personal uses with peak demands on evenings or weekends (Millard-Ball et al., 2005).

-Parking pressures. Car ownership is more expensive in places where parking is scarce, making carsharing a relatively more attractive option (Millard-Ball et al., 2005).

The variables that have been described in this literature theme are summarized in table 2.1 below:

Table 2.1: Geographic and Socio-Demographic variables connected to carsharing

Socio-Demographic	Geographic
Single or small households	High density
Well-educated	Ability to live without a car
Higher than average income	Mix of uses
Low car ownership	Parking pressures
Public transport for daily commutes	

As said, this theme is fundamental to identify the variables that will be part of the correlation analysis, and for which the impact on the usage of two-way and one-way carsharing in Metro Vancouver will be assessed. The next chapter provides all the specifics on the variables and indicators that have been used considering the findings of the literature review and the data available.

Chapter 3.

Data sources and Methodology

As this thesis is based on a significant amount of data that has been collected and analyzed, the purpose of this chapter is twofold. Firstly, it introduces all the data, along with its sources, which has been included in the thesis. Secondly, it thoroughly describes the methodology used to analyze the data to respond to the research question.

3.1. Data sources

This research has been realized with the collaboration of two carsharing providers, Modo (two-way scheme) and Evo (one-way scheme), and of TransLink, the public transit authority of Metro Vancouver. Their involvement has enormously contributed to the research thanks to their willingness to share a massive amount of data. The data provided from these agencies, along with the data from Statistics Canada and the data from Insurance Company of British Columbia, has been used to illustrate the usage patterns of carsharing in Metro Vancouver in relationship with public transit and geographic, socio-demographic features. This data constituted the fundamental basis for the development of a comprehensive statistical and graphic analysis whose findings provide the response to the research question.

3.1.1. Statistics Canada

The first source of data is represented by Statistics Canada which is the Government of Canada agency commissioned with producing statistics to help better understand Canada, its population, resources, economy, society, and culture. This is the resource used to obtain most of the data for the geographic and socio-demographic characteristics defining Metro Vancouver locations.

This information is described by a series of variables that have been chosen considering the findings from the third theme of the literature review illustrated in section 2.3. These variables are either related to the built environment (geographic) or the characteristics of the individuals (socio-demographic). The reason why they have been chosen is that, as demonstrated in previous research and other urban contexts, they have either a positive or negative influence on the usage of carsharing.

Due to data availability limitations, not all the variables indicated in the literature review have also been included in this analysis. However, it is safe to say that the chosen ones are more than enough to provide an exhaustive description of the relationship between carsharing usage and the locations' characteristics in the study area.

The geographic and socio-demographic variables obtained from Statistics Canada that are included in this analysis in order to be correlated with the usage of carsharing are:

- Population density
- Type of dwelling
- Size of Households
- Rental housing
- Education
- Income
- The preferred mode of commute to work

All these variables have been gathered from the most recent 2016 Statistics Canada Census. Section 3.2.1 provides detailed descriptions of how these variables have been included in the analysis and what are the specific indicators chosen to represent them.

3.1.2. Insurance Corporation of British Columbia (ICBC)

The second source of data is represented by the Insurance Corporation of British Columbia (ICBC), which is a publicly owned auto insurance provider. The reason why this entity has been involved in the data collection is that, by law, any vehicle registered and driven or parked on public streets in British Columbia must be covered by ICBC's insurance. Therefore, ICBC represents an appropriate source in order to obtain information regarding the vehicle population in Metro Vancouver.

As said in the literature review, information on private automobile possession is very important to carsharing. Different studies have shown how members of households owning multiple vehicles are significantly less likely to join a carsharing program compared to members of families with either one or zero private cars (Millard-Ball et al., 2005; Communauto, 2006) Understanding how car ownership levels vary in Metro Vancouver and how they are correlated with carsharing usage represents an important part of the analysis.

The data provided by the insurance corporation includes the number of vehicles registered in each postal code of British Columbia as of September 2017. As for the other socio-demographic and geographic variables, section 3.2.1 in the second part of this chapter will provide the details describing how this data has been included in the analysis and which indicator has been chosen to delineate the data.

3.1.3. TransLink

The public transit data represents a crucial element of this thesis, as the relationship between carsharing and public transit constitutes the focus of this thesis.

In order to describe the public transit information, including the transit availability, the level of service and the usage of the transportation network for different locations of the Metro Vancouver region, it has been necessary to collect a series of data from TransLink, which is the statutory authority responsible for the regional transportation network of Metro Vancouver. In particular, TransLink manages various modes of transportation including buses, SkyTrain, West Coast Express, and SeaBus.

The first data inputs from TransLink consisted of the geographic coordinates of every transit stop belonging to the Metro Vancouver transit network. Each transit stop has been classified based on its level of service, and six categories were identified:

- Skytrain Stations
- Seabus Terminals
- West Coast Express (WCE) Stations
- B-Line Stops
- Frequent Transit Network (FTN) Stops
- Other Bus Stops

The SkyTrain represents the metropolitan rail system of Metro Vancouver serving Vancouver and the surrounding municipalities. Its peculiarity is that it uses fully automated trains on separated tracks running on elevated guideways or underground. This feature makes the SkyTrain not only the fastest public transit mode to travel within Metro Vancouver but also the most reliable one. It provides high-frequency service, with trains arriving every 2-7 minutes at every station during peak hours. Trains operate between 5 am and 1.30 am on weekdays, with reduced hours on weekends. SkyTrain currently has 53 stations serving three lines: Expo, Millennium and Canada Line.

The Seabus is a passenger-only ferry service that crosses Burrard Inlet connecting the cities of Vancouver and North Vancouver, where the two terminals are located. The current Seabus fleet consists of three vessels that operate between approximately 6 am and 1 am with a frequency of 15 minutes, or 30 minutes during the evenings or early weekends.

The West Coast Express (WCE) is a commuter railway that serves the Lower Mainland providing a link between Metro Vancouver and the Fraser Valley Regional District. The WCE operates only during weekdays, with five trains per day running from Mission to Downtown in the morning peak hours and returning to Mission in the evening peak. There are currently eight stations: Waterfront, Moody Centre, Coquitlam Central, Port Coquitlam, Pitt Meadows, Maple Meadows, Port Haney, and Mission.

The B-Line is an express bus line with bus rapid transit elements. There are currently 3 B Lines: 95 B-Line connecting Simon Fraser University with Burrard Station (34 stops), 96 B-Line joining Guilford Exchange and Newton Exchange in Surrey (25 stops) and the 99 B-Line connecting the University of British Columbia to Commercial-Broadway station (40 stops). Also, four new rapid transit B-Line routes are launching in Metro Vancouver in 2019.

The Frequent Transit Network (FTN) represents a network of corridors where transit service runs at least every 15 minutes in both directions throughout the day and into the evening, every day of the week. In the analysis, all the bus stops that belong to this network of corridors have been considered as FTN stops. The study considered 6396 bus stops as part of the FTN corridors.

Other bus stops include all those stops that are neither served by an express bus (B-Line) nor part of the FTN. The analysis considered 9021 stops as part of bus corridors that are not identified as FTN.

Figure 3.1 below illustrates the distribution of the six different types of transit stops that can constitute the entire public transit network of Metro Vancouver.

The second data input from TransLink was obtained through the latest version of the annual Transit Service Performance Review (TSPR) which was released in July 2018 (TransLink, 2018). With the publication of the TSPR, for the first time in their history, TransLink made publicly available data on the usage of their transportation network at the transit stop level of detail. This means that it has been possible to gather the daily average number of boardings and alightings for every single transit stop in Metro Vancouver, including bus stops, SkyTrain stations, SeaBus Terminals and West Coast Express Stations. Section 3.2.2, in the second part of this chapter, will provide more details on how this data has been incorporated into the analysis.

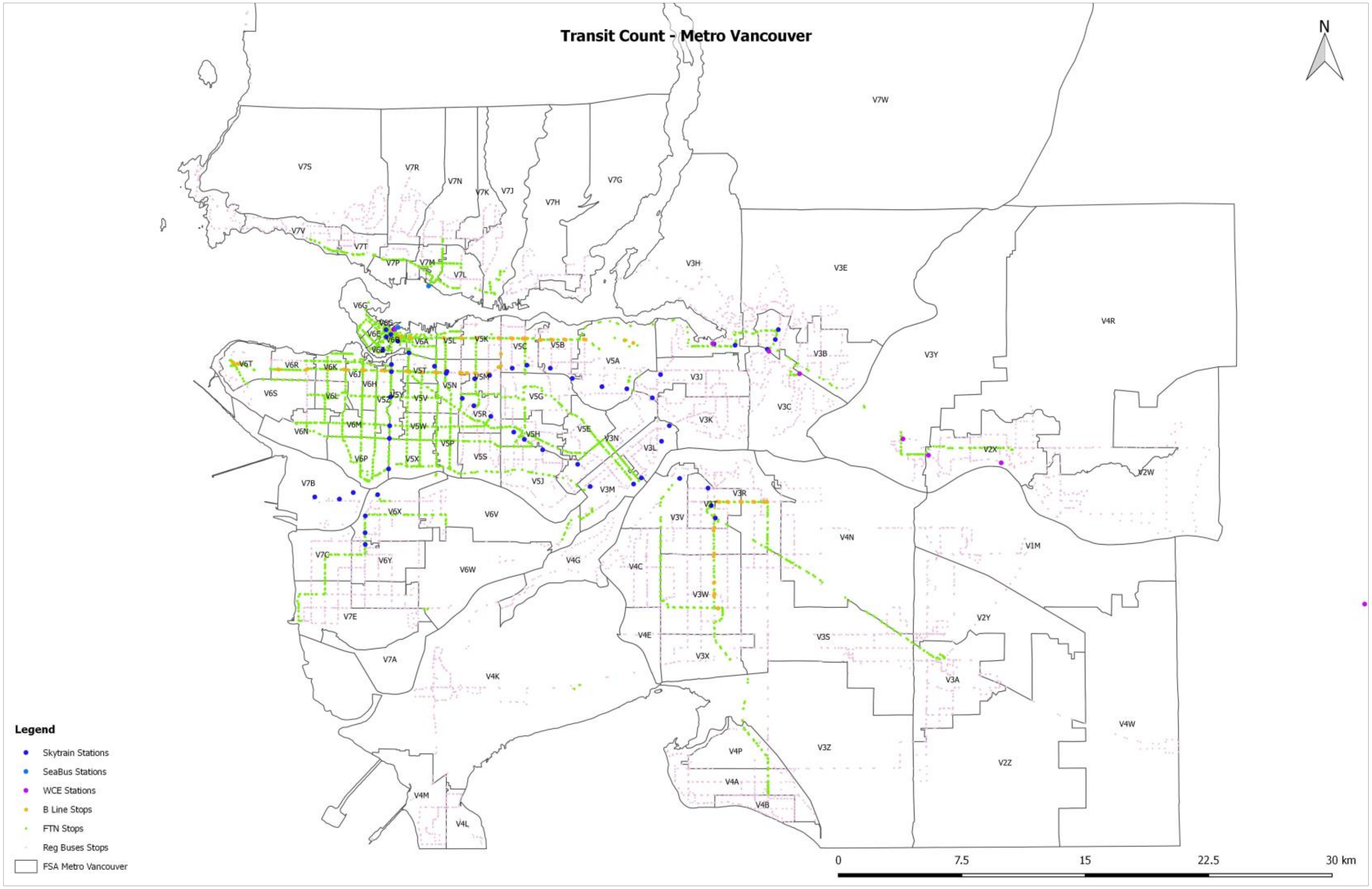


Figure 3-1: Transit Stops distribution in Metro Vancouver
Source: Author's illustration of TransLink and Statistics Canada data, 2018

3.1.4. Modo Co-operative

Modo represents, along with ZipCar, one of the two-way carsharing providers that operate in the Metro Vancouver area. As said before, the two-way scheme implies that all the vehicles must be picked up only at specific designated locations, which is also where the vehicle must be returned at the end of the trip.

Modo started its operations in 1997, being the first carshare in British Columbia and the second in North America. Its goal was to provide his members with a service that could reduce the need for private vehicle ownership while supporting an affordable lifestyle and reduce traffic congestion and parking problems. In other words, they aimed to improve the livability of the community.

Nowadays, the service is used by more than 20,000 private members, businesses, developers and municipal partners across the Lower Mainland, Vancouver Island, and the Okanagan.

As of December 2017, considering the Metro Vancouver region (which is the area of study of this research), Modo counted around 13,000 active members, who are using 544 cars distributed in 412 different locations.

For the thesis, the data that has been received from Modo consisted of a spreadsheet containing all the trips that have been effectuated in the Lower Mainland between January 1st, 2017 and December 31st, 2017. Within this period, there have been 229,070 trips made with Modo cars. Each one of them is listed in a separate line of the spreadsheet.

Specifically, each line of the spreadsheet contained the following information associated with every single trip:

- The location (unique ID, name and geographic coordinates in latitude and longitude) where the Modo car was picked up (and also returned as Modo operates following the two-way carsharing scheme)
- The vehicle used for the trip (unique ID, car model, year)
- The distance of the trip (in kilometers)

- The duration of the trip (given by the trip start time and the trip end time)

- The driver that made that trip identified by a unique ID and by the geographic coordinates of his home address. However, for privacy reasons, the geographic coordinates did not represent the exact location of the driver's home address. Instead, they indicated a point, randomly chosen, falling within a 400 meters radius around the actual driver's home address. More information about this approximation and how it has been handled is given in section 3.2.3.

3.1.5. Evo Carshare

While Modo represents the main two-way carsharing provider in Metro Vancouver, Evo is, along with Car2Go, one of the one-way carsharing companies in the region. The main feature differentiating Modo from Evo is that this latter gives users the possibility to pick up and drop off its cars in different locations, as long as they are within the so-called "home area" or in one of the designated "satellite parking locations" (such as Metrotown, BCIT, SFU, Cypress Mountain, etc.).

For the thesis, the data received from Evo consisted of a spreadsheet containing all the trips that have been effectuated in the Lower Mainland between January 1st, 2017 and December 31st, 2017, which is also the same range of dates for Modo's data. Within this period, the total number of trips made with an Evo car is 2,247,354 (about ten times the number of trips effectuated during the same period by Modo). Each one of them is listed in a separate line of the spreadsheet.

Specifically, each line of the spreadsheet contained the following information associated with a single trip:

- Unique trip ID

- The geographic coordinates (latitude and longitude) of the location where the trip started and ended (contrary to Modo, whose trips start and end in the same place, Evo operates following the one-way carsharing scheme, meaning that a trip can end in a different position from where it started)

- The distance of the trip (in kilometers)
- The duration of the trip (given by the trip start time and the trip end time)

Figure 3.2 below illustrates the distribution of Modo cars locations and the extension of Evo home area, including the satellite parking, in Metro Vancouver. As the map shows, Modo cars are spread throughout the whole region, with a higher concentration within the City of Vancouver and a presence in more suburban areas, mostly following the SkyTrain network. There are also two locations at the Horseshoe Bay ferry and Tsawwassen ferry terminals (even if this last one is not part of the map).

On the other hand, the operational area of Evo only covers the whole City of Vancouver, the University of British Columbia campus and the most central areas of North Vancouver and New Westminster (starting in May 2017). In addition, there is a series of satellite parking positioned in five specific locations within the region: YVR airport, Simon Fraser University, Metrotown, BCIT and Cypress Mountain.

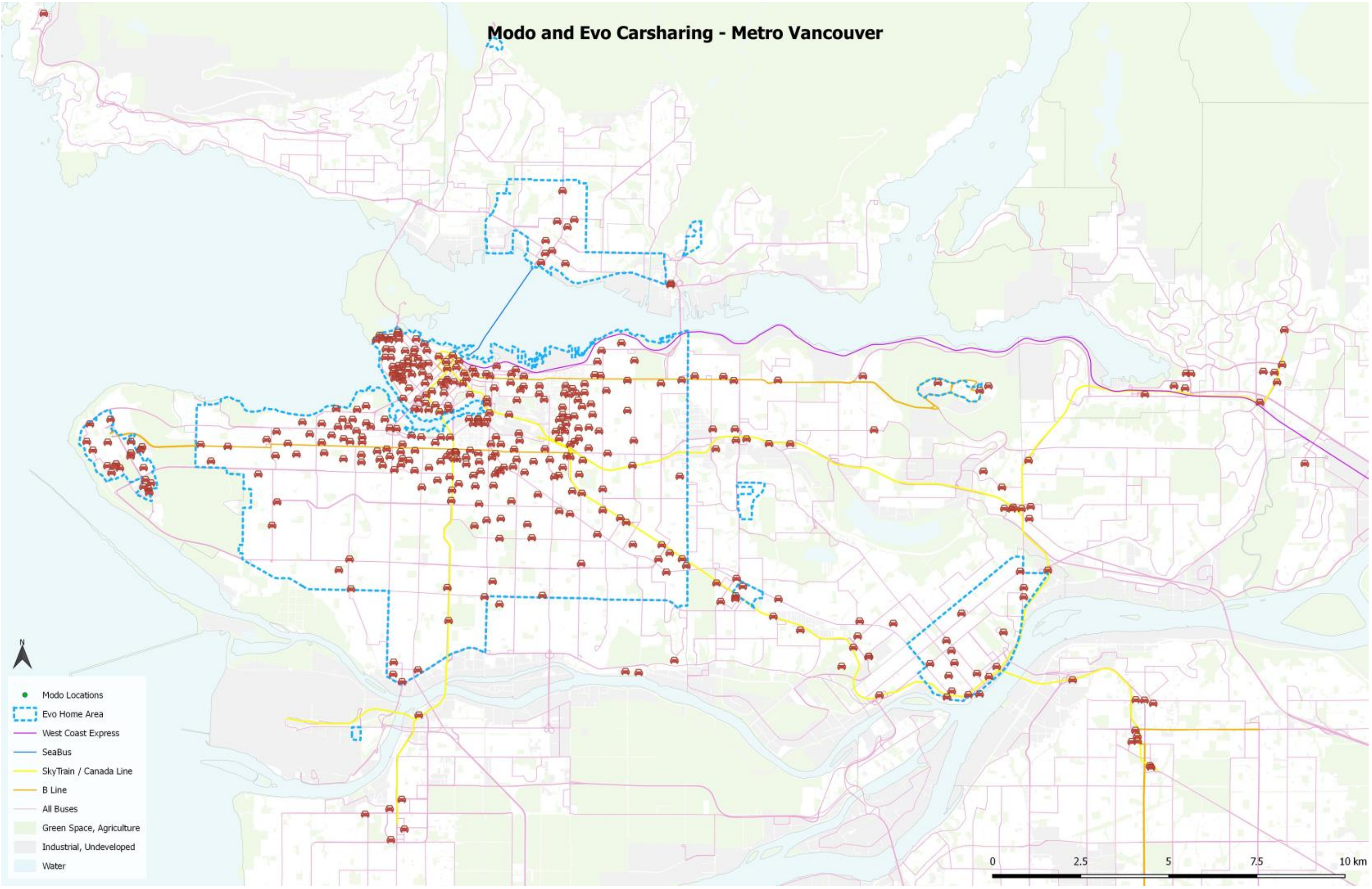


Figure 3-2: Distribution of Modo Locations, Evo Home Area and satellite parking spots in Metro Vancouver
Source: Author’s illustration of Modo, Evo, TransLink and Statistics Canada data, 2018

3.2. Research Methodology

While the first part of this chapter listed all the sources and the specific data that has been collected for the research, this second part provides a detailed description of the methodology used for the analysis to illustrate the relationship between carsharing, public transit and geographic, socio-demographic variables in Metro Vancouver.

Once again, the goal of this thesis is to understand the correlation between the usage of two-way and one-way carsharing, i.e., the dependent variables, and the public transit, geographic and socio-demographic variables, i.e., the independent variables. The general strategy to realize this objective consists in dividing the Metro Vancouver region in smaller geographic parts and in correlating the values assumed by the dependent and independent variables in each location.

Each geographic part, in which the Metro Vancouver region has been divided, corresponds to a Dissemination Block (DB). Statistics Canada defines a DB as “an area bounded on all sides by roads and/or boundaries of standard geographic areas. The dissemination block is the smallest geographic area for which population and dwelling counts are disseminated. Dissemination Blocks cover all the territory of Canada” (Statistics Canada, 2018). As roads define the DB’s shapes, their size is not constant: they are smaller in the denser neighborhoods with a tight road network and larger in peripheral and rural areas. In this research, the total number of DBs in which Metro Vancouver region has been divided is 15,197.

After dividing the study area in DBs, this research associates with each one of them, the values that the dependent and independent variables assume in that specific location. The result is the creation of a database with 15,197 different areas, each one identified by a unique DB.

Once every DB has been associated with the two-way carsharing usage, one-way carsharing usage, public transit features, geographic and socio-demographic characteristics, it is possible to correlate the variables based on the values that they assume in each location.

While the correlation analysis occupies the entire Chapter 4, the following sections of Chapter 3 explain in detail the methodology chosen to associate every single DB with a value for the dependent and independent variables and what are the indicators that have been used to describe the variables considered in the analysis.

3.2.1. Geographic and Socio-Demographic Variables

In the first part of this chapter, we introduced the eight geographic and socio-demographic variables that have been chosen for the analysis. As said before, this choice is based on the literature review: these variables have been proven to have a specific influence, either positive or negative, on the usage of carsharing.

In order to describe these eight variables, one or multiple indicators have been associated with each one of them. The specific indicators have been chosen based on the type of data available from Statistics Canada Census 2016 and ICBC, which represented the two sources for the geographic, socio-demographic information. The following table lists the variables and the chosen indicators associated with each:

Table 3.1: Geographic and Socio-Demographic Variables and Indicators

Variable	Indicator
Population Density	Population Density (person/km^2)
Type of Dwelling	% of Single-detached houses
Size of Households	% of 1-person households
Rental Housing	% of Rental housing
Education	% of Post-secondary degrees
Income	Average income per recipient
Preferred mode of commute to work	% of people driving to work
	% of people using public transit to work
	% of people walking to work
	% of people biking to work
Car Ownership	Number of cars per person

Statistics Canada Census 2016 provides the data for the first seven variables listed above for different level of geographic detail including Provinces and Territories, Census Divisions, Census Tracts, etc. As said previously in this chapter, the entire correlation analysis is done at the geographic level of a Dissemination Block. However, only the population data is available at this geographic level of detail. The information for the other nine indicators is available at the geographic scale of Dissemination Areas (DA). As a single DA is constituted by multiple DBs (generally around five), all the DBs belonging to the same DA are assigned the same values for the different indicators.

On the other hand, ICBC data came in the form of automobile population per postal code. In this case, it has been necessary to associate every postal code of Metro Vancouver with the corresponding DAs and DBs. In general, each DA contains within its borders multiple postal codes. In this case, the number of vehicles per DA corresponds to the sum of vehicles of the postal codes enclosed. However, it is also possible that a single postal code crosses multiple DAs. In that case, the number of vehicles associated with that postal code has been proportionally partitioned to the DAs intersected, based on their population. Again, as multiple DBs constitute a single DA, all the DBs belonging to the same DA are assigned the same indicator values

At the end of this first step of the analysis, the final result is that each one of the 15,197 DBs of Metro Vancouver has been assigned eleven values, one per indicator, describing the geographic and socio-demographic characteristics of that specific location.

3.2.2. Public Transit Variable

After having associated the different locations of Metro Vancouver with values describing their geographic and socio-demographic features, it is now time to associate the independent public transit variable with the different DBs. The public transit aspect represents a core element of this research, and great importance is given to the specific relationship existing between the availability, quality of service and utilization of transit and the usage of two-way and one-way carsharing. To describe the public transit variables, two indicators have been chosen: the “Transit Score” and the “Transit Activity”.

Transit Score

In order to describe the availability and quality of service of transit, a Transit Score indicator has been created. The purpose of the Transit Score is to assign to each DB in Metro Vancouver a different score based on the quality and quantity of transit service that is available nearby. To do that, the input data is represented by the entire set of transit stops in the Lower Mainland region that has been listed in section 3.1.3.

The idea of the Transit Score methodology is that each DB receives a score based on the number of transit stops that are located in proximity (i.e., walking distance) of its geographic centre. To account for the different level and quality of the transit service, each transit stop is given a different multiplying coefficient. Specifically, the following multiplying coefficients have been chosen:

- SkyTrain: 3x
- Seabus: 2.5x
- B-Line: 1.5x
- Frequent Transit Network: 0.5x
- West Coast Express: 0.5x
- Other Buses: 0.25x

These coefficients have been chosen considering the quality and level of service of the different components of the transit network of Metro Vancouver. It is important to notice that, in case this Transit Score methodology is applied to another urban context, it might be possible that the multiplying coefficients are different. The reason is that they strongly depend on the specific peculiarities of the city’s transportation system.

The other important thing of the Transit Score methodology is that transit stops are assigned to a DB in case they are situated in proximity of its geographic centre. Proximity is considered differently for each type of transit stop, and it can be described as the distance that people are ready to walk in order to access a specific type of transit service. Therefore, this distance varies with the quality of the service propose at the transit stop. Considering the Metro Vancouver transportation network, it is generally accepted that most people will walk up to 800m to access limited-stop rapid transit (SkyTrain), up to 600 meters to access a limited stop transit (B-Line), and up to 400 meters to access frequent local transit stop (FTN). (TransLink, 2012). Also, 800 meters has been chosen as proximity for the Seabus terminal and WCE stations and 400 meters for the other buses not belonging to the frequent transit network.

Having set a multiplying coefficient and a threshold of proximity for the different type of transit stops, each DB receives a score. This score is generated by the sum of the transit stops, multiplied by the coefficient that takes into account the quality of the service, that fall within a particular buffer, whose radius is equal to the proximity distance for that specific type of service. It is necessary to specify that if the same transit stop is in proximity to more than one DB, each DB will have that transit stop counted in its score.

Once every DB receives a score based on all the transit stops located in proximity, a ranking is created. At the top of the ranking are the DBs that have the most and best transit available nearby and, at the bottom, the DBs that have no transit available nearby. The calculations showed the highest Transit Score is 205.5 and the lowest score is 0.

However, since the measure of the number of stops in the transit infrastructure has its unique range, it is necessary to normalize the Transit Score and to generate a score from 0 to 100. This has been done by converting the original score on a logarithmic scale, where the highest value becomes 100 and the lowest 0. This logarithmic conversion has been chosen as it might match a rider’s experience better. The main reason for this is that the added utility of an additional bus in an area with poor transit service may exceed the addition of more new routes in more central areas with stronger service (Walk Score, 2018).

The Transit Score procedure has been developed using a GIS software. The GIS allowed to join each DB to the transit stops whose proximity buffers include the geographic centre of the DB. This is represented in Figure 3.3.

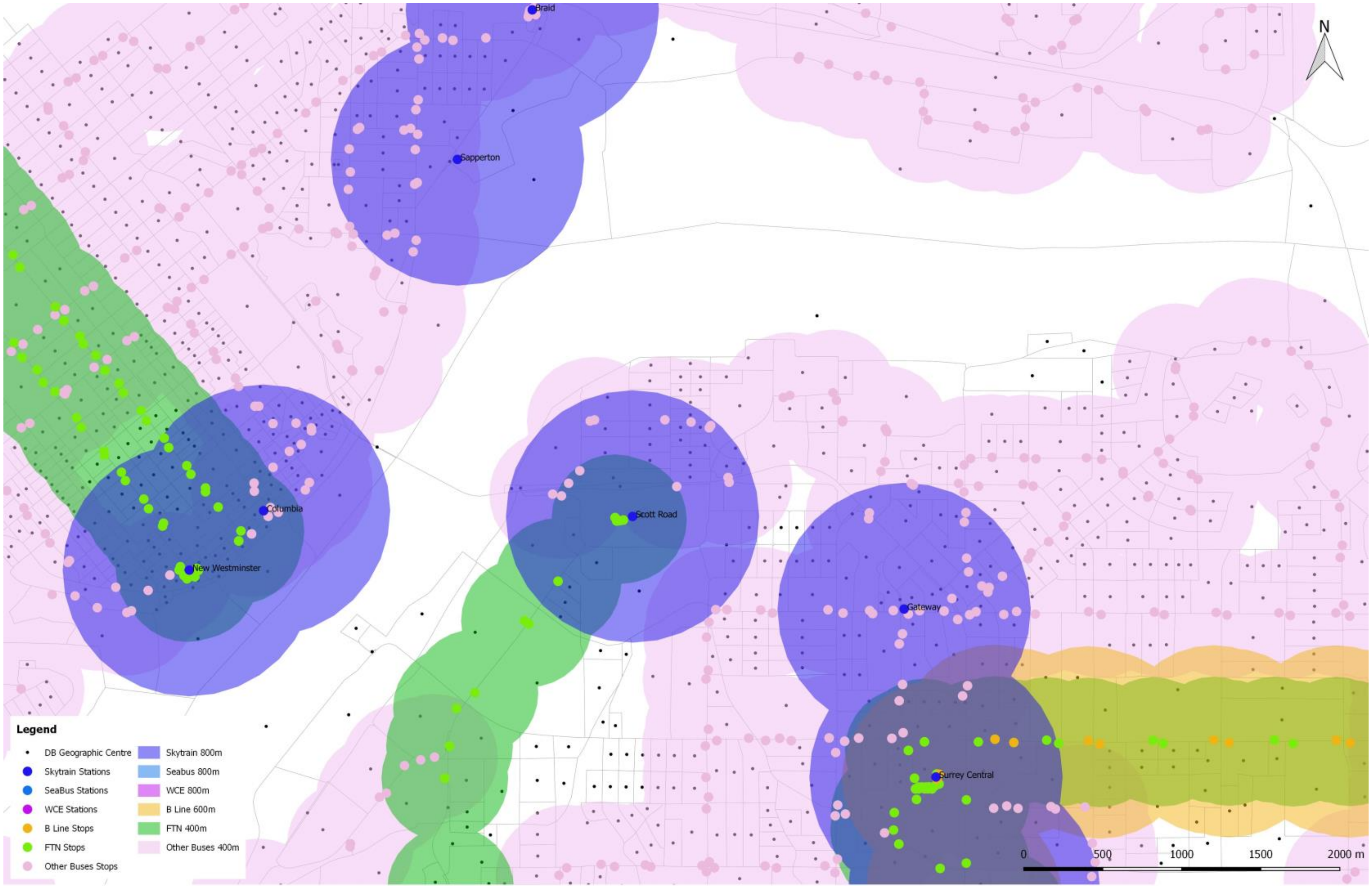


Figure 3-3: Example of Transit Stops counting using GIS software
Source: Author's illustration of TransLink and Statistics Canada data, 2018

Transit Activity

While the Transit Score has been created to describe the availability and level of service of public transit, the Transit Activity indicator measures how much the Metro Vancouver transit network is being used in the different locations of the region.

The creation of the Transit Activity indicator has been made possible by the fact that, in 2018, for the first time in its history, TransLink included a new data point in its annual Transit Service Performance Review: namely the network usage at the transit stop level of detail. This means that the data available included the average daily boardings and alightings for every single transit stop, including bus stops, B-line stops, SkyTrain stations, SeaBus terminals and West Coast Express stations.

In order to create the Transit Activity indicator, the same methodology used for the Transit Score has been applied. Each DB of Metro Vancouver receives a value for the Transit Activity which is the sum of the activity of all the transit stops that are located in proximity (i.e., walking distance) of its geographic centre. In this case, the activity of each transit stop is measured as the sum of average daily boardings and average daily alightings. The proximity considered is the same that has been used for the Transit Score: 800 meters for SkyTrain stations, SeaBus Terminals and West Coast Express Stations, 600 meters for B-Line stops and 400 meters for all other bus stops. As happened for the Transit Score, in case a transit stop is located in proximity to more than one DB, each DB will have the activity of that transit stop counted in its Transit Activity indicator value.

The creation of the Transit Score and the Transit Activity indicators provide a clear picture of the pattern of the public transit system infrastructure and usage in Metro Vancouver. With the eleven geographic and socio-demographic indicators introduced in the previous section and these two public transit indicators, the independent variables included in the analysis are fully described. The following two sections explain in details the indicators used to describe the dependent variables, i.e., the usage of the two-way and one-way carsharing.

3.2.3. Two-way Carsharing Variable

The previous two sections described the process of assigning to each DB of Metro Vancouver the indicators representing the geographic, socio-demographic and public transit variables, i.e., the independent variables used in the correlation analysis. The next step is to assign to each DB a series of indicators that can describe the use of two-way and one-way carsharing in the Lower Mainland, i.e., the dependent variables.

It is useful to recall that, to correlate the usage of two-way carsharing with the geographic, socio-demographic and public transit variables, it is necessary to outline Modo usage for each DB.

Given the data obtained from Modo, two different aspects of the usage of the two-way carsharing service have been included in the analysis. The first one considers the usage of the different carsharing locations, while the second one considers the usage by Modo members. In the analysis, the first aspect will be described by an indicator called “Modo Location Activity”, while the second one will be described by an indicator called “Modo User Activity”.

As said in section 3.1.3, the available data from Modo contains all the trips that have been made between January and December 2017. Among the other information, each trip is associated with the carsharing location where the trip originated (and terminated) and with the geographic coordinates of the home address of the users who made that trip. This is the crucial information that has been used to create the Location Activity and the User Activity indicators.

Modo Location Activity

The first indicator, the Location Activity, provides the total number of carsharing trips associated with each DB that is in proximity of one or multiple Modo locations.

The first step for its construction consists of using a pivot table to aggregate the trips per location and then obtaining the total number of trips that have been made from each location in the time-period considered (January 2017 – December 2017).

The second step consists of assigning to each DB the number of trips made from the Modo locations that are located in walking distance proximity. To perform this, the same method seen before in the association of DBs with the nearby transit stops has been used. A buffer is created around every carsharing location, and all the DBs whose geographic centers fall within the buffer are considered as being in proximity of that specific carsharing location. To specify, one DB can be associated with multiple carsharing locations and multiple DBs can be associated with the same carsharing location.

The walking distance threshold for considering a carsharing location in proximity has been set to 800m, the same used for SkyTrain stations, SeaBus terminals, and West Coast Express stations. The reason of this is that different studies have demonstrated that carsharing users are very concerned about their mobility choices. Many members have the financial capacity to own a car but decide not to. Consequently, members can be considered to be highly motivated to use this mode of transport (Grasset & Morency, 2010). This is why proximity to a carsharing location has been considered in the same way as the proximity to a rapid transit service or with limited stations.

Following these two steps, each DB in Metro Vancouver receives a value for the Location Activity indicator equal to the sum of all the trips that have been made from all the carsharing locations considered in proximity to that specific DB.

Modo User Activity

The second indicator, User Activity, provides the total number of carsharing trips associated with each DB in which the user that made that trip has its home address. This indicator is also proportional to the total number of persons living in that DB.

Contrary to the Location Activity, which considered the fixed Modo locations distributed in Metro Vancouver and the number of trips made from each one of them, the User Activity considers the home address of the drivers associated with every trip made. In other words, the User Activity outlines the locations where the most active Modo carsharing users live.

The first step to create the User Activity indicator is using a pivot table to aggregate the trips made by the same driver, who has a specific geographic coordinate indicating his home address. In this case, an approximation is required by the fact that the user location, for privacy reasons, is not the exact location of the home address but a randomly chosen point that falls within a 400 meter radius around the actual driver's home address. For this reason, a carsharing user and the number of trips made by that user cannot be automatically associated with the DB that contains the geographic coordinates of the user's home address.
Instead, each Modo user and its number of trips made are associated with all the DBs, whose geographic centre is within 400m from the user's home address, that contain a residential land use destination and that have a population different from zero. Also, in order to make the approximation the closest possible to reality, Modo users (and trips associated) are partitioned to the DBs proportionately to the population of that specific DB.

These two examples will better illustrate this aproximation:

1. Modo's User A has made ten trips between January and December 2017. User A's home address is located within 400m of two DB's geographic centers (DB1 and DB2). DB1 has a population of 10 people, while DB2 has no residential land use destination and zero people living within it. In this case, DB1 will be assigned one car sharing user and ten trips, while nothing while be assigned to DB2

2. Modo's User B has made 12 trips between January and December 2017. User A's indicated home address is located within 400m of two DBs' geographic centers (DB3 and DB4). DB3 has a population of 10 people, while DB4 has a population of 20 people. In this case, both DBs will be assigned a certain amount of users and trips proportionately to their population. DB3 will be assigned a share of 0.33 carsharing users and four trips, while DB4 will be assigned a share of 0.66 carsharing users and eight trips.

This way, each DB can be assigned a share of all the users (and trips) whose home address is within 400m from the user's location, proportionately to the number of people who live in that DB.

Finally, the User Activity indicator is represented by the sum of all the trips made by drivers assigned to each DB divided by the number of people living in the DB.

The following two figures represent the geographic distribution of the two indicators introduced: the Modo Location Activity and the Modo User Activity.

In Figure 3.4, the total number of carsharing trips made in DBs in proximity to carsharing locations is represented. Of course, only the DBs whose geographic center is within 800m of a carsharing location show a value greater than zero for this indicator. From the map, it is possible to understand that there is a significant difference in the concentration of trips made in different locations of the region.

It is important to notice that DBs with the highest values of the Modo Location Activity, such as those in Downtown or along the Broadway/Commercial corridor, have the highest number of associated carsharing trips, not only because the Modo locations in those areas are used more than other locations, but also because their density is much higher than the location's density in suburban or more external areas. This results in a DB being in proximity to multiple Modo locations and consequently having a much higher value for the Location Activity indicator.

In Figure 3.5, the number of carsharing trips per 100 persons made by users living in a DB is represented. Even if the User Activity values are slightly more spread out in the region, they generally follow the distribution of the location's activity. In other words, the majority of Modo users have their home address in areas where Modo locations are nearby.

The reason for that might be twofold. On the one hand, it is possible that the opening of a Modo location pushed the people living nearby to start utilizing the service. On the other hand, it might suggest that Modo decides to open new locations based on the highest concentration of its users to serve them better.

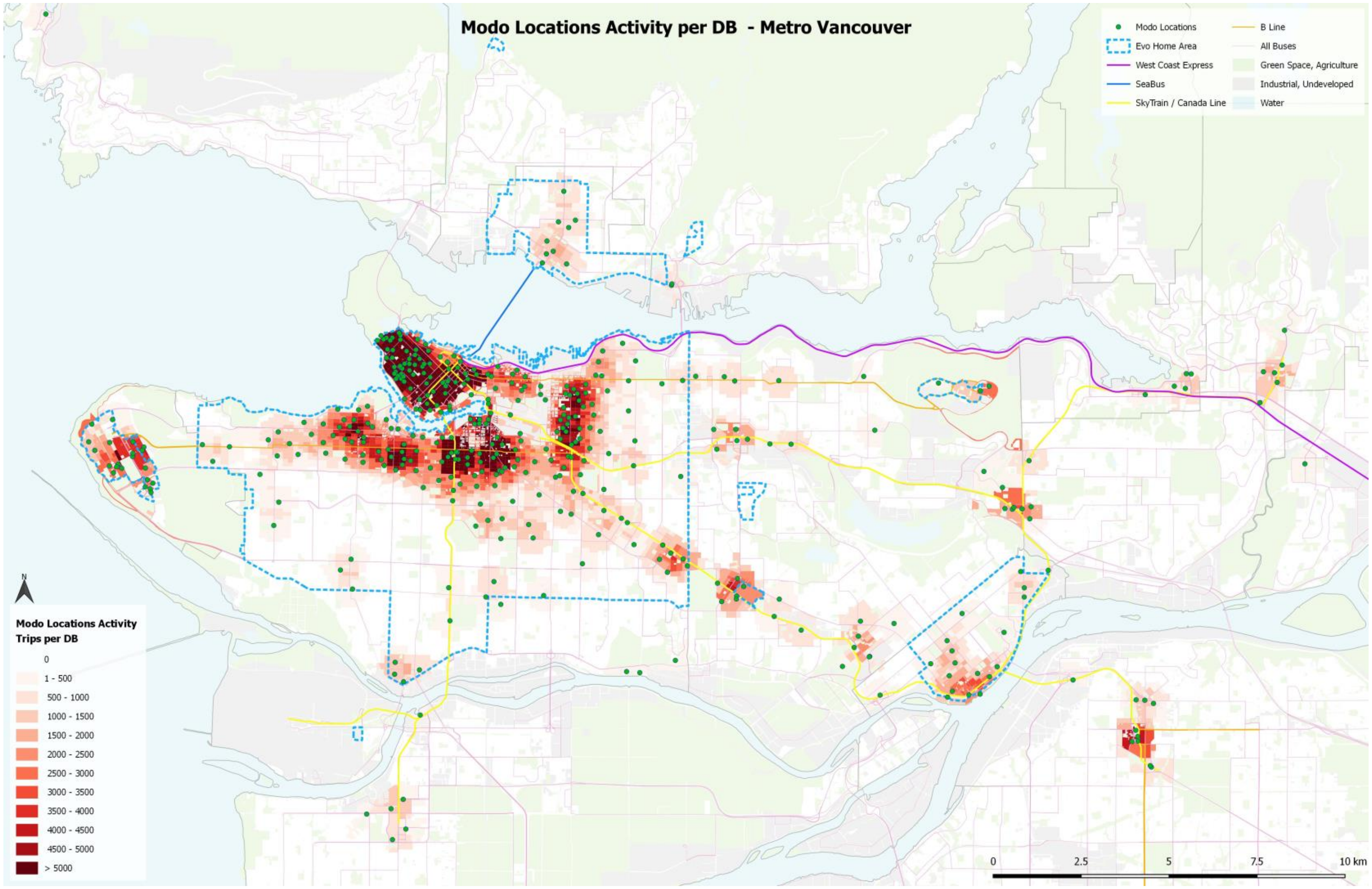


Figure 3-4: Modo Location Activity: number of trips per DB associated with Modo Locations
Source: Author’s illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

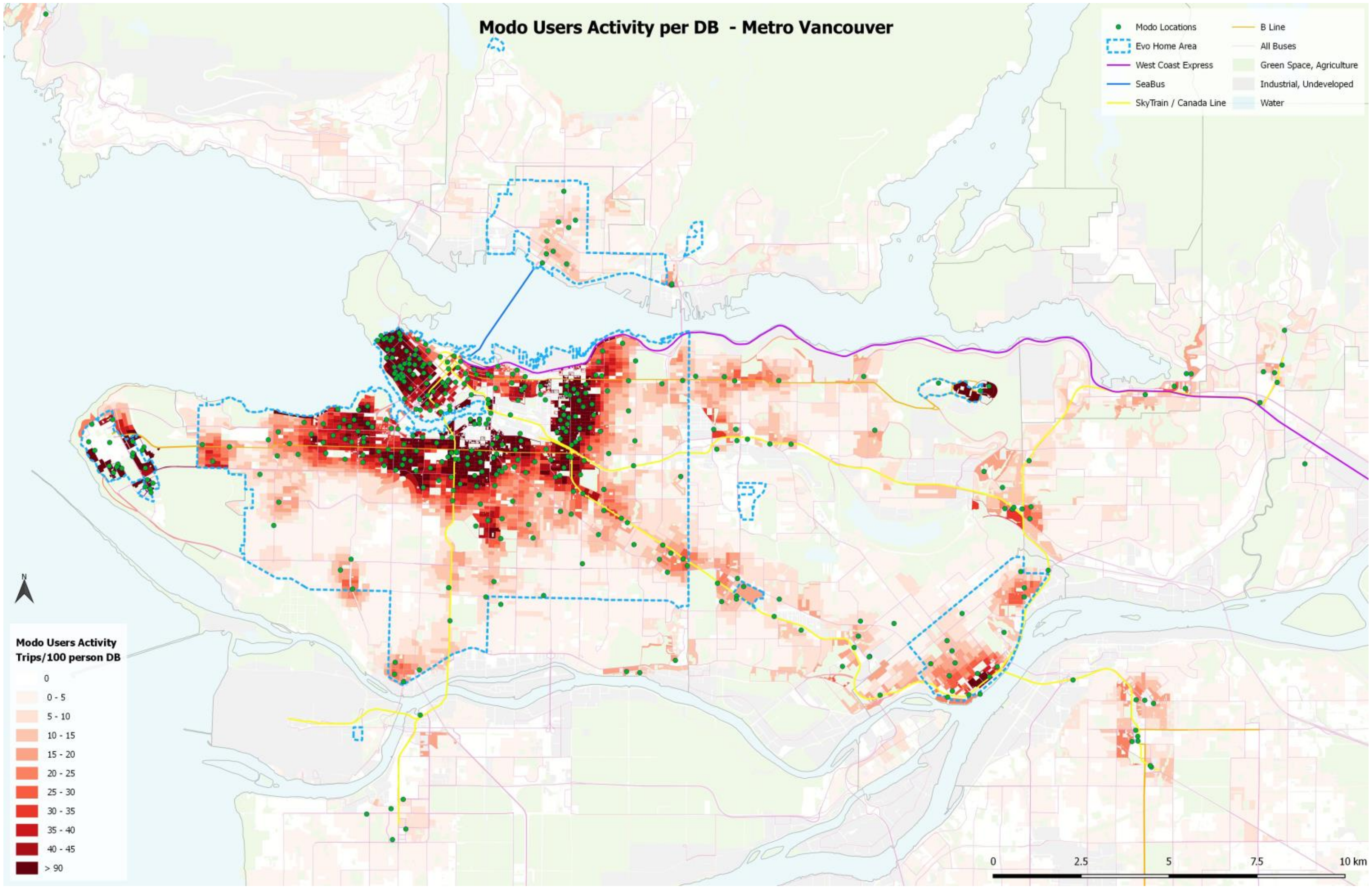


Figure 3-5: Modo User Activity: number of trips per DB per person associated with users' home address
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

3.2.4. One-way Carsharing Variable

The last variable that needs to be prepared is the usage of one-way carsharing, i.e., Evo Carsharing. Before providing the details of the indicators for one-way carsharing, it is worth recalling that its operational scheme is different from Modo's, as there are no fixed locations where shared cars are picked up and returned. Instead, the car return can be done anywhere inside a designed operational area or within satellite parking places located in specific positions around Metro Vancouver. In addition, while every Modo's trip was associated with user in the database, the same is not true for Evo. For this reason, we only have information about the trip's origins and destinations, but not on the home address of the users that made each trip.

Evo's data introduced in section 3.1.4 contains information on the origin and destination of every single trip that has been made between January 2017 and December 2017. This data allows us to build two indicators to describe the one-way carsharing usage. The first one is called the Total Activity per DB while the second one is called the Activity per Person per DB.

These two indicators are built by assigning to every DB in Metro Vancouver the sum of all trips' origin and trips destination that occurred within the DB's boundary in the period considered. The first indicator is simply the sum of the trip's origins and the trip's destinations that happened within the DB, while the second indicator also takes into account the number of persons who live in that DB.

As for the previous variables, each one of the 15,197 DBs in Metro Vancouver received two specific values for the two Evo's indicators describing the usage of the one-way carsharing for that location. Figure 3.6 and 3.7 illustrate the distribution of Evo's Total Activity and Evo's Activity per Person in each DB of Metro Vancouver. Of course, trips can only have an origin or destination within the designated operational area or in one of the satellite parking locations. Therefore, all the external DBs have been assigned a zero for this indicator. Similarly to what was seen for Modo, the areas with the highest usage are close to downtown and along the Broadway/Commercial corridor. Usage is also strong in the satellite parking areas such as the Airport, the three main universities, and Metrotown. On the other hand, New Westminster's lower activity is also due to the fact that it became part of the Evo operational area only in May 2017.

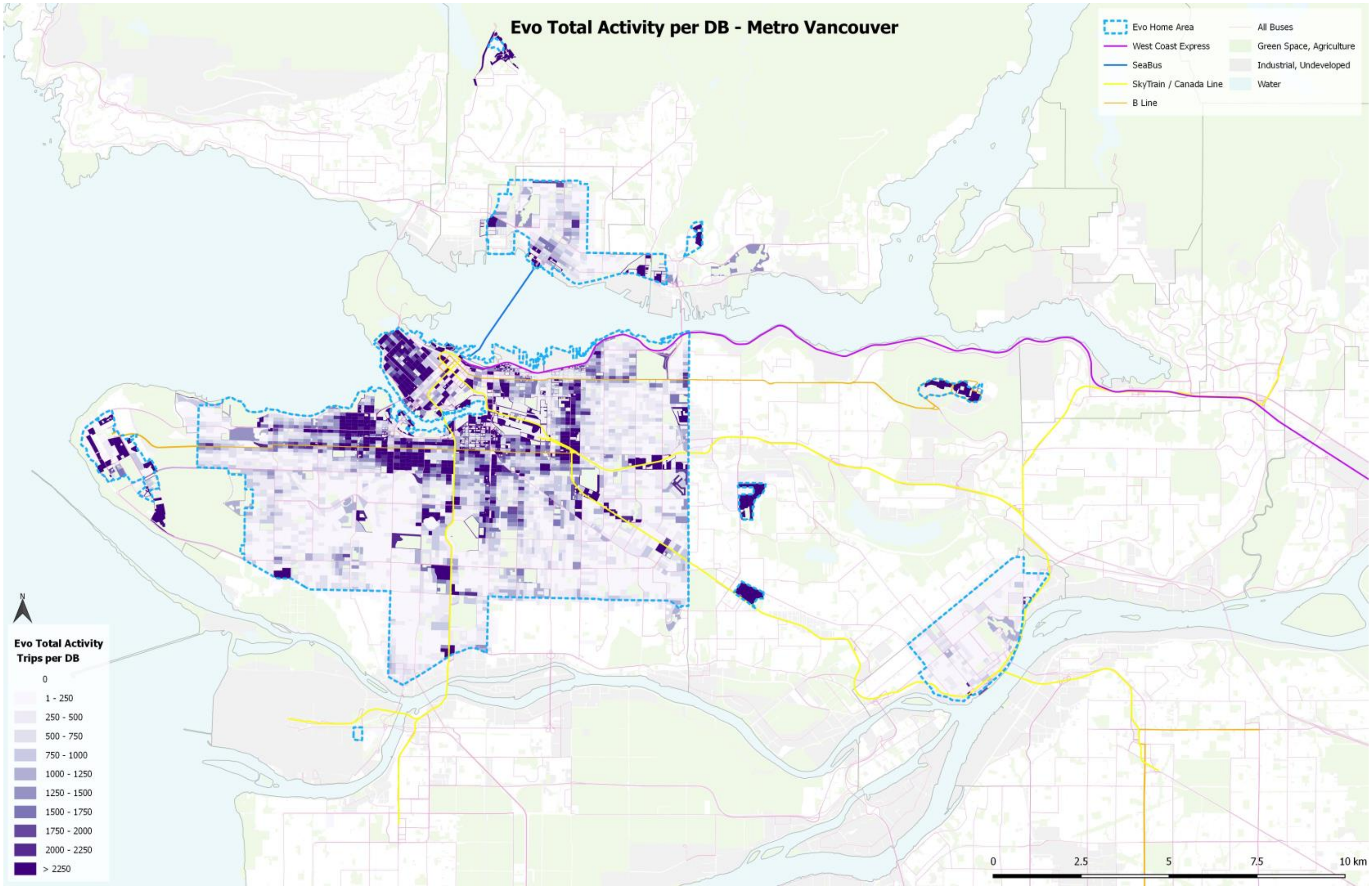


Figure 3-6: Evo Total Activity per DB: Number of trips' origin and destination per DB
Source: Author's illustration of Evo, TransLink, and Statistics Canada data, 2018

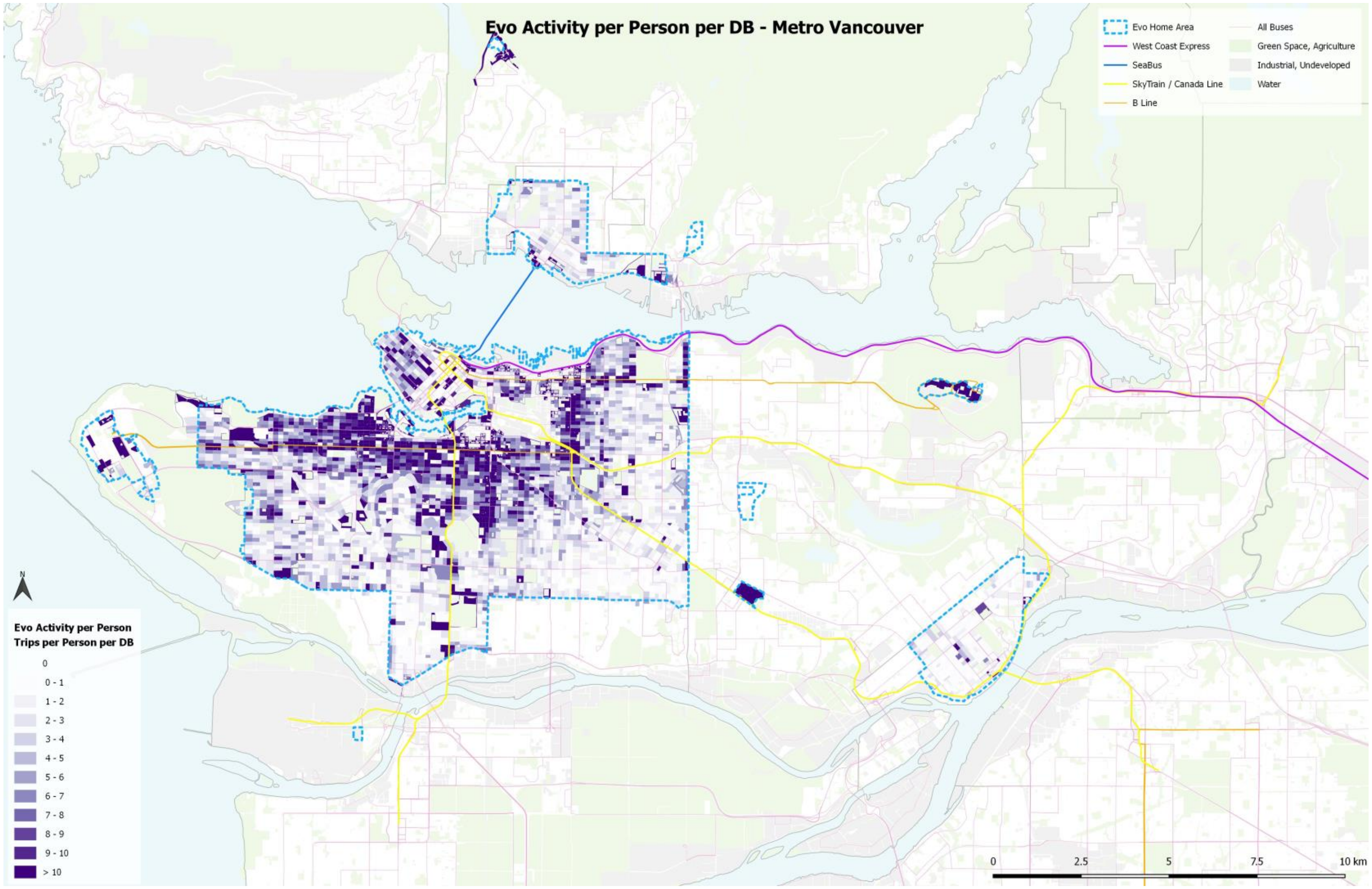


Figure 3-7: Evo Activity per Person per DB: Number of trips' origin and destination per person per DB
Source: Author's illustration of Evo, TransLink, and Statistics Canada data, 2018

The first part of Chapter 3 introduced the data sources that have been used in the thesis. The second part described how this data has been used to prepare a series of indicators to be used in the research analysis. These indicators describe both the independent variables related to the socio-demographic, geographic and public transit features and the dependent variables for the two-way and one-way carsharing usage. The purpose of the next chapter is to illustrate how all these variables are correlated with each other and how the usage of carsharing in Metro Vancouver varies according to each location's characteristics.

Chapter 4.

Data Analysis

4.1. Correlation of the Variables

The previous chapter described in detail the thesis methodology and illustrated the necessary steps made in preparation for the data analysis. The key outcome of the data preparation is that the two-way and one-way carsharing usage, as well as the public transport and the geographic, socio-demographic variables, have all been described by a series of indicators. The indicator values have then been assigned to every single DB in Metro Vancouver. With the data ready for analysis, the purpose of this chapter is to show what correlation may exist between the usage of Modo and Evo carsharing and each independent variable.

Specifically, the following sections illustrate the correlation between the usage of two-way and one-way carsharing and each independent variable, describing the geographic, socio-demographic and public transit characteristics.

It is necessary to say that all the independent variables are continuous or continuous in an interval, which means that they can assume an infinite number of possible values. Therefore, categorization of variables is necessary in order to make the correlation possible. The categorization consisted of dividing the values assumed by the indicators into a certain number of categories (usually 10). As the independent variables have been categorized, the graphs presented in the following sections show the correlation between the average value that the dependent variables' indicators assume for each category of values of the geographic, socio-demographic and public transit variables.

As explained in the previous chapter, the indicators used to describe the usage of two-way and one-way carsharing contain an essential difference. While the Modo data describes both the usage associated with the locations where vehicles are parked and to the users who made the trips, Evo data only describes the usage associated with the vehicles, with no information about the users.

The two indicators describing Modo usage in each DB represent the sum of all the trips made from all the Modo locations in proximity to each DB (Modo Location Activity) and the sum of all the trips made by drivers living in each DB divided by the total population of the DB (Modo User Activity).

The two indicators describing Evo usage in each DB represent the sum of trips' origin and trips' destination that occurred in each DB (Evo Total Activity) and the sum of trips origin and trips destination that happened in each DB divided by the number of persons living in that DB (Evo Activity per Person).

4.1.1. Carsharing and Population Density

The first correlation analyzed is between the independent variable population density and the usage of two-way and one-way carsharing. In this case, the population density, which in Metro Vancouver's DBs ranges from 0 to values around 100,000 people per square kilometer, has been divided into ten categories. Category 1 includes DBs with less than 2,000 persons per square kilometer. Category 10 includes DBs with more than 18,000 persons per square kilometer. Categories from 2 to 9 increase in density from Category 1 with an interval of 2,000 persons per square kilometer each. The rationale behind the variables categorization has been to maintain a similar number of elements (DBs) in each category.

The map in Figure 4.1 illustrates how population density is distributed in Metro Vancouver. The map also includes the position of Modo Locations (green dots) and the extension of Evo home area and satellite parking spots (dashed blue line). Industrial areas and natural/agricultural areas are represented respectively in grey and green.

The most densely populated areas are the neighborhoods of Yaletown, West End, Gastown as well as the core of North Vancouver, Richmond, Metrotown, New Westminster and Surrey. Very dense areas are also located along the SkyTrain corridors in proximity of the train stations and along the Broadway corridor.

Figure 4.2 shows the correlation between Modo usage and the population density. It is evident that there is a positive correlation for both the Location Activity indicator and User Activity. More specifically, the average number of total trips and the average number of trips per person have a sudden increase between category 9 and category 10 of population density. This logically suggests that the highest usage of the service occurs in areas with a very high concentration of people.

On the other hand, Figure 4.3 represents the correlation between Evo activity and population density. In this case as well, both Total Activity and Activity per Person increase with increasing values of population density, with a steeper growth between category 9 and category 10. However, it is interesting to notice the very high value for Evo activity per person in DBs with a very low density (category 1). This can be explained by the fact that some of the most used Evo's satellite parkings, such as Cypress Mountain or Sea Island (Airport) are located in areas with extremely low population density.

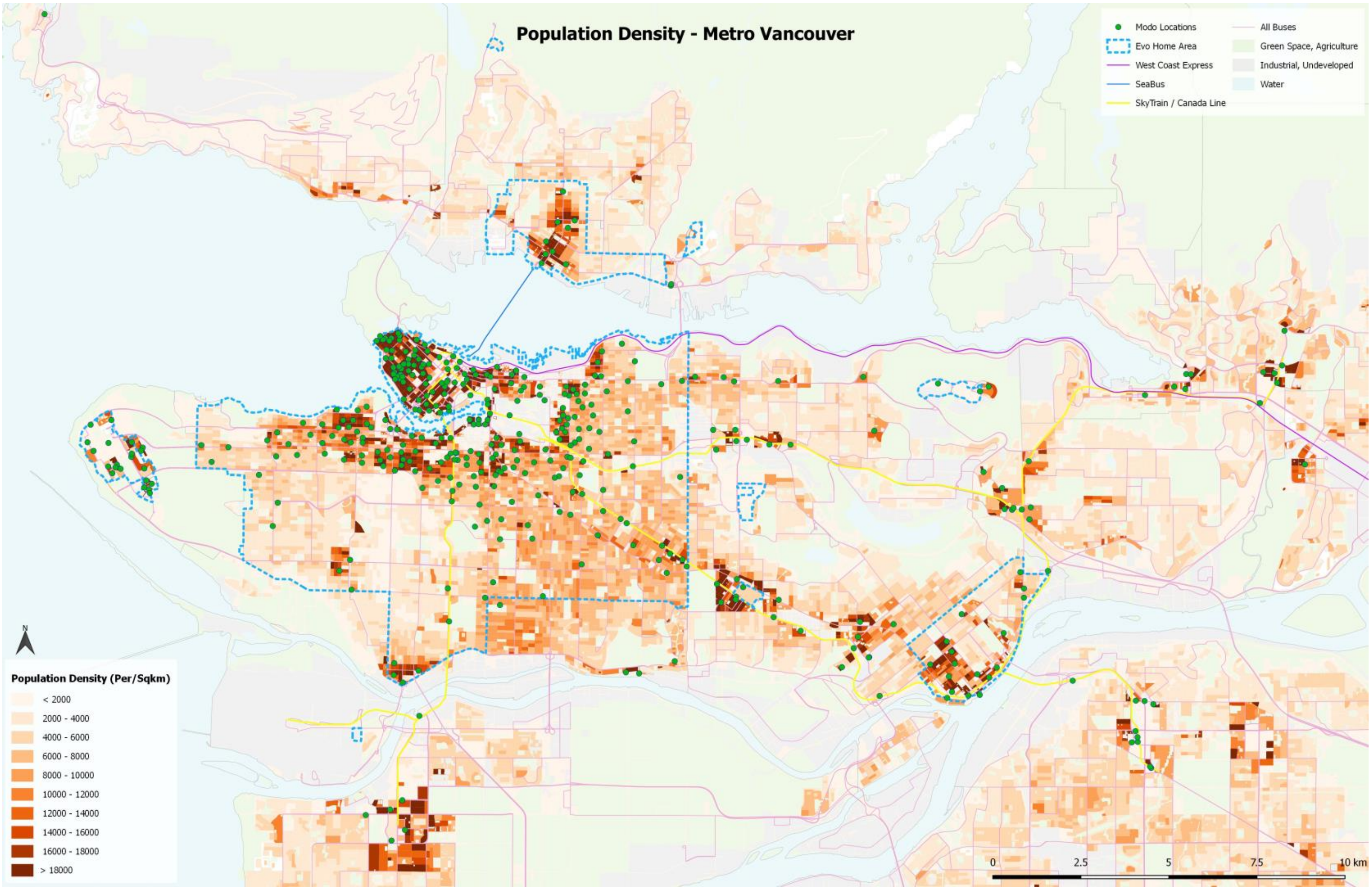


Figure 4-1: Population Density per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

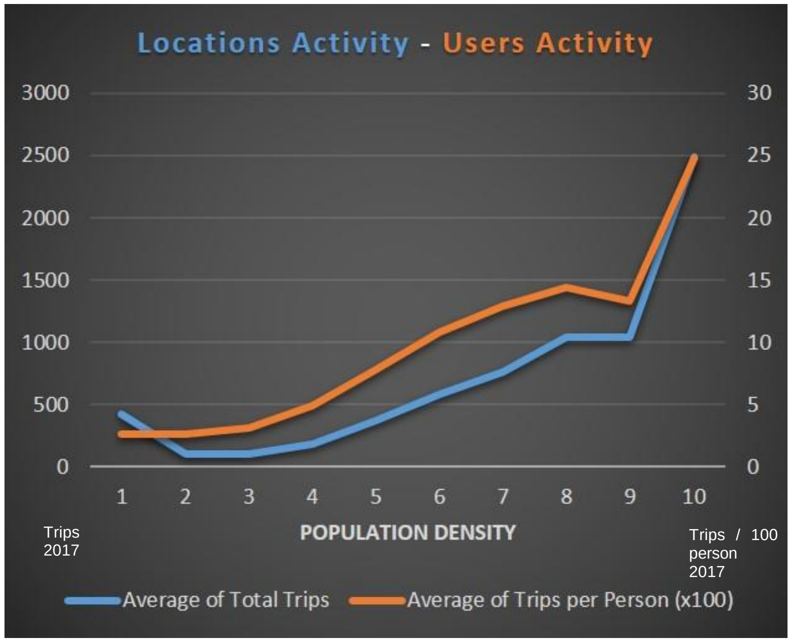


Figure 4-2: Correlation between Modo Activity and Population Density
Source: Author's illustration of Modo and Statistics Canada data, 2018

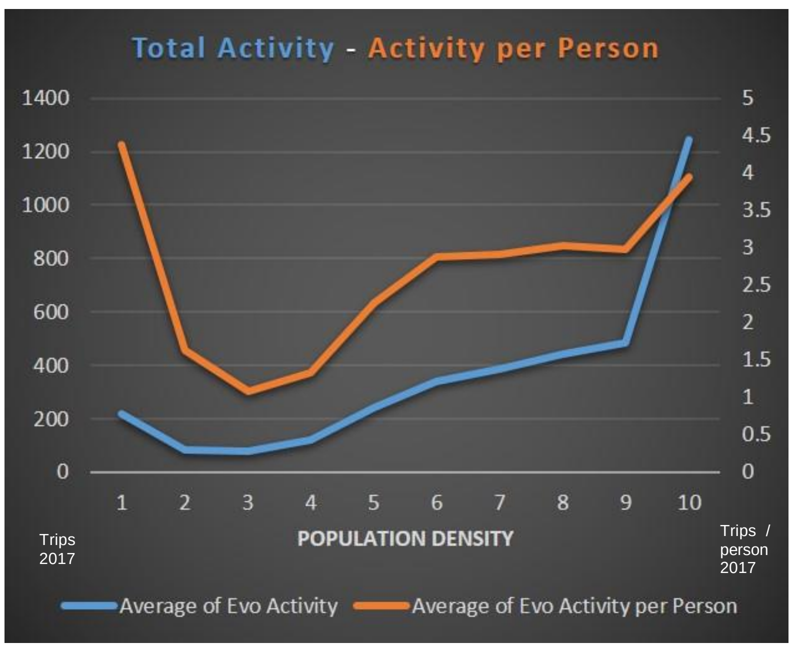


Figure 4-3: Correlation between Evo Activity and Population Density
Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.2. Carsharing and Dwelling Type

The second correlation is between carsharing usage and dwelling type. Here the independent variable is described by the percentage of single-detached houses among all the dwellings located in each DB. In this case, the variable is continuous in an interval, with values that can vary between 0 and 100. Therefore, the variable can be categorized in ten different classes, with a 10% interval between each class.

Figure 4.4 displays what areas of Metro Vancouver have a predominance of single detached houses. Not surprisingly, these places correspond to the most suburban areas. In particular, a very high concentration of single-detached houses (more than 80% of the total dwellings) can be found in West Vancouver, North Vancouver, The North East Sector (Coquitlam, Port Coquitlam, and Port Moody), Richmond and the West Side of Vancouver.

The correlation with carsharing usage represented in Figure 4.5 and Figure 4.6 indicates that the usage of both two-way and one-way carsharing services increase when the percentage of single-detached houses decrease. Therefore, there is a negative correlation between the independent and dependent variables.

This finding reinforces the positive correlation found in the previous subsection between carsharing activity and population density, as the high presence of many single-detached houses is an index of low-density and sprawling areas. In addition, the results of the first two correlations reflect the findings from the literature review (Millard-Ball et al.,2005). Similarly to other urban contexts, carsharing strongly depends on the characteristics of the built environment. In denser areas, more carsharing trips are made and there is a higher number of drivers per resident.

Finally, a strong presence of single-detached houses hinders the possibility of having a mix of uses in the neighborhood. This is not helpful to carsharing as a mixed environment allows citizens to do a large part of their activities (groceries, recreation, dining, etc.) locally. Not having this opportunity will force people to frequently travel to further locations, most likely by private vehicles. It is extremely difficult for carsharing to be a viable option in such places (Millard-Ball et al., 2005).

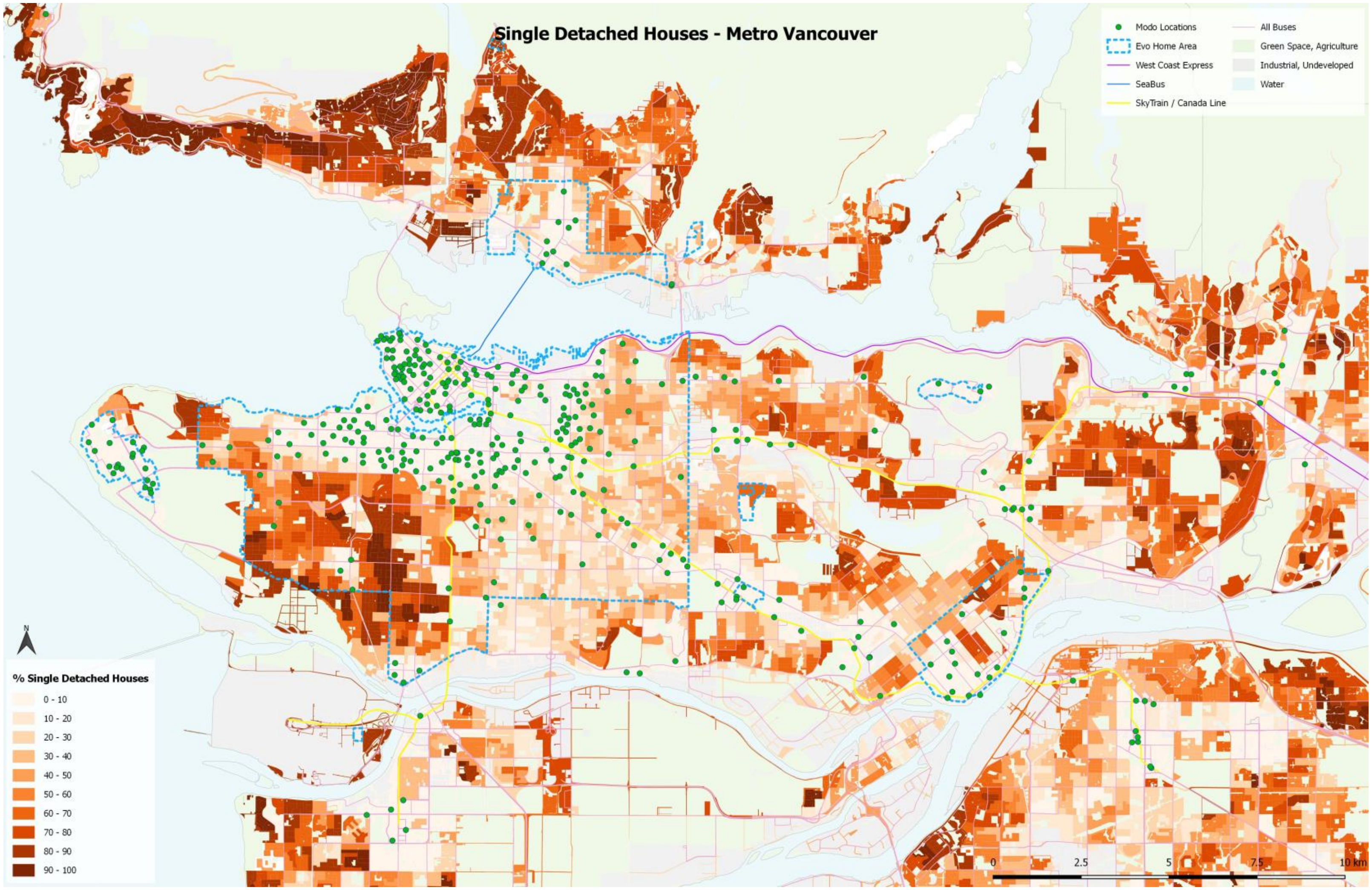


Figure 4-4: Percentage of single-detached houses per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

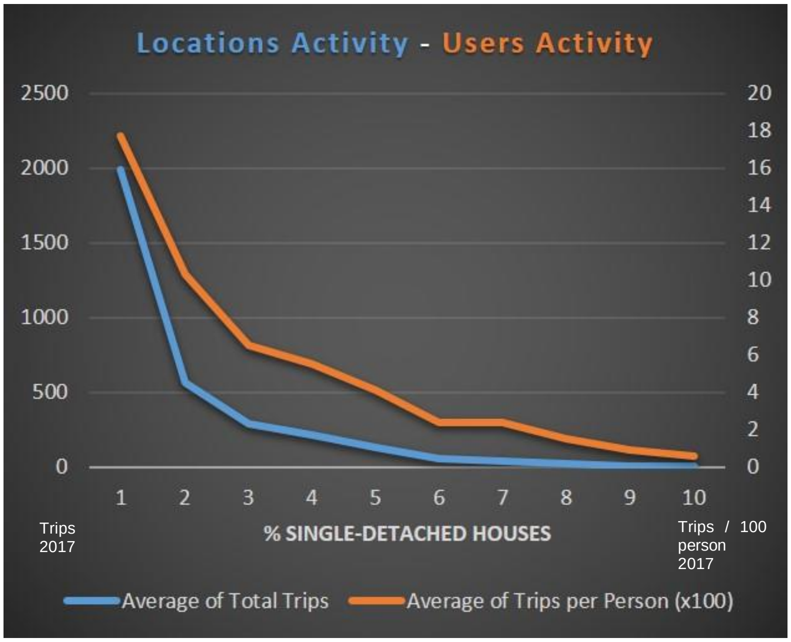


Figure 4-5: Correlation between Modo Activity and percentage of single-detached houses

Source: Author's illustration of Modo and Statistics Canada data, 2018

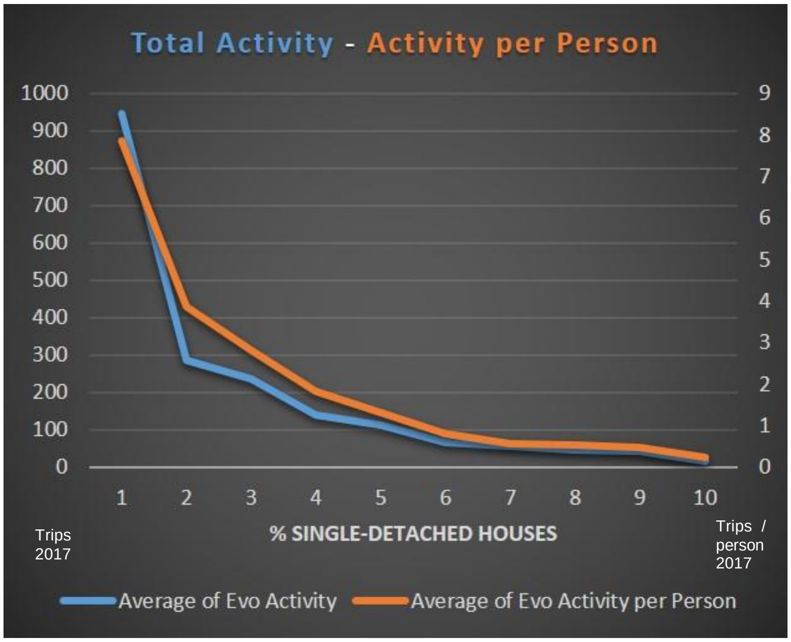


Figure 4-6: Correlation between Evo Activity and percentage of single-detached houses

Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.3. Carsharing and Household Size

While the first two correlations were made considering geographic characteristics that referred to the built environment, this third one considers a socio-demographic aspect which is the dimension of the households. In this case, the variable is described by the percentage of single person households that live in each DB. As before, the variable, being continuous in an interval, has been categorized and its values have been divided into ten categories. The range between each class is 5% and category 10 includes all DBs with more than 45% of single person households among the total number of households. Again, this choice has been made in order to have a similar number of DBs in each category.

Figure 4.7 shows the distribution of single person households in Metro Vancouver. It is interesting to notice that the geographic concentration of single person households follows very closely the distribution of the population density introduced in subsection 4.1.1. The areas where the smallest households live correspond to the central cores of Vancouver, North Vancouver, Richmond, New Westminster, Surrey and along the Broadway corridor. Also, the transit-oriented developments around the SkyTrain stations, which are generally much denser areas compared to their surrounding neighborhood, show a higher concentration of single person households.

As areas with single person households are areas that are densely populated, it is easy to deduce that the correlation between the usage of carsharing and single person households looks similar to the one found for population density.
Figure 4.8 and Figure 4.9 confirm this idea by showing how the activity of both two-way and one-way carsharing increases in DBs where there is the highest concentration of single person households.

This finding is also consistent with what has been found in the literature review, where other studies demonstrated that carsharing users are more likely to be singles or part of very small households (Millard-Balll et al., 2005; Cervero & Tsai, 2003; Harmer & Cairns, 2011; Loose, 2010).

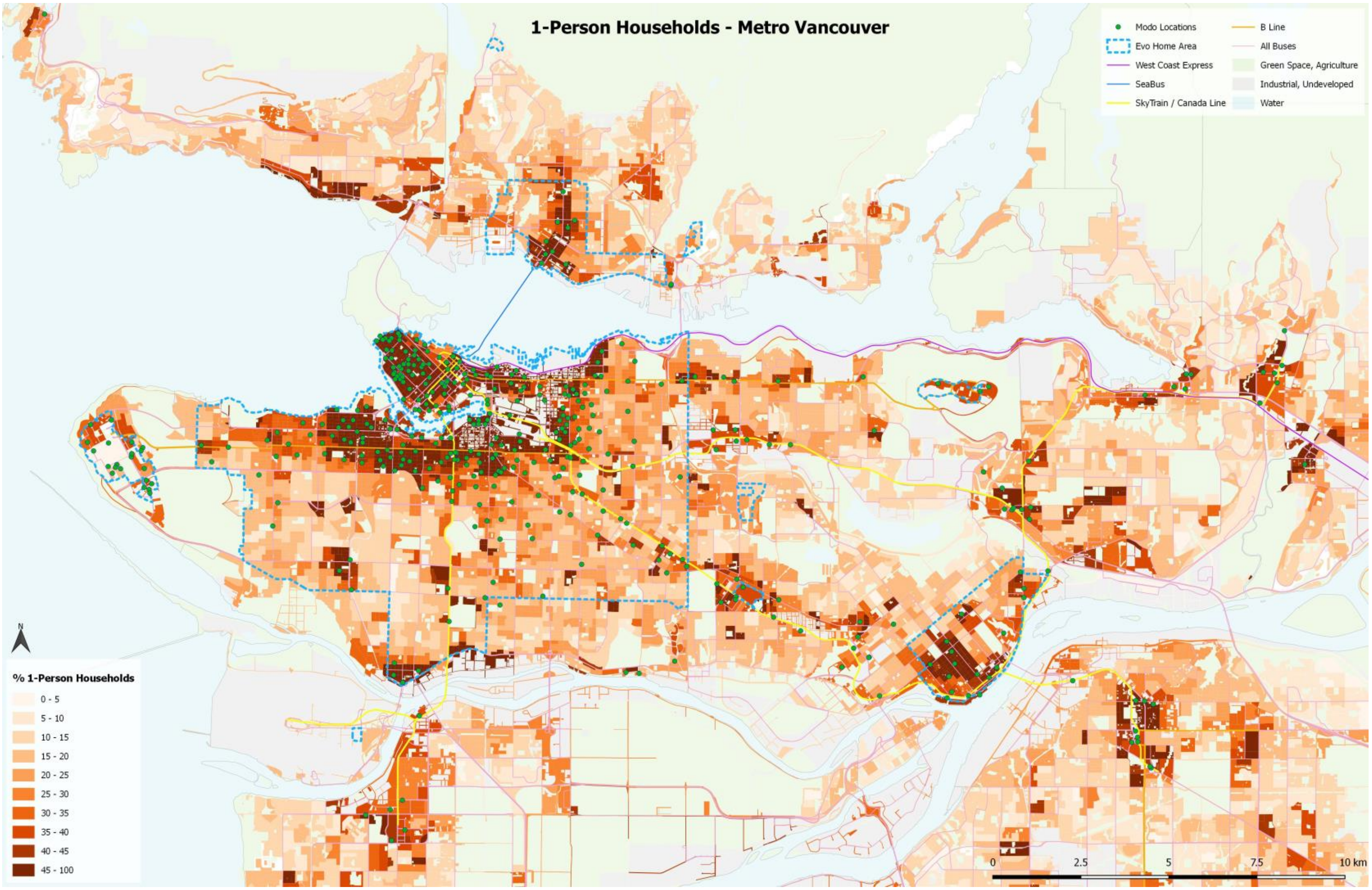


Figure 4-7: Percentage of single person households per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

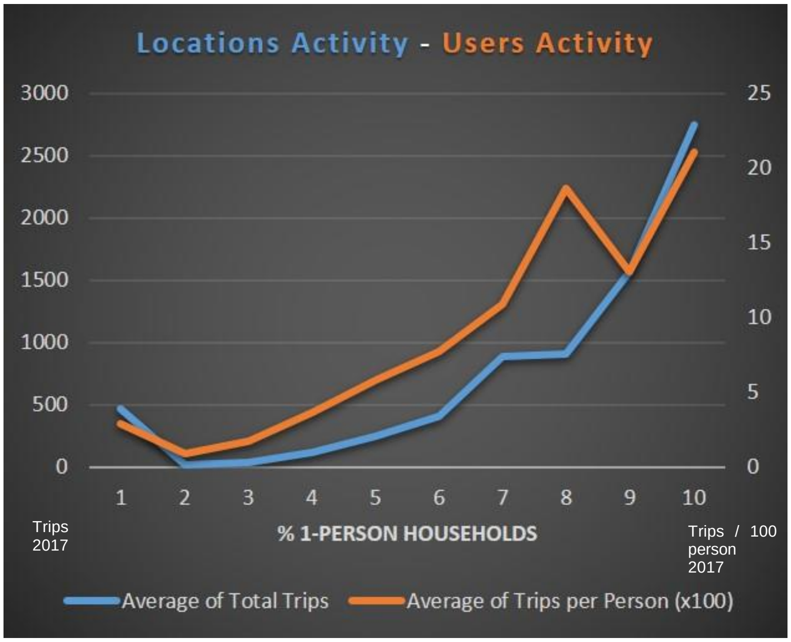


Figure 4-8: Correlation between Modo Activity and percentage of single person households

Source: Author's illustration of Modo and Statistics Canada data, 2018

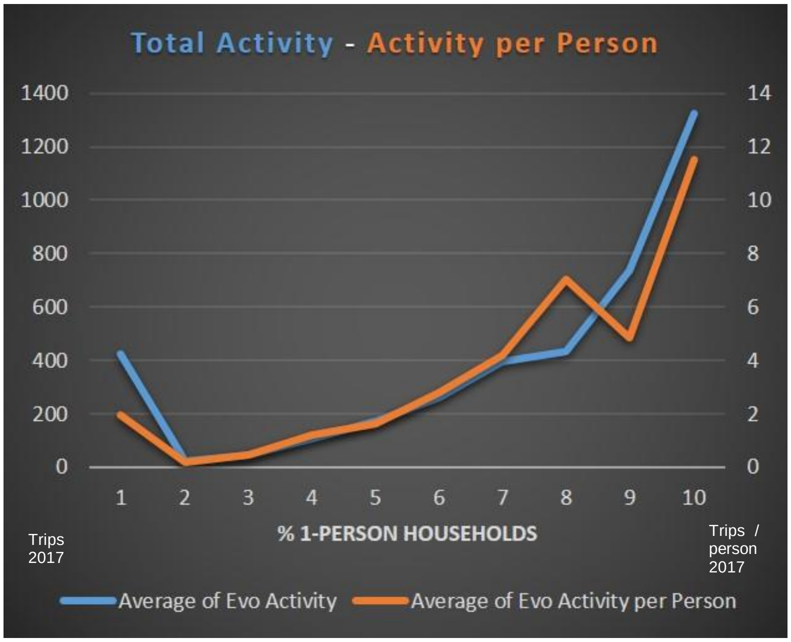


Figure 4-9: Correlation between Evo Activity and percentage of single person households

Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.4. Carsharing and Rental Housing

A second socio-demographic variable that has been correlated to carsharing indicates the tenure status of private households in the place where they live. This variable is described by the percentage of private households that are renters. As for the previous variables, a categorization was required to make the correlation with carsharing usage possible.

Figure 4.10 displays the distribution of rental housing in Metro Vancouver. Interestingly, this generally adheres to the distribution of population density and single-family households. A logical consequence of this is shown in Figure 4.11 and Figure 4.12. Both graphs indicate a positive correlation between the percentage of renters and the four different indicators chosen to describe the Modo and Evo carsharing usage. Areas with more renters are areas with higher usage of Modo locations, with a higher presence of Modo users and with a higher activity of Evo trips.

The fact that rental housing and carsharing usage are positively correlated might not only depend on the fact that rental housing is generally higher in a more densely populated area. Rental housing is mostly associated with students or non-permanent residents, both categories of people that have reduced levels of car ownership and therefore are more inclined to consider using carsharing in order to satisfy part of their mobility needs that can only be covered by the usage of a private vehicle.

Other studies analyzed in the literature review did not directly mention any relationship between rental housing and carsharing. However, this aspect has been included in this research and, because of its closeness with single households and high density, it shows a positive correlation with the usage of carsharing in Metro Vancouver.

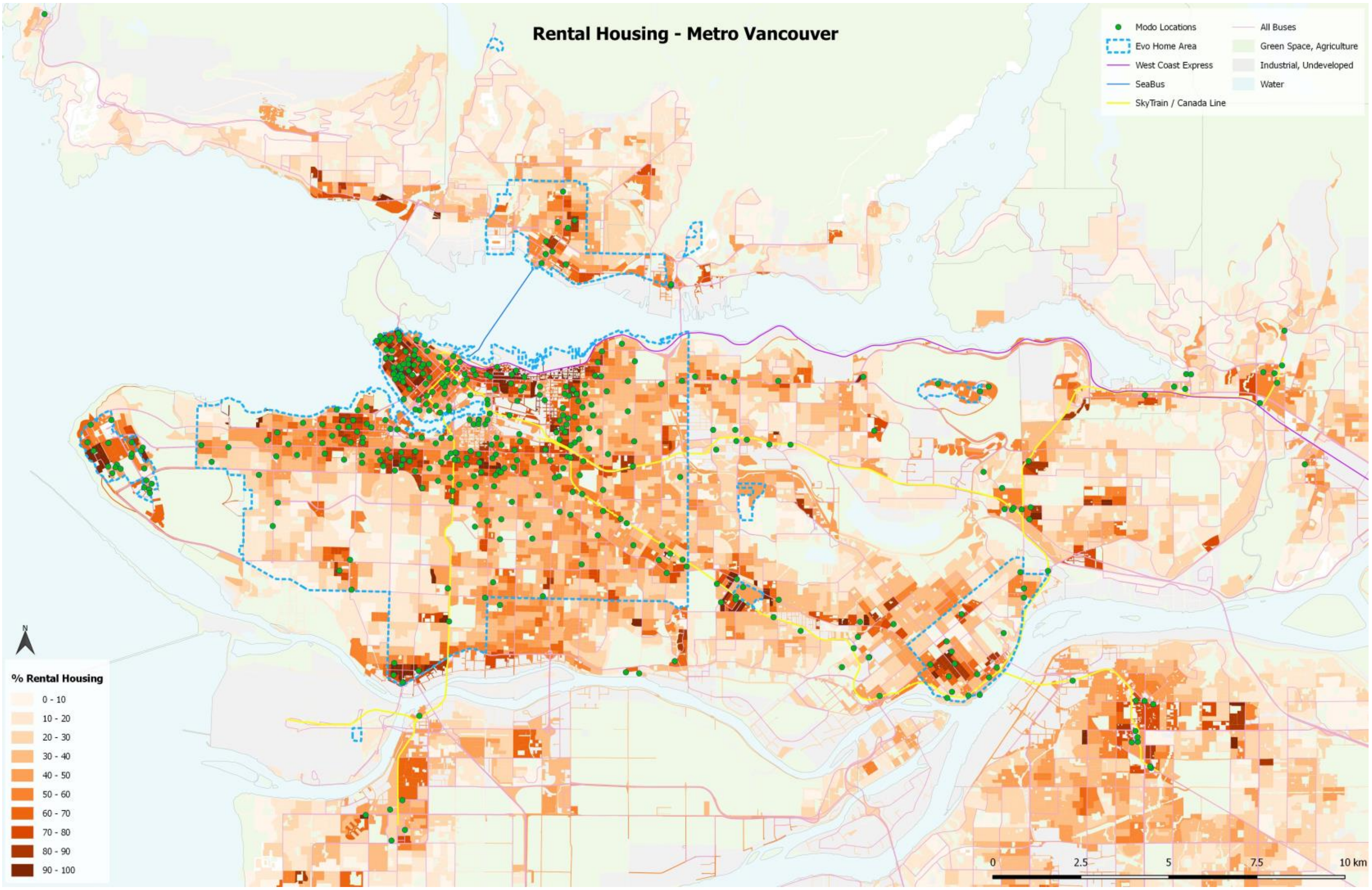


Figure 4-10: Percentage of rental housing per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

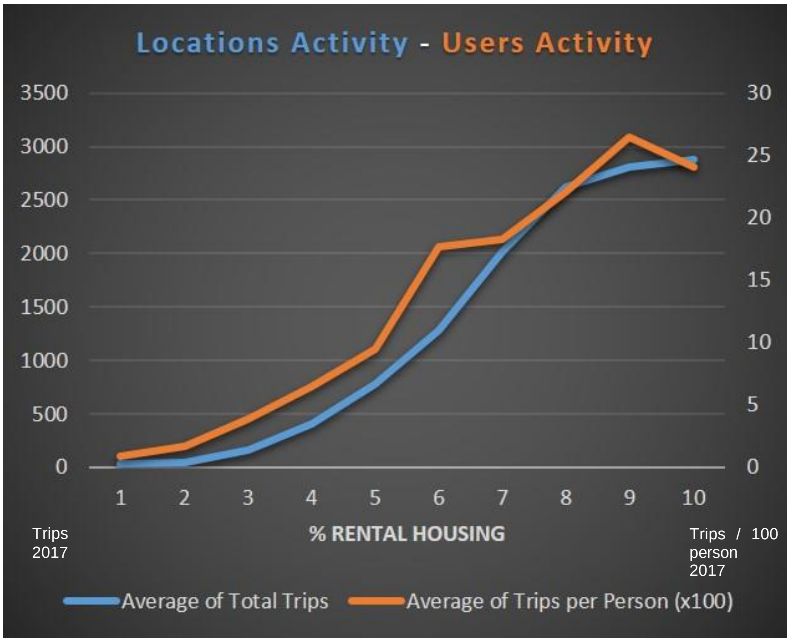


Figure 4-11: Correlation between Modo Activity and percentage of rental housing
Source: Author's illustration of Modo and Statistics Canada data, 2018

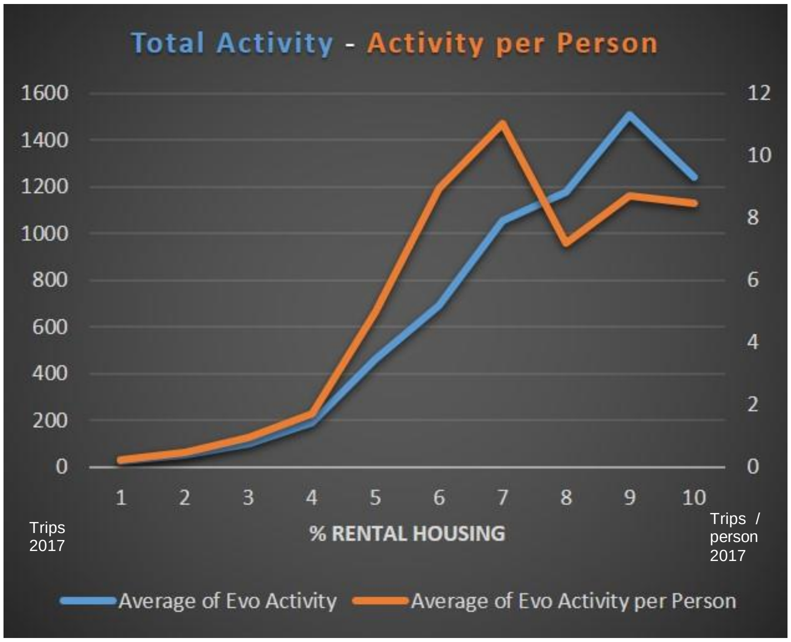


Figure 4-12: Correlation between Evo Activity and percentage of rental housing
Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.5. Carsharing and Education

Fascinating observations result from the correlation between the usage of carsharing and the level of education in Metro Vancouver. In this case, the independent variable is described by the percentage of people that hold a post-secondary degree in each DB.

From Figure 4.13 it is possible to understand the areas of Metro Vancouver with higher than average educational levels. Not surprisingly, the DBs around the two main university campuses (the University of British Columbia and Simon Fraser University) have a very high concentration of people with a university degree. The same can be said for most of North Vancouver, West Vancouver, and the West End, Arbutus, West Side, Kerrisdale neighborhoods in the City of Vancouver. Interestingly, areas of the region that historically have a higher concentration of immigrants such as Richmond, Surrey, and East Vancouver have the lowest levels of university education.

Considering the trends shown in Figure 4.14 and Figure 4.15, Modo Location Activity and User activity increase in areas with higher levels of education. The same can be said for Evo Total Activity and Activity per Person. However, both Modo and Evo usage experience a significant drop in DBs where the percentage of highly educated people is very high (more than 90%). This can be explained by the fact that a large portion of these areas are situated in West Vancouver, the northern part of North Vancouver where there are no Modo locations and are outside the operational area of Evo. Similarly, the neighborhoods on the west side of Vancouver, have a low presence of Modo locations.

Finally, the positive correlation between the education level and the Modo User Activity tells us that there is a higher proportion of active members in areas of the city that have a higher percentage of university degrees. This is also consistent with the findings illustrated in the literature review, where different studies underlined that carsharing members tend to be well-educated people (Millard-Ball et al., 2005; Andrew & Douma, 2006; Cervero et al., 2007; Muhr, 2009).

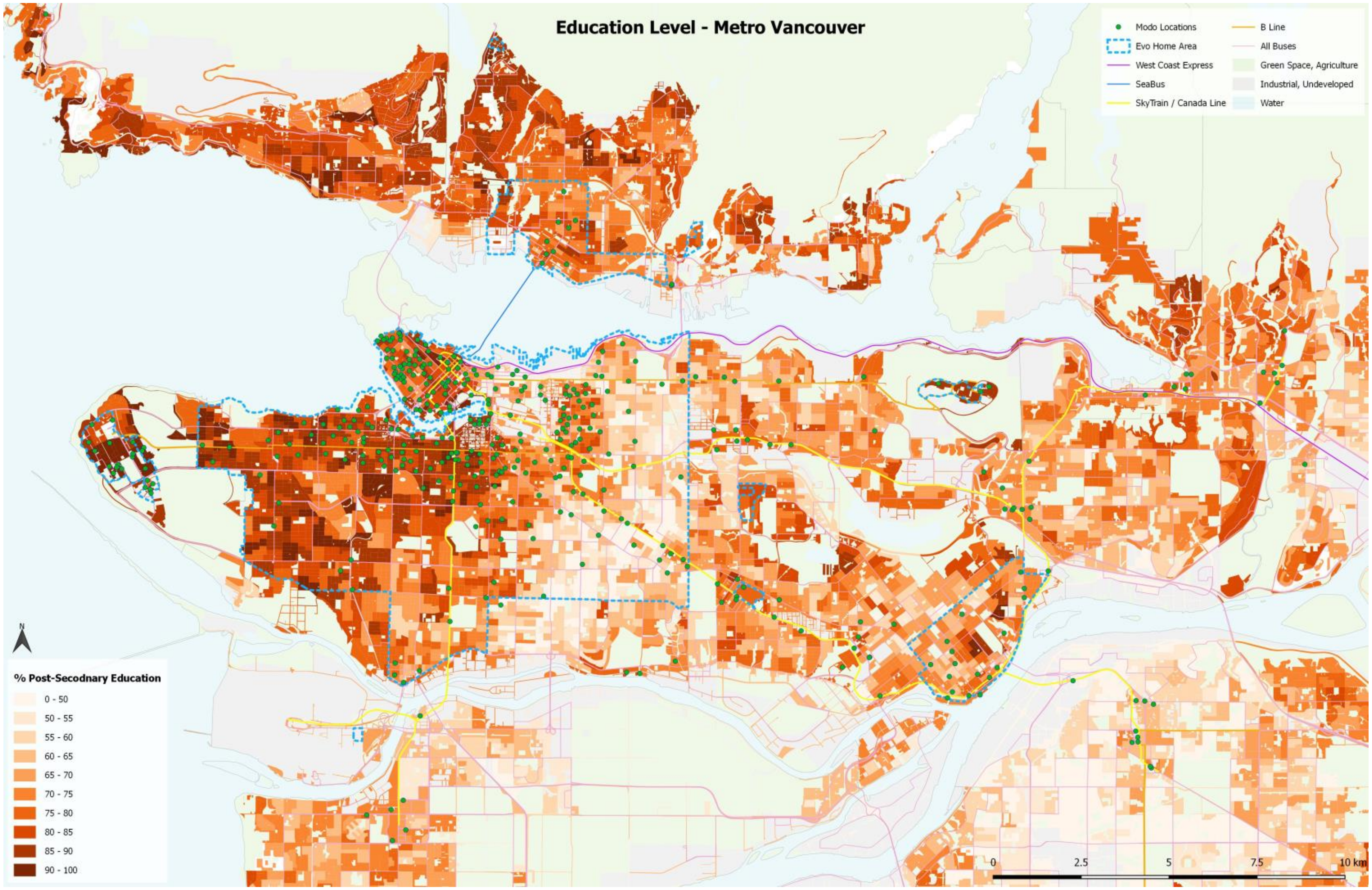


Figure 4-13: Percentage of post-secondary education per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

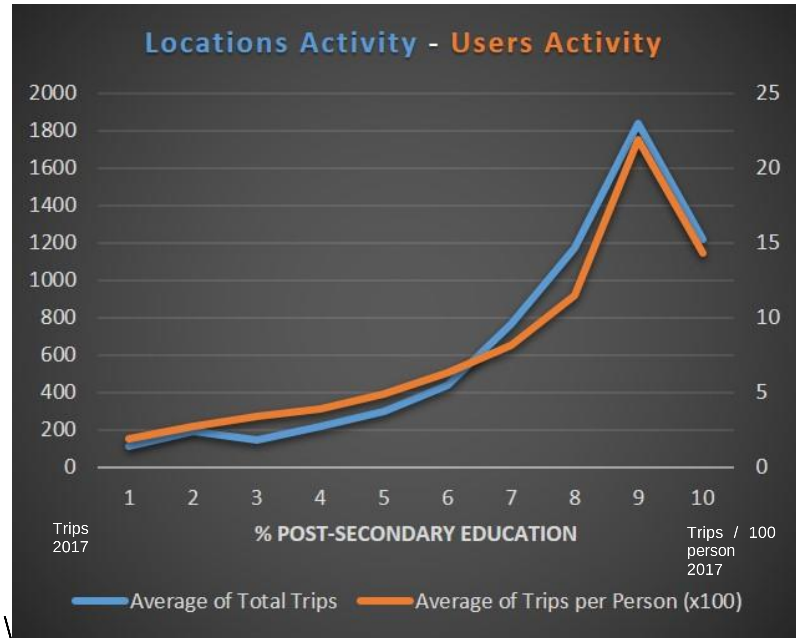


Figure 4-14: Correlation between Modo Activity and percentage of post-secondary education

Source: Author's illustration of Modo and Statistics Canada data, 2018

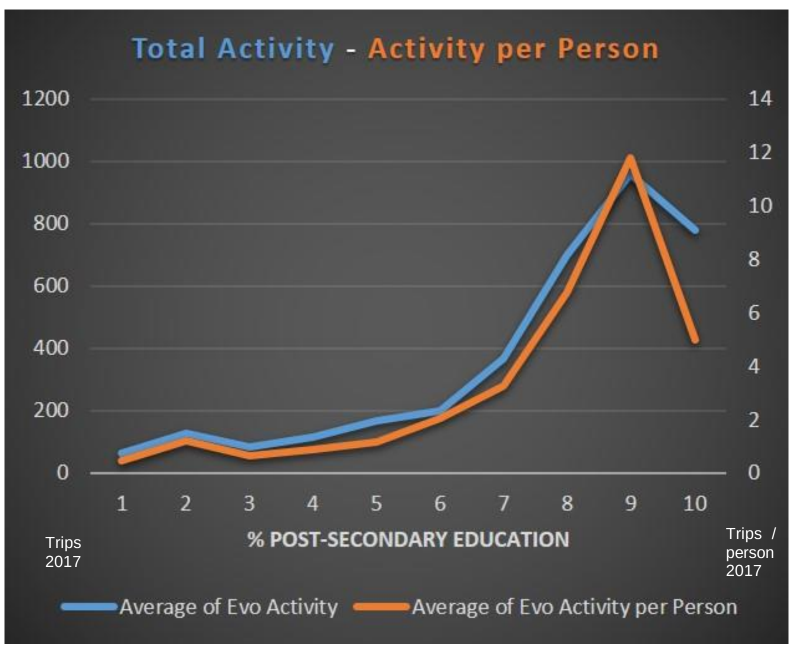


Figure 4-15: Correlation between Evo Activity and percentage of post-secondary education

Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.6. Carsharing and Income

Income is another variable that is interesting to correlate with carsharing. This variable captures the average income per recipient divided into ten categories. Category 1 includes DBs where the average income per recipient is lower than $20,000 per year while Category 10 includes values of $60,000 or more. Once again, this choice has been made to have categories with similar numbers of DBs.

Looking at Figure 4.16, many areas in Metro Vancouver that have a higher than average income are the same ones where education levels were the highest. North Vancouver, West Vancouver, the western neighborhoods of the city of Vancouver, New Westminster and some parts of the Northeast Sector are among the wealthiest places in the region. The big difference between the two variables is represented by the University of British Columbia and Simon Fraser University campuses. The education level for those areas was among the highest while the average income is among the lowest.

Looking at the graphs in Figure 4.17 and Figure 4.18, both Modo and Evo activity shows two peaks: one corresponding to category 1 of income and another to category 9. However, it is difficult to evince from the graph any significant (either positive or negative) correlation between the usage of two-way or one-way carsharing and the level of income of Lower Mainland residents. There might be different reasons for that. The fact that both university campuses, where the utilization of carsharing is high, also have the lowest income is one of them. Also, considering the City of Vancouver, the usage of carsharing is high both in the Downtown area and along the Broadway corridor. However, there is a vast difference in income leves of these two areas. Again, the downtown areas of New Westminster and Surrey have a comparable usage of Modo carsharing in terms of total trips (see Figure 3.4 in paragraph 3.2.3), but the average income of the first area is considerably higher than the second one.

These considerations lead to the conclusion that this analysis, in the way it has been structured, does not show any correlation between carsharing usage and income in Metro Vancouver. This is different from the literature review findings, where studies, based on member surveys, showed that carsharing members usually have median or higher than average income (Millard-Ball et al., 2005; Andrew & Douma, 2006; Cervero et al., 2007; Muhr, 2009).

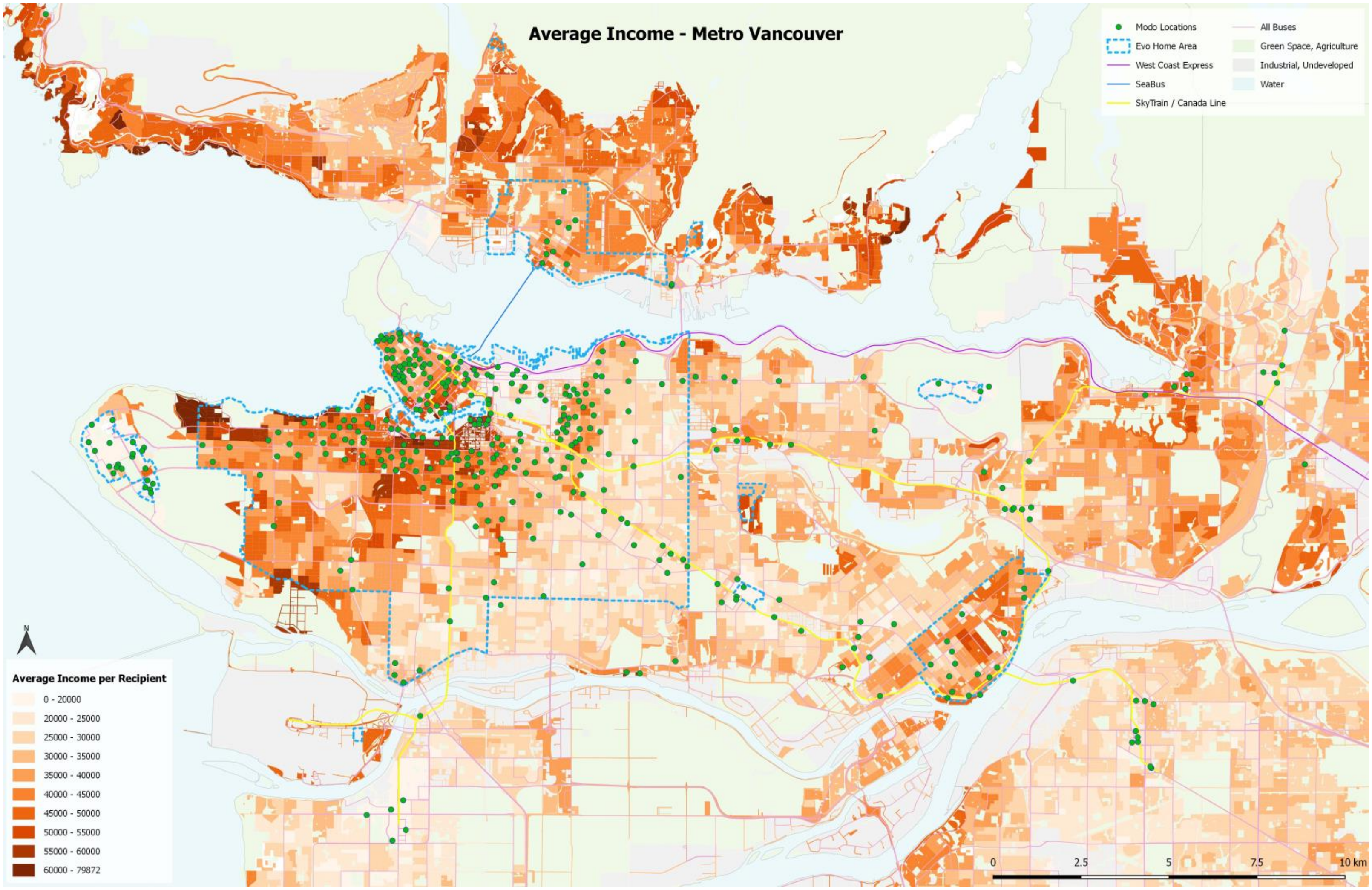


Figure 4-16: Average income per recipient per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

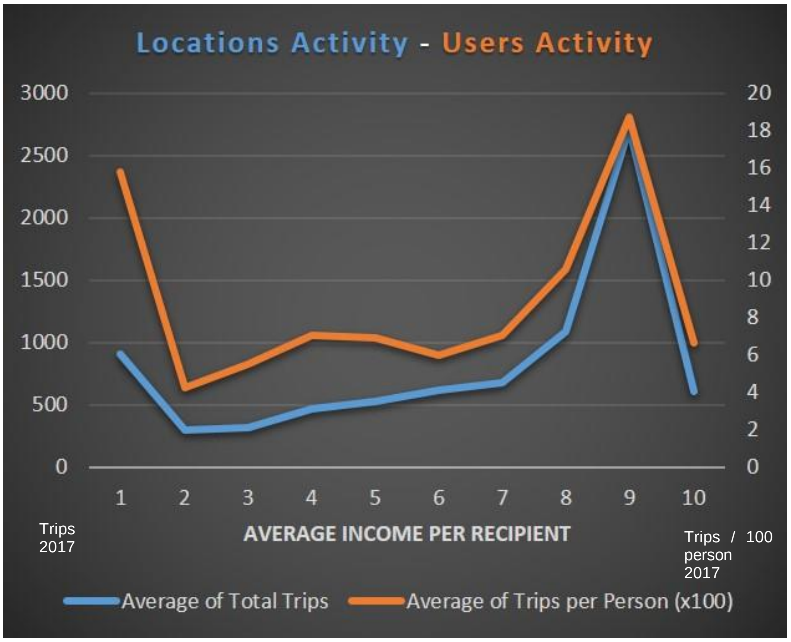


Figure 4-17: Correlation between Modo Activity and average income per recipient
Source: Author's illustration of Modo and Statistics Canada data, 2018

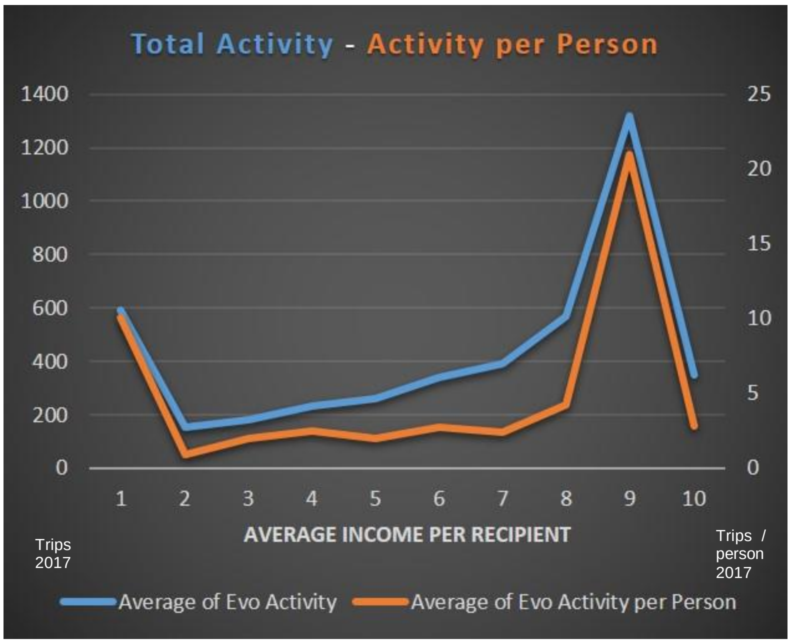


Figure 4-18: Correlation between Modo Activity and average income per recipient
Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.7. Carsharing and Preferred mode of commute to work

A crucial socio-demographic variable that has been considered in the analysis is represented by the preferred mode of transportation chosen by Metro Vancouver residents for their daily commute to work. Four different indicators describe this variable: the percentage of people who drive to work, the percentage of people who take transit to work, the percentage of people who walk to work and the percentage of people who bike to work.

As done for the previous variables, these four indicators have been divided into ten categories to make the correlation with carsharing usage possible.

Figure 4.19 illustrates that the vast majority of Metro Vancouver residents rely on their private car for their everyday commute to work. This is especially true in the suburban areas where these numbers are generally over 70%, with many zones reaching peaks of over 90%.

Of course, a strong dependency on private cars and their daily use for work commute is not a favorable situation for carsharing. This is represented in both Figure 4.20 and Figure 4.21, where the usage of Modo and Evo declines as the usage of a private cars for commuting increases.

The next map, Figure 4.22, shows the percentage of people using transit to go to work and it can be considered the opposite version of the previous map showing the percentage of people using private cars. Not surprisingly, the areas where residents rely the most on public transit are along the SkyTrain corridors, close stations, along the B-Line corridors or close to the SeaBus terminal in North Vancouver. These are the strongest and most reliable transit services in Metro Vancouver, and their presence justifies the residents' choice to choose public transit for their journey to work. These are also the geographic locations where people use private cars less.

We can interpret from this a general positive correlation between the usage of carsharing and the usage of transit to work. This is shown in Figure 4.23 for Modo carsharing and in Figure 4.24 for Evo carsharing. However, it is interesting to notice how the Evo activity has a slight decline in DBs where the percentage of public transit usage is the highest. The fact that there are multiple transit-oriented developments built around SkyTrain stations that are not within Evo operational area might be an explanation of this trend, as these are areas with very high transit ridership. The two principal examples of that are Richmond City Centre and Surrey City Centre.

A positive correlation is also found between carsharing and the choice of active transportation modes, such as walking and biking to work. The highest concentration of people walking to work, as shown in Figure 4.25 is found in the Downtown of the City of Vancouver, in the two main university campuses, in the Broadway area and around the central cores of other municipalities such as North Vancouver, Richmond, Metrotown, New Westminster, Coquitlam and Surrey. On the other hand, the areas where people bike the most, illustrated in Figure 4.28, are located around the Broadway and Commercial corridors.

For both active transportation solutions, the correlation with the usage of Modo and Evo is positive. The areas of the Lower Mainland where people tend to rely more on active transportation modes, are also the places where two-way and one-way carsharing are used the most and where the Modo drivers are more likely to live.

Once again, the findings in this section are aligned with the results reported in the literature review. Most of the carsharing users live in households where public transit or active modes are generally the most common transport choices for daily commuting (Millard-Ball et al., 2005; Synovate, 2007).

Many other interesting breakdowns could be made looking at the preferred modes that people choose to commute to work. However, a more detailed explanation of the relationship between carsharing and public transit is deepened in the following sections of this chapter, which provide the correlation with the Transit Score and the Transit Activity indicators and further analysis of the interaction between Modo locations and transit quality and availability.

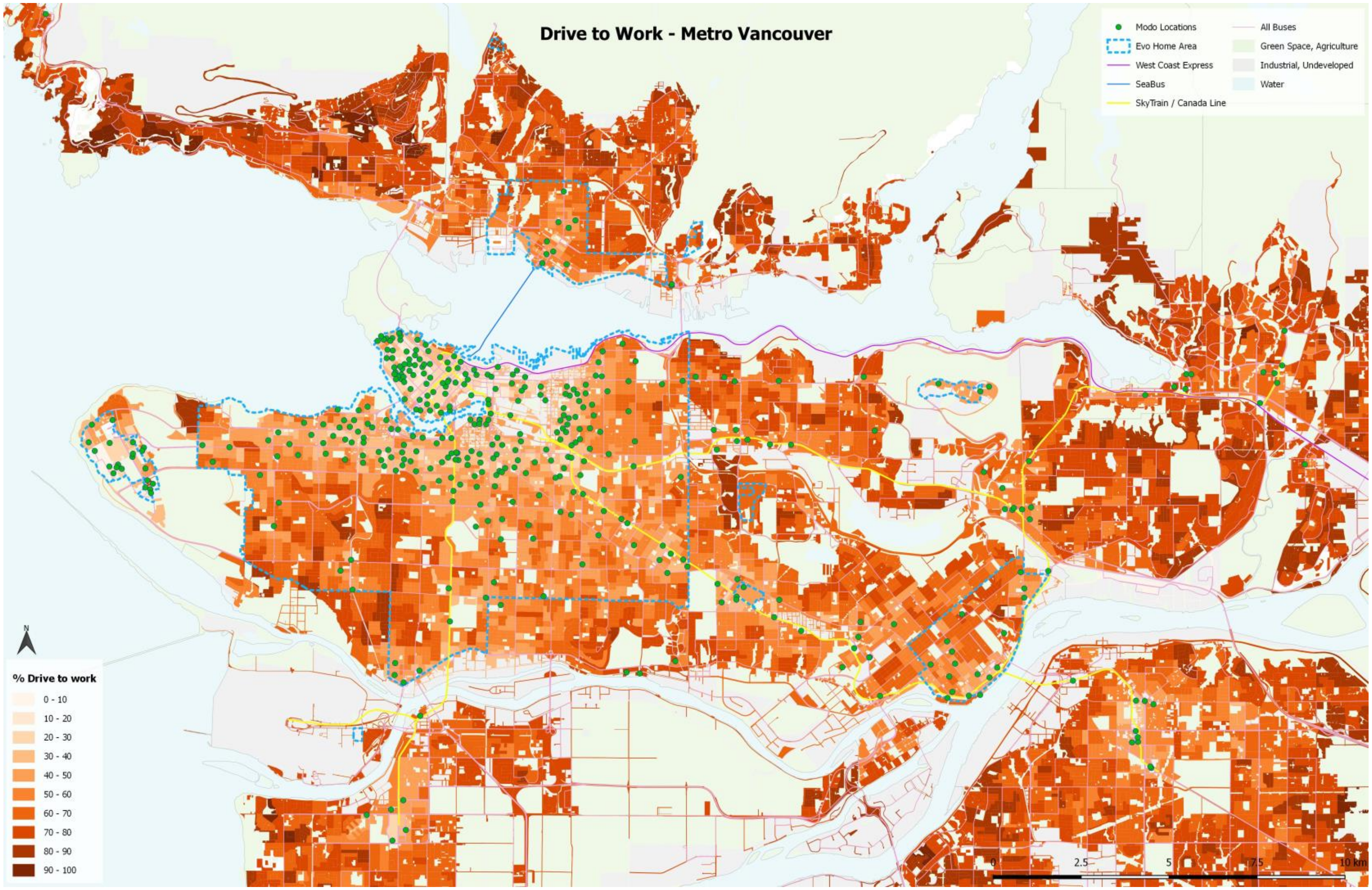


Figure 4-19: Percentage of people who drive to work as commuting mode per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

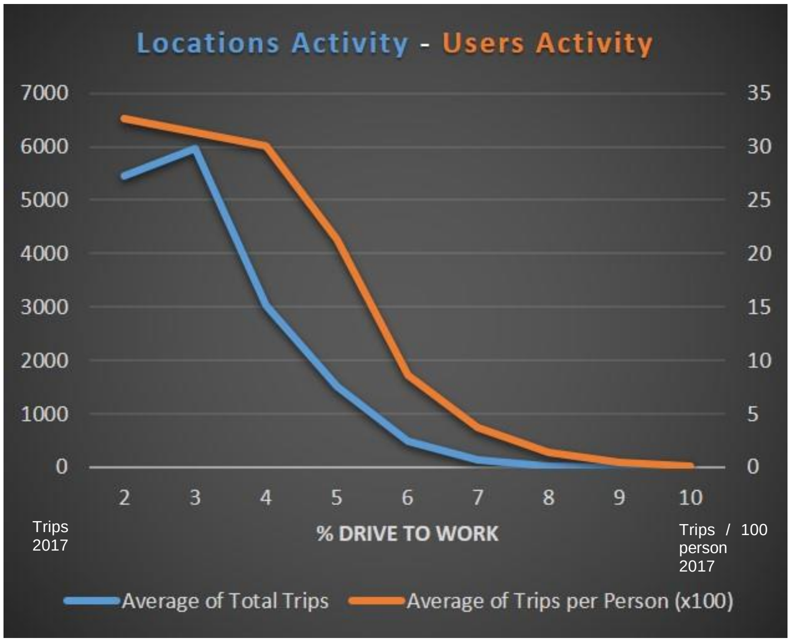


Figure 4-20: Correlation between Modo Activity and percentage of people who drive to work

Source: Author's illustration of Modo and Statistics Canada data, 2018

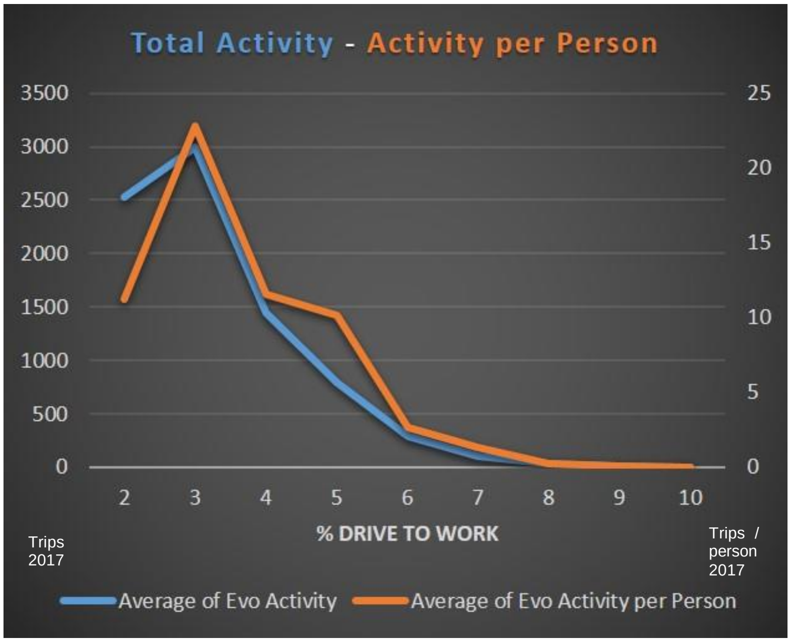


Figure 4-21: Correlation between Evo Activity and percentage of people who drive to work

Source: Author's illustration of Evo and Statistics Canada data, 2018

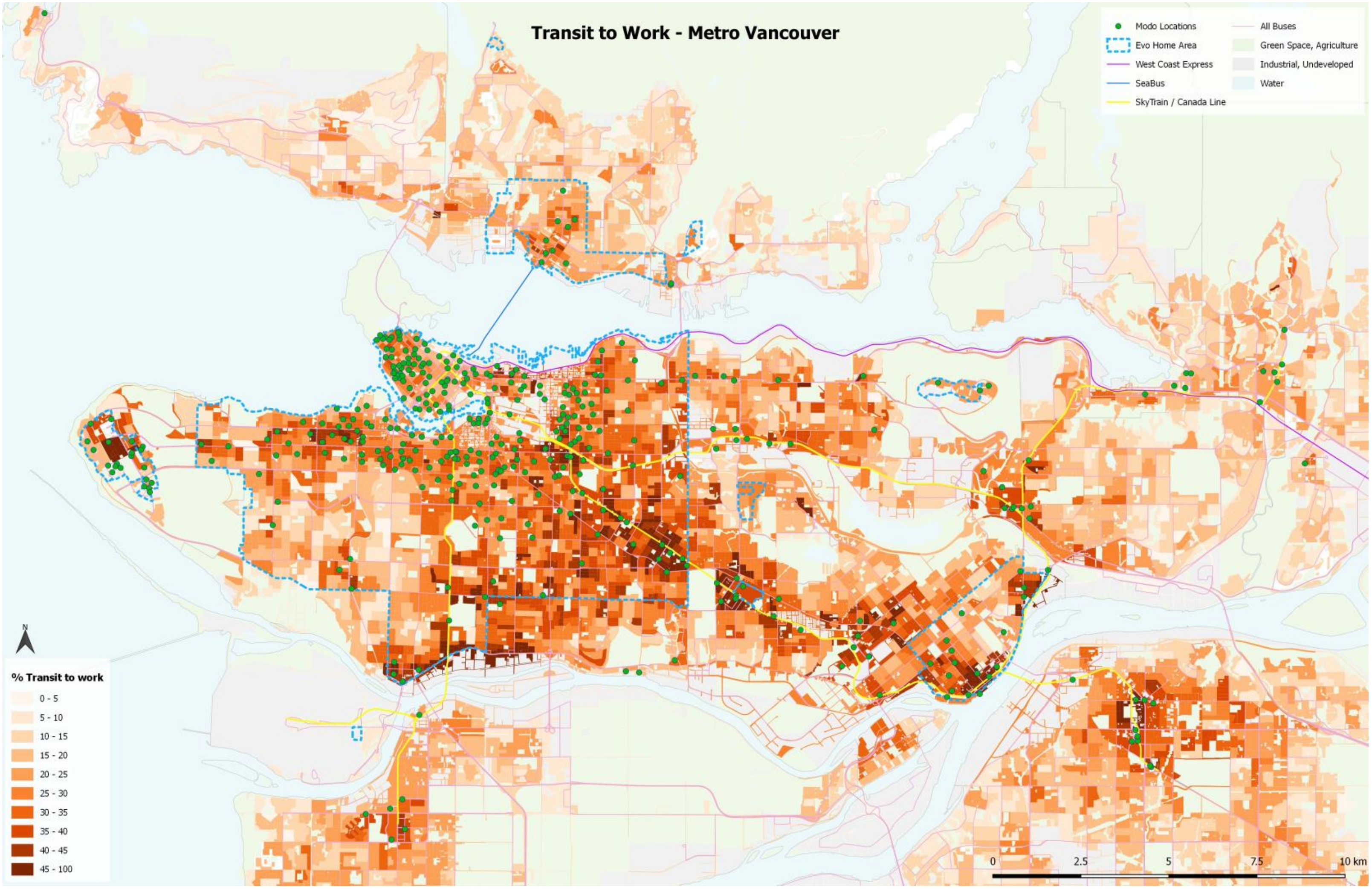


Figure 4-22: Percentage of people who transit to work as commuting mode per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

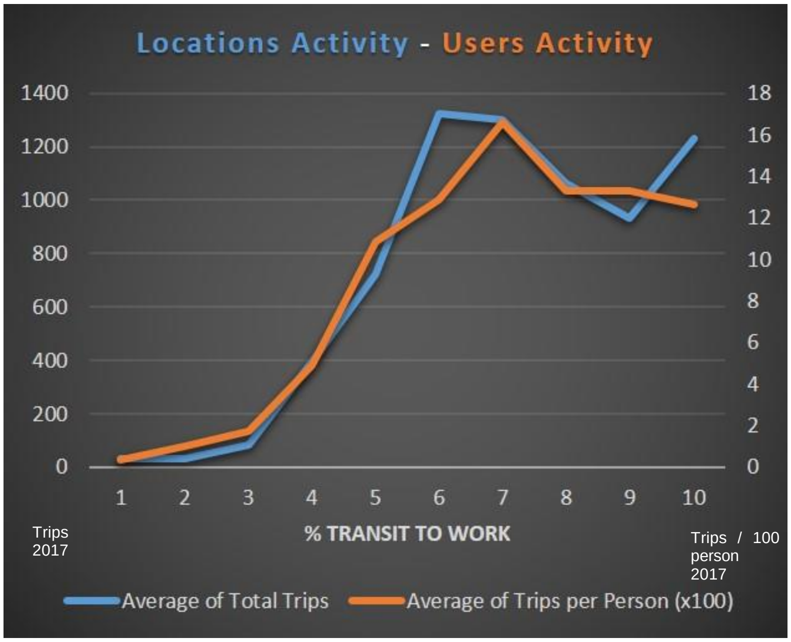


Figure 4-23: Correlation between Modo Activity and percentage of people who take transit to work

Source: Author's illustration of Modo and Statistics Canada data, 2018

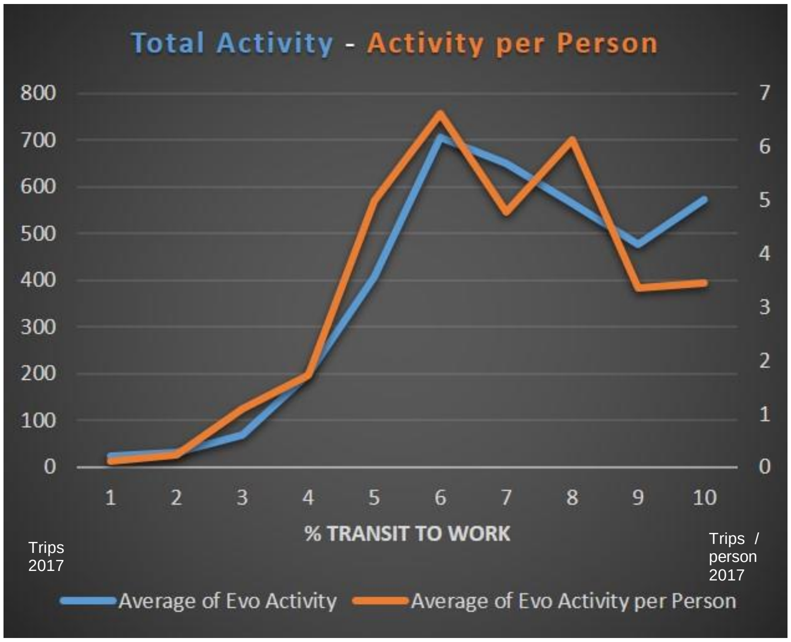


Figure 4-24: Correlation between Evo Activity and percentage of people who take transit to work

Source: Author's illustration of Evo and Statistics Canada data, 2018

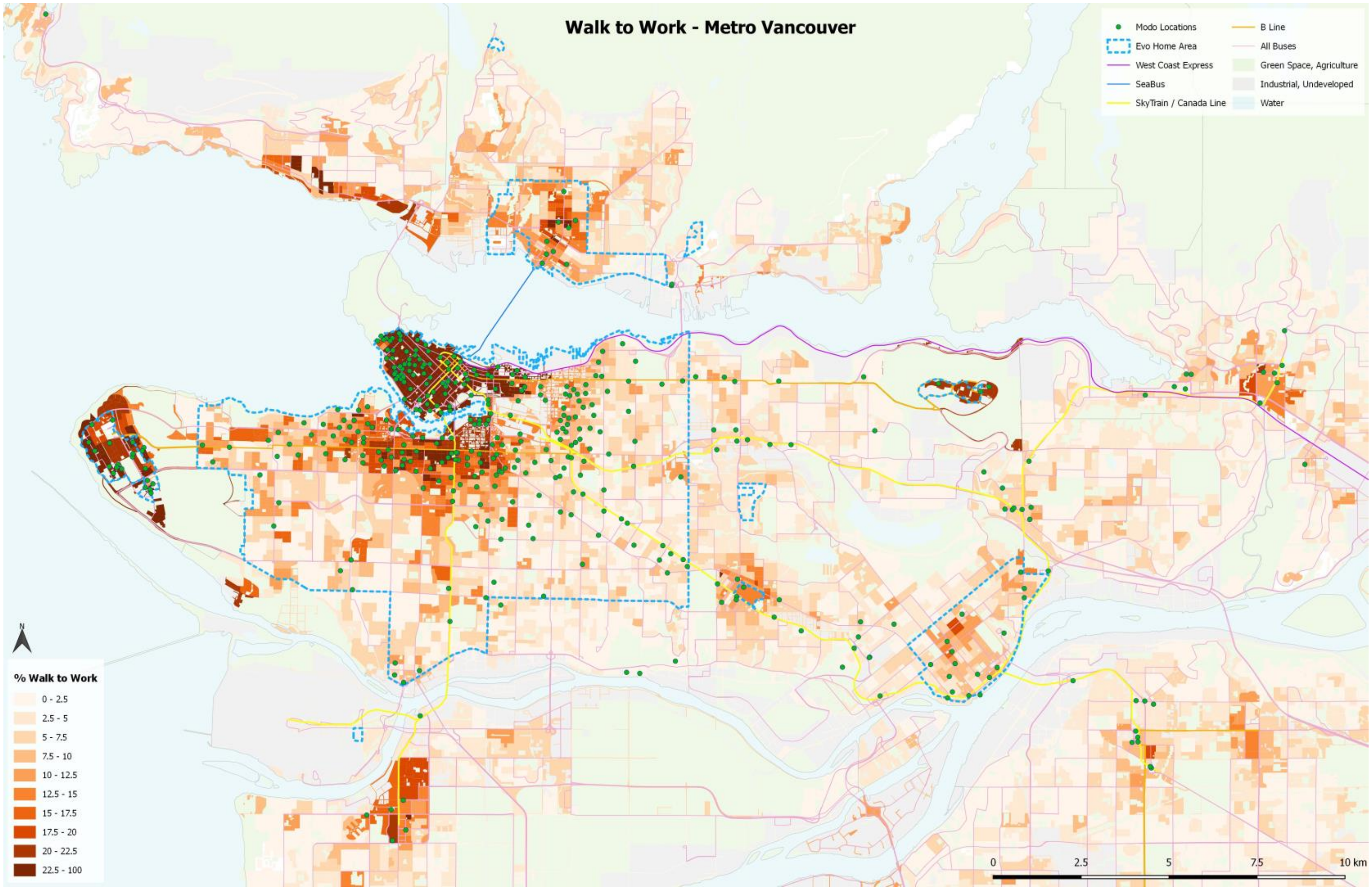


Figure 4-25: Percentage of people who walk to work as commuting mode per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink and Statistics Canada data, 2018

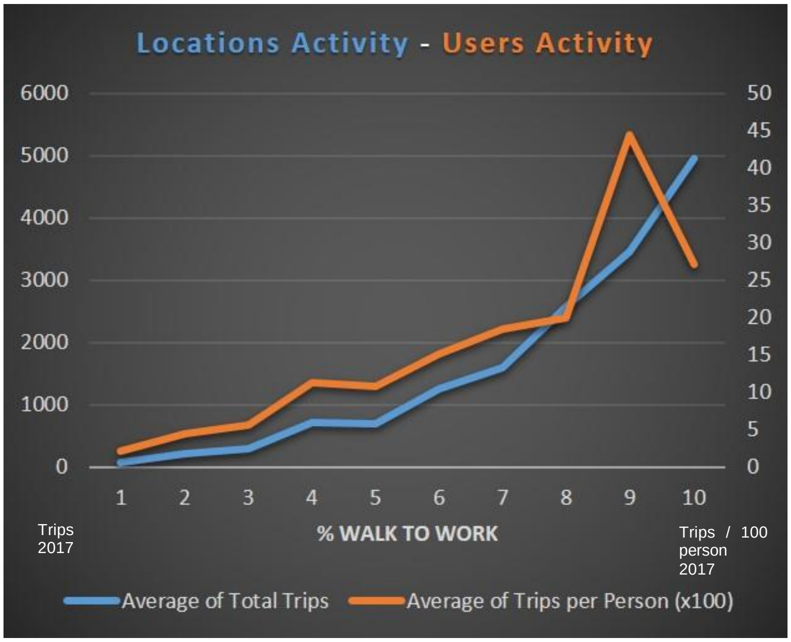


Figure 4-26: Correlation between Modo Activity and percentage of people who walk to work

Source: Author's illustration of Modo and Statistics Canada data, 2018

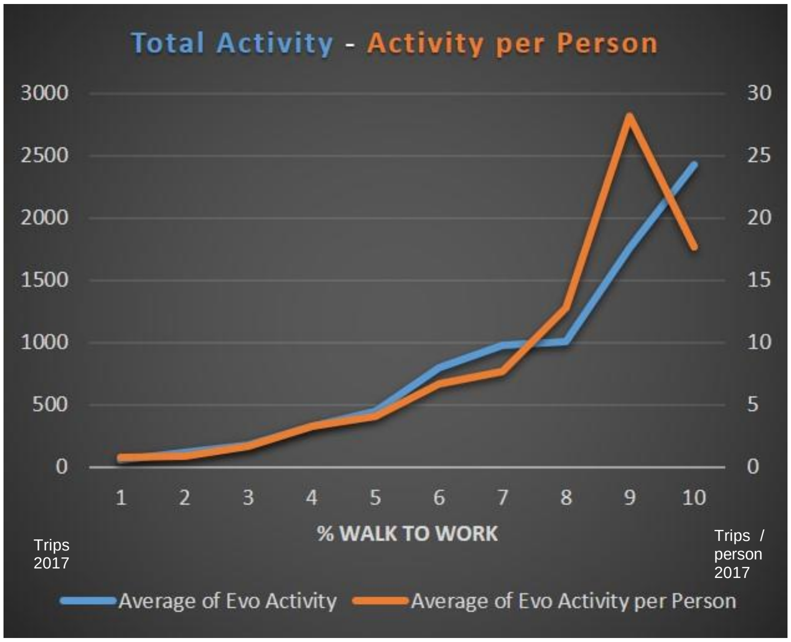


Figure 4-27: Correlation between Evo Activity and percentage of people who walk to work

Source: Author's illustration of Evo and Statistics Canada data, 2018

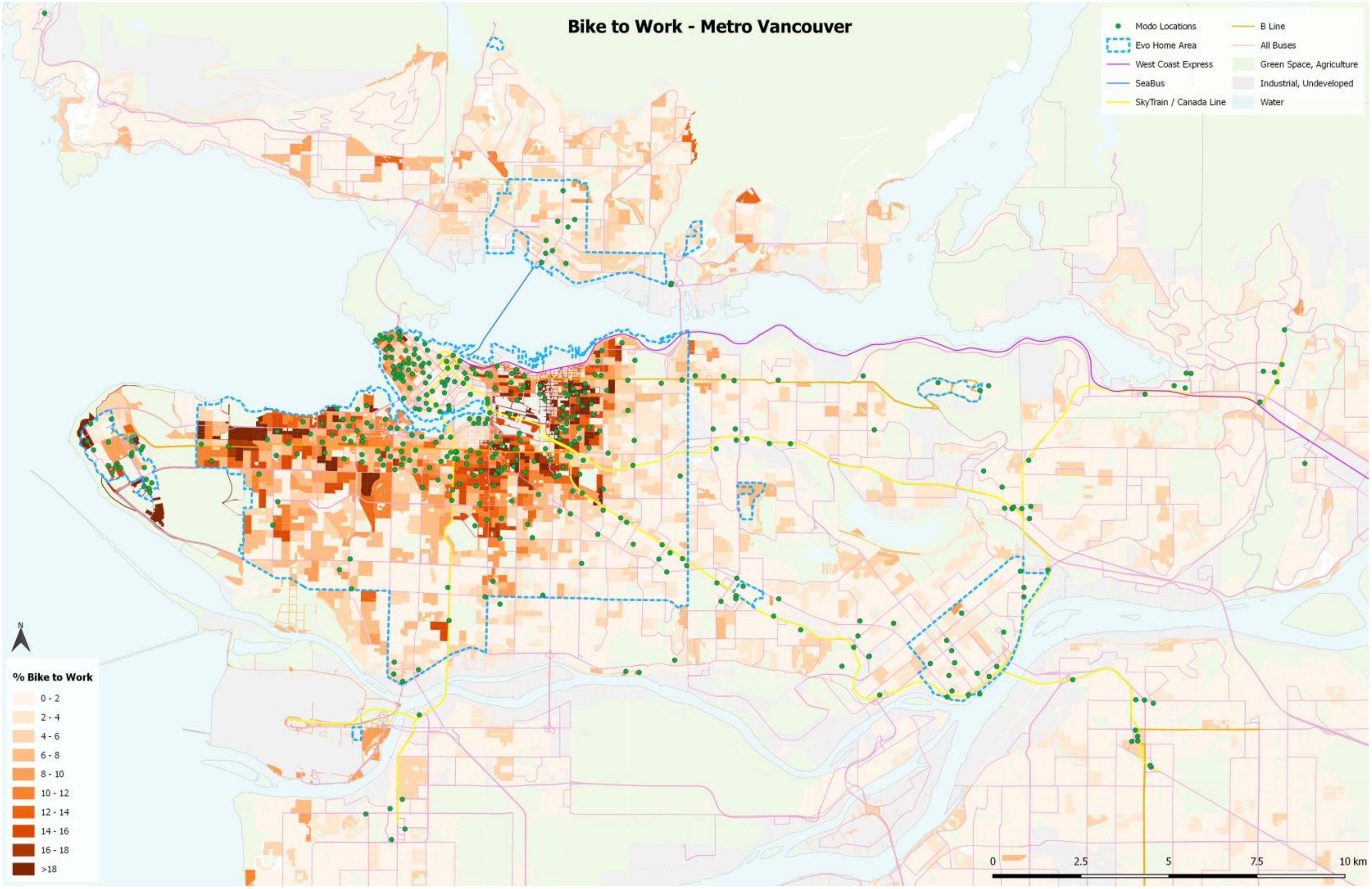


Figure 4-28: Percentage of people who bike to work as commuting mode per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

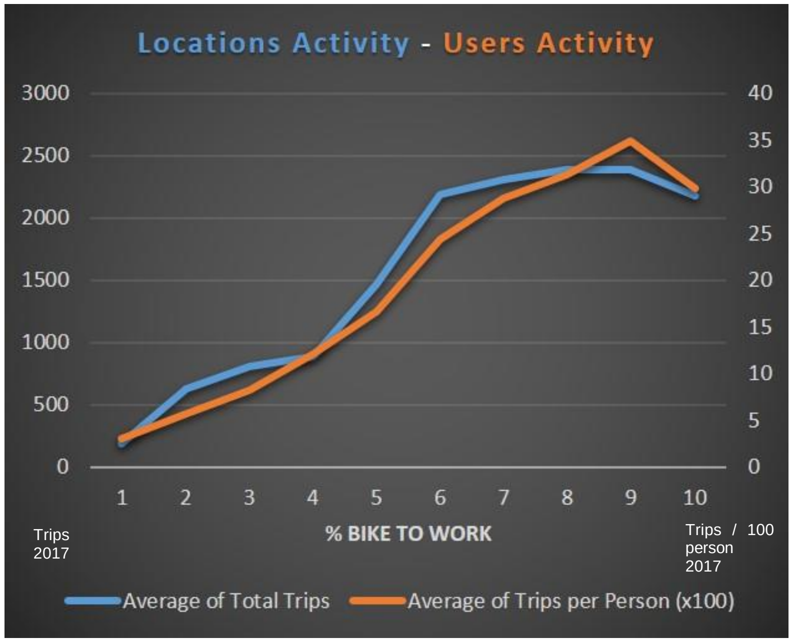


Figure 4-29: Correlation between Modo Activity and percentage of people who bike to work

Source: Author's illustration of Modo and Statistics Canada data, 2018

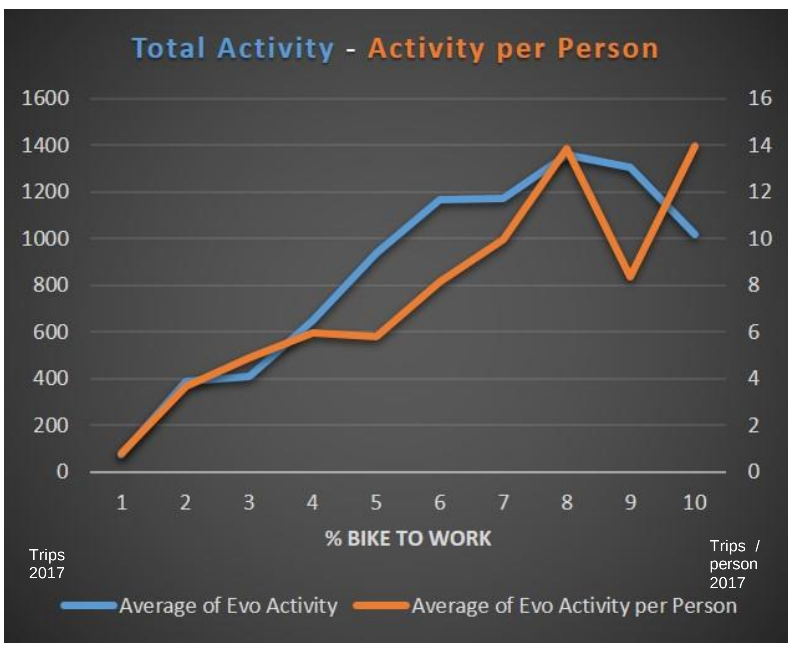


Figure 4-30: Correlation between Evo Activity and percentage of people who bike to work

Source: Author's illustration of Evo and Statistics Canada data, 2018

4.1.8. Carsharing and car ownership

In the previous section, we have seen that the success of carsharing is related to the mode of transport that people choose for their daily work commute. A place where citizens strongly rely on the usage of private cars to go from home to work and vice versa is not suitable for carsharing. In this sense, including the car ownership variable in the analysis provides some interesting insights.

As done for all the other socio-demographic variables, car ownership data has been divided into ten categories. Category 1 includes DBs where there are less than two cars every ten persons, category 10 includes DBs where there is more than one car per person.

Figure 4.31 illustrates the distribution of car ownership in Metro Vancouver. Looking at the map, it is possible to evince that, throughout the region, car ownership levels do not vary as much as other variables. Most of the study area's DBs tend to have an average value of one car every two or every three persons. Less surprisingly, the highest values of car ownership are found either in areas where income is the highest (West Vancouver, North Vancouver, Arbutus / West Side in the City of Vancouver) or in suburban areas where public transit is very weak. On the other hand, the lowest values are generally in the neighborhoods with the lowest income.

Looking at the two graphs in figures 4.32 and 4.33, both Modo and Evo activity tend to decrease as the car ownership levels increase. However, for both services, there is a significant increase in carsharing usage in areas with more than one automobile per person. More analysis would be required to better explain this trend. Looking at the map, it is evident the spotted presence of DBs with very high car ownership in areas where carsharing is generally successful, such as near Waterfront Expo Line Station or Vancouver City Hall Canada Line Station.

Even with the presence of some outliers (Category 10), it is possible to conclude that the usage of two-way and one-way carsharing is higher where the car ownership is lower. As many studies have demonstrated, most of the carsharing users belong to households with either zero or one car (Millard-Ball et al., 2005; Communauto, 2006; Cervero et al., 2007).

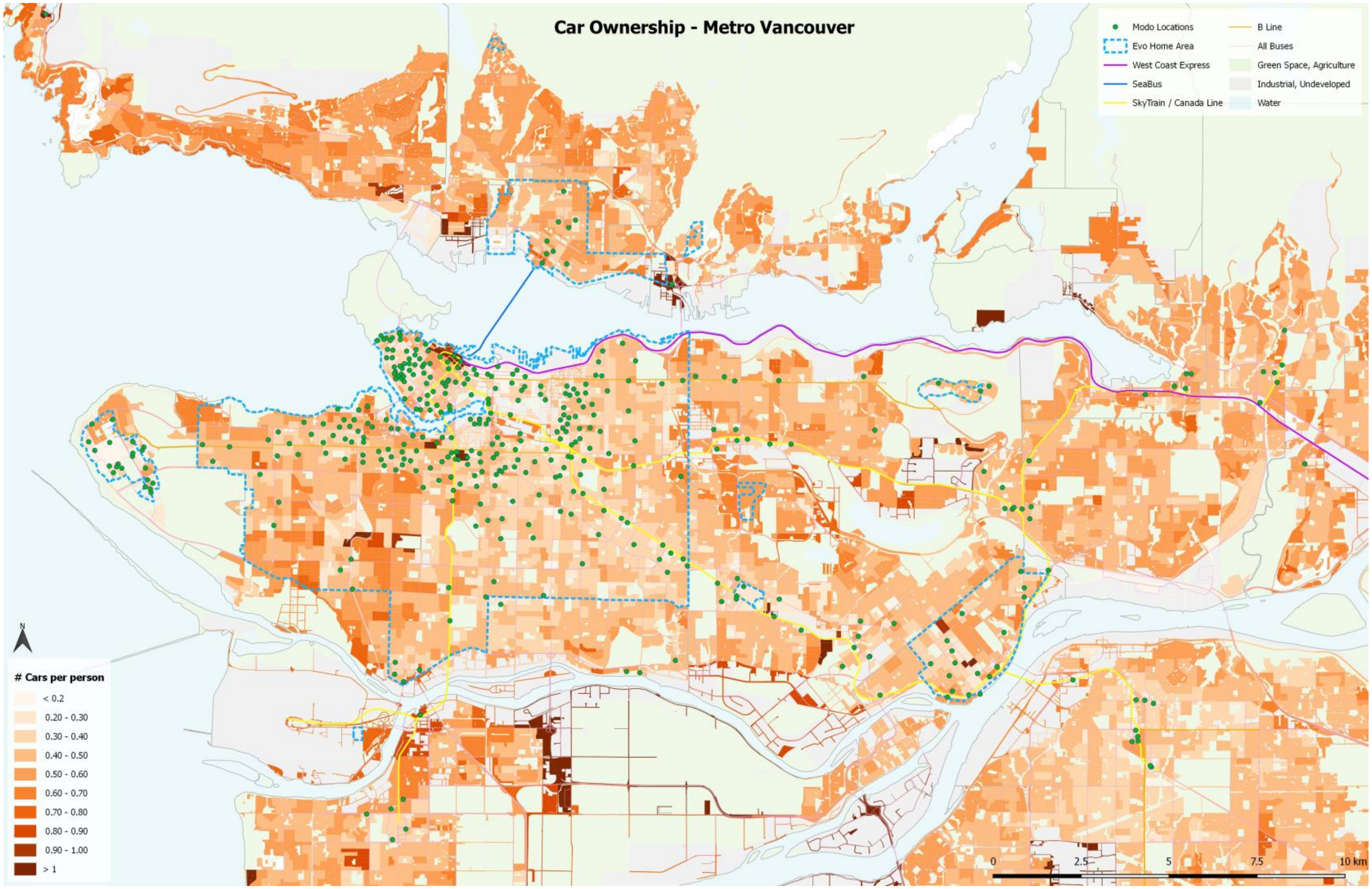


Figure 4-31: Number of cars per person per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, Statistics Canada, and ICBC data, 2018

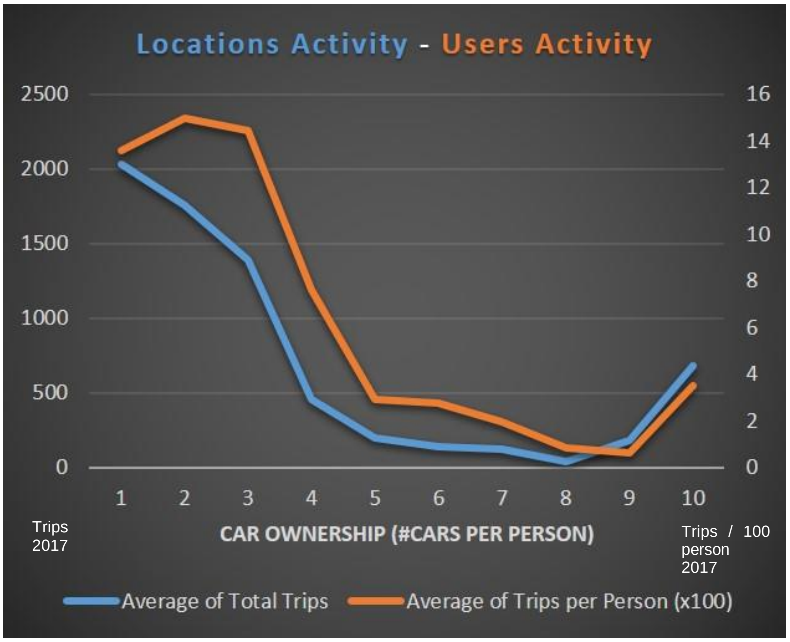


Figure 4-32: Correlation between Modo Activity and car ownership
Source: Author's illustration of Modo and ICBC data, 2018

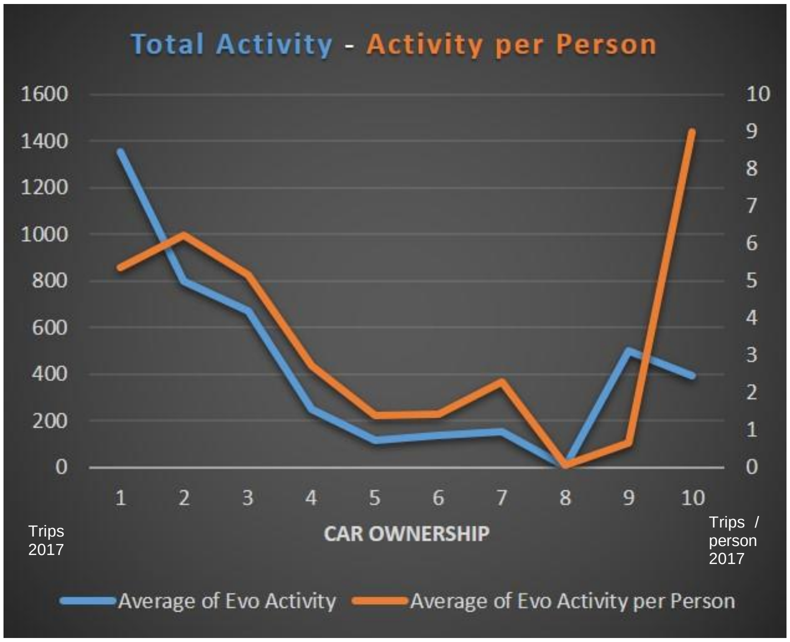


Figure 4-33: Correlation between Evo Activity and car ownership
Source: Author's illustration of Evo and ICBC data, 2018

4.1.9. Carsharing and Transit Score

In section 4.1.7, the correlation between the commuting mode options and the usage of carsharing showed that there is a strong positive relationship with public transit choice. Areas where public transit covers a larger part of the residents' transportation alternatives are also areas where Modo locations are used more (Location Activity), where the users who make more Modo trips have their home address (User Activity) and where Evo cars are parked or picked up more frequently than average.

A large part of the literature review focused on the idea that a strong, reliable and efficient public transit infrastructure is necessary in order to allow carsharing to succeed successfully in an urban environment. This is because carsharing is not supposed to be the solution for all transportation needs, but instead, to fill the gap that cannot be met by any other means of transport which is not a private car. In other words, carsharing is meant to be the perfect complement for public transit and other alternative modes to allow everyone to satisfy all mobility needs without having to rely on the ownership and usage of private cars.

For the reasons above, a large part of the analysis attempted to understand which areas of Metro Vancouver can be considered stronger than others in terms of public transport and to evaluate the importance that carsharing has in those zones. To do that, a Transit Score indicator has been created following the methodology described in subsection 3.2.2. The outcome of this process has been the assignment to each DB of Metro Vancouver a score based on the quantity and level of service of transit that is available nearby. The higher the score, the more and the better transit is accessible in that DB.

As done for the socio-demographic and geographic variables, the Transit Score, whose values range between 0 and 100 points, requires a categorization. Figure 4.34 illustrates how the Transit Score varies in Metro Vancouver. As foreseen, the single area with the highest score of the region is the central core of Vancouver Downtown, where the quantity and quality of transit stops are very concentrated. Very high scores are also found along the SkyTrain corridors, not only because the rail rapid transit is the most efficient transportation system of the region, but also because many stations are functioning as mobility hubs, with multiple bus lines converging and offering inter-modal opportunities.

Figure 4.35 identifies a clear positive correlation between the usage of Modo carsharing and the Transit Score. In general terms, locations with better transit service, are locations where carsharing is used more. More specifically, it is useful to look at the two different indicators. Considering the Modo Location Activity (the blue line in the graph), its value remains very low for DBs with a transit score lower than 60 (category 1 through category 6) and they rapidly increase in the highest categories. This trend can be explained by the lack of Modo locations in areas with poor transit service availability. On the other hand, the User Activity (the orange line in the graph) shows more rapid growth for the first categories than the Location Activity. This means that in areas with poorer transit service and with no Modo locations, there are still active carsharing members. That being said, the User Activity steadily increases with the escalation of the transit score, until category 9, where it shows a considerable drop. This drop occurs in those DBs where the transit score is higher than 90, i.e., in the central core of Vancouver Downtown. In this case, the fall in the average number of trips per person might be associated to the higher presence of business offices rather than residential apartments.

Similar considerations can be made looking at Evo Activity in Figure 4.36. The number of one-way carsharing trips starting or ending in DBs with a low transit score is almost null, suggesting that the operational area of the one-way carsharing only covers areas with good public transit service. As for Modo Location Activity, the Evo Activity starts to grow after category 6 and reaches its peak in category 9, before falling in DBs with the highest transit score. In this case, the fall might not only be due to the lower presence of residential apartments, but it can be explained by looking at the parking restrictions of Downtown Vancouver. In fact, at the moment of writing, Evo cars are not allowed to be parked on streets with parking meters. In downtown, where almost every street parking is metered, cars can only be found in specific parking locations. The result is that some DBs, whose area can be tiny in the very densest neighborhoods, have no one-way carsharing activity associated, in cases where they do not have Evo parking locations within their boundary. In addition, the decline in the areas with the highest Transit Score might explain a reduced need for carsharing inside a very complete and extremely well transit-served community, such as Vancouver Downtown, compared to other areas of the region with very good but not excellent public transit.

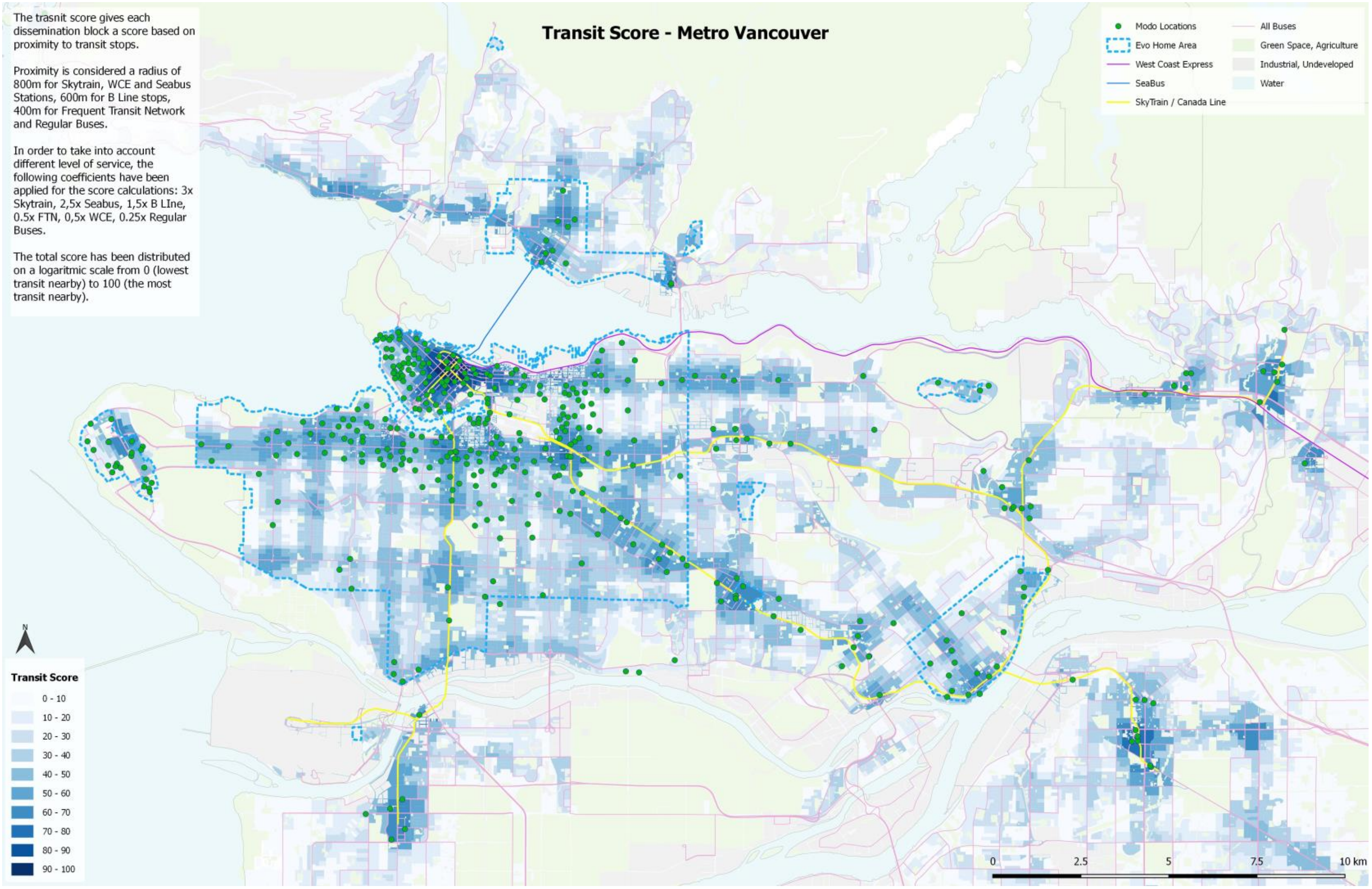


Figure 4-34: Transit Score per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

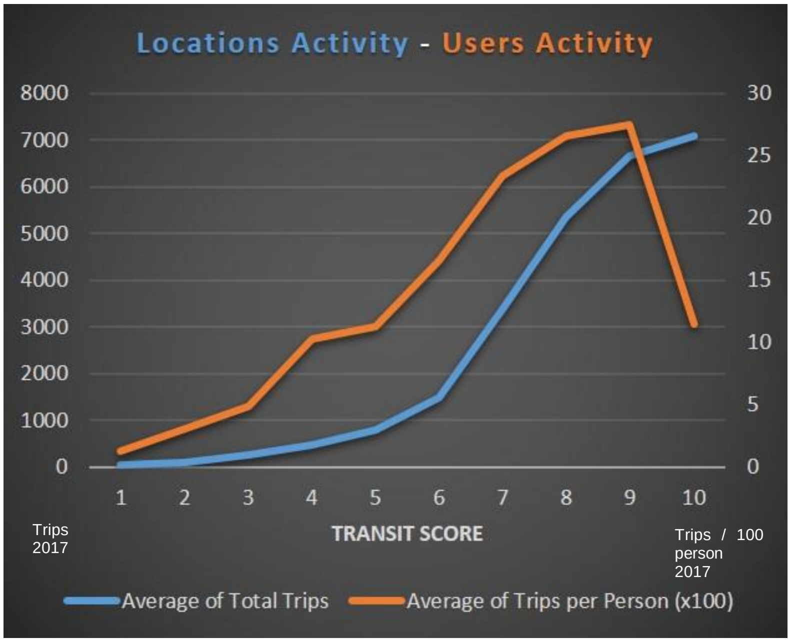


Figure 4-35: Correlation between Modo Activity and Transit Score
Source: Author's illustration of Modo and TransLink data, 2018

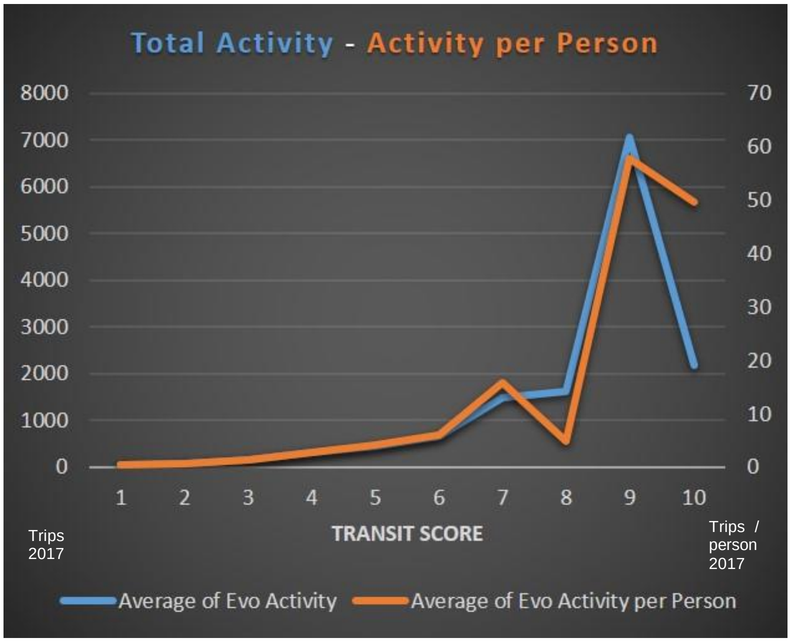


Figure 4-36: Correlation between Evo Activity and Transit Score
Source: Author's illustration of Evo and TransLink data, 2018

4.1.10. Carsharing and Transit Activity

The previous section showed the correlation between carsharing usage and the Transit Score, an indicator capable of ranking the DBs of Metro Vancouver based on the quantity and service quality of the public transit available nearby. On the other hand, this section focuses on the usage of the transit network itself. To do that, the chosen indicator is the Transit Activity. As explained in section 3.2.2, the Transit Activity indicates for each DB the sum of the activity (average daily boardings + average daily alightings) of all the transit stops that are located in proximity of that specific DB.

While the subdivision of the Transit Score in 10 categories was quite obvious, the categorization of the Transit Activity was not as easy due to the fact the values assumed by the indicator have an extremely high variation throughout the region. On one side, there are locations with no transit in proximity and no activity. On the other, there are locations near hundreds of transit stops and total values of activity that can reach up to 300,000 daily passengers. Once again, the rule for the categorization has been to maintain approximately the same number of DBs in each category.

Figure 4.37 shows how the Transit Activity varies throughout Metro Vancouver. Not surprisingly, there are visible gaps between the DBs that have a good quality of transit in proximity and all the other areas of the region. In particular, it is clear how the highest values of transit usage are in the areas of the SkyTrain lines and the B-Line, with specific regard to the 99 B-Line which runs along Broadway and is considered one of the busiest bus routes in North America (Jaffe, 2014).

Looking at the graphs in Figures 4.38 and 4.39, we can say that the higher the usage of public transit, the higher the usage of both Modo and Evo carsharing. This result was certainly expected considering the findings from the literature review, and it confirms a first important answer that this research provides: two-way and one-way carsharing usage in Metro Vancouver are strongly correlated to the public transit variable. This idea has been demonstrated by the results of the correlation between the usage of carsharing and three different indicators: the percentage of people that use transit to commute to work, the Transit Score and the Transit Activity.

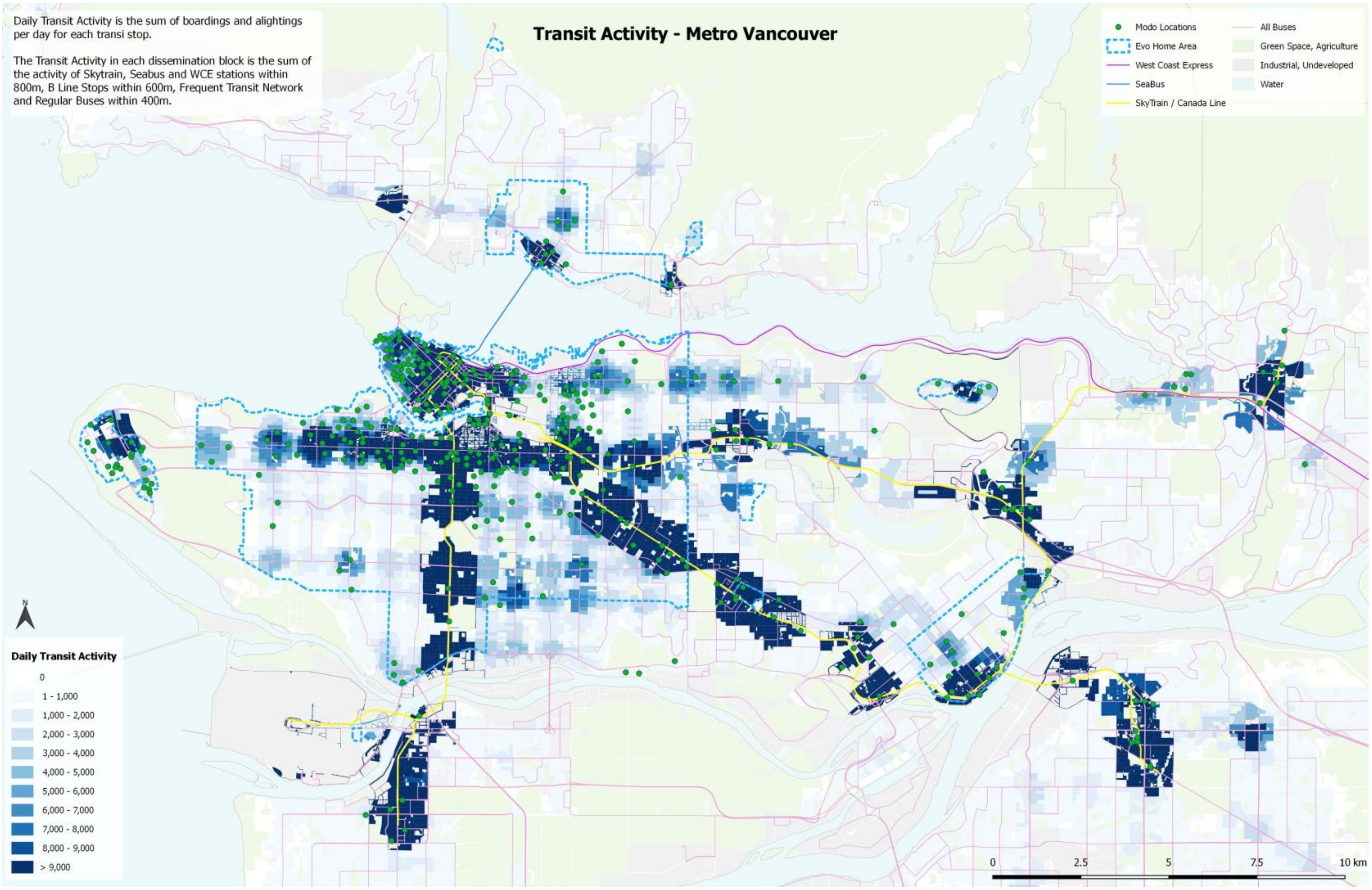


Figure 4-37: Transit Activity per dissemination block in Metro Vancouver
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

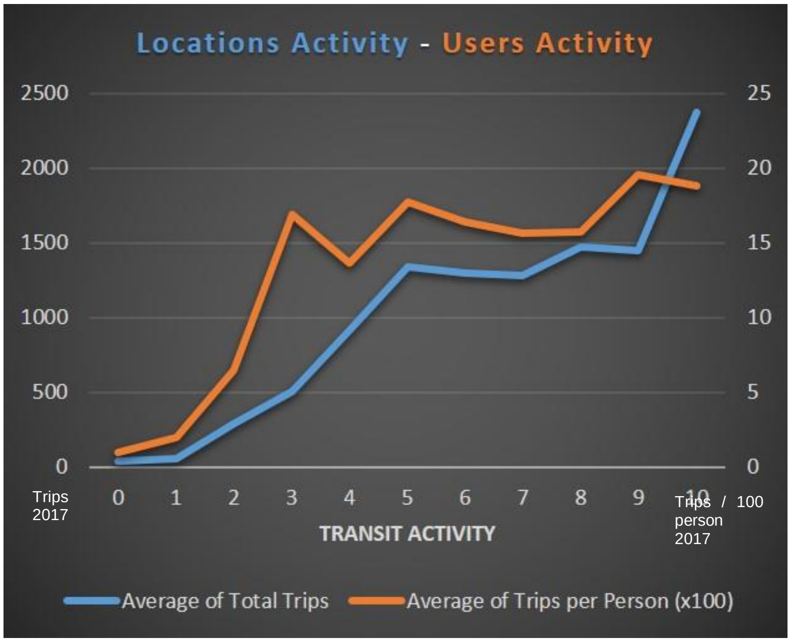


Figure 4-38: Correlation between Modo Activity and Transit Activity
Source: Author's illustration of Modo and TransLink data, 2018

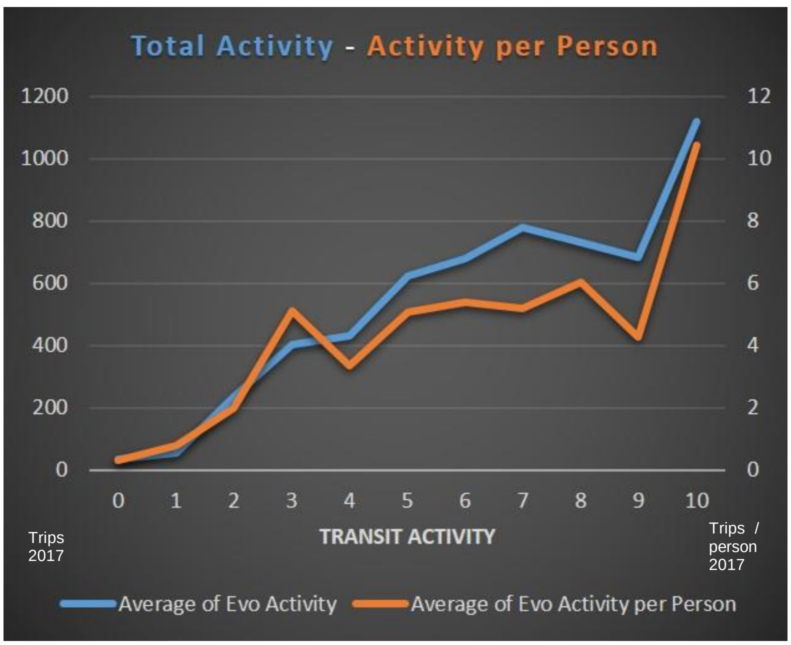


Figure 4-39: Correlation between Evo Activity and Transit Activity
Source: Author's illustration of Evo and TransLink data, 2018

4.1.11. Correlation Summary

In the previous subsections, the variables describing the geographic, socio-demographic and public transport features of every location in Metro Vancouver have been correlated with the usage of two-way and one-way carsharing. The correlation analysis that has been presented through the graphs showed either positive (population density, percentage of single person households, percentage of rental housing, percentage of post-secondary education, percentage of people who take public transit to work, percentage of people who walk to work, percentage of people who bike to work, transit score), negative (percentage of single-detached houses, percentage of people who drive to work, car ownership) or non-existent correlation (average income per recipient).

Interestingly, net of few discrepancies, the correlation with the independent variables showed very similar general trends for both the indicators describing the usage of Modo and Evo. This might suggest that in Metro Vancouver, the socio-demographic, geographic and public transit characteristics have similar influences on both two-way and one-way carsharing.

Another way to summarize the data analysis and an opportunity to understand more deeply the correlation results is to look at Table 4.1. In this case, the table provides the average values that the independent variables assume in different locations. Specifically, these locations are divided based on specific conditions. The first condition divides the DBs into two groups: those ones with the presence of at least one Modo user (column 1) and those without any Modo user (column 2). The second condition separates the DBs with at least one Modo location nearby (column 3) from those without any Modo location nearby (column 4). Finally, the third condition divides the DBs where there has been at least one Evo trip (either started or ended) from those with no Evo activity at all.

	At least 1 Modo Driver	No Modo Drivers	At least 1 Modo Location	No Modo Locations	At least 1 Evo Trip	No Evo trips
Population Density	11,405	3,575	8,409	3,398	7,322	3,632
Single Detached Houses	15%	48%	17%	53%	27%	50%
1-Person Households	36%	21%	35%	19%	31%	20%
Rental Housing	50%	28%	48%	24%	43%	25%
Post-Secondary Education	74%	66%	73%	66%	73%	65%
Income per Recipient	34,882	34,496	33,946	34,806	34,807	34,438
Drive to Work	47%	70%	48%	73%	51%	73%
Transit to Work	30%	17%	30%	15%	28%	15%
Walk to Work	11%	5%	11%	4%	10%	4%
Bike to Work	7%	2%	6%	1%	6%	1%
Transit Score	51	33	52	30	48	30
Transit Activity	16,214	3,848	17,336	1,204	13,802	1,974

Figure 4-40: Correlation Summary per Dissemination Block
Source: Author's illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

The values shown in the table confirm what has been found from the correlation analysis described in the previous chapters.

For example, in the first line, the average population density is more than three times higher in DBs with at least one Modo users' address than in DBs without any. The density value is also the double in DBs with Modo locations nearby compared to DBs further away from any Modo locations. The same happens in DBs with Evo activity compared to DBs without that activity.

Looking at the other values and comparing locations with or without carsharing usage, essential differences can be found for the percentage of single detached houses, the percentage of rental housing, the percentage of people who drive to work, the percentage of people who take transit to work, the percentage of people who walk to work, and the percentage of people who bike to work. All these variables have much higher values in locations where there is carsharing presence. The same happens for the Transit Score and the Transit Activity. Indeed, all these variables demonstrated to have a positive influence on the usage of carsharing in Metro Vancouver.
The percentage of post-secondary education has a less marked difference than the previously-mentioned variables, but it still shows higher values in areas with carsharing presence.
On the other hand, the percentage of single-detached houses and the percentage of people who drive show much higher values for locations without carsharing activity or users. For these two variables, there is a negative influence on carsharing usage that was also found in the correlation analysis.
Finally, the values of average income show no difference between the groups of DBs with or without carsharing activity, suggesting that there is almost no correlation between the average income and the usage of carsharing in Metro Vancouver.

Spearman Correlation

A third, and final way, to examine the correlation between the dependent and independent variables is to introduce the Spearman's rank-order to analyze the data. The Spearman correlation determines the strength of the association of two variables. This correlation expresses the depth of linkage between the variables in a single value between -1 and +1. This value is called the correlation coefficient. A positive correlation coefficient indicates a positive relationship between the two variables (the larger the independent variable, the larger the dependent variable), while a negative correlation coefficient expresses a negative association (the larger the independent variable, the smaller the dependent variable or vice versa). A correlation coefficient close to zero indicates that no connection between the data exists at all.

The Spearman correlation coefficients between the independent variables (geographic, socio-demographic and public transit) and the dependent variables (two-way and one-way carsharing usage) have been calculated using the IBM SPSS software. The results of the correlation are shown in Table 4.2.

The Spearman coefficient values confirm what has been reported previously in this chapter. The population density, the percentage of single person households, the percentage of rental housing, the percentage of public transit to work, the percentage of people who walk to work, the percentage of people who bike to work, the Transit score and the Transit Activity all have a positive correlation with Modo Location Activity, Modo User Activity and Evo activity. The percentage of post-secondary education shows a positive relationship, but the coefficient values are lower than the other variable just mentioned. On the other hand, the percentage of single-detached houses and the percentage of people who drive to work show a negative correlation.

Another interesting observation can be made by looking at the differences between the Spearman coefficients values for Modo Location Activity and Modo User Activity. Focusing on the variables with a positive relationship, the coefficients' values for the User Activity are always smaller compared to the ones for the Location Activity, except for the population density. This might be interpreted in multiple ways. One could be that Modo locations' placement and their usage is more dependent on the characteristics of the area compared to the areas where more active Modo users live, which is slightly less correlated. In other words, Modo locations have definitely a higher usage in areas with specific characteristics. These areas are also the places where Modo users tend to have their home address, even if this last relationship is less strong. This confirms what has been outlined in Figure 3.4 and Figure 3.5 in Chapter 3. The distribution and the carsharing usage made by Modo users is more spread throughout the region compared to the distribution and usage of Modo locations.

Finally, it is worthwhile to note the values assumed by the Spearman coefficients for the indicators related to public transit have higher values than any other indicator. Once again, this reinforces the importance that the Metro Vancouver public transit network has to ensure the success of both two-way and one-way carsharing.

	Dependent variables			
	Modo Locations activity	Modo Users Activity	Evo Activity	
Independent variables	Total Trips	Trips per Person per DB	Activity per DB	Activity per person per DB
Population density	0.327	0.595	0.341	0.437
% of single-detached households	-0.569	-0.301	-0.396	-0.305
% of single person households	0.531	0.258	0.396	0.319
% of rental housing	0.53	0.334	0.438	0.362
% of post-secondary degrees	0.286	0.233	0.319	0.288
Average income per recipient	-0.019	-0.072	0.019	0.021
% of people who drive to work	-0.678	-0.529	-0.648	-0.566
% of people who take public transit to work	0.555	0.519	0.523	0.474
% of people who walk to work	0.447	0.204	0.37	0.296
% of people who bike to work	0.469	0.36	0.555	0.505
Transit Score (Logaritmic)	0.577	0.432	0.48	0.423
Transit Activity	0.649	0.506	0.557	0.492

Figure 4-41: Results of Spearman Correlation Analysis
Source: Author’s illustration of Modo, Evo, TransLink, and Statistics Canada data, 2018

4.2. Two-way Carsharing and Public Transit

In the previous subsections, the correlation analysis between the usage of two-way, one-way carsharing and the independent variables defining Metro Vancouver locations has been widely considered. Each DB has been connected with the dedicated information describing carsharing usage, geographic, socio-demographic and public transit characteristics in that specific location at a very fine grain of detail.

In addition to what seen before, this second section of Chapter 4 provides a further, deeper analysis of the relationship between the usage of two-way carsharing and public transit in Metro Vancouver. This part of the research only considers Modo carsharing locations and the features of the areas in which they are placed.

4.2.1. Modo Location Total Activity and Location Net Activity

In the previous part of the analysis, the two-way carsharing usage was described by two indicators: the Location Activity per DB and the User Activity per DB. In particular, the first one indicated the total number of Modo trips made in each DB having Modo locations in proximity. On the other hand, this second part does not associate the usage of carsharing with the DBs surrounding each location. Instead, it directly analyzes the Modo locations, their usage features, and the public transit characteristics in their proximity.

As of December 2017, in Metro Vancouver, it was possible to access a Modo car in one of the 412 active locations spread throughout the Lower Mainland. Of course, not all the locations are being used at the same rate, and the Location Activity indicator showed which DBs have the highest number of trips made in locations nearby.

Figure 4.40 below shows the Location Total Activity for the 412 Modo locations.

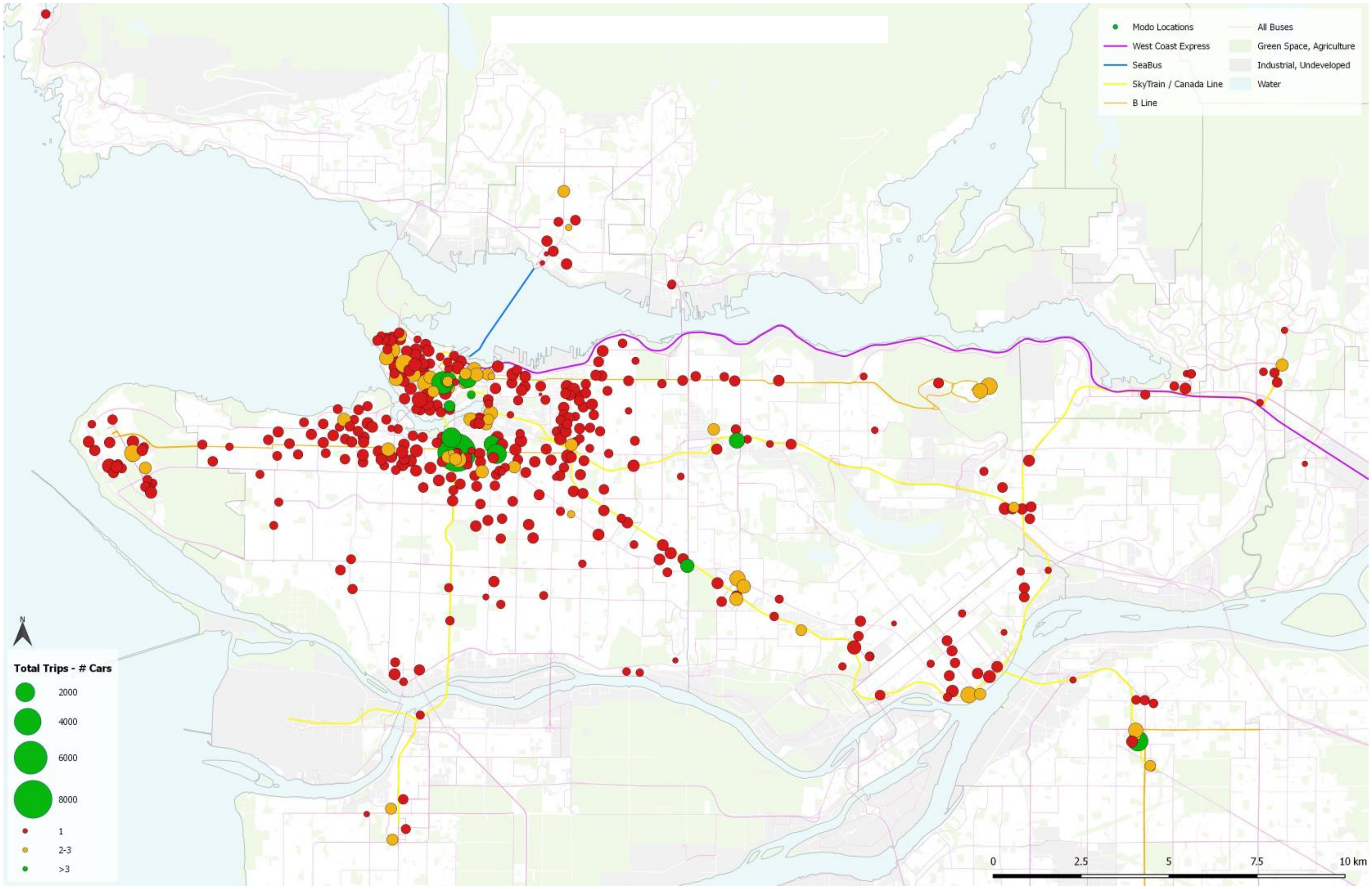


Figure 4-42: Modo Location Total Activity: Number of total trips per location
Source: Author's illustration of Modo, TransLink, and Statistics Canada data, 2018

In the figure, the size of the dot is proportional to the total number of trips made from that location between January 2017 and December 2017, while the color indicates the number of cars available. The map clearly shows that the total number of trips made from each Modo location varies significantly throughout the region, with some locations having a considerably higher number of trips than others. Even if the total number of trips made per location represents a good indicator to describe the usage of carsharing in Metro Vancouver, this number strongly depends on two other factors: the number of cars that are available at that specific location and the number of months that the location has been active.

For this reason, it is appropriate to introduce a new indicator that also takes into account these two factors when describing the two-way carsharing usage. This indicator has been called Location Net Activity and indicates the number of trips made per each Modo location between January 2017 and December 2017, divided by the number of cars available in that location and by the number of months that the location has been active.

Figure 4.41 illustrates the Location Net Activity in the Lower Mainland region. The number of monthly trips per location per car available is proportional to the size of the dots, while their color indicates the number of months that the location has been in operation. Even if there are locations where the Location Net Activity is higher than others, there are not the same remarkable differences that emerged in the Location Total Activity. Even locations that have started to operate more recently, generally show a Net Activity that is in the same range of more mature locations.

Looking at the values shown in the map for the Location Net Activity, it is safe to deduce that the usage of a location strongly depends on the number of cars available. At the same time, it is evident that an equal distribution of the Location Net Activity is the result of a careful planning strategy from Modo, whose primary interest should be to guarantee that every car on the network is being used enough.

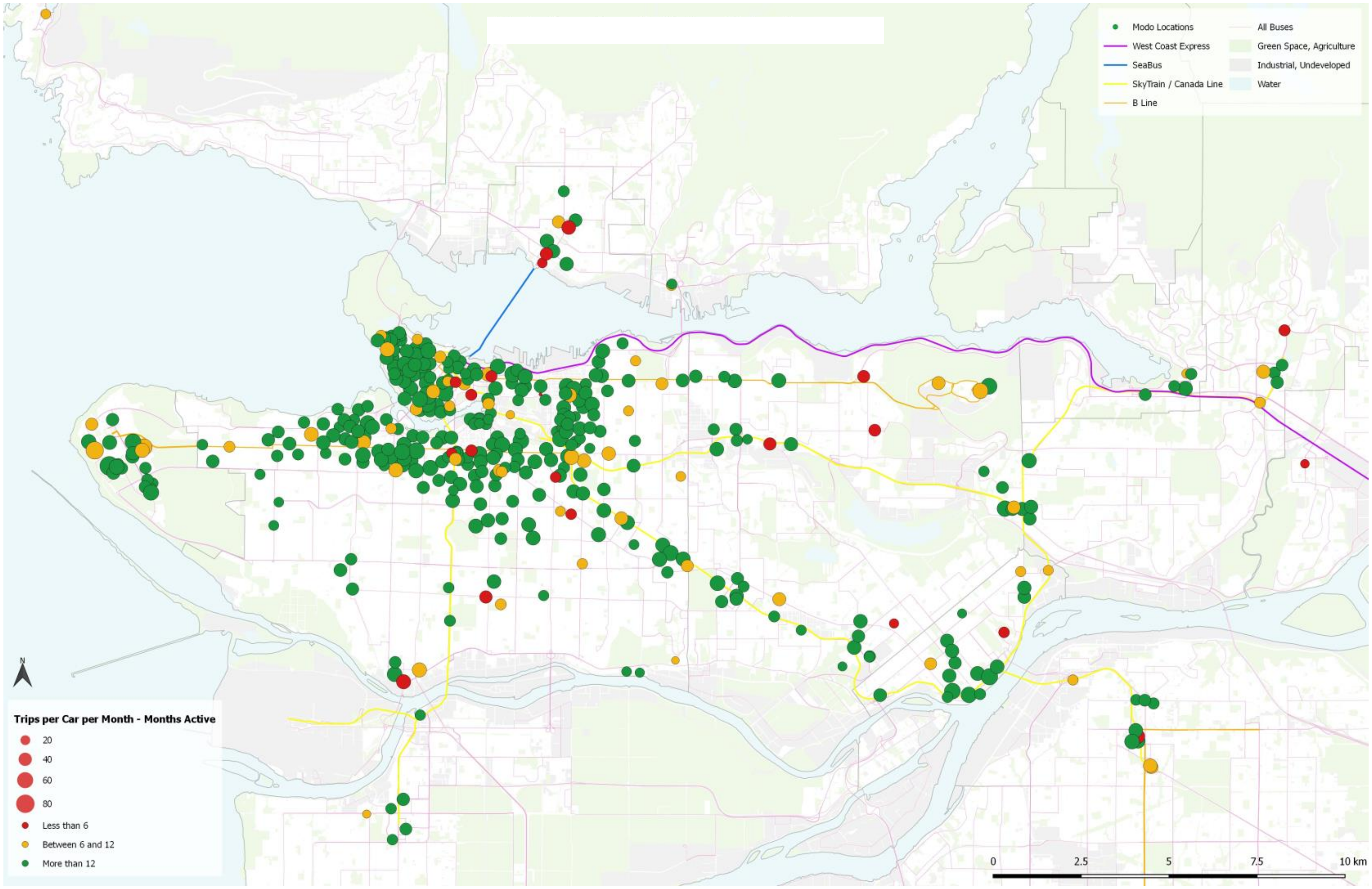


Figure 4-43: Modo Location Net Activity: Number of monthly trips per car per location
Source: Author’s illustration of Modo, TransLink, and Statistics Canada data, 2018

4.2.2. Modo Locations and Transit Score

In section 4.1.9 of the correlation analysis, the number of total carsharing trips made per DB (Modo Location Activity) has been correlated with the Transit Score assigned to each DB in Metro Vancouver. Not surprisingly, the results showed that the better the transit service gets, the more two-way carsharing trips are made. In part, this was also influenced by the fact that the analysis considered the whole Metro Vancouver region, and included the most suburban areas, with very poor transit service, and no Modo locations nearby.

In this subsection, instead of every DB in Metro Vancouver, only Modo locations are considered, and each one of them is associated with a Transit Score based on the public transit available nearby. The procedure is the same as the one seen before, in which each of the 15,197 DBs of Metro Vancouver has been assigned a transit score. The difference is that, in this case, the analysis only includes the 412 Modo carsharing locations. A radius of 800m from each Modo locations is considered, and every transit stop that falls within this radius is counted to determine the score assigned to that location. The multiplying coefficients applied to give to each transit stop different importance based on the level of service, are the same used before (3x SkyTrain, 2.5x Seabus, 1.5x B-Line, 0.5x Frequent Transit Network, 0.5x West Coast Express, 0.25 Other buses). The rationale behind these coefficients was explained in section 3.2.2.

The following Figure 4.42 represents the 412 Modo locations with a size proportional to their assigned transit score. The bigger the size of the dot, the better transit is available nearby.

Looking at the map, it is evident that not all Modo locations have the same transit accessibility. The ones located in Vancouver downtown or close to SkyTrain stations have higher scores associated with compared to those that are only accessible by regular bus lines. The goal is now to understand how the usage of each location changes depending on the Transit Score.

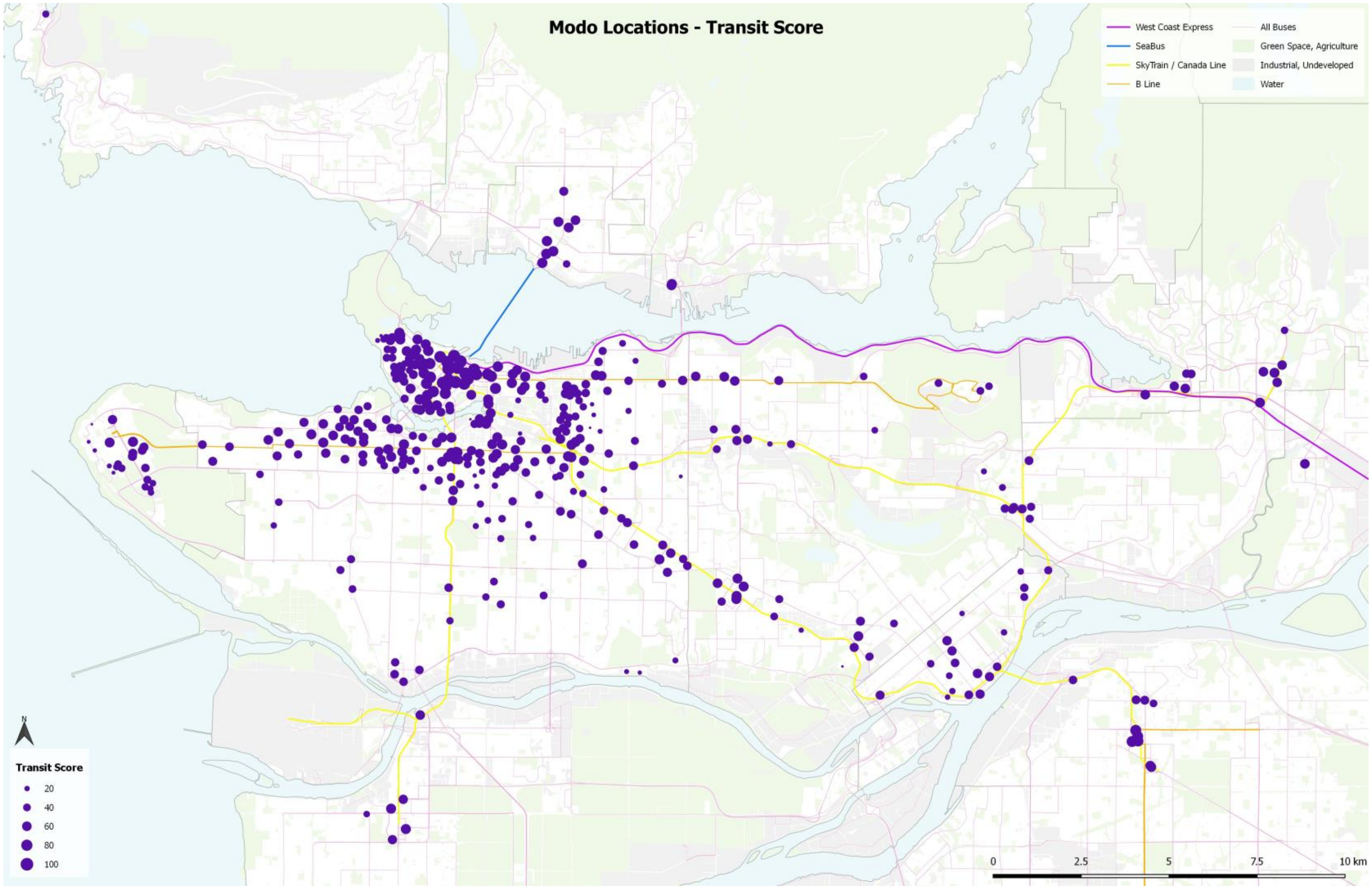


Figure 4-44: Transit Score per Modo Location in Metro Vancouver
Source: Author's illustration of Modo, TransLink, and Statistics Canada data, 2018

As for the previous analysis, to make the correlation between carsharing usage and the Transit Score, it is necessary to categorize the independent variable. Therefore, the indicator has been divided into 10 different categories and correlated with the average values that the dependent variable assumes in each class. The graphs illustrating the correlation between the variables are shown in the following two figures.

Figure 4.43 shows the relationship between the categorized transit score, on the x-axis, and the average value that Modo carsharing usage assumes in each category. Two indicators describe the carsharing usage: the Location Total Activity (blue line), expressed in total trips per location, and the Location Net Activity (orange line), expressed in trips per month per car per location.

Looking at the lines trends, it is possible to notice that, while the Location Total Activity increases for Modo locations that have higher transit scores (except for the very last category), the Location Net Activity does not seem to have a strong dependence on the transit score.

Furthermore, Figure 4.44 shows the relationship existing between the categorized Transit Score indicator, the average number of cars available in each location (blue line) and the number of months that the location has been active (orange line). In this case, there is a definite positive correlation between the number of cars and the Transit Score, as locations with better transit service tend to have more cars. On the other hand, the number of months that the location has been active does not offer any significant correlation with the Transit Score.

Considering these two graphs, it is safe to say that Modo locations positioned in areas with better transit service have a higher Location Total Activity than locations placed in areas with poorer transit nearby. However, this difference might be explained by the higher number of cars found in locations with better transit service. In fact, looking at the Location Net Activity, the discrepancies among locations become much less accentuated.

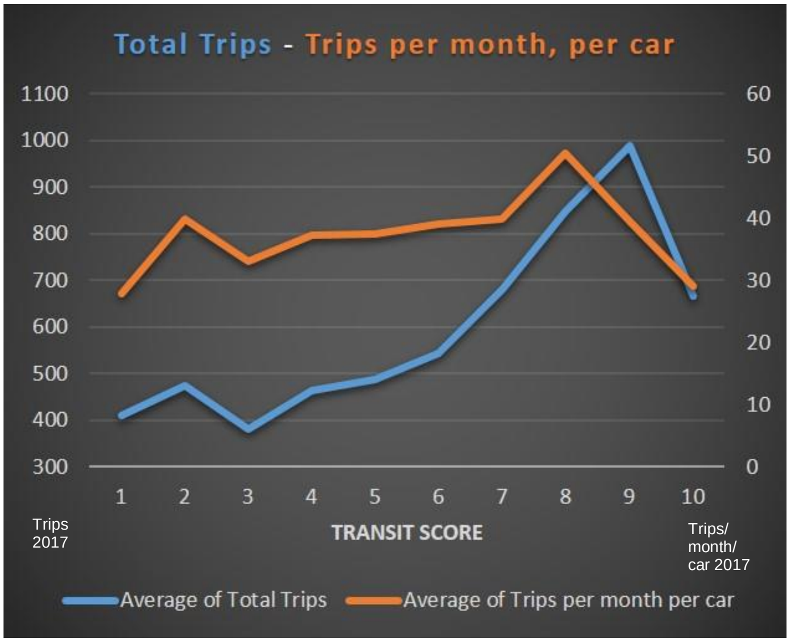


Figure 4-45: Correlation between total trips, trips per month per car and Transit Score
Source: Author's illustration of Modo and TransLink data, 2018

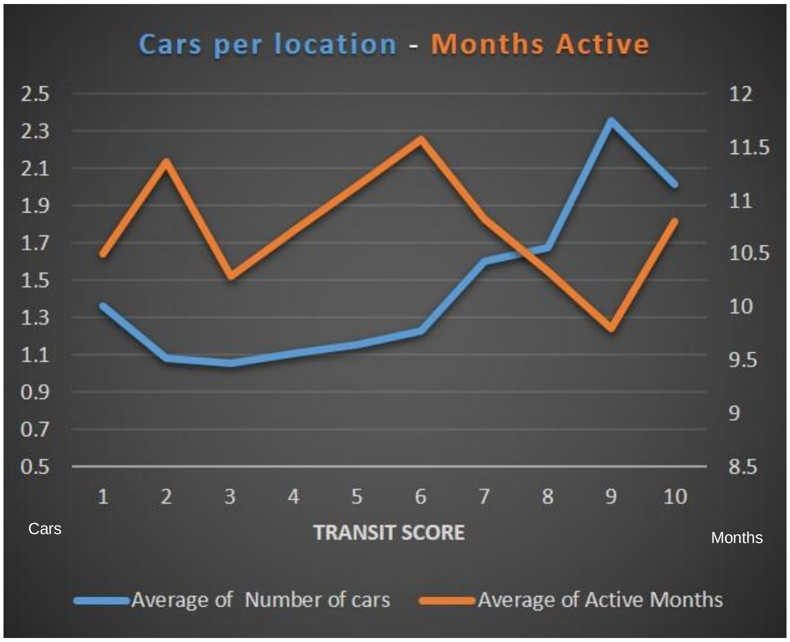


Figure 4-46: Correlation between number of cars per location, number of months active and Transit Score
Source: Author's illustration of Modo and TransLink data, 2018

4.2.3. Modo Locations and Transit Activity

The similar analysis seen in the previous section has also been replicated for the Transit Activity. In this case, instead of correlating the usage of Modo locations with the Transit Score of that location, the Transit Activity indicator has been considered. The procedure to connect Modo locations with the Transit Activity is the same as the one seen before: each of the 412 locations will receive a value of Transit Activity which is the sum of the number of boardings and alightings for all the transit stops that are within walking distance of that Modo location.

In Figure 4.45, the size of each Modo location is proportional to the value of Transit Activity indicator associated. The bigger the size of the dot, the higher is the number of transit boardings and alightings in that location.
The map shows that the transit usage around Modo locations has a certain variation. Locations placed in the Downtown core of Vancouver or close to some of the main mobility hubs have significantly higher than average values of transit activity.

That said, looking at the graph in figure 4.46, it is evident how the Location Total Activity keeps growing as the Transit Activity increases. However, as happened for the Transit Score, the Location Net Activity has almost constant values for every category of Transit Activity. The number of monthly trips per car available is very similar regardless of how much transit is used nearby. Again, looking at figure 4.47, the number of cars available at each location grows in areas with very high usage of transit.

Considering the relationship between two-way carsharing locations and the two public transit indicators, a first conclusion that can be made is that Modo locations are used with similar ratios throughout the Lower Mainland. The reason why locations with better, and more frequented, transit nearby are used more in terms of total trips might be explained by the higher number of cars that are available in these stations.

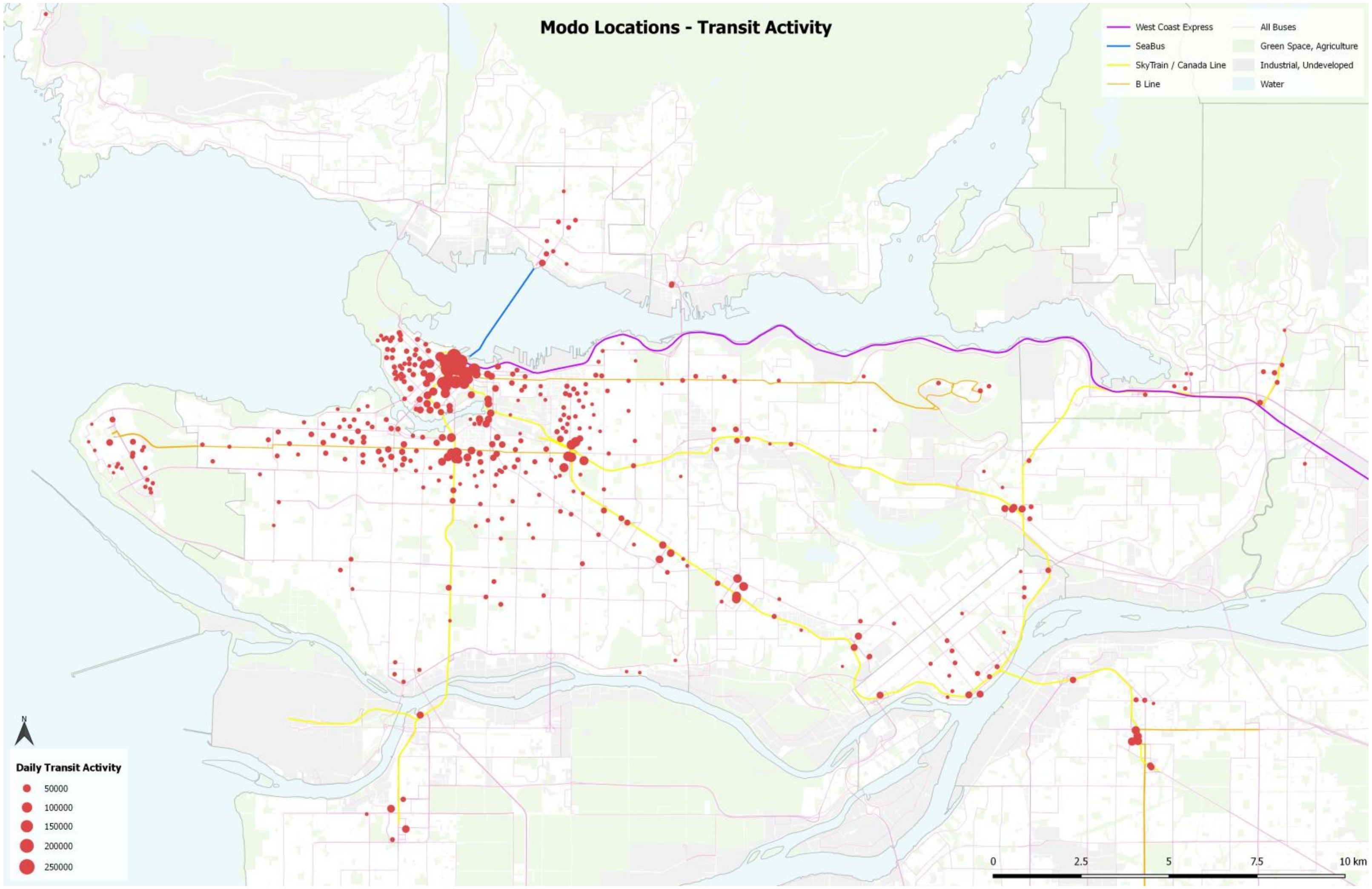


Figure 4-47: Transit Activity per Modo Location in Metro Vancouver
Source: Author's illustration of Modo and TransLink data, 2018

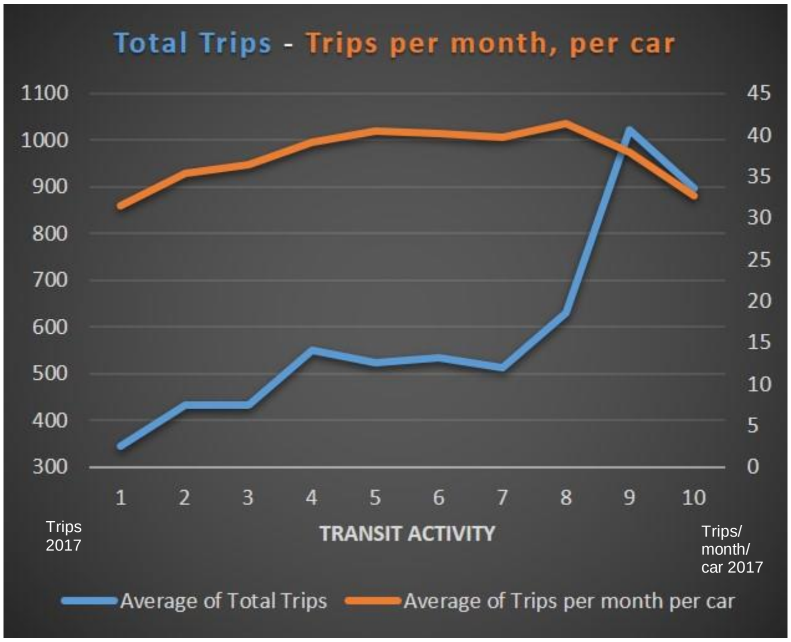


Figure 4-48: Correlation between total trips, trips per month per car and Transit Activity
Source: Author's illustration of Modo and TransLink data, 2018

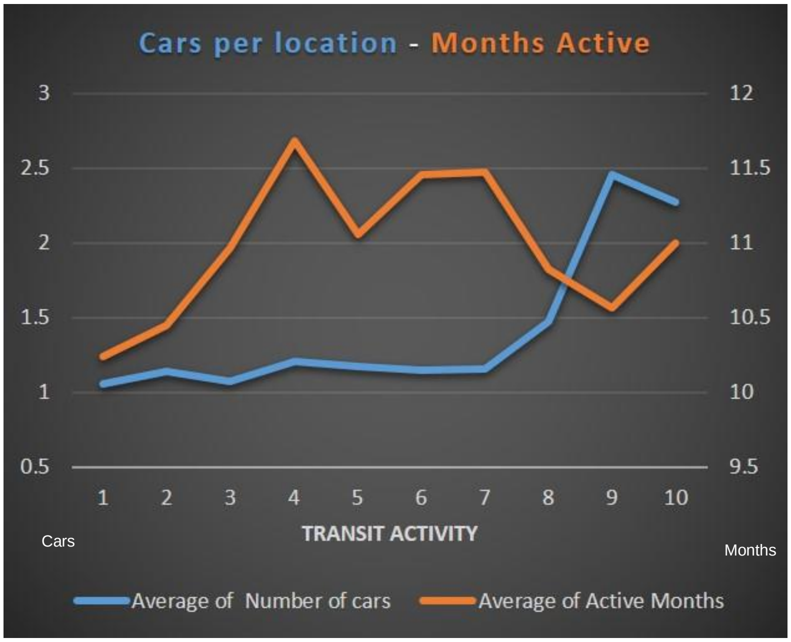


Figure 4-49: Correlation between number of cars per location, number of months active and Transit Activity
Source: Author's illustration of Modo and TransLink data, 2018

4.2.4. Modo Locations and Local/Non-Local Users

The previous two sections analyzed how the Modo Location Total Activity and the Locations Net Activity vary depending on the quantity and quality of service transit (Transit Score) and on the usage of transit (Transit Activity). Now, it might be interesting to understand if Modo locations are principally utilized by users who live nearby, referred as “Local Users”, or by users who live further away, referred as “Non-Local Users”.

Recalling the Modo data introduced in chapter 3, every trip contains the information relative to the car location and the home address of the driver. Therefore, it is possible to calculate the percentage of trips that have been made by drivers living within a certain distance from the location used for the trip.

Figure 4.48 displays the 412 Modo locations in the Lower Mainland. The size of the dots is proportional to the Location Net Activity introduced before, i.e., the number of trips per month per car, while the colors represent the percentage of trips that have been made users who live within 800m from the carsharing location, i.e., the Local Users. If the location has an orange or red color, it means the majority of users are Non-Local. On the other hand, if the location has a light green or dark green color, the majority of members that used that location are Local.

Looking at Figure 4.49, which is a zoom on the Vancouver Downtown and the Broadway corridor, it emerges that Modo locations situated in areas with a higher transit score, i.e., where DBs have a darker color, or very close to SkyTrain stations, tend to be mostly utilized by Non-Local Users.

The correlation between the independent variable transit score and the average percentage of trips made by drivers Local Users is displayed in Figure 4.50. The blue line and the orange line represent the percentage of trips made by users living within 800 meters and 500 meters from the Modo location used. The graph underlines how locations with poorer transit service nearby tend to be mostly used by Local Users. As the transit score increases, so does the percentage of Non-Local Users that constitute the most significant share of usage in locations that have the best transit score.

In figure 4.51, a very similar trend is shown for the correlation between the percentage of Local Users and the Transit Activity indicator.

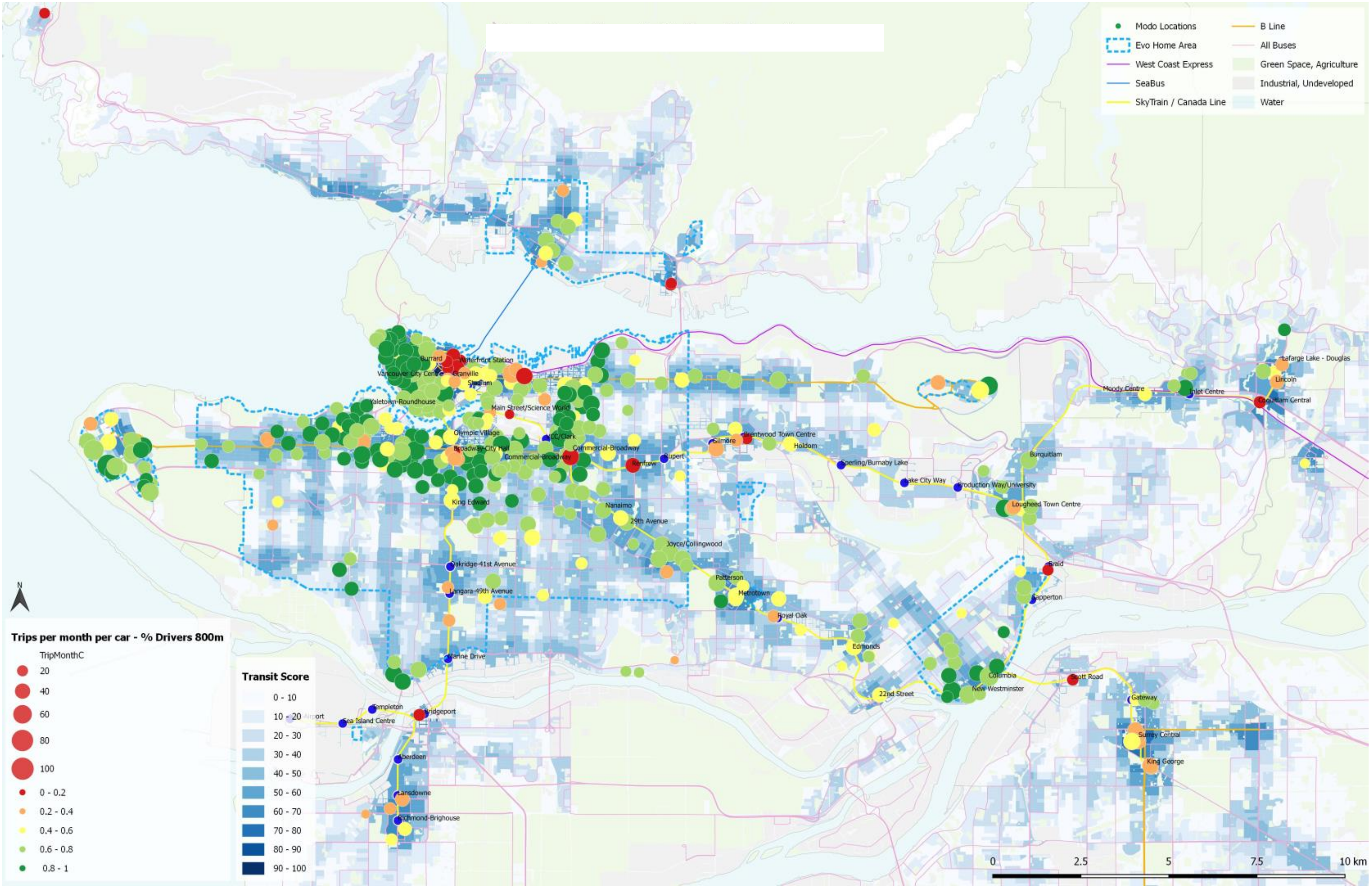


Figure 4-50: Number of trips per month per car & percentage of drivers living near Modo location used
Source: Author's illustration of Modo, TransLink, and Statistics Canada data, 2018

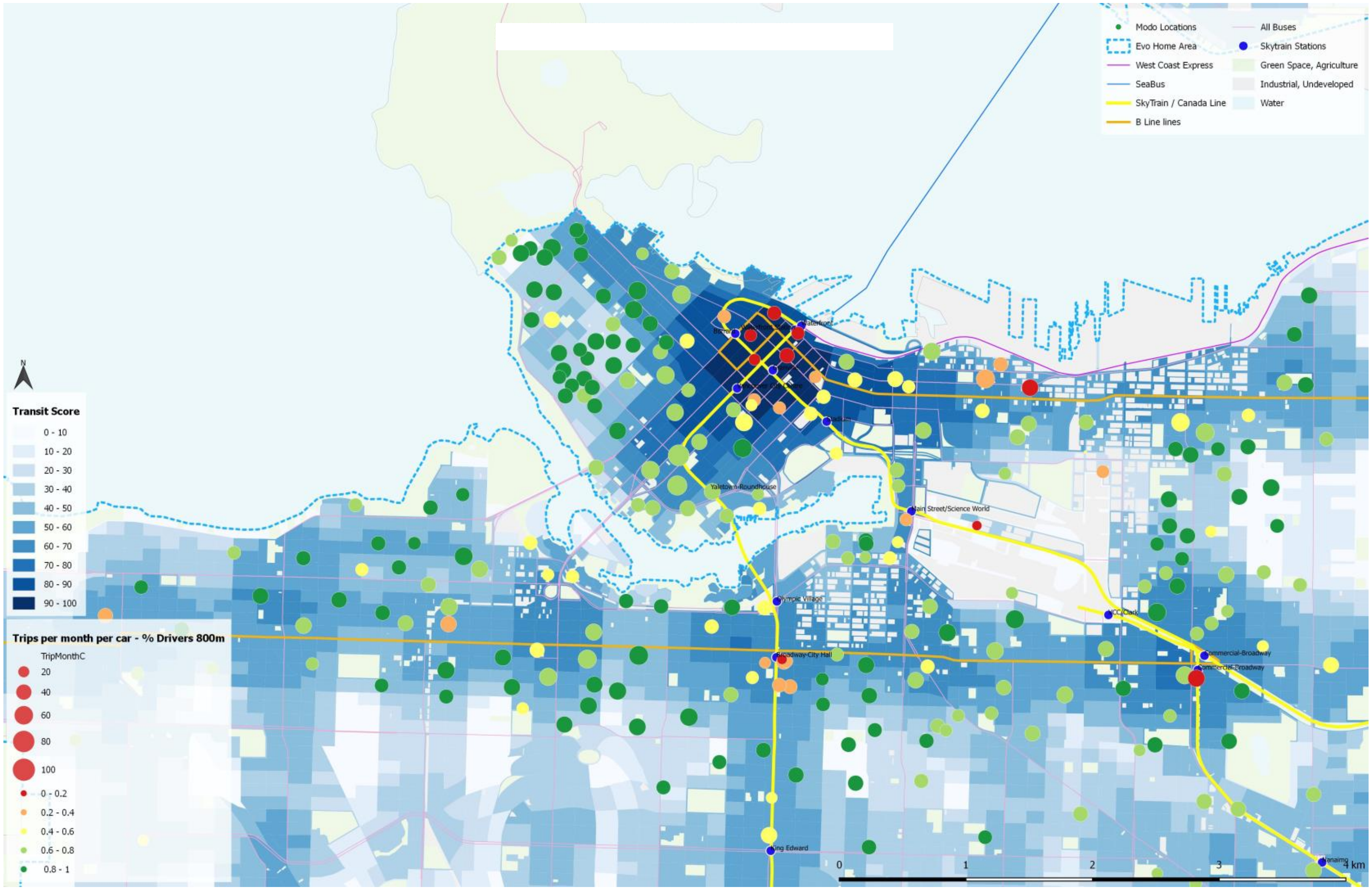


Figure 4-51: Number of trips per month per car & percentage of drivers living near Modo location used (Downtown)
Source: Author's illustration of Modo, TransLink, and Statistics Canada data, 2018

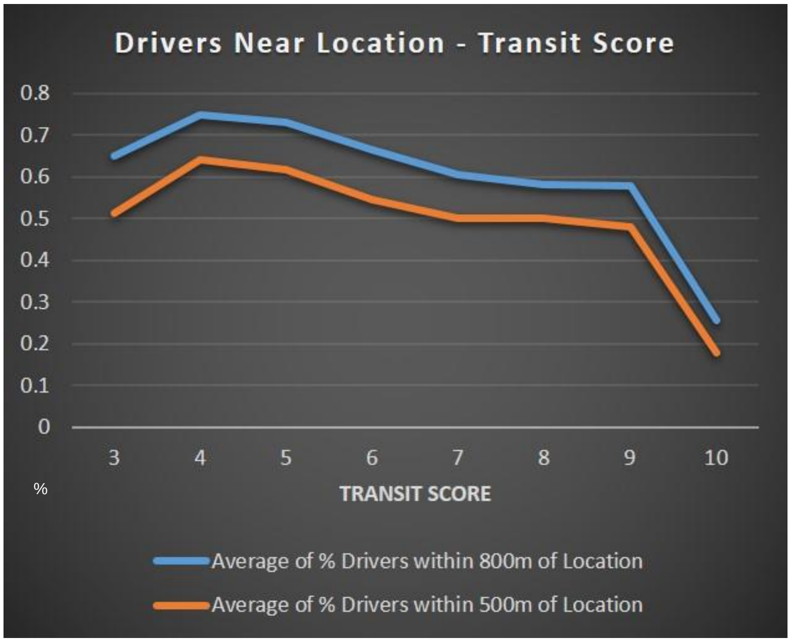


Figure 4-52: Correlation between percentage of drivers living near Modo location used and Transit Score

Source: Author's illustration of Modo and TransLink data, 2018

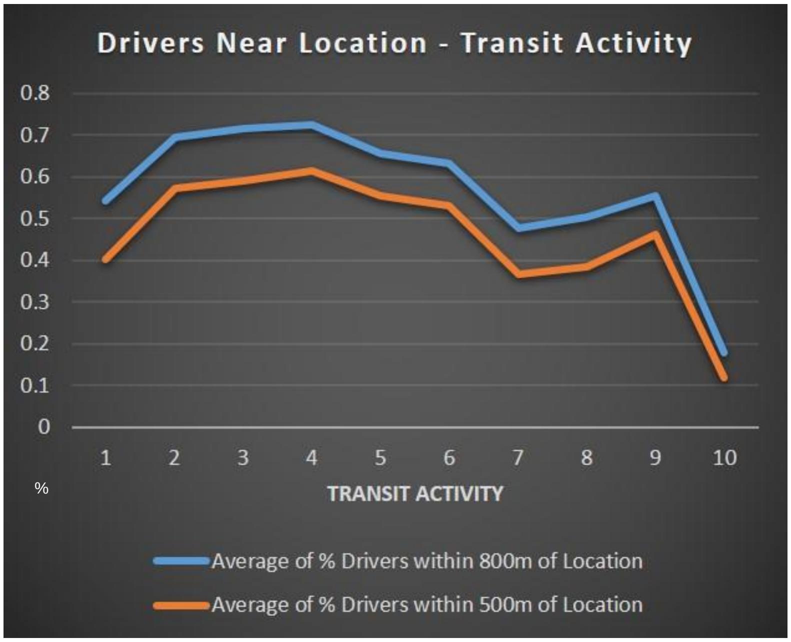


Figure 4-53: Correlation between percentage of drivers living near Modo location used and Transit Activity

Source: Author's illustration of Modo and TransLink data, 2018

4.2.5. Summary of correlation between Modo and Public Transit

This second part of Chapter 4 has illustrated and deepened some aspects of the relationship existing between Modo carsharing locations and public transit. It is now necessary to summarize what has been analyzed and how the two-way carsharing usage patterns change depending on the characteristics of the public transit that is available nearby. This summary is proposed in Table 4.3.

The table has nine different lines. Each line groups together all the Modo locations that follow certain conditions. The first line (in yellow) considers all the Modo locations of Metro Vancouver. The next three lines (in red) include only Modo locations where public transit is not very strong: either because locations have Transit Score lower than 50 (line 2), or have Transit Activity lower than 10,000 boardings and alightings per day (line 3), or are located more than 500 meters away from both a SkyTrain station and a B-Line stop (line 4). The other lines (in green) consider Modo locations that, for different reasons, are considered in proximity of good public transit service: locations with Transit Score higher than 80 (line 5), locations with Transit Score higher than 90 (line 6), locations with Transit Activity higher than 100,000 (line 7), locations within 200 meters from a SkyTrain station (line 8), locations within 200 meters of a B-Line stop (line 9), location within 200 meters from both Skytrain and B-line (line 10) and locations with more than one SkyTrain station within 500 meters.

In the 7 columns, different attributes of Modo carsharing locations are listed: number of total trips made, number of cars available, number of monthly trips per car, trip distance, trip duration, percentage of trips made by drivers living within 800m of location used and percentage of trips made by drivers living within 500m of location used. The values contained in the cells indicate the average values per each attribute, totalized by all Modo locations that fall under the different conditions.

In column 4 and column 5, the average trip distance and trip duration are shown. These are two features that haven’t been discussed yet in this thesis. That said, the differences between the values displayed by Modo locations in areas with excellent transit service and by those in areas with worse transit are not significant. This is also a reason why these two variables indicating the trip patterns haven’t been considered in the analysis.

A significant difference is found for the Location Total Activity (number of total trips, column 1) and the number of cars available at each location (column 2). In this case, Modo locations positioned in areas with excellent transit service register significantly higher values compared to locations in areas with poorer transit. However, looking at the Location Net Activity (number of trips per month per car, column 3), these differences are cleared. This reinforces the findings from the previous paragraph. The difference regarding the usage for Modo locations that are close to good transit service is given by the fact that these locations tend to have a higher number of cars available, compared to locations that have worse transit service nearby.

Finally, the values contained in column 6 and column 7 reinforce the findings from the previous paragraph. For both columns, the number of trips made by drivers living near the carsharing location used (Local Users) is much higher in Modo locations that have poor transit nearby. In such locations, the percentage of Local Users is almost the double than in locations that are surrounded by good public transit service.

This chapter 4 constituted the backbone of the research and provided an extensive correlation analysis between several independent variables related to the public transit, socio-demographic and geographic features, and the usage of two-way and one-way carsharing. Also, the second part of the chapter provided additional findings referred to the association between Modo locations and public transit. The next chapter summarizes the key findings evinced from this thesis, identifies possible options for future research, determines what outcomes this research might have and provides some remarks about the role that carsharing is expected to have in the future of transportation.

Conditions	Total Trips	Number of cars	Trips per month per car	Trip Distance (km)	Trip Duration (h)	% Drivers within 800m of Location	% Drivers within 500m of Location
Total	557	1.3	38	50	6.3	66%	55%
Transit Score <50	463	1.1	37	51	6.3	72%	60%
Transit Activity < 10,000	471	1.1	37	49	6.1	71%	59%
Distance to Skytrain and B Line >500m	475	1.2	37	49	6.2	72%	60%
Transit Score >80	829	2.2	34	60	7.4	42%	33%
Transit Score > 90	667	2.0	29	68	8.1	26%	18%
Transit Activity > 100,000	896	2.3	33	62	7.6	33%	26%
Distance to Skytrain <200m	791	1.9	37	61	7.4	40%	30%
Distance to B Line <200m	848	2.0	39	50	6.2	48%	38%
Distance to Skytrain and B Line <200m	1101	2.8	37	54	6.8	32%	24%
More than 1 Skytrain station within 500m	1051	2.6	35	52	6.5	42%	33%

Figure 4-54: Summary of correlation between Modo Locations and Public Transit
Source: Author’s illustration of Modo and TransLink data, 2018

Chapter 5.

Conclusions

The goal of this thesis has been to describe the existing relationship between the usage of carsharing and multiple characteristics of Metro Vancouver's transportation and urban development. These characteristics included the geographic, socio-demographic and public transit features, which have been described by a series of associated variables and indicators.
The research objective has been pursued through an extensive analysis that tested the correlation between several independent variables, describing the locations characteristics, and the usage of two-way and one-way carsharing. Further analysis also deepened our understanding of the relationship between public transit and two-way carsharing. The results yielded a detailed understanding of the current usage patterns of two-way and one-way carsharing in the Lower Mainland, revealing which variables have a positive, or negative, association with carsharing, and to what extent they influence the usage of the service.

This research complemented other studies that have been mentioned in the literature review, exploring the relationship between carsharing and the factors that are necessary for the service to succeed. However, most of the previous studies attempted to describe the groups of people more inclined to use carsharing based on survey results among existing users. This research adopted a different approach and described the characteristics of the locations where carsharing is used more and where the most frequent users live. This has been done at a fine grain level of detail, using 15,197 Dissemination Blocks to capture each area of Metro Vancouver. This study has been innovative being the first to compare two-way and one-way carsharing schemes in the same geographic context.

The results are generally in line with the principal findings of the literature review. The correlation analysis confirmed, for most of the variables, what researchers on carsharing, including Martin, Shaheen, Millard-Ball, Cervero, and many others, have demonstrated elsewhere. Both two-way and one-way carsharing activity in Metro Vancouver have a positive synergy with denser areas, where people tend to be part of

small households, to be renters, to use active modes of transport, and to have lower than average car ownership. On the other hand, weak or no correlation has been found between the usage of the two carsharing schemes and the level of education and average income referred to the population of area of study.
The strongest correlation was found between the usage of carsharing and the public transit indicators. Areas where people use public transit to commute to work and where the supply of transit offer is plentiful, help to ensure two-way and one-way carsharing success. However, the research also showed some decline in carsharing activity in the areas of the city with the strongest public transportation offer, suggesting that in such complete urban environment using an automobile is not a necessity.

Looking more deeply into the relationship between two-way carsharing and public transit, the total usage of the service increases in areas with very good transit available and where transit is highly used. The same happens for the number of cars that are available in each location. The better the transit offer is, the more cars it is possible to find and the higher the number of total carsharing trips. However, if the total activity per location is higher where transit is better the same cannot be said for the net activity per location. In locations with poorer transit availability, there are less cars, but these cars are used with similar frequencies to the ones placed in locations with better transit nearby. In this sense, it is possible to understand a good planning strategy from Modo, whose main interest is to ensure that every vehicle in their fleet is used enough.

Another interesting finding regarding the association between two-way carsharing locations and public transit is that Modo locations with lower Transit Score and lower Transit Activity are mostly used by members who live nearby. On the other hand, locations with higher values of the two transit indicators are mostly used by members who live further away. Even if additional analysis might be needed on this topic, this result adds to the idea that carsharing and public transit are strong complements to each other: members living far away from a carsharing location can rely on public transit to access the car and to complete their journey. This is the concept that has been emphasized several times in this thesis. Carsharing is supposed to be the missing piece among the intermodality transport options to allow people to make certain journeys that are otherwise impossible without a private car.

A limitation of this study was represented by the type of data available to describe the carsharing usage. In fact, Modo data contained information on both the vehicle locations used and the areas where active users live. This allowed the creation of two very distinct indicators to describe these two aspects of Modo's usage: the Location Activity and the User Activity respectively. On the other hand, Evo data did not include any information about the distribution of its users. In this sense, the correlation analysis showed that Modo Location and User activity have pretty similar trends in relationship to the independent variables. This suggests that the spatial distribution and usage of vehicles follows the distribution and usage by the users and vice-versa. However, this might not be the case for one-way carsharing and having this information available from Evo would have brought additional insights to the analysis and a better comparison between the two different carsharing schemes.

In addition, the analysis only considered the usage of carsharing without including additional information such as the time and day, the demographic of the users or the travel purpose associated to each trip. Including this type of data in the analysis would have definitely provided a more detailed description of the carsharing usage and of the patterns of its trips in Metro Vancouver.

Similarly, the possibility of including data from the two other carsharing providers that operate in Metro Vancouver, i.e. Car2Go and ZipCar, might be considered in a future research. Adding this information could help to either reinforce the results found from this study or to show eventual differences within the two-way and one-way schemes, for what concerns the carsharing usage patterns in the region.

Another questionable point about the analysis might be represented by the area of study that has been considered for the correlation. In fact, while Modo cars are spread throughout Metro Vancouver, Evo operates in a much more restricted territory, with only a few satellite parking spots located in key locations. Further research should only consider DBs that are part of Evo operational area and to perform the correlation analysis for places where it is possible to pick up or drop an Evo car. That said, the choice of considering the entire area of Metro Vancouver for this research has been considered the most appropriate for the purpose of the analysis.

It is also worth noting that this research adopted a methodology that consisted in an objective correlation of the dependent and the independent variables based on a geographic association: in each Dissemination Block of Metro Vancouver, the values of carsharing usage have been correlated to the values that the socio-demographic, geographic and public transit variables assumed in that specific location. In order to have a more complete understanding and clearer description of the carsharing trend, it would be useful to complement the results obtained from this thesis with the ones given by other research methodologies, including, for example, trip diary surveys or activity-based models. These methods could predict the travel choices that are made for different trips associated to different activities and would help to estimate the travel demand for carsharing and eventually to evaluate different scenarios and policies.

Considering the potential relevance of the research, it is expected that it can have a positive impact on a series of different actors. First of all, analyzing the usage patterns of carsharing and showing its correlation with the characteristics of Metro Vancouver locations might help the service providers when making their planning decisions on future expansions of the service. Knowing in detail the characteristics of the areas associated with the highest usage of carsharing will be very useful to choose how to manage the vehicle distribution and eventually in which new areas to expand the service. However, for carsharing providers, increasing their fleet and expanding their service might be very challenging. External support and the creation of new policy mechanisms are fundamental to advance the service. In this sense, a clearer understanding of the relationship between carsharing and public transit might help the local transit authority to improve its collaboration with the service providers. This is fundamental to support carsharing expansion and foster a higher penetration of inter-modality choices of transport. The same support would also be required by municipalities, who should consider more and easier provision of carsharing reserved parking, especially within Transit Oriented Developments.

In this sense, this thesis reinforced the idea that Transit Oriented Development and carsharing can be considered a good marriage (Cervero, 2009). Through a combination of proximity advantages and lifestyle predispositions, living near transit can significantly reduce the number of automobile trips. And with the option of carsharing, it can also reduce the requirement for parking. Supposing that providing one shared car to apartment building within a Transit Oriented Development leads residents to buy 10 fewer personal cars, the city parking requirements can allow one shared-car parking to substitute for ten private ones. This arrangement would save money for both the developer, who needs to provide less parking, and residents, who have a reduced need to own personal car, without sacrificing the ability to use one when needed.

Metro Vancouver represented an excellent place to study carsharing. Four different providers currently operate in the area and the number of users per shared vehicle are among the highest in the whole North America. That said, carsharing can still be considered relatively new and it is growing and changing quickly. However, an important aspect that needs to be considered is the absence of ride-hailing in the region. It is not clear how such service, if approved to enter the market, could affect the usage of carsharing in Metro Vancouver. What is clear is that technology is transforming transportation. The ability to conveniently request, track and pay for trips via mobile devices is changing the way people get around and interact with cities.

In this sense, it is worth saying that shared mobility is often mentioned for its potential to disrupt the current transportation system and to help creating a more sustainable one, especially if combined with electrification and automation (Sprei, 2018). This idea is supported by the incessant growth of such systems and a relatively large literature assessing its benefits. That said, the current market shares of shared modes is still a niche and their impact on the transportation system will only be evident once these systems will grow further. To accurately predict the impact of shared mobility, including two-way and one-way carsharing, on urban transportation, it will be fundamental to understand when and under which circumstances they represent a complement or an alternative to other modes (Ciari & Becker, 2017).

It is reasonable to assume that the creation of a robust network of mobility options, including carsharing, ride-hailing, and bikesharing, might help to change the travel behavior of people, to reduce car ownership and to increase use of public transit, which will continue to function as backbone of an integrated, multimodal transportation system. In this sense, greater integration between shared mobility and public transit is a key next step in harnessing the complementary value of shared mobility (Mowat Centre, 2016).

Understanding carsharing and its patterns in any urban environment is fundamental. The service provides citizens with an additional transportation option that is complementary with other sustainable modes and that will allow people to not rely anymore exclusively on their private cars. This research should be a special opportunity to obtain useful findings to better comprehend the potential impact of carsharing on sustainable transportation strategies.

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