Integrating gender-specific mobility needs in transport modeling

Analyzing Bogotá's 4-step transport model as a tool to improve decision-making processes around gender equity.

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Submitted in partial fulfillment of the requirements for the Degree of Master of Science in Urban Management at Technische Universität Berlin

Berlin, February 1 2023

Statement of authenticity

This thesis contains no material which has been accepted for the award of any other degree or diploma in any institution. To the best of my knowledge and belief, the research contains no material previously published or written by another person except where due reference has been made in the thesis text.

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Berlin, February 1 2023

Abstract

The author examines the special considerations needed when planning transportation systems using transportation modeling with a gender-sensitive approach. The findings of this thesis are highly relevant as they demonstrate how traditional planning processes are blind to the needs and experiences of women in transportation. Using mixed methods, combining transportation survey data, an existing 4-step model, and expert interviews, the case of Bogotá, Colombia, is examined. This thesis evaluates the clear differences between women's mobility behavior and men's, exploring how, if so, 4-step models can represent and evaluate these different behaviors. The results of this thesis demonstrate the need to develop more precise and disaggregated transportation models to develop gender-sensitive policies in the field of urban mobility. Furthermore, this thesis presents a way forward for incorporating gender criteria into transportation modeling, which can be useful for cities to develop long-term plans to improve their technical processes.

Acknowledgments

I want to thank my supervisor for his invaluable and enriching comments and feedback throughout the process of writing my thesis. Without his support and encouragement, this endeavor would not have been possible. Likewise, I would like to thank the Urban Management program for providing a team of professors and courses over the past year and a half that have provided me with the tools and knowledge necessary to complete this thesis.

I would be remiss if I did not mention and thank the interviewees consulted for this thesis, who have provided me with incredibly valuable information and knowledge that has enriched this thesis beyond my most optimistic expectations. Likewise, I would like to thank the team of the modeling group, the Secretariat of Mobility in Bogotá, for sharing the information on the 4-step model and always being open to providing more insights and data needed for this project.

I am also incredibly grateful to my colleagues in the 2022-2023 cohort of the program for sharing their inspiring experiences from around the world and for their moral and emotional support during our stay in Berlin. I would also like to thank COLFUTURO and the DAAD for funding the unparalleled experience of participating in the Masters in Urban Management.

Finally, I could not have made this journey without my parents, Piedad and José, and my sisters, María Alejandra and María José, who inspire and motivate me every day to become a better professional and even a better person. To my personal friends who have supported and helped me over the last few months, you will always have a special place in my heart.

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1 Introduction

1.1 Problem statement and hypothesis

Researchers have studied measuring and accounting for women's needs in urban transport since the late 70s. However, so far, the developments in gender theory have been focused on the theoretical approaches needed to understand women's dynamics in the urban space (Law, 1999). On the other hand, traditional transport planning has developed tools, models and simulations that allow urban planners and governments to understand how infrastructure and policy changes can alter a city's development. By abstracting the supply (network) and demand (users) into mathematical models, these models can forecast and estimate the results in the network derived from changes in infrastructure or mobility policies.

The main discussion around the gender bias in critiques like the ones raised by Madariaga around the intrinsic gender bias in those models and planning practices are becoming more prevalent (Sánchez de Madariaga and Roberts, 2013, p. 34). Those discussions gravitate around how those models' foundational assumptions and concepts are based on typical men's daily activities. Consequently, these analyses and simulations result in data used for decision-making processes that cannot account for urban policies and investments negatively affecting women's lives. In that regard, the appearance of urban management practices around transport in which women's needs and impacts towards them are not correctly measured results in incomplete policy frameworks. The existence of transit lines that do not properly connect clusters of activities of care in cities with majority women-led workplaces, highways and road networks that segregate schools and hospitals from neighborhoods and many other traditional planning practices are evidence of a faulty policy development system. As a result, when decision-making processes occur, an incomplete picture of gender equity is used when criteria that improve women's everyday lives are omitted.

These problems are not foreign to infrastructure planning and development in Bogotá, Colombia's capital and biggest city, especially considering how the current transport model, used to evaluate all kinds of projects and policies, is a clear example of this break. This model assesses the benefits and impacts of the city's master plan, the first metro lines, and even housing development projects. However, this model cannot distinguish impacts by gender, making this tool an insufficient strategy for developing equitable transport policies. Building on the criticisms raised by Madariaga, Levy (Levy, 2013; Sánchez de Madariaga and Roberts,

2013) and other authors around the gender and structural biases of traditional transport engineering and planning, this thesis proposes a theoretical framework to include parameters, indicators and strategies for practitioners and decision makers that allow them to effectively measure gender impacts of transport policies and investments in Bogotá. A bridge between discourses on gendered transport planning and transport modeling is done via a series of measurable and quantifiable indicators suggested for the 4-step transport model (4SM)[1].

At this point, it is important to consider the complexity, importance and utility of the 4-step transport model to explain the city's mobility system. As its name suggests, using four steps of analysis in an iterative mathematical framework allows the modeler to represent at an almost neighborhood level how **(1)** daily trips are generated and attracted, **(2)** how they are distributed between different neighborhoods of origins and destinations, **(3)** which modes of transport the inhabitants of those neighborhoods prefer, and **(4)** which routes do they take. As a result of the different mathematical models in each step, analysts can determine expected travel times, mode-shares and general accessibility measures at a network and local level. In the case of Bogotá, there is a disconnection between the policy objectives of building a city that accounts for care activities and facilitates women's movements and a city that builds a network of transport and services that can facilitate them (Unión Temporal Steer - CNC, 2019; Alcaldía Mayor de Bogotá, D.C., 2021).

This thesis expects to fill a void in practices at the local policy development level by developing a framework to implement additional metrics inside the 4-step model. This will help decision-makers construct the multicriteria analysis required to assess the real impacts of projects and policies in the city's mobility system. As a result, a more equitable decision-making process can be achieved by using gender-aware data, specific indicators and other measures to ensure that women's needs are considered in transport planning in the city.

1.2 Research aim

There is a clear lack of assessment of gender criteria in the traditional 4SM development process, as it is currently implemented in many cities worldwide. This thesis aims to add, adapt and rethink key performance indicators of the current model to allow for additional gendered-focused evaluations using this tool with a special focus given to the model developed for the Bogotá D.C. metropolitan region in 2019. Using already developed

[1] For ease of Reading, this thesis will also use the acronym 4SM for the 4-step model throughout the document as suggested by McNally(McNally, 2000).

concepts around equitable gendered mobility in the social sciences, this thesis aims to bridge concepts to operationalize the intentions behind women-centered policies in transport. An analysis of the possible strategies to evaluate gender-oriented policies in transport modeling is done by analyzing the case study of Bogotá to achieve this goal. This thesis will examine how policies focused on improving women's mobility can be evaluated in Bogota's 4SM.

Finally, while it is true that there is a need for an account of experiences from the LGBTQ+ community in transport planning as well as other identity characteristics (e.g., race and ethnicity) (Sánchez de Madariaga and Roberts, 2013, p. 12), the scope of the thesis would be too broad to comprehend those perspectives. There is a need for additional research and developments in that field to reduce those gaps.

1.3 Research questions

General research question

How can gender focus transport planning be added to the development and evaluation of transport models?

Specific research questions

- What gender-specific characteristics of mobility behavior need to be considered to measure gender inclusion in transport modeling?
- How does the current 4SM work, and which indicators does it use to assess gender inclusion in mobility assessment?
- Which strategies can be used to measure gender-oriented policies in the 4SM or its outputs?

1.4 Background and context

Data-based policy decision-making processes are taking a bigger role in cities all around the globe as they try to define policy paths that minimize negative impacts associated with urban mobility and to choose the policies that are less likely to fail (Unión Temporal Steer - CNC, 2019). Applied to transport planning, this means finding ways to analyze externalities derived from transport dynamics like congestion, pollution, changes in productivity associated with improved connectivity or increased travel times by commuters, road safety and many others (Ortúzar and Willumsen, 2011). Alongside these externalities, researchers, governments, NGOs, activists, and many others have pushed for more concrete goals around transformations in gender equity when designing and implementing urban policies (Levin and Faith-Ell, 2019; Montoya Robledo, Montes Calero and Bernal Carvajal,

2021; European Commission. Directorate General for International Partnerships, 2022). However, there is still a void in the literature and practices on how transport models can incorporate these measures accurately representing the current situation of cities or give insights into how future developments can be measured by improving women's mobility conditions.

Using the example of Bogotá as a way to develop this thesis is useful in the sense that, as the city transitions into a new master plan focused on sustainability and social equity, this thesis will use the 4SM model developed in 2019 to understand how these models can be adapted to understand better how women move, what are their biggest problems when traveling through the city and how planers can measure those facts and plan accordingly. It is worth noting that the model itself, as it is today, does not have the built-in tools to do that. In this case, the mobility survey, which was carried out in parallel with the model and was used to update the 2015 4SM, contains relevant data to understand the travel patterns of women and men separately and can give insights into how people travel in the city when doing their day-to-day activities in conjunction to activities of care and others purposes which can be linked to gender-specific conditions as the literature shows.

From a political and local perspective, the newly approved master plan for Bogotá calls for a more humane and equitable way to organize the city. In that sense, there is a need to measure better and develop policies around gendered transport, starting with the 4SM, looking for equity and sustainability. That is why a tool is needed to evaluate current and proposed policies aiming at those goals. Considering the context of decision-making in the city, where the results of the transport model heavily influence decisions, the political environment is asking for a solution that allows measuring those transformations using the model. The 4SM should work as a tool to measure those aspects as the 4SM, considering that it is the tool with which financing entities and other stakeholders trust to assess transport projects in the city inside or outside the master plan. It is key to evolve this tool to represent better dynamics that affect women in transport, and this thesis aims to achieve that goal.

1.5 Relevance and applicability

A political and technical need is added to a political decision to develop a new way the city relates to its population across the whole gender spectrum. That aligns with the academic and activist agenda around gender to fight structural inequities developed by centuries of men-oriented or gender-blind approaches to urban development. This agenda, which has

called for a gender mainstreaming inside transport planning practices, needs to be oriented to action and concrete goals to achieve gender equity (Sánchez de Madariaga and Roberts, 2013, p. 327; Levin and Faith-Ell, 2019, p. 103). In order to do that, the 4SM should be used to evaluate and demonstrate the effectiveness of policies and projects toward gender equity.

The applicability of the findings in this thesis reflects the need to develop a policy-driven action, which should be reflected in all aspects of transport planning and development. However, as the academic research has been mainly done from the social sciences, the transport engineering space has not been fully involved in this aspect (Dobbs, 2007). A clear example is how most transport models are being developed in cities around the globe based on the traditional 4SM. This approach abstracts daily mobility in cities as a set of pendular movements of people from their residences to work or study. Consequently, this results in investments focused on attending to those travel patterns and policies focused on optimizing them. There is evidence in the case of Bogotá of how designs aimed at financial sustainability, as is the common practice, result in structural inequities for women, who have to go to work and study and take care of the home and have different travel behaviors and choose how to transport themselves in a unique way (Lecompte and Bocarejo S., 2017). As Dobbs mentions, the lack of binding social sciences and transport planning is a problem that should be addressed, given its profound repercussions on the lives of women all around the globe.

> *Research into transport planning and practice has consistently failed to apply a social science perspective to transport policy or to fully understand the way in which social organization can play a role in determining patterns of transport and travel. It has also demonstrated a systematic lack of understanding of the cultural and institutional structures which result in mobility deprivation.*
>
> (Dobbs, 2007, p. 86)

This thesis proposes a set of indicators and strategies that can be added to the traditional process by which projects are evaluated based on the 4SM with an added layer of gender-oriented criteria. In this case, embedding those indicators into the 4SM can be an effective way to use an already proven tool to develop a gender-centered agenda following the concepts developed by Wankiewicz (Wankiewicz, 2013, p. 135).

The results of this thesis are developed to be easily communicated with communities and activist groups to bring them closer to decision-makers when developing policies—understanding that setting priorities is a political issue that can escape the model itself—considering that developing clear, relatable and communicable indicators is key in a context where political discourses around gender in transport can be used to advance agendas. That is because, at last, if the policy decisions around transport are not relatable and are not based on

awareness of everyday realities, they can result in unfeasible visions of the city and unrealizable city-wide plans (Levy, 2013).

> *"Because transport implies accessibility and mobility to city-wide activities and opportunities, it also offers a cross-scalar configuration of politics, enabling women and men to access different political spaces in the city"… "legitimacy is fundamental and often the basis for moving beyond either being invisible or being bulldozed to more constructive policies and planning."*
>
> (Levy, 2013, p. 53)

1.6 Motivation

As personal experiences in the public and private sectors have shown me, it is important to rethink how transport modeling is used in the transport planning processes in Bogotá. Being part of the team in the public agency dedicated to updating, maintaining and evaluating the four steps macro-model of the city, I became acutely aware of its importance. At the same time, as policies have shifted in the last years to focus on more active and gendered mobility, given the scale and structure of the model, there has not been an intention to assess and include traditionally overlooked users as pedestrians or bike riders into that model. Moreover, given the traditional and problematic way the model has been built over the years, there is even less attention to evaluating the gender impact of different projects, as this was considered an even greater challenge.

In that same line, during the literature review and the interviews developed in this thesis, I also realized the need to advance the diversification of the labor pool in transport modeling by including more women. As experienced in other contexts (Sánchez de Madariaga and Roberts, 2013, p. 158; Rouhanizadeh and Kermanshachi, 2021, p. 12), there is no equal number of women who frequently work with Bogota's 4SM. And thus, the visions, evaluations and assessments of the model are heavily influenced by men's views. This is a call to action to universities, consulting companies and the government to implement programs that promote women in transport modeling to develop more equitable and sensible models for their experiences.

1.7 Thesis structure

This thesis is structured as follows: after the introductory section, the research goals statement and the motivation, a theoretical framework and literature review are developed to clarify how gender is related to and influences transport activities, and planning, as well as how are four steps models developed, what is their theoretical basis, and how do they work.

After this section, a research design and methodology are proposed based on the literature review findings. Then, a thorough review of the mobility conditions in Bogotá, with a special focus on the differences by gender, is complemented by an analysis of how the 4SM of the city represents the global patterns. Consequently, an analysis of the differences between the observations by gender, the conditions of the model, and the contrasting of the ideas suggested in the interviews are made to formulate strategies and indicators that allow for the inclusion of gender criteria in the modeling process.

2 Theoretical framework and literature review

This chapter is divided into three sections of literature review that are used to understand the development of this thesis. From a review of the existing academic tradition on the understanding of gender and mobility to a description of the theories that explain the operation of the four-stage models. The chapter ends with a review of practices and guidelines that have already been implemented and tested to develop gender-responsive transport systems.

2.1 Recognizing women's needs in urban mobility

The longstanding academic discourse around gendered perspectives in transport states a clear distinction in how men and women experience public spaces to travel across the city. Law (1999) explained this need to recognize those differences as the urgency to evolve the conceptions in transport from a neutral commuter to a diverse and gendered commuter. According to her, this divergence surges from the intrinsic differences between women as different commuters and the violence imposed by men that alter their commutes.

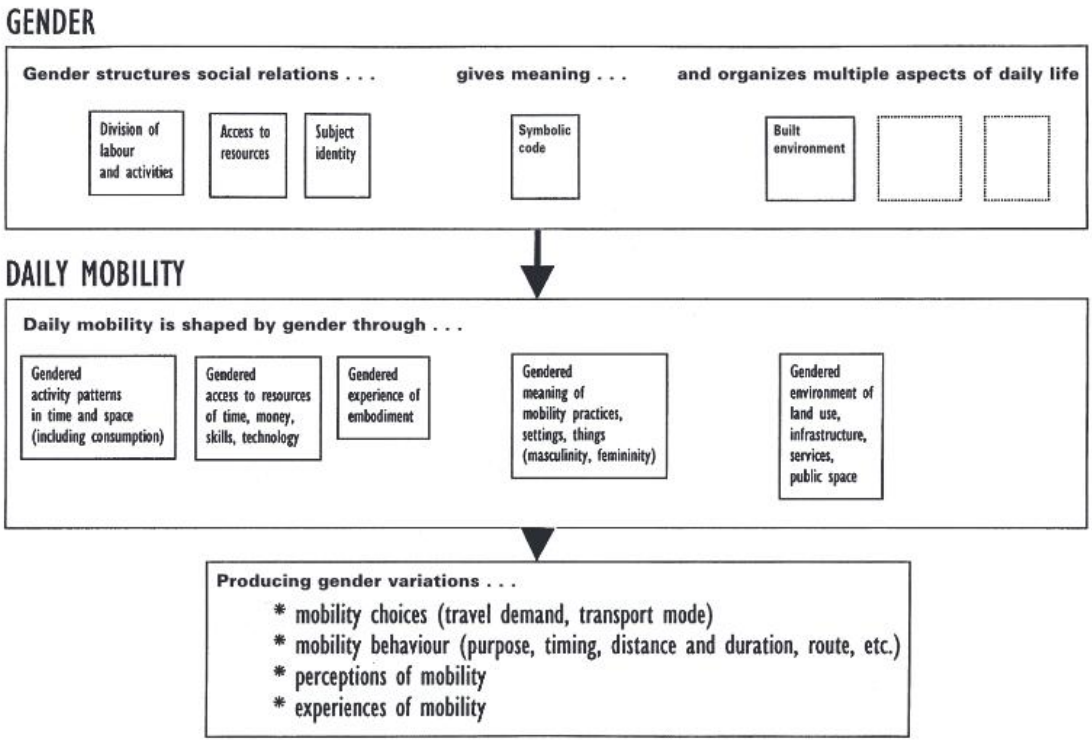


Figure 1 A framework for understanding gender and mobility according to Law
Taken from (Law, 1999, p. 576)

Law's framework for understanding gendered mobilities is shown in Figure 1, but as the discourse evolved, the need to operationalize this agenda became more important. To

achieve that, Levy synthesized how gender affects travel choices and behaviors. For instance, travel choice is driven not only by socioeconomic determinants but also by how political, environmental, and especially gender dynamics have been developed. Levy also supported Law's proposal that interactions made in the public space between different actors are also explained through a gender perspective from the moment of public space design and through the occurrence of those encounters between travelers. Finally, Levy explains how cultural oppression mechanisms change women's travel behaviors based on the "support and/ or permission, persuasion and/or prohibition, verbal and/or physical" decisions to travel or not (Levy, 2013, p. 52).

In order to explore in detail, the impacts of these relations between gender and mobility, this thesis analyzes two roles of women as they approach transport in an urban environment: their role as caregivers and paid workers. Even if these two are intertwined in everyday life, this division is useful for exploring the rest of the academic work related to the subject. Finally, as suggested by Levy and others (Turner and Grieco, 2000; Dobbs, 2007; Levy, 2013; Gauvin *et al.*, 2020), this thesis will also approach how violence and cultural barriers affect women's travel behavior.

As explained in the introduction, this thesis will focus on three aspects that explain the particular aspects of women's transport in urban environments and can be analyzed in a 4SM. These are (1) the role of women as caregivers, (2) women as a key part of the productive environment of cities and (3) violence towards women and girls in public spaces when they make their daily trips. A detailed analysis of the available literature on each of these three conditions is done in this chapter. Then, combining the works produced by different authors, I review policy and infrastructure gender-oriented solutions to assess how to include them in the 4SM.

2.1.1 Mobility of care

Madariaga developed this concept (Sánchez de Madariaga and Roberts, 2013, chap. 3), stating how city planning should be able to recognize the implications derived from the activities of care. Understanding by activities of care all the tasks traditionally assigned to women like looking after children, setting them up and taking them to school, buying groceries and cleaning the home or taking care of the elderly and sick in the family. However, the conceptual roots of this idea go as far as the '80s in different directions, according to Grieco et al. (2000).

According to Madariaga, the traditionally assigned role of women in caring results in more activities done by them than men. Because of this additional amount of activities, they have to make more trips in their day-to-day activities. Madariaga studies in depth this additional number of trips and their chained configuration. For example: leaving the children at school to grocery shop and returning home in the middle of the day. She explains how this contrasts with the usual pendular patterns done by men going from home to work and returning home at the end of the day. This difference results in more trips done by women, with a more diverse array of destinations and especially the trip chaining dynamics between them. A graphic example of these differences is presented in Figure 2

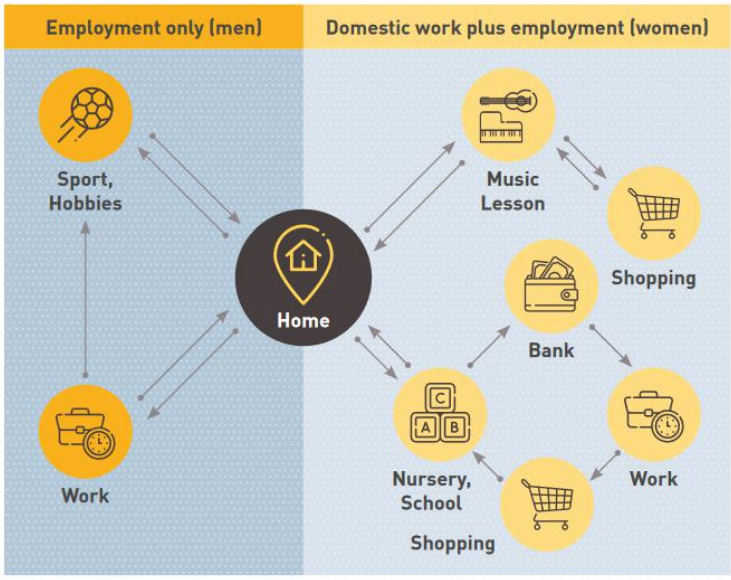


Figure 2 A normal day for men and women from Western Europe
Taken from (Drăguțescu, Land and Meskovic, 2020)

Additionally, Madariaga shows how these care activities are carried out mainly by women. Understanding the established practice of misrepresenting these trips from transport surveys and planning also recognizes the gender bias implicit in transport planning (Sánchez de Madariaga and Roberts, 2013, chap. 3). However, she states that recognizing these trips is just the beginning of understanding the logic that allowed for other omissions in traditional transport planning. For example, she notes that as travel patterns of movement from work and study-related trips are not equal to the patterns and concentration of care-related trips, the focus on providing better transport for work-related trips can result in infrastructure that negatively affects women in their everyday life.

Madariaga also recognizes this idea as revolutionary in discussing how transport is planned and oriented. Besides the activities themselves and the number of care-related trips made by women, Madariaga mentions how these trips are arranged in a polygonal way instead

of the pendular behavior used to build transport models and polices (Ortúzar and Willumsen, 2011; Sánchez de Madariaga and Roberts, 2013, p. 40). Also, by the mere intention of planning at a regional scale, transport plans and policies tend to omit or filter trips under 10 or 15 minutes from the computation to assess their economic benefit. She goes into detail to explain how this filtering results in additional biases based on the length of care trips which tend to fall in this window of time.

The relevance of the work carried out by Madariaga resides inside a larger academic and social discussion about the need to include care-related activities in the economic discourse. Maradiaga's studies are especially relevant when the discussion on how families are being shaped in Latin America is considered, as the proportion of female-led households is rising (Chant, 2013), highlighting how mobilities of care in planning become even more important.

2.1.2 Women as paid workers

Connecting to this concept, and in the last part of the typical trip-chain explained by Madariaga, is the aspect of women as paid workers and their need to access jobs and opportunities. Here, Dobbs analyzes how these trips cannot be explained in a similar condition to those made by men. She explains how economic conditions and structural inequities result in differences in transport access and reduced time budgets and are more affected by inconsistent or unreliable systems. She also insists that for the same reasons, traditional planning – focused on long-distance and pendular trips – results in a discriminatory system against women (Dobbs, 2007, p. 97). This point is key in understanding deeper questions about structural privileges experienced by men. Women perform more care activities at home, so they have to operate in a job market that allows them to have more time budget for family duties. That hinders their ability to improve their careers in the long term or reduces their capacity to work in places far from home.

2.1.3 Safety of women in transport

One of the most common lines of development in the literature reviewed for this thesis revolves around the physical experiences of women in transportation as a gendered subject and how it translates into increased risks for their personal safety. Law explains how there is a whole research tradition around the changes in travel behavior derived from self-imposed constrains when choosing a transport mode or a given route to minimize risks (Law, 1999, p.

570). Roberts also explains how the increased perception of risk at night means that women tend to use longer routes, avoid overcrowded streets near bars or adopt group strategies to not go alone in the street. Roberts explains that even if this phenomenon is recognized, policies have not been developed to address concerns or provide safe routes for women at night (Roberts, 2013). In the same line, Dobbs recognizes how women value not only time and cost when determining their travel choices, but there is also a strong emphasis on how security and perceptions of safety play a key role in determining travel decisions (or not to travel at all), especially at night, but also throughout the day (Dobbs, 2007, p. 97). In the same line, Levy stated the importance of planning with this violence in mind and adapting to every particular context, developing strategies to grant women access to the city by granting safe transport resources (Levy, 2013).

2.2 The 4-step transport model framework

As put up by Martens (Martens, 2017, p. 52), the first step in traditional transport planning is the forecasting of the future needs of travel in order to define the scale and types of infrastructure to support those needs. The dynamic of demand forecasting against a proposed infrastructure supply is often analyzed using the well-known four-step travel-demand forecasting model framework. This section will approach the theoretical concepts behind that framework, which sources of information are used to build them, and how it is often used in the transport planning decision-making process.

McNally described (McNally, 2000) the traditional approach to represent and analyze transport at a macro scale – analysis at a city or metropolitan scale- is to use a 4SM. These models are representations of land uses and activities of inhabitants in a given area, which are then given a network of roads, public transport routes or other kinds of represented infrastructure to measure how they use the network to carry out those given activities. This process is made by defining modes, times of the day and other travel characteristics that represent how trips in the network are made as a derivate demand from a given set of activities. Using spatial aggregation of a given area, an iterative process is carried out to represent how **(1)** typical trips are generated and attracted, **(2)** how they are distributed between different zones of origins and destinations, **(3)** which modes of transport the inhabitants of those zones prefer, and **(4)** which routes do they take. These trips are then calibrated and validated, which means comparing them against observations on the field, verifying their accuracy and precision, and doing additional cross-validations against other

models and sources of information. This calibration process allows modelers to confirm that the abstractions made in their models represent real-life attributes of the system (McNally, 2000; National Academies of Sciences, Engineering, and Medicine, 2010). The process presented in Figure 3 synthesizes the 4SM framework as a flowchart. This flowchart is key to understanding how this process is carried out and how policies can be developed.

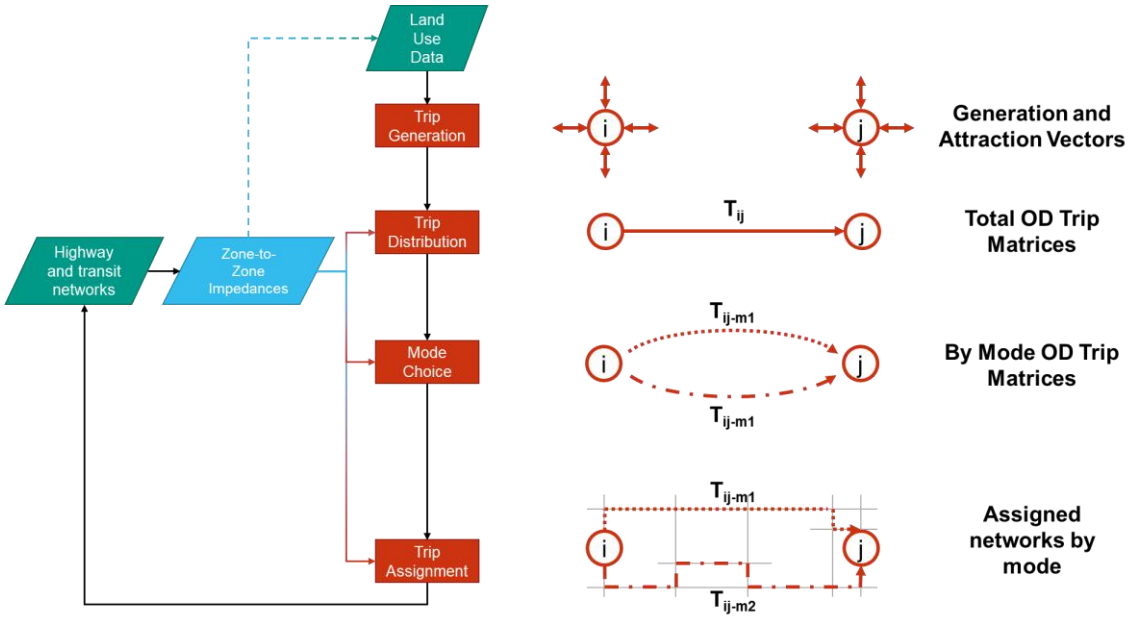


Figure 3 Flowchart and representation of how 4SMs work

Own making based on the data from (The Australian Department of Infrastructure, Transport, Regional Development, Communications and the Arts, 2017)

2.2.1 How do 4-step models work?

Ortúzar and Willumsen explain how the process of building a 4SM is done in an ends-to-means manner, beginning with the definition of the goals and expectations of the model to understand then how to develop a model to satisfy those requirements. The process begins by identifying the area, scale, and scenarios to be modeled, then a set of information accordingly, and then building the model itself (Ortúzar and Willumsen, 2011). The usual structure of a 4SM is one in which a network of links and nodes, which can represent streets, highways or transit lines, is connected to a collection of spatial polygons representing semi-homogenous areas from which its inhabitants and other area's habitants desire to travel. This combination is then processed using a series of mathematical procedures that allow the modeler to represent the flows of passengers, cars and people in a given area.

The process usually begins with collecting data needed in a geographic database to be operated into four iterative analysis steps, as shown in Figure 4. It is important to recall that building the database is made from a zonification of the area to be analyzed and that

zonification is called Traffic Analysis Zones (TAZs), which represent a semi-homogenous set of activities. For each zone, the model will develop a set of indicators, factors and volumes to be used in each model step to analyze its properties. Then, base-year data is collected using an area-wide survey made of household surveys to characterize the population's travel habits and preferences, traffic and public transport counts for validating the assignation stage of the model. At the same time, an exercise of building a representation of the physical network of roads and transit systems is developed. Ultimately, a set of future investments and policies is identified to be parametrized into the network. In parallel, projections of land use and population are introduced into the model to be combined with those future scenarios.

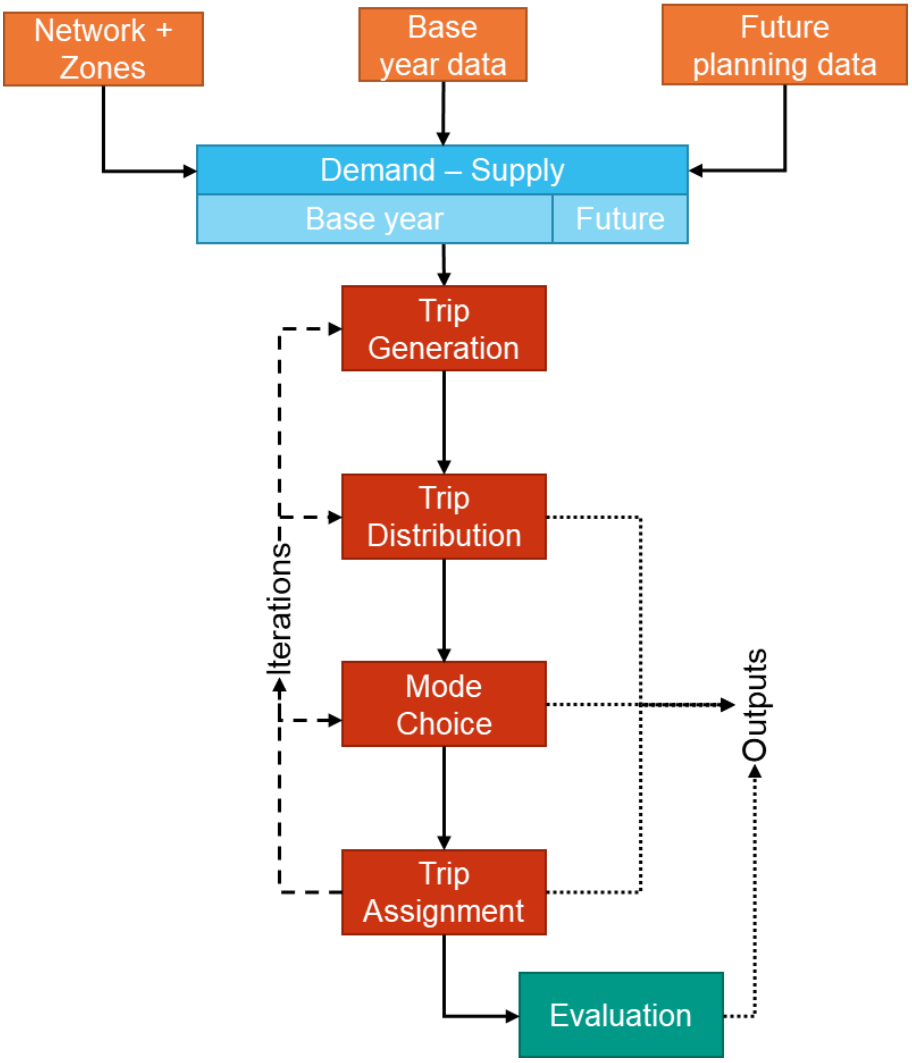


Figure 4 The classic four-stage transport model

Adapted from (Ortúzar and Willumsen, 2011)

As Figure 4 shows, after the base data is collected, the development of the model itself then goes through the four steps that give the model its name. Each of them uses a different input from the database to generate, in return, a series of values of trips by zone, trips by

Origin-Destination Pair (OD pair) in the shape of a matrix, or a series of volumes of passengers/vehicles assigned to the network.

1. **Generation and Attraction:** The first step allows the modeler to estimate the number of trips generated and attracted to each zone using land use information and population characteristics. It uses a regression model to estimate how many trips originated and have a destination in a given TAZ. Then a correction step is done to ensure the same number of trips is made in the whole network and is adjusted to the number of trips found in the mobility survey; this step determines the total trips of the network.
2. **Distribution:** With socioeconomic (SE) information of average inhabitants of each zone, like income levels, and the purpose of the trips, a series of matrices are built by each combination of SE levels and purpose called demand segments. By analyzing impedances (or the total costs of a trip) for each demand segment, an estimate of which OD pair is more probable to be populated to form the matrix. These values are validated against the transport survey results by combination of attributes.
3. **Modal choice:** With different matrices by the demand segment, a mathematical model is developed to estimate which transport mode gives users the most utility for their trips. As a result, combined with the previous segregation of matrices, the result of this step is segregated matrices by mode and demand segment.
4. **Assignment:** The last step uses all the matrices produced in the previous segment to simulate the most probable paths used to connect the different zones in each available mode; this process is usually segregated by private and public transport. As a result, the input of trips in a matrix is converted into a network of nodes and links with some passengers or users going through them,
5. **Iterations:** Not being a step on itself, as expressed in Figure 4, as a result of the assignment process, a new matrix of impedances between zones can be estimated considering congestion and time traveled in the assigned network. Consequently, improved inputs for the previous steps can be used to refine the model. This process is done several times until convergence[2] of results is reached.

With a convergent model built, a process of calibration and validation of the assignment process is done against the traffic and passenger count data in the initial survey. This process allows the modeler to confirm the base assumptions of the model and validate its mathematical formulations. When a model is calibrated to the current state of the network, a series of projections and possible planning scenarios can be evaluated. However, this is not an easy task. As Ortúzar and Willumsen mention, this process is "more of an art than a technique

[2] In this case, the convergence of a model means a step in the process where the differences in a given set of variables between iterations are small enough to be considered the most probable representation of reality.

and requires a good deal of engineering expertise combined with sound political judgment; unfortunately, these are scarce resources seldom found together in planning teams" (Ortúzar and Willumsen, 2011, p. 22). This problem arises as combining sensible planning and cost-effective developments tends to fall outside the realm of modelers. The authors suggest that a sensible approach from modelers is to develop consistent and realistic scenarios which can be communicated in sensible ways to decision-makers in order to find the most attractive set of policies and infrastructures from an investment point-of-view

The description by McNally (2000) explains more in detail how 4SMs are done and why the combination of supply and demand used to build them can be used to develop policies. By linking the Manheim/Florian Transport Systems Analysis Framework, the analysis of activity systems –representing activities made by the population in an urban space – can be combined with representations of the transport systems in the same area. Both can be mixed in an equilibrium process to understand the flows of passengers in the network. On the side of the activity system, understanding where demand is generated and directed in a given time window is the first half of the process. Then, understanding the purposes and constraints of that travel demand can be used as input into the framework to understand how a flow of people will be directed in a given transport network. On the other side, in the case of transport systems, understanding how infrastructure (physical and operational) is supplied is the other input of the process. The combination of both systems results in flows of passengers (which can go in vehicles or public transit) that react to the conditions of the network.

At last, an iterative process is done to balance the inconsistencies made by disbalances between both systems to represent conditions observed in the field. However, it is worth noting how the 4SM framework is, at last, an abstraction of reality. Ortúzar and Willumsen (2011) recall transport models as abstractions and as-close-as-possible to an objective representation of reality under the limitations and assumptions defined by the modeler. As abstractions of reality, they are composed of three main components, the network representing the physical conditions of the area to be studied, a representation of the inhabitants of that area, and a series of mathematical models representing the interactions between them.

2.2.2 The role of the 4-step model in policy making and monitoring.

To accomplish accurate abstractions and add to representative data to develop these models. Ortúzar and Willumsen recognize the role of transport models in institutional structures where they can be validated and used to analyze urban policies that manage travel

demand. In their words, as demand has been rising steadily, it "has resulted in congestion, delays, accidents and environmental problems well beyond what has been considered acceptable so far" (Ortúzar and Willumsen, 2011, p. 3). Their work centers around tools to develop models that help transport planners represent supply and demand at a given set of conditions. From an analytical perspective, they suggest a series of equations and mathematical models that help represent how transport models are built. These equations abstract a transport system composed of infrastructure (such as road networks or transit systems), management systems (traffic rules, control devices and policies), and a given set of transport modes and their operators and users.

Ortúzar and Willumsen display a deeper understanding of those relations in Figure 5. There they explain how changes in investment priorities, and policies regarding transport, can be analyzed into transport models to improve urban environments. For that example, they evidence how transferring subsidies from private-owned vehicles to public transport infrastructure can result in a positive development cycle of these latter systems. Each of the arrows in the graphs can be represented in the model as either a change to the network or a change to users' characteristics.

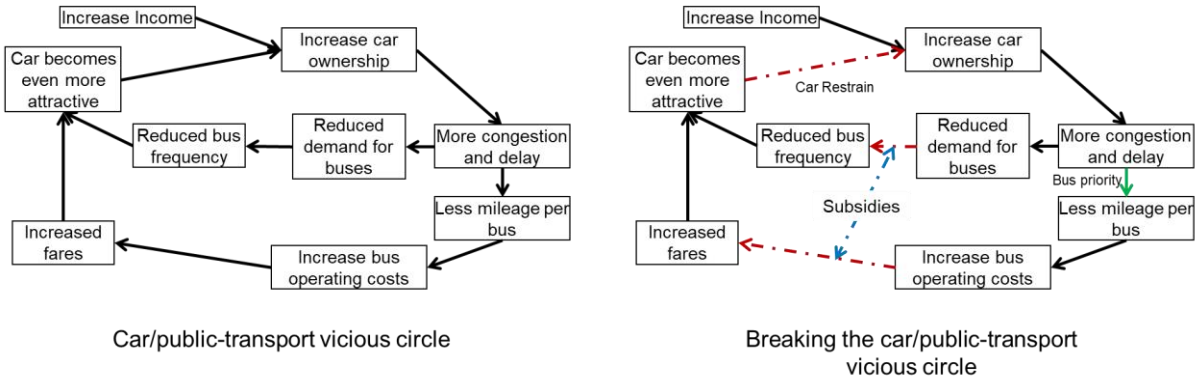


Figure 5 Cycles of transport planning and policies
Adapted from (Ortúzar and Willumsen, 2011)

Ortúzar and Willumsen also clearly state that modeling alone is not a vehicle for developing and implementing policies alone. In their book, they mention how two approaches to decision-making can be linked to the development of the models and how transport modeling can be structured to allow for these decision-making strategies: substantive rationality and muddling through. The first one resides more in quantification, in evaluating how different scenarios can be measured in different metrics and allows decision-makers to prioritize impacts and benefits. This method is usually accompanied by multicriteria strategies to select investments or cost-benefit analyses. By contrast, they mention the "muddling through" process as a more hands-on approach in which decision-makers act under a series of

conditions and implement actions and experiments to achieve goals and objectives that tend to be not so quantifiable. In both cases, the authors recall the importance of developing appropriate models that allow the following of top-of-mind goals with clear, traceable, and forecastable inputs and metrics.

To achieve this, they explain in detail how a series of principles should be followed in each case to develop a successful model: establish the precision and accuracy required for the model while considering the level of detail required. Understand the decision-making context and, in turn, understand the achievability of the scenarios to be proposed and the key metrics to follow. The availability of relevant data in the form of historical counts, precise models, and, in general, state of the art in modeling in the area of the model should be considered. And at last, it is key to understand the resources available for the study in the form of budget and time constraints from agencies to self-develop or hire the building of models and how different modeling scales can result in different data processing requirements. All this, in conjunction with adequate training and skills of the analysts who build and operate the models.

After explaining how the 4-step model is developed according to Ortúzar and Willumsen, it is worth noting how the authors indicate that modeling should be included in planning processes. This view from the literature will be useful in understanding how gender-oriented policies can be introduced into the model. For example, in Figure 6, the authors represent how different aspects of a complete transport system can be understood in the framework of a transport model. From here, the authors mention the importance of setting an adequate set of perspectives and indicators to be measured. In the same sense, they mention the relevance of setting an adequate scale that allows for an adequate process of balancing between steps, an acceptable level of calibration and convergence and especially a representative model.

As suggested by Martens (Martens, 2017), a classic example of this type of use is the implementation of a new transportation line or highway. In one example, a model is built considering the affected populations and their expected behavior in the project. Then a new set of roads and transit lines is added to a calibrated model of the area. But also, a set of additional charges for using these links. The expected result is a simulation of possible pricing schemes that affect how much the future population will use those systems or highways.

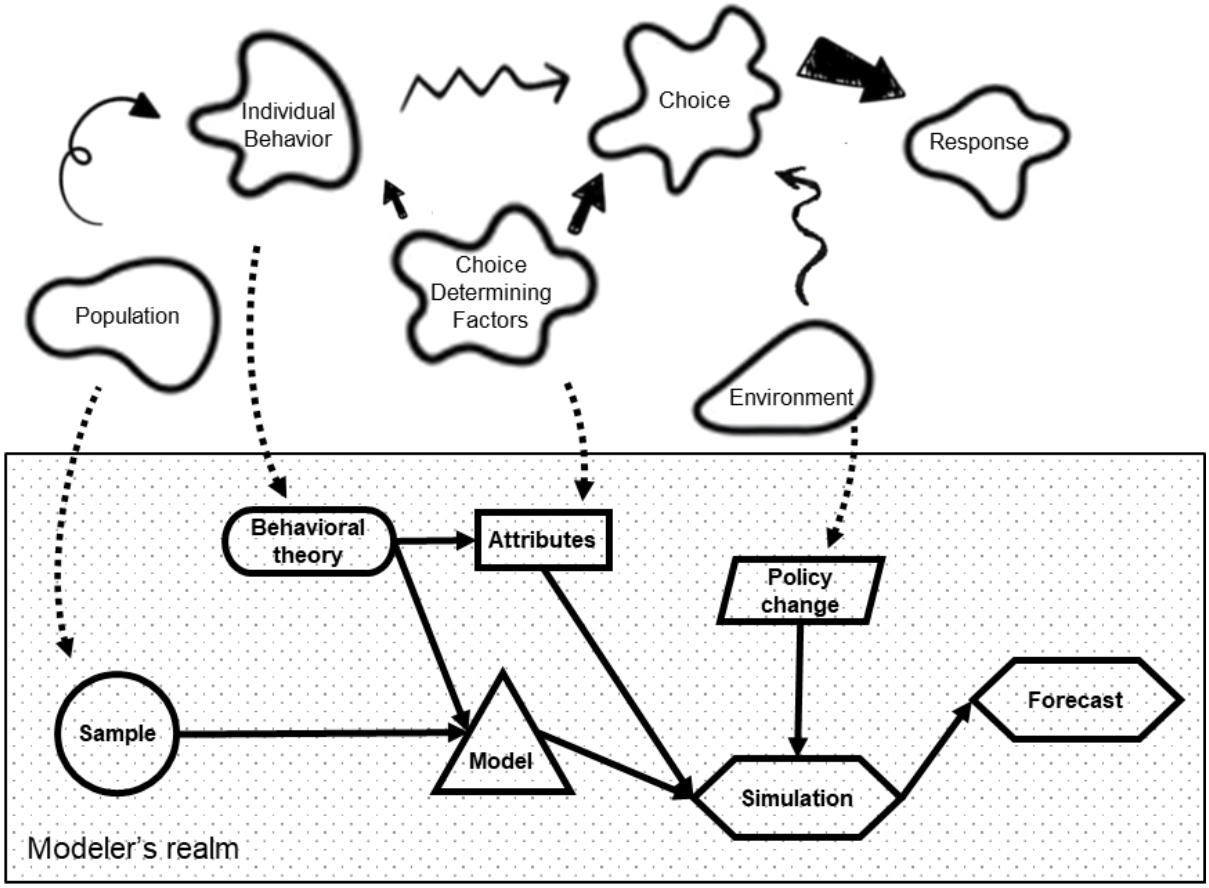


Figure 6 Comparison between real-world conditions and conditions in a model

Adapted from (Ortúzar and Willumsen, 2011)

The importance of developing a time-efficient model is based on the need to run a comprehensive test of alternative paths of land uses, population changes, policies and infrastructure packages in the forecasted scenarios. As an extension of the concept explained by the authors, modeling future scenarios involves a combination of modeling and forecasting that requires a series of evaluations of the assumptions and factors used in those scenarios. This process is typically made by projecting expected land uses based on existing master plans, demographic changes based on census expectations and policies and projects are usually inputs made by local governments at the time of construction of the models. Combining these different data sources can result in scenarios that are not feasible or that use poorly assessed base variables. Here, the authors call for a keen eye from modelers and an appropriate time frame. The authors describe an example of this process in Figure 7: on the left is the traditional approach of building a model without a complementary following of its results. By contrast, on the right, an additional layer of monitoring is proposed to evaluate and control the results obtained when constructing the model. This will result in an always-evolving model that improves the information given to decision-makers.

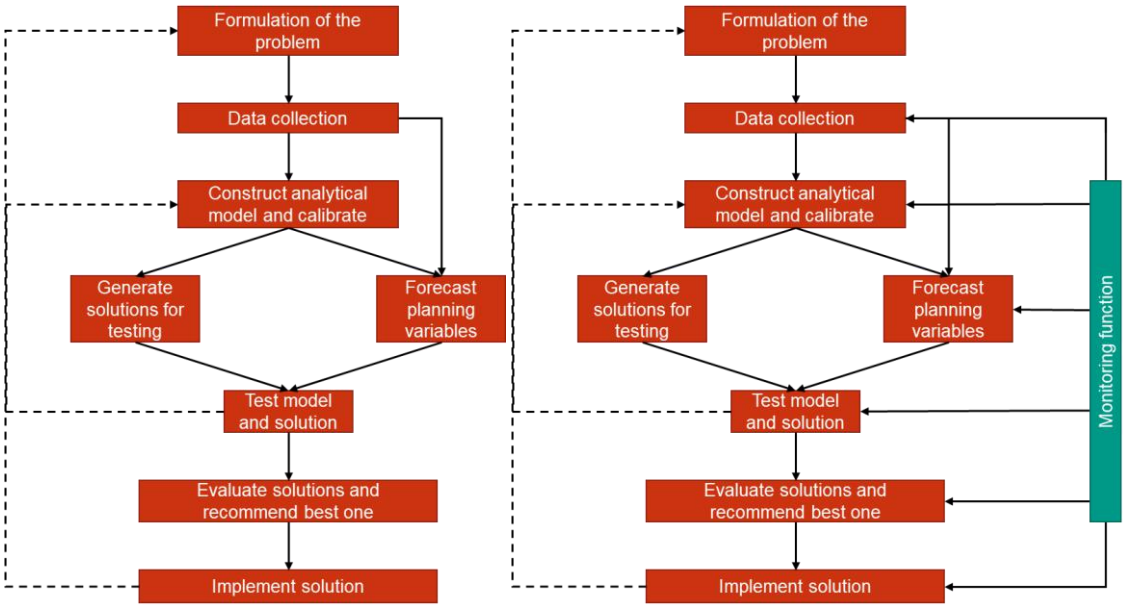


Figure 7 Frameworks of planning and modeling for decision-making processes

Adapted from (Ortúzar and Willumsen, 2011)

2.2.3 Criticism of the 4SM framework

At last, it is important to recall some criticism about the modeling processes and the limitations that should be considered when developing models. Ortúzar and Willumsen (2011) mention that most assumptions and developments in traditional transport modeling are derived from random utility theory (RUT). As many authors in the Behavioral Economics and Psychology realm have demonstrated in recent years, humans are not completely rational nor consistent in how they behave. Those inconsistencies are also present in the models used in transport. Ortúzar and Willumsen then connect this consideration with the problem around data availability. Depending on the data culture wherever a model is built, the possibility of building a more detailed and hopefully less noisy behavioral model is determined by the possibility of gathering historically reliable data. If there is enough historical data, more demand strata, more detailed TAZs, or better-detailed networks can be used.

Additionally, considering the RUT's mathematically simplified nature, the authors highlight the impossibility of including certain criteria in the models, given the constraints of money and time. Adding up to the conflicting interest inherent to transport policies (they mention the conflict between improving speeds and congestion against noise pollution). And also recall how complicated results can result in additional work for modelers to give decision-makers information that is hard to communicate.

Finally, more questions about the pertinence of the 4SM have appeared in the new century. Especially as questions about transport policies go into more complex issues like

road pricing, increasing fuel costs on travel behavior, Transport Oriented Development (TOD) and complex freight management policies. Several authors and local authorities have pushed to move into more advanced and complex models around the globe (National Academies of Sciences, Engineering, and Medicine, 2010).

2.3 Perspectives and solutions moving forward

As a way to understand different approaches to measure and evaluate how to develop more sustainable and equitable transport, two main approaches are described in this section. On one side, the movement to asses transport planning from a fairer point of view. And the proposed and implemented policies to develop gender-aware policy planning.

2.3.1 Justice and equity transport planning

Martens (Martens, 2017) develops an integrated approach to rethink how planning practices should be carried out, to reduce inequalities in mobility. His work focuses on the need to reorient the goals of mobility planning toward improving accessibility rather than focusing on reducing congestion. In his book, he explores the policy discourses around the need to rethink how the impacts of different projects are traditionally measured in terms of reducing congestion for private vehicles and transit users. However, he argues that this focus can lead to solutions that discriminate against some communities, given their physical and economic segregation conditions.

To achieve the goal of an accessibility-centered planning process, he explains how developing indicators that focus on the density of a transportation network and its quality can result in a more equitable way to measure projects. He proposes an indicator that establishes a relationship between an expected level of accessibility to address existing social injustices set by policy and decision-makers. Then he measures how improvements in accessibility can be measured in a way that policy decisions target more communities with a lower degree of existence in the current condition. In addition, Martens invites decision-makers to involve in more cost–efficiency analysis than benefit–cost analysis. He argues that this change removes the need, and sometimes opacity, of monetary valuations of time or accessibility. And pushes for a fairer way to measure projects when is considered the differential impact of different population groups.

He also notes how difficult it can be to design transport systems with accessibility in mind. He addresses this criticism from two fields: on one side, he argues for an improved way

to develop alternative analysis and also discusses how to finance these projects. To improve the alternative analysis process, he suggests inviting decision-makers and transport planners to disaggregate impacts by population groups and weigh the existing disparities between those groups. Martens calls this approach Prioritarianism and explains in detail how to assign priority weights to certain groups as a function of their current disadvantages in the whole mobility system. Parallel to that, he invites us to rethink the concept of self-sufficiency of the projects as their main line of financing. He develops a section of his book into developing a framework to transfer tax collection from the user who already has good levels of accessibility to those who cannot pay for the accessibility improvements they need in a fair system.

Coinciding with Martens, the focus on accessibility is also present in the works by other authors as the key indicator when designing fair transport systems. Lättman et al. (Lättman, Friman and Olsson, 2016) analyzed how different population groups react to different conditions of transport systems in order to use them or not. They found that users are more interested in using systems where better quality is provided and tend to perceive this quality in terms of accessibility measures. Besides time and physical accessibility, the users cited aspects like time coordination, payment options and punctuality as key indicators of accessibility and quality. Especially in women, they found that additional emotional aspects, such as a sense of safety and closeness, are more influential in their perceptions. Along the same line, Mcray (McCray and Brais, 2007) insists on understanding accessibility as a key indicator to providing fair systems. Using mixed methods of surveys and focal groups. He explains how the availability of accessible networks is correlated to access to economic opportunities and social connections.

2.3.2 Gender-oriented transformations in the transport sector

As this thesis focuses on finding strategies for measuring women-oriented policies in mobility systems, it is useful to understand the solutions given in the existing literature to comprehend how the authors assess the value of those given solutions. By doing this, the subsequent process of proposing metrics that allow measuring baselines of the dynamics of women in transport in the 4SM will have a sound theoretical foundation. There is a need to divide the special needs around public and private transport to understand how these complex systems should be developed.

In principle, public transport systems should be able to respond to the need of the communities they serve (Turner and Grieco, 2000). The literature review in this thesis shows that it is essential to increase focus on improving women's conditions in transit systems to achieve gender-equitable policies. Special attention should be paid to the frequency of routes and accessibility. Madariaga mentions that as women make more polygonal and short trips, access to routes that frequently run and near local destinations is key to facilitating trips of care (Sánchez de Madariaga and Roberts, 2013, p. 72). Research by Liu also supports this by analyzing patterns of women's behavior through their transit cards. As women are subject to making more trips in a day, the variance of their entry trips is higher than that for men. In that same line, Halsall recalls how future policy decisions around public transport in the UK consider that putting connectivity and accessibility as the main focus of policy interventions can be a way to improve women's conditions in transport (Halsall, 2001).

> *This study indicates that age and gender play an important role in the intrapersonal and interpersonal variability in PT[3] usage. Female users exhibit higher intrapersonal variability than their male counterparts, and the weekly patterns are more diverse over time for the elderly aged 65 or over.*
>
> (Liu *et al.*, 2020, p. 4255)

Regarding accessibility, Levy calls for a women-led appropriation of the space based on two axes: targeted and improved accessibility and a comprehensive mobility system. She recalls the importance of an improved mobility view, which builds legitimacy as it is "fundamental and often the basis for moving beyond either being invisible or being bulldozed to more constructive policies and planning" (Levy, 2013, p. 53). Equally, Halsall found how accessibility and connectivity developed with communities across socioeconomic and gender levels to improve women's conditions in a bigger proportion than from top-down approaches. (Halsall, 2001). Similarly, Turner and Grieco found out that Demand Oriented Transport (DoT) can be a way to improve local connectivity and reduce the time burden on short trips, which women account more for, thus can be a tool to improve gender equity (Turner and Grieco, 2000). These transport services, which are planned and operated to satisfy the un-homogenous demand of a given area, are more flexible in their pick-up and drop-off stations. Different kinds of vehicles can also provide them to satisfy particular needs, improve connectivity to more robust transit lines, and, given their flexible planning, can be an affordable service for intra-neighborhood trips (UK DfT, 2022). Nasrin and Bunker (2021) demonstrated how alternative transport, like rickshaws, can act as DoT and improve women's

[3] Public transport

mobility and safety experiences. This example is particularly relevant as it can be understood as an experience from the global south that has already proved effective.

Another line of solutions around public transport centers on assessing accessibility as essential to developing gender-sensitive policies. As Nasrim and Bunker mentioned, the trip-chained nature of women's mobility patterns makes deficient and physically inaccessible locations in the city around care facilities segregate against them. In the broad sense, the authors recognize that accessibility should be measured as the capacity to access certain areas and to have an adequate set of physical infrastructures that allow them to carry packages and baby carriages or facilitate the displacement of sick and older adults.

By contrast, in the case of private transport, a deeper social and cultural transformation is proposed. Several authors agree that economic disparities hinder women's ability to access motorized vehicles in the household, or when at their disposal, the less reliable vehicle is usually assigned to them. A holistic strategy is proposed that allows access to different ways of independent, safe and reliable movement: from expanded access to bicycles to subsidies to vehicles in women-led households, to solve these inequities. However, as these measures tend to be more resource-intensive, promoting public bike or car-sharing schemes near care-intensive locations can be viable alternatives.

Another argument in the considerations around public and private transport, Gauvin et al. (2020, p. 11) find the results interesting when policies are being designed. Even if some policies tend to be generally inclusive, not all redistributive and progressive impacts are distributed equally between men and women. This goes hand in hand with the recommendations made by other authors, which claim that it is needed to make social-progressive policies and affirmative action toward policies that favor women. For example, Maradiaga's call to action around gender mainstreaming separates the need to develop gender agendas that maximize gender equity criteria from agendas that push for general equity (Sánchez de Madariaga and Roberts, 2013, p. 13,29).

In a more general sense, and outside the role of women as caregivers, the authors agree to reflect on women's work-related and education patterns, specifically when designing transport policies. That can mean specific analysis of clusters of women-led jobs or education to increase the supply of public transport, evaluating different periods of the day to ensure that maximum capacity attends to women's peak demands and especially including women in all stages of development and implementation.

Regarding already implemented solutions, the compendium developed by the Interamerican Development Bank (IDB) shows how many cities in LATAM have developed

and implemented to improve women's transportation conditions (Montoya *et al.*, 2021). This work highlights how solutions should be aimed at different aspects of planning and implementing gender-sensitive transport systems. They mention how it is needed to work in the following lines: Awareness raising and education, new technological tools, knowledge, access to justice, job opportunities, gender-sensitive infrastructure and prevention. From this compendium is worth highlighting the following solutions, as these solutions can be used in different stages of the planning process of transport systems:

- Several projects in LATAM and the Caribbean to sensitize planners and decision-makers about the implications of thinking, planning and developing transport policies and infrastructure with a gender focus in mind.
- Adapting stations and infrastructures to supply facilities and safety to women on their daily trips. Actions such as implementing only-women transit lines and stations specially tailored to satisfy women's needs were highly appreciated by women and increased ridership in transit systems.
- The use of new technologies and mobile applications to map insecure spots and streets near transit stations in Bogotá was recognized as a way to collect data useful to improve accessibility conditions of women to transit systems.

At last, it is relevant to mention the handbook developed by the European Union to include gender in the development of Sustainable Urban Mobility Plans or SUMPS (Drăguțescu, Land and Meskovic, 2020). These guidelines adapt the integral process of developing SUMPs in many dimensions to consider the special needs of women in transportation. As a result, they mention four stages of development in which a gender approach should be added:

1. To understand the different target groups to involve in the planning and implementation process: Here, they mention the need to characterize qualitatively and quantitatively correctly how women perceive, experience and live the mobility system of a city before developing the SUMP.
2. To facilitate the participation of women and representatives of vulnerable groups in decision-making processes: The authors insist on the need to collect visions and ideas from women and representatives not only in the base-line characterization of the SUMP but also when developing and testing future scenarios in order to evaluate policies and investments which have popular support over time.
3. To include gender-specific measures or measures that target increased accessibility: Across the document, the authors insist on the need to measure the impacts of policies on women's mobility continuously. They mention strategies to measure impacts and to account for changes with a focus on women's trips.

4. To establish monitoring and evaluation systems that provide clear evidence on gender mainstreaming and accessibility levels. They recognize the need to supervise the implementation of the measures proposed in the SUMPs. In that sense, they mention alternatives to verify the implementation of the policies and interventions in conjunction with the communities that formulated them.

3 Research design and methodology

This thesis seeks to make links between feminist research on women's transport practices, discourses, and transport modeling practices for practitioners to implement in their everyday work. Consequently, the methodology used in this thesis reflects the need to understand a 4-step model and the dynamics of transport by gender in an urban area. Given the need for consistent and reliable data regarding an implemented 4-step model and transport data by gender, a case study was the most reliable way to develop this thesis. The research design of this thesis revolves around understanding both concepts, using the example of Bogotá as a case study to achieve this goal. The city of Bogotá combines a tradition of transport planning using a robust and tested 4-step model with efforts by successive governments to collect better and more data, including gender-sensitive data, making Bogotá an ideal case study for this thesis.

3.1 Research design and methodology

On top of the literature review, the research for this thesis includes the revision of official statistics, Bogotá's 2019 mobility survey, and a series of semi-structured interviews with key actors. As the case study for this thesis is the 4-step transport model of Bogotá, a multifaceted analysis where the patterns of mobility are analyzed under a gender-aware focus, the model is then reviewed to understand how it works and how it is built, and interviews with key actors.

3.1.1 Analysis of patterns of mobility in Bogotá

Using data from the mobility survey carried out in 2019 by the Mobility Secretariat (SdM)[4] and several field studies carried out by the national statistical bureau (DANE)[5], a quantitative and qualitative analysis is done to compare mobility patterns described by several authors in the literature review and their pertinence in Bogota to understand the differences between women and men. Aspects such as mode share, income and access to vehicles, travel times, the purpose of travel, the time distribution of the trips and demographic characteristics of the survey respondents are used. The surveys and studies have public access and

[4] To improve readability from here on, thesis will use the acronym of the Spanish name of the District Secretariat of Mobility (Secretaria Distrital de Movilidad): **SdM**.
[5] The same applies to the National Administrative Department of Statistics (Departamento Administrativo Nacional De Estadística): **DANE.**

anonymized databases with representative samples for the metropolitan area populations. These are sufficient evidence to understand the city's mobility patterns and demographic conditions.

Using these data sources, a geographic database for comparing demographic characteristics and mobility behaviors is constructed. These comparisons represent structural patterns and characteristics in how women and men differ in their mobility behaviors. This exercise will test the qualitative hypothesis proposed by authors in the literature review and the findings of the interviews with key actors applied to Bogota's background. Additionally, with data from the calibrated functions and rates from the 4-step model, this thesis analyzes if those variables calibrated to an average traveler can produce gender biases that affect planning against women.

As identified in the literature review, the analysis for this thesis should also include a spatial and time-dependent perspective. It is necessary to recognize the importance of having anonymized data georeferenced to a very high level of detail for all the national-level surveys and censuses. Cross-referencing characteristics missing in the mobility survey of Bogota, which is only referenced at a TAZ level, to aspects such as household income and time used outside transport, which is not captured by the mobility survey, is a key aspect of this work. Combining different sources provides a wider perspective on the time and financial budget differences between women and men, resulting in a more appropriate reflection on their travel behaviors.

A brief description of each of the studies and data used [6]:

- *Encuesta Origen Destino a Hogares* (EODH 2019): The city carries out a household origin-destination survey every four years to update the 4-step model. It is a tool developed to improve understanding of the mobility patterns in Bogotá and its metropolitan region (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019). With micro-data available at the TAZs scale, this planning tool is not only aimed to collect information used to update the 4-step model but also is intended to complement the model to develop policies and improve decision-making processes in the city.
- *Censo Nacional de Población y Vivienda - 2018* (CNPV 18): The national census is the most important and biggest statistical and demographic operation made by the national government to characterize and quantify the demographic conditions of the Colombian population. Data available at a household level contains information regarding housing conditions, household structure and

[6] This thesis will use the abbreviations of this list (EODH 19, CNPV 18 and ENUT 2021) in order to refer to each of these surveys to facilitate readability.

compositions, fatalities and inhabitants (Dirección de Censos y Demografía - DCD, 2018).

- *Encuesta Nacional de Uso del Tiempo* (ENUT 21): The national time use survey is a statistical tool developed by the national government to assess how the country's population distributes and spends their time. Also, it characterizes how households are composed and how the time is distributed between members of the same household. With information at a household level, the versions of this survey of 2016-2017 and 2021-2022 will be used in this thesis. Those two surveys are used to mitigate possible impacts of the COVID-19 pandemic in the information available in the last survey and to take advantage of information regarding care activities as is available in this last survey. (Dirección de Metodología y Producción Estadística - DIMPE and Dirección de Censos y Demografía - DCD, 2017, 2021)

3.1.2 Model review

Using official reports from the contract process carried out by the SdM to update the 4SM model and carry out the mobility survey, a descriptive analysis of the model, its inputs and results are carried out to understand its particularities. In this step, the thesis aims to understand the unique traits of Bogotá's model compared to the general description of the 4-step modeling process done in the literature review. Furthermore, an open data request was sent to the modeling office of the SdM in order to request particular outputs of the model. This data is then incorporated in the geographic data based constructed to consolidate the information of the previous chapter in order to able to compare it.

The reports and additional documentation of the model reviewed for this analysis are listed below:

- An official report on the model update process results made by the consultancy group hired for that process in 2019.
- The request for open information to the SdM containing:
    - Calibrated matrices for each demand segment used in the base scenario
    - Trip generation rates of each socioeconomic stratum, age group, and travel purpose
    - Trip attraction rates for every demand segment, travel purpose and land use.
    - Vectors of trip generation and attraction for each demand segment and travel purpose.
    - Distribution matrices by trip purpose and demand segment.
    - Cost matrices used in the distribution process for each mode (Private vehicles, motorcycles, public transit)

- Coefficients of the distribution function for each travel purpose and demand segment. Including alpha and beta parameters.
- Utility coefficients for each nest, socioeconomic level, travel time per mode, access time per socioeconomic level, transfer time per mode, and mode-dependent constants for the process of modal selection.
- Geographic database file with the delimitation of the analysis areas used in the model (TAZs and UTAM)
- Geographic database file with the links used in the model, with all the descriptions of each field
- Geographic database file with the nodes used in the model, with all the descriptions of each field
- Geographic database file with the turns used in the model, with all the descriptions of each field

3.1.3 Interviews

Finally, interviews with key actors were conducted to gather an expert perspective around gender, gendered mobilities, transport modeling, and mobility policy development in a general sense, but especially with a focus on Bogotá, given the interviewees' experience in developing projects and research in the city. The interviews, carried out between October and November of 2022, were done online, in Spanish, and recorded with the previous consent of the participants. The focus of the interviews was to bring experts from both areas regarding this thesis (transport modeling and gender studies of mobility) to a common understanding of the concept to be carried out in this thesis. Then a series of questions were made to gather how gender is considered in modeling in the current practices, and by contrast, how much gender academics are aware of the modeling process and how they shape decisions around transport.

As the intention behind these interviews was to cover a wide range of experiences and knowledge, the non-representative sample of practitioners includes experts that work or have worked with the local government in different agencies. The role of those practitioners varies from project managers and transport modelers from the two main consultancy groups that work with Bogotá's 4-step model to gender researchers from a local university and the GIZ. The sample of 10 interviews includes four researchers in gender and transport, four current transport modelers and two former transport modelers who now work as project managers, including transport modeling. Four interviewees work or have worked with SdM, four have publications, projects or research regarding gender in transport, and seven have direct

experience with the 4-step transport model. A complete list of the interviewees, their roles and daily tasks can be found in Annex A.

The structure of these semi-structured interviews was designed to gather a basic demographic base of the interviewees, their perspective on gender and mobility with an extended focus on the particularities of Bogota's mobility system and their previous knowledge of the transport process in which the 4-step model is involved. After the discussion of the two previous topics were covered, an additional discussion was made to analyze which changes and transformations should be made for planning transport with a gender focus in Bogotá. The guiding questions used for the interviews were:

- Regarding gender: Interviewees were asked about their previous knowledge regarding gender, how women and men experience transport differently and regarding their experiences using, or not, gender as a determinant in their daily work. Additionally, they were asked about the particularities of women's experiences in Bogota's transport system. Travel patterns and concentration of trips were made primarily by women in their opinion and experience, which is the biggest problem for women in transport in Bogota in their opinion.
- Regarding modeling: Questions regarding their previous knowledge or acknowledgment of the 4-step model and how results are typically communicated and used in planning processes inside and outside the SdM. They were also asked how the model was calibrated and how the calibration process was communicated and reviewed.
- Regarding planning: In a more openly phrased structured, the interviewees were asked to think about ways in which planning processes, and the use of the model in those processes, can be done with a gender lens. They were asked for ways to improve the mobility survey. And last, in their opinion, Bogota's transport planning has been done with a gender equity perspective.

Finally, an inductive analysis is carried out with all the collected responses to extract visions of gender, transport planning, transport modeling and perspectives on possible solutions. This collection is not always done in a literal way, as some interviewees asked for special consideration to be given to certain quotations, as they shared perceptions and technical considerations that may not be shared officially by the organizations or bodies in which they work.

4 Gendered mobility patterns in Bogotá and their modeling

To analyze the case context of Bogotá and its 4SM model, this section of the thesis focuses on two tools developed by the city: the mobility survey of 2019 and the 4SM built with its results. This comparison is made with a focus on gender in the case of the survey and with a focus on peak hour trips as in the model case, as this hour is used for modeling and planning. Considering this, an additional layer of analysis is needed to understand how the 4SM works, even if conditions essential to understand the relations of gender and transport happen outside this hour. Finally, a summary and analysis of the interviews are done to contrast the findings and explore additional considerations given by the interviewees.

4.1 Current situation of women's mobility in Bogotá

Even if most of the global research around women's travel behavior can be extrapolated to many places in the world, as Levy mentions, building mobility systems that respond to each community's needs and voices in their development is necessary. It is crucial to develop systems approved and used by the communities they will serve (Levy, 2013, p. 54). In this aspect, works led by the Mobility Secretariat (SdM), NGOs, think tanks and individual researchers have gone deep to understand the particularities of women in Bogotá's transport system. Works by NGOs like Despacio and WRI, as the study led by Moscoso (2019), and by different offices from the local government evidenced the importance of analyzing the nuances of transport in Bogotá with a special lens on women's travels.

Analyzing the particularities of the mobility system in Bogotá, with a focus on gender impacts, results are especially important as the literature on this section evidences. A clear example is the data shown in Figure 8. Developed by Moscoso et al., the isochrones of travel times to the central district of Bogotá (where most jobs are located) express a clear set of disparities for women. Lack of access to first and last-mile means of transport, irregular bus frequencies and a transport system that lacks a vision for reducing gender disparities in transport are constant in the city planning history (Moscoso *et al.*, 2019).

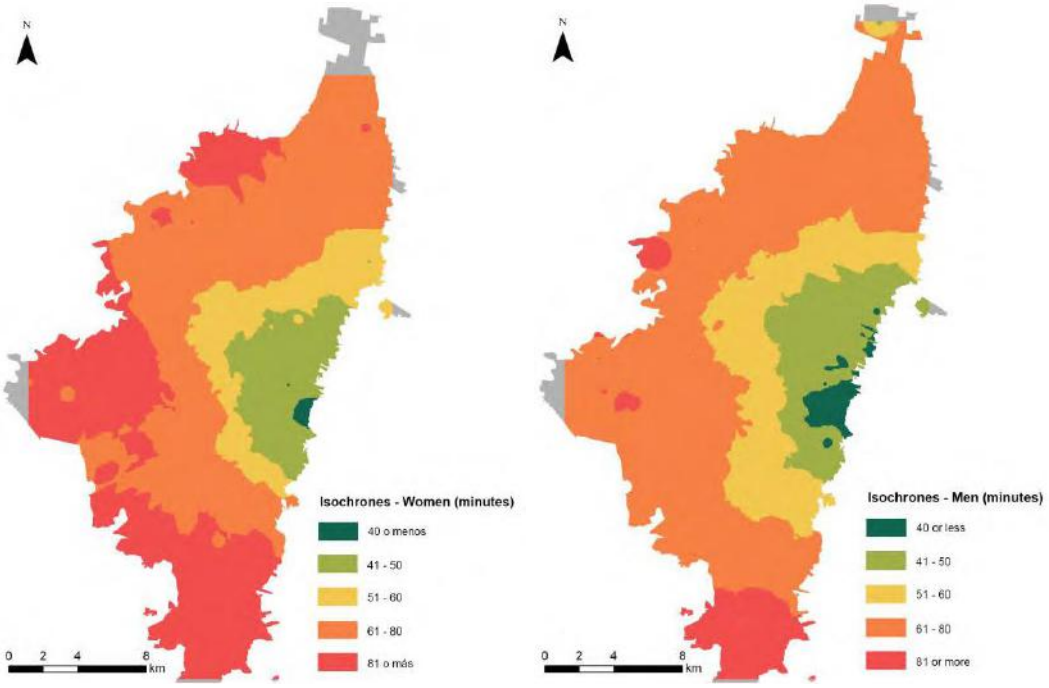


Figure 8 Isochrones for work trips to the central business district (CBD) made by women (L) and men (R).

(Taken from Moscoso et al., 2019)

Regarding structural determinants, the work done by Moscoso et al. makes a deep dive into understanding how women experience transport in Bogotá from all aspects. Their work follows the same structure used in this thesis of understanding one side the mobility patterns of women and how personal safety plays a key additional role. Using information from the transport surveys from 2011 and 2015, they presented changes and transformations in the transport system with a focus on gender criteria. Their analysis is centered on the intrinsic characteristics of the trips surveyed by the SdM and the population's demographic characteristics. It is also worth noting how, even if their conclusions can be understood at a city-wide level, they disaggregate several indicators by economic brackets and from a spatial perspective (Moscoso *et al.*, 2019). The main findings in each of those aspects can be summarized as follows:

- Mode share, income and access to vehicles: the authors find that in line with other cities, women use more transit than men in Bogota. However, they allege that they use more local buses than BRT because of safety concerns. Additionally, they find that lower-income women use much more transit than higher-income women who use more private vehicles.
- Travel times: on average, women in Bogotá have commutes 11 minutes longer than men. However, this varies between socioeconomic levels, where lower incomes travel doubles the time than higher incomes. The authors suggest that these figures can be related to the higher use of cars and taxis among higher income brackets.

- Purpose of travel: women heads of households make fewer trips than men, but they do more care and health trips on lower incomes and on average. However, the number of care trips women make is reduced at the highest income brackets.
- Time distribution: women tend to make more trips in the morning and near noon. According to the authors, this contrasted with the peak hours of trips made by men, mainly done in the morning and afternoon.
- Age: regarding age, a progression was found by the authors, in which women early in life ride more bikes and walk, then tend to use more transit, and older women prefer to use private transport.
- Road safety: even if men are more prone to be involved in traffic crashes and be killed on the roads in an aggregate of the city, the authors found out that in local roads and poorer areas, women are more exposed than men and tend to have more crashes and deaths.
- Bike use: cross-analyzing data from 2011 and 2015, the authors found that the share of women who bike is still low even if bike trips have increased. The authors allege a lack of gender-oriented criteria to prioritize infrastructure developments as a possible cause.
- Spatial trip distribution: analyzing the spatial patterns of the trips, the authors found how lower-income women make more local trips (associated with care), and their work-related trips are longer than other segments of the population. Also, they found how job offers for men are distributed around the city and have better accessibility than jobs made by women, which are concentrated in the city center, and have poor last-mile connectivity, according to the authors.

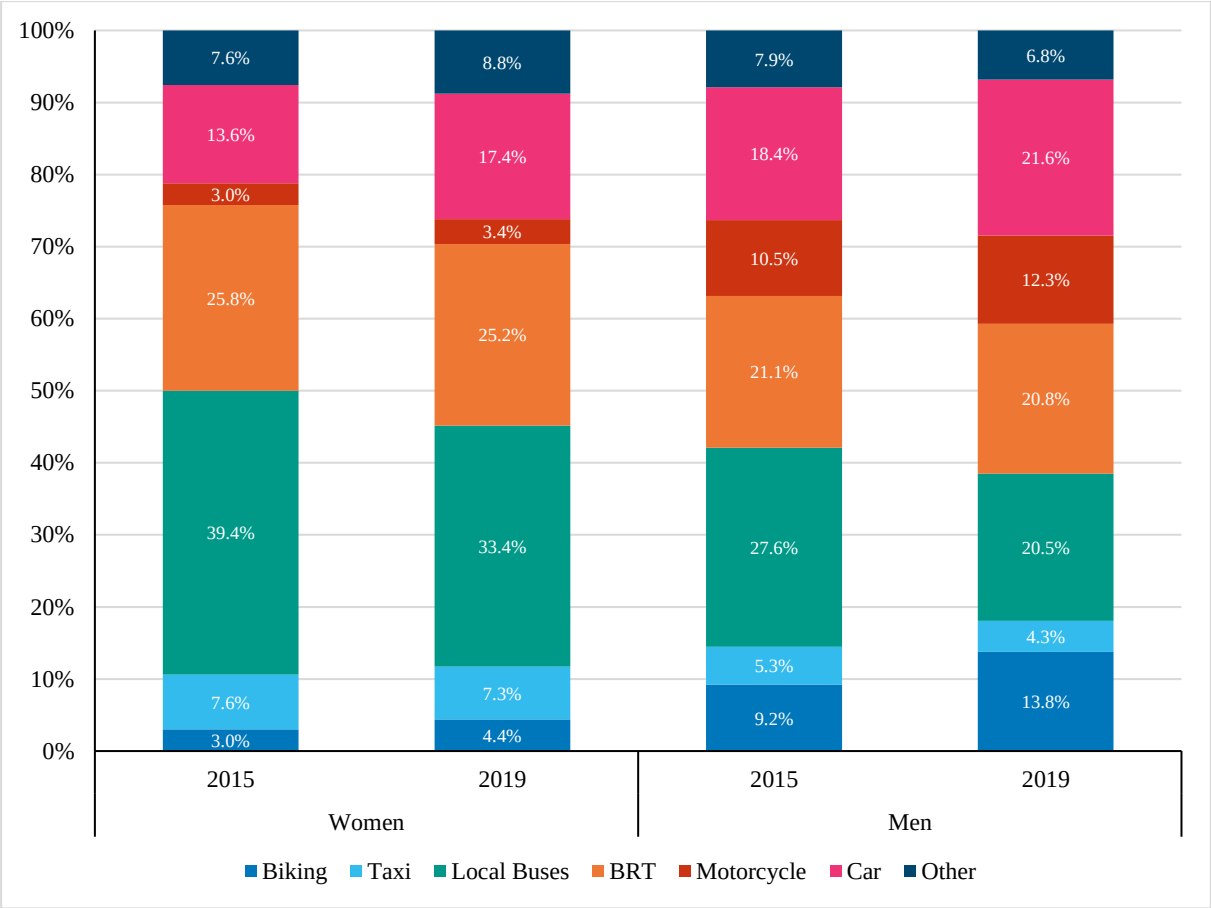


Figure 9 Modal distribution of trips by gender in 2015 and 2019 according to the mobility surveys
Self-elaboration from (Moscoso et al., 2019; Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

Following the analysis conducted by Moscoso et al., this thesis deepens into how women's mobility behaviors differ from men's, using the data derived from the Household survey of 2019. This analysis, with updated data, is key to understanding how some of the patterns and conditions found in the survey of 2015 by Moscoso et al. are still relevant and can be understood as standard in Bogotá—in that regard, beginning with the analysis of the share of trips made by women and men, and how trips made by women have changed over time. In Figure 9, the changes across genders reveal what several authors have concluded about a change in users from public transport to private transport (Rodriguez-Valencia *et al.*, 2021). While not able to compare the number of walking-based trips because of how each survey was done, the results show how women are starting to use more private means of transport. However, compared with walking trips, between genders, it is clear that women are still the biggest users of public transport and the ones who walk more in the city to carry out their everyday trips.

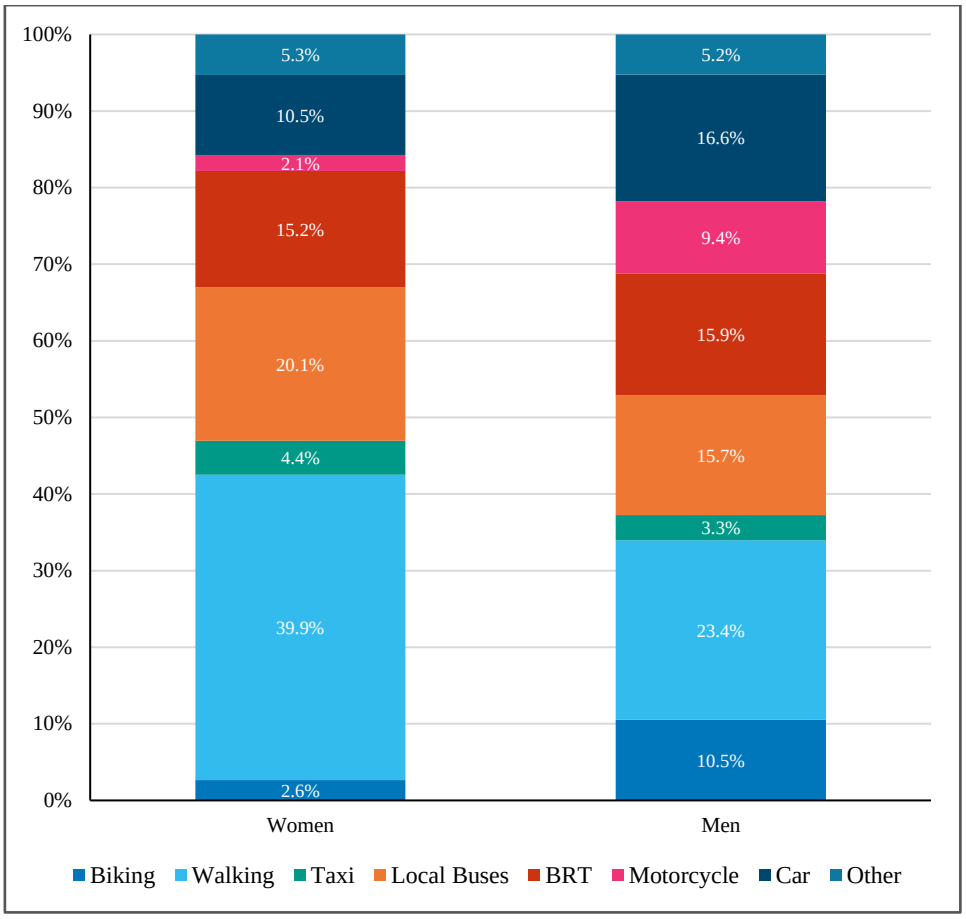


Figure 10 Modal distribution of trips by gender according to the 2019 mobility survey
Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

As was mentioned by several interviewees and recognized in the literature review, the analysis of gender and transport should not be disconnected from a transversal analysis of income and class. For this thesis, the socioeconomic strata are used as the national standard of the economic level at a household level. This value, linked to the spatial position of residence in the city, is often used in surveys and population analysis as a proxy to estimate the income level of a surveyed. In the case of Bogotá, as shown in Figure 11, comparing not only the differences between gender but also strata are highly revealing. It is worth noting how lower strata levels are associated with lower-income households, and higher levels are related to higher incomes. Across genders, inhabitants of lower-income strata rely more on public transport, not only because of the high transport times but also because of reduced vehicle access. In these strata, travelers resort to using more motorcycles and other means of transport, as described by Rodriguez-Valencia et al. (2021). It is also important to note how motorcycles in lower strata are more widespread than private vehicles.

When analyzed by gender, meaningful differences appear, which explains why it is important to start analyzing women and men separately and not only by strata. For example,

in the case of strata 1 and 2, men use four times more motorcycles for their trips than women. By contrast, women use between 10% and 20% more transit than men in those strata. Then, observing the higher strata, as household income increases, using taxis as an alternative to transit is more prevalent for women than for men who resort to using more cars. Another aspect worth noting is how even when the highest income strata tend to be the ones where a provision of transit is higher, users from both genders tend to use it less. As the interviewees noted and the work of Rodriguez-Valencia found, this phenomenon can be related to poor quality of service and perceptions of insecurity.

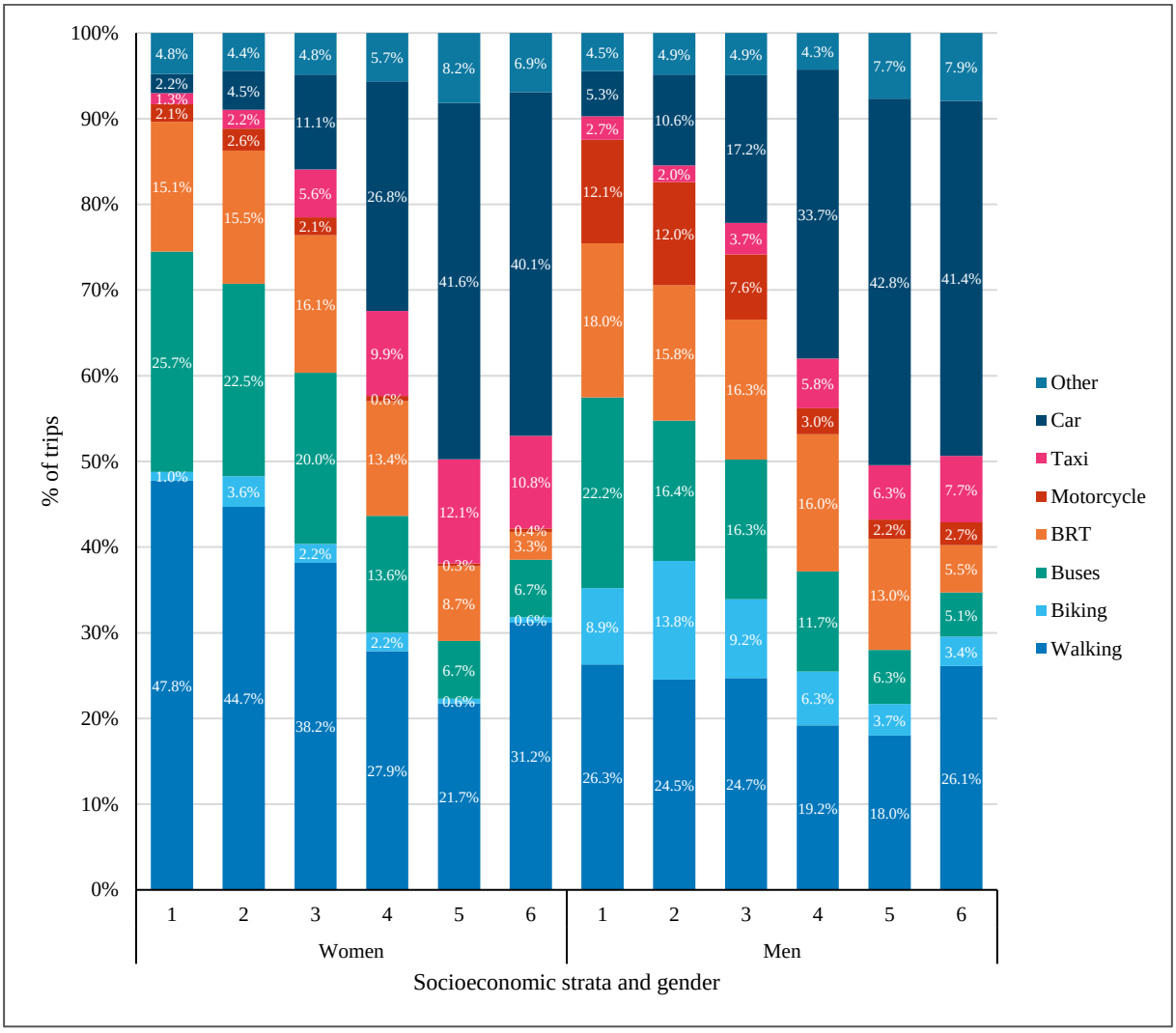


Figure 11 Modal distribution of trips by gender and socioeconomic strata in 2019

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

The importance of differentiating not only for strata but also for gender is shown when analyzing the modes and purpose of the trips. In Figure 12, the comparison of purposes and strata reveals how, as incomes grow in the household, the number of trips dedicated to leisure and other purposes increases while the number of dedicated to caring work decreases. The work of Moscoso et al. and the interviewee's responses agree that these characteristics are

linked to the additional time budget available derived from lower total travel times throughout the day and the additional remanent budget after taking care of basic needs. In other words, the additional constraints in financial and time budgets result in fewer possibilities to access leisure activities.

When compared to men, continuing the trend of the survey of 2015, women are the ones who make more care-related trips on average in the same strata except in the highest strata. Access to own vehicles and an increased budget to delegate care activities are the causes for this, according to the interviewees.

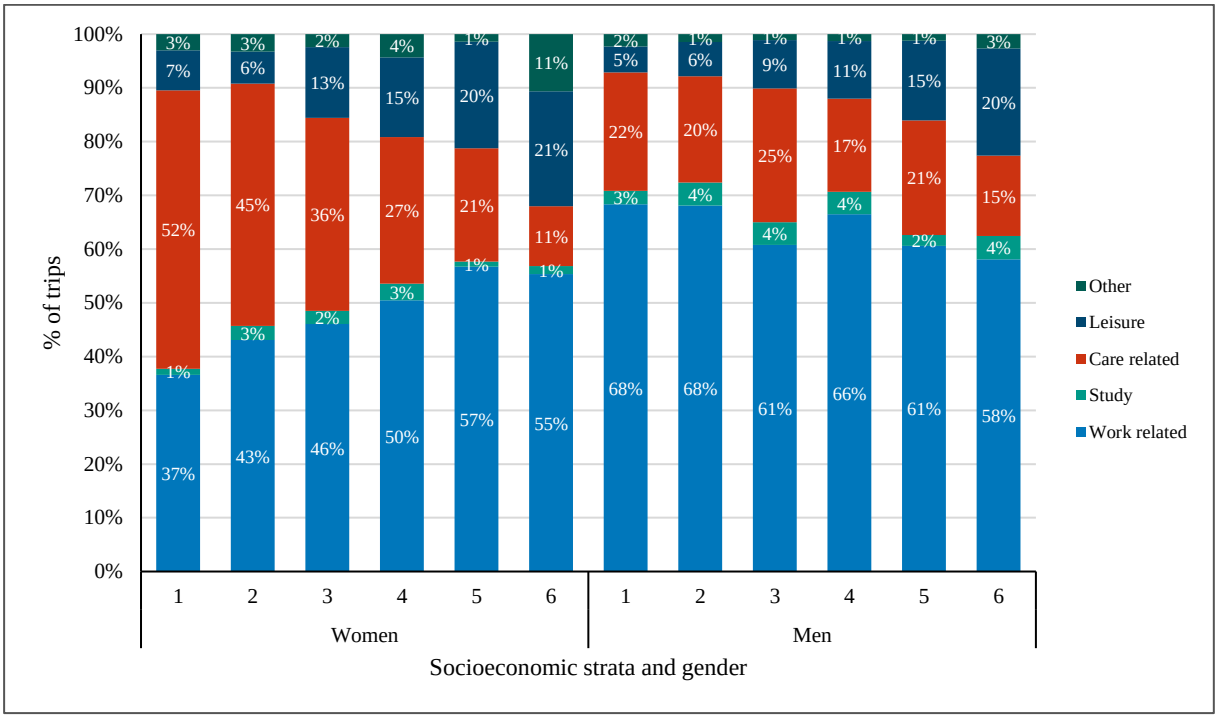


Figure 12 Purpose of trips by gender and socioeconomic strata in 2019 for the heads of household
Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

As shown in Figure 13, the considerations of time budgets across strata tend to be more influential in understanding a given group than those across gender. The graph was built using a question introduced in the 2019 survey regarding the amount of time used to make care activities, finding how workers and students who have to perform care activities have similar times across genders. However, when observing the differences between strata, it is clear that lower-income households have a higher impact on their time budgets when making their main daily trips (work or study).

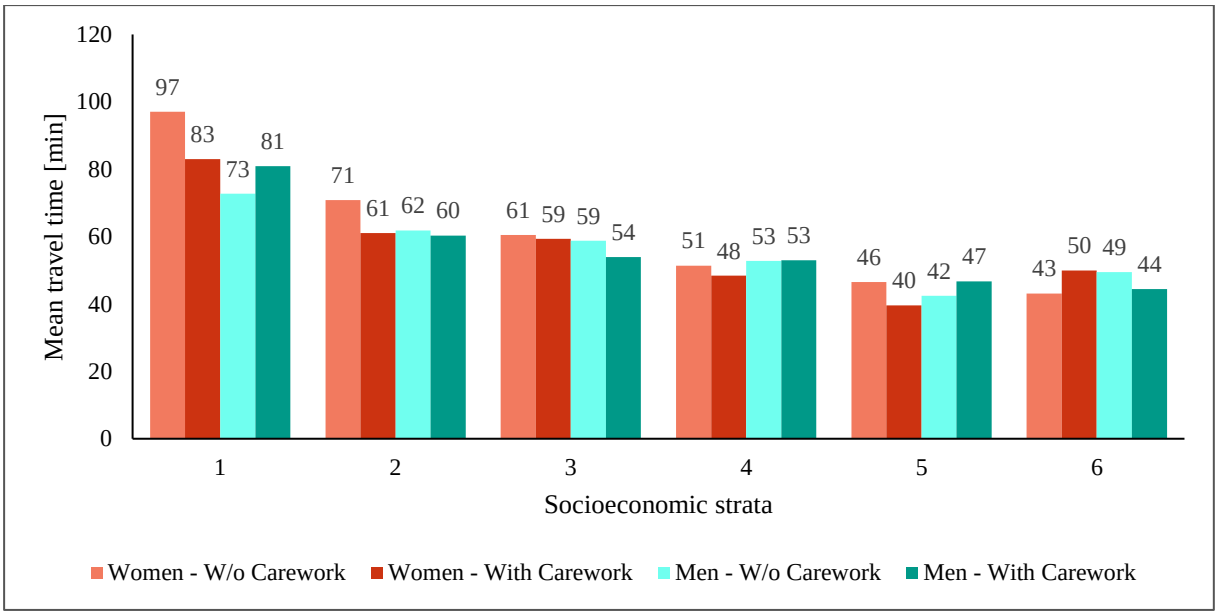


Figure 13 Mean travel time for work and study by gender for people who do care work across socioeconomic strata in 2019 against a population who does not do care work

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

In Figure 14, additional data regarding the use of different modes is presented, in this case, showing the dynamics across age groups. Consistent with the analysis of Moscoso et al. for the 2015 survey, the transition across time is to go from walking as the main transport strategy in lower age groups to then using more transit and private transport in the middle of life, to then going back to walking in the case of older people. However, the differences between genders are clearer at the top of the graph. Men are the ones who tend to maintain consistent use of the car across age groups. And in general, men are also less likely to walk compared to women of the same age. As mentioned in the literature review, this can be linked to increased vehicle access and a dominant position in the home to use it, compared to women.

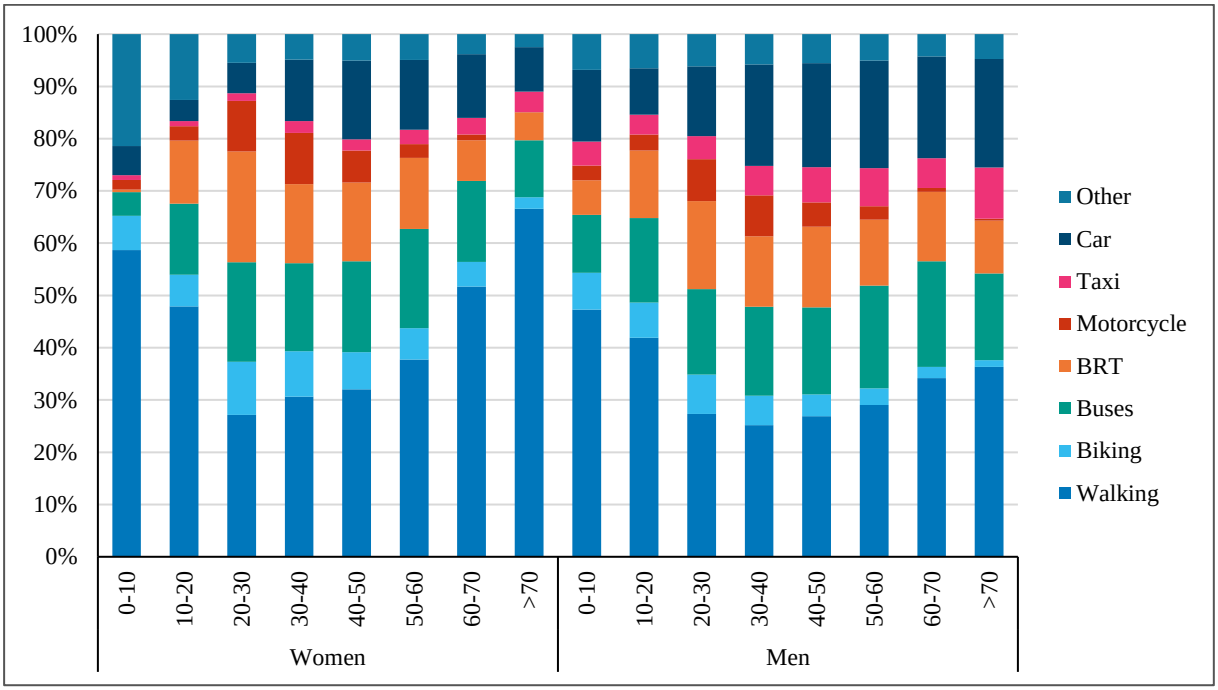


Figure 14 Modal distribution by age group

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

The case for individually analyzing women and men in planning practices, according to Madariaga (2013) and mentioned by several authors, is the need to understand the differences in their daily activities profiles. As evidenced in Figure 15, women in Bogotá make more trips than men during peak hours but also have other activities throughout the day. These peaks are related to care activities and are a reason to plan for those activity patterns in detail. In fact, in 11 of the 13 hours where women make more trips than men, women make more care-related trips than men. Across the day, as expected, women also make more trips than men.

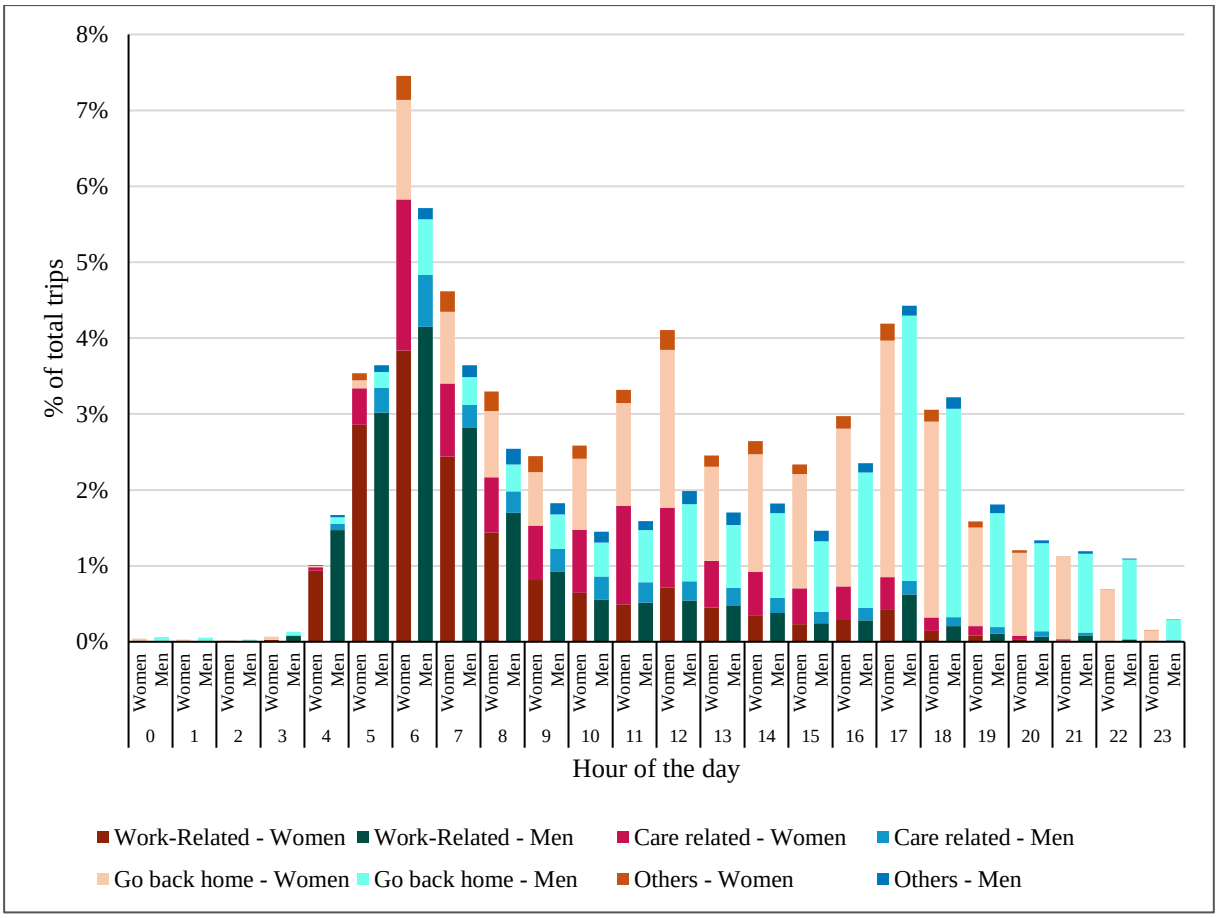


Figure 15 Time profile of trips as a % of the total of the area trips by gender and purpose

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

As found in the literature review, the classical modeling theory mentions the idea of planning for work and study trips which are the ones that influence the peaks in transport demand. But an important difference appears when analyzing how household heads are represented in those peaks. Figure 16 reveals that male heads of households in Bogotá are the main transport system users in those peaks. In contrast, female heads of households have activities that tend to be more dispersed throughout the day. This evidences the need to advance in models that correctly represent the difference between women and men when evaluating policies.

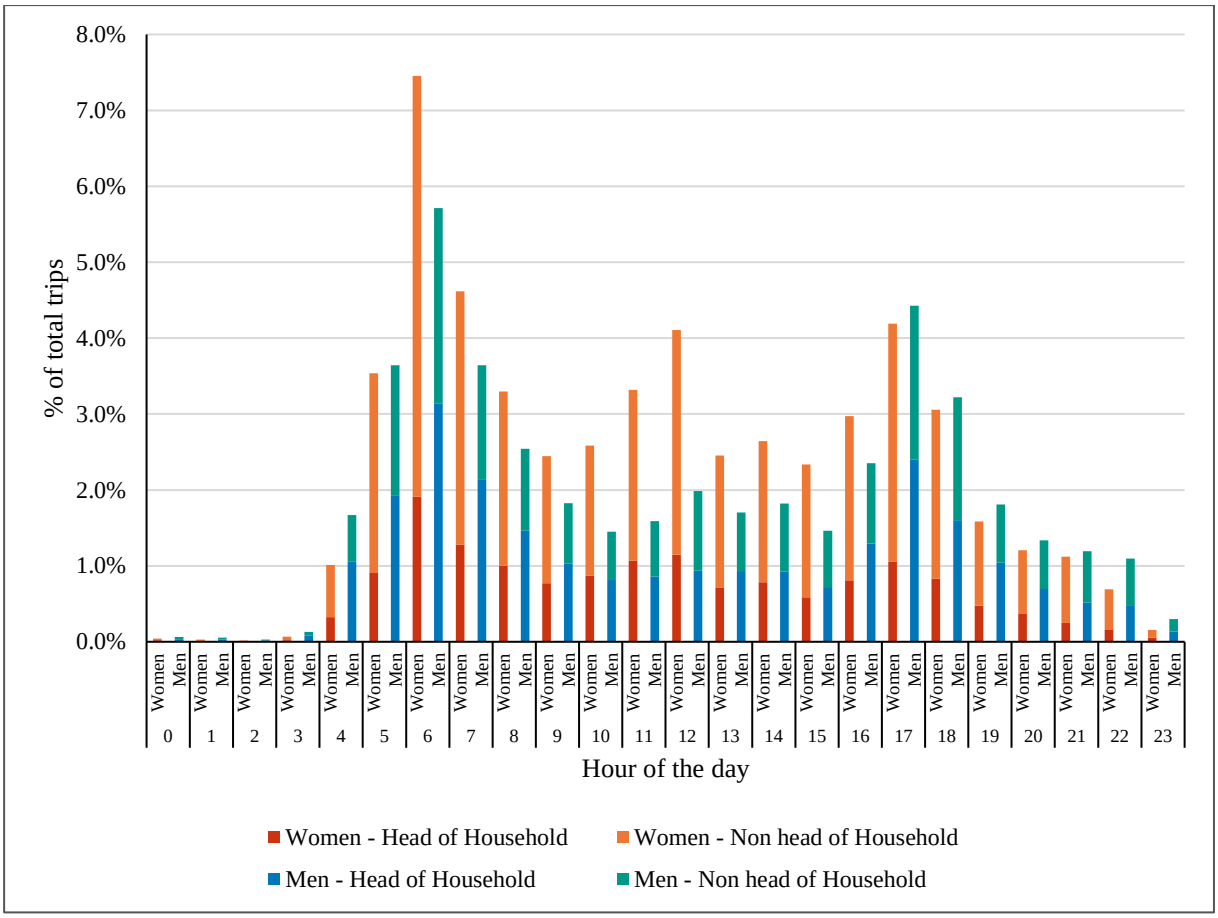


Figure 16 Time profile of trips as a % of the total of the area trips by gender for heads of households

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

Even if aggregated data by strata or gender is important to understand the mobility of men and women in Bogota, it is also highly important to understand how the geography and shape of the city shape mobility in the city. The following part of the survey analysis includes a geographic analysis of patterns of trips and their differences between men and women. Nonetheless, for these analyses, the concept of work-related trips dimension was added as a proxy to explain the trips occurring in the peak hours and the dynamics of trips outside those peaks.

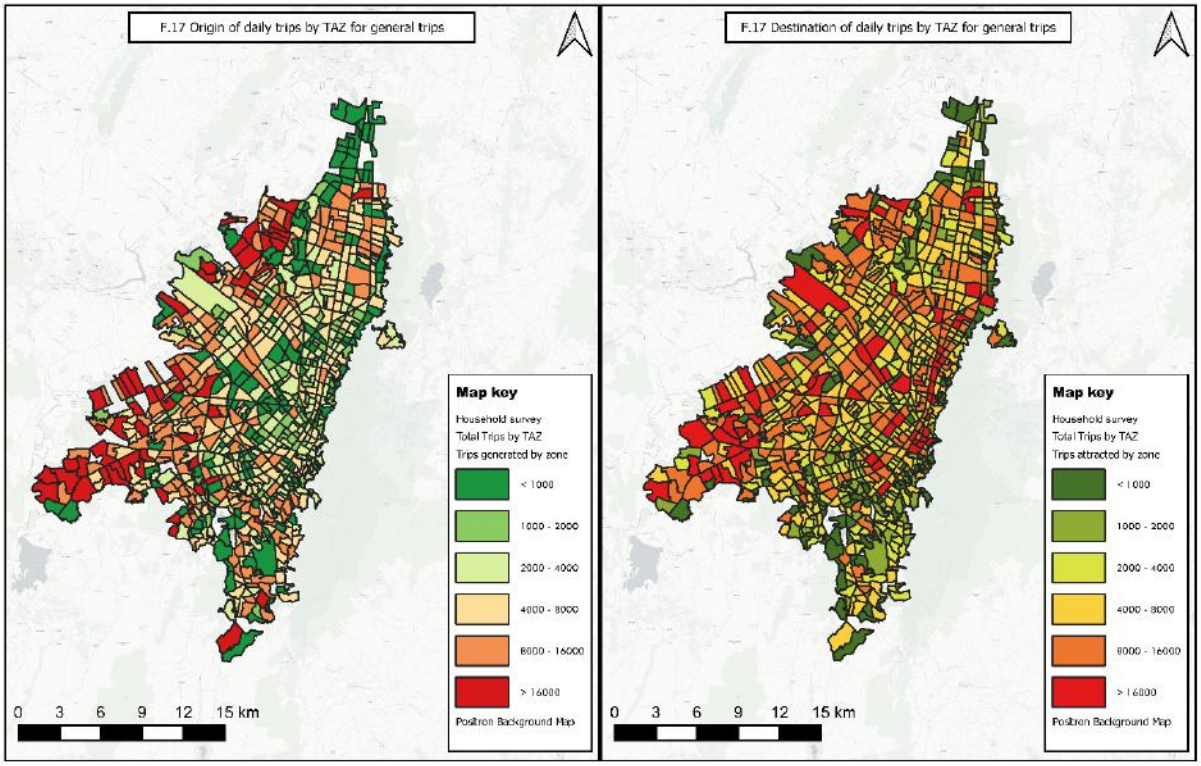


Figure 17 Origin(L) and destination(R) of daily trips by TAZ for general trips

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)7

To begin, Figure 17 reveals the clear disbalance of trips in the city. In the city outskirts to the west and south, where a larger portion of trips originate (left), contrasting with the distribution of the destination of the trips (right). The differences are related to activities, population density, and housing dynamics. It is in these origin-heavy areas where most of the population lives and also where there is a bigger concentration of lower strata households (as can be seen in Figure 26).

[7] All the maps that were developed for this thesis can be found in Annex B.

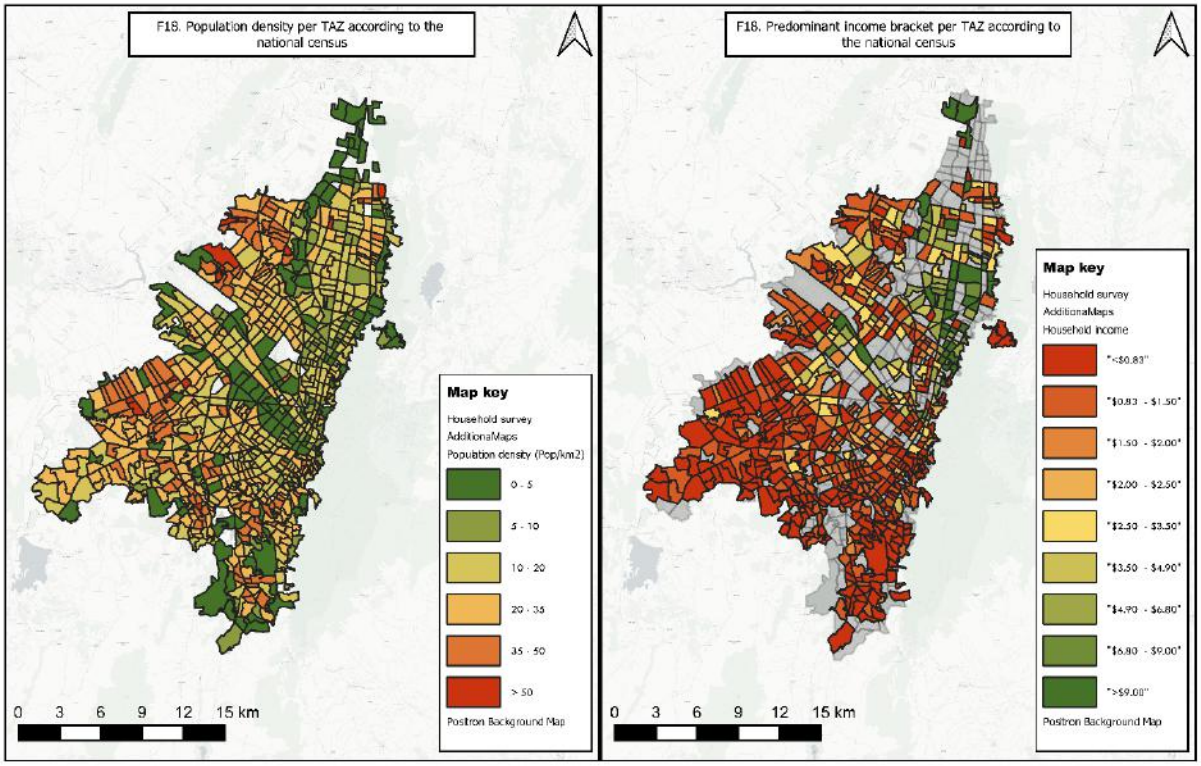


Figure 18 Population density and predominant income bracket per TAZ according to the national census
Self-elaboration from (Dirección de Censos y Demografía - DCD, 2018)

This disbalance between origins and destinations tends to affect most workers from those areas in the outskirts. The average time of trips originating in each TAZ is shown on the left, and the trip times for the work trips originating in those areas are represented on the right evidencing this problem. This radical difference speaks of several phenomena: first, the average times of over 30 minutes across the city are linked to the size of the city and its need to re-centralize activities and develop policies that reduce general times. By contrast, the concentration of travel times of over 60 minutes for work-related trips (which tend to be similar by gender, as evidenced in Figure 13) reveals spatial segregation of the city where people with lower incomes are exposed to incredibly high daily commutes that affect their time budget and their capacity to do other activities.

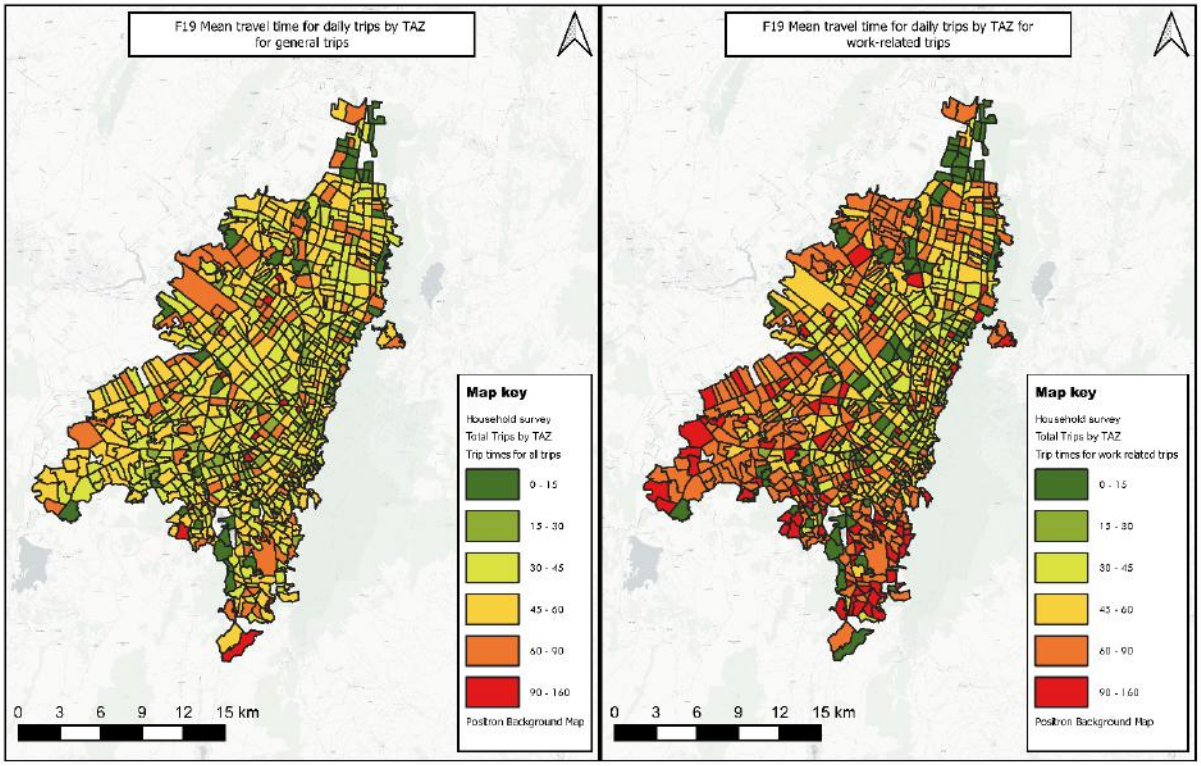


Figure 19 Mean travel time for daily trips by TAZ for general trips(L) and work-related trips(R)
Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

Another explanation of why mean travel times differ so much between work-related and general trips across the city is the concentration of intrazonal or self-contained trips. These trips, which have their origin and destination in the same TAZ, are not represented in the model and are made mostly by women. As evidenced in Figure 14, these self-contained trips are mostly located in the city's peripheries and coincide with strata 1 and 2 homes.

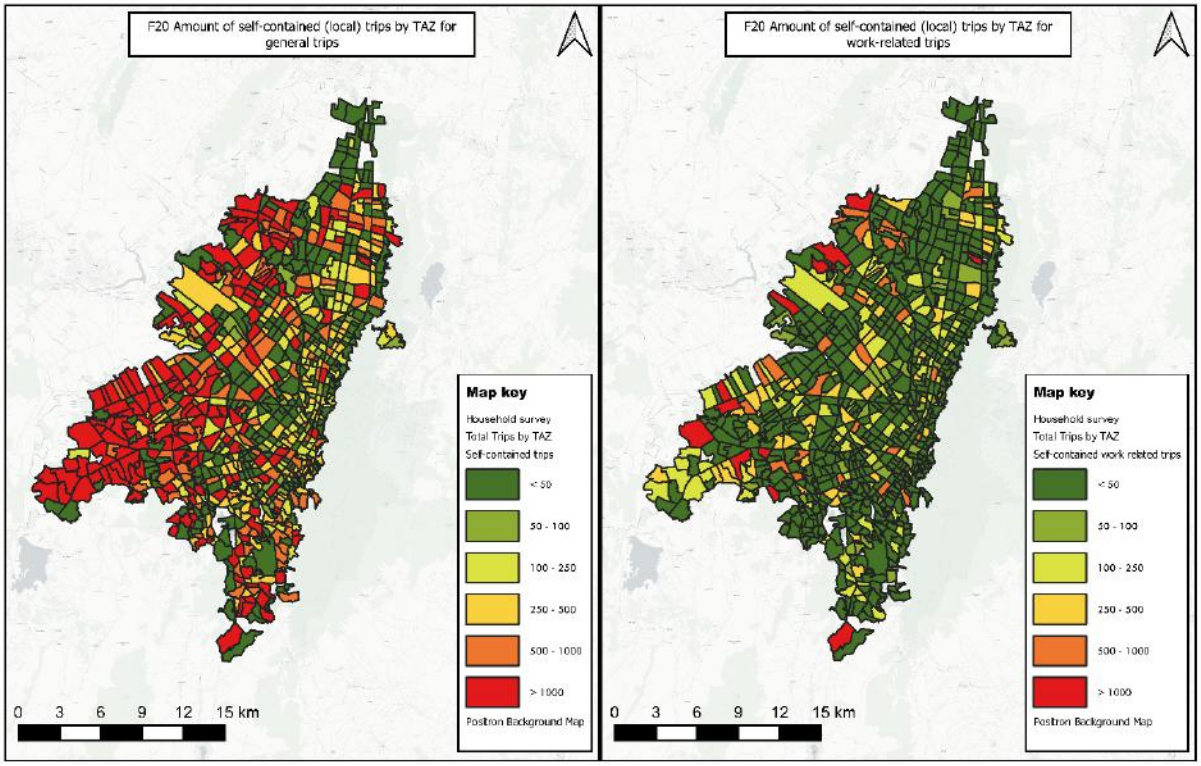


Figure 20 Amount of self-contained (local) trips by TAZ for general trips(L) and work-related trips(R)
Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

Considering the disparities in access to resources and how the job market of women and men varies significantly in the city, a report commissioned by the SdM (Secretaría Distrital de Movilidad, 2019) to recognize the importance of women in the job market has a very insightful perspective for the city. They start by stating how the pay gap between men and women in Colombia was around 17% in 2019. That same year, unemployment for women was double that of men (16.9% vs. 9.8%). Additionally, the report highlighted how care work hours for women is 22.7 vs. 9.8 for men per week. Both indicators show the differences in financial and time budgets between genders. Using focal groups, they found how work-related trips for women are highly determined by their perceptions of accessibility, enjoyability, autonomy and sense of security. In those focus groups with workers from different employees from several bureaus of the mayor's office, they evidenced how terrible the trip experience in public transport was under those conditions, except in the last-mile section. They also suggested improving work-related trips like improving conditions to access individual mobility (accessible bike parking, flexibilization of time schedules). They also asked to rethink the night and plan to make it safer for women.

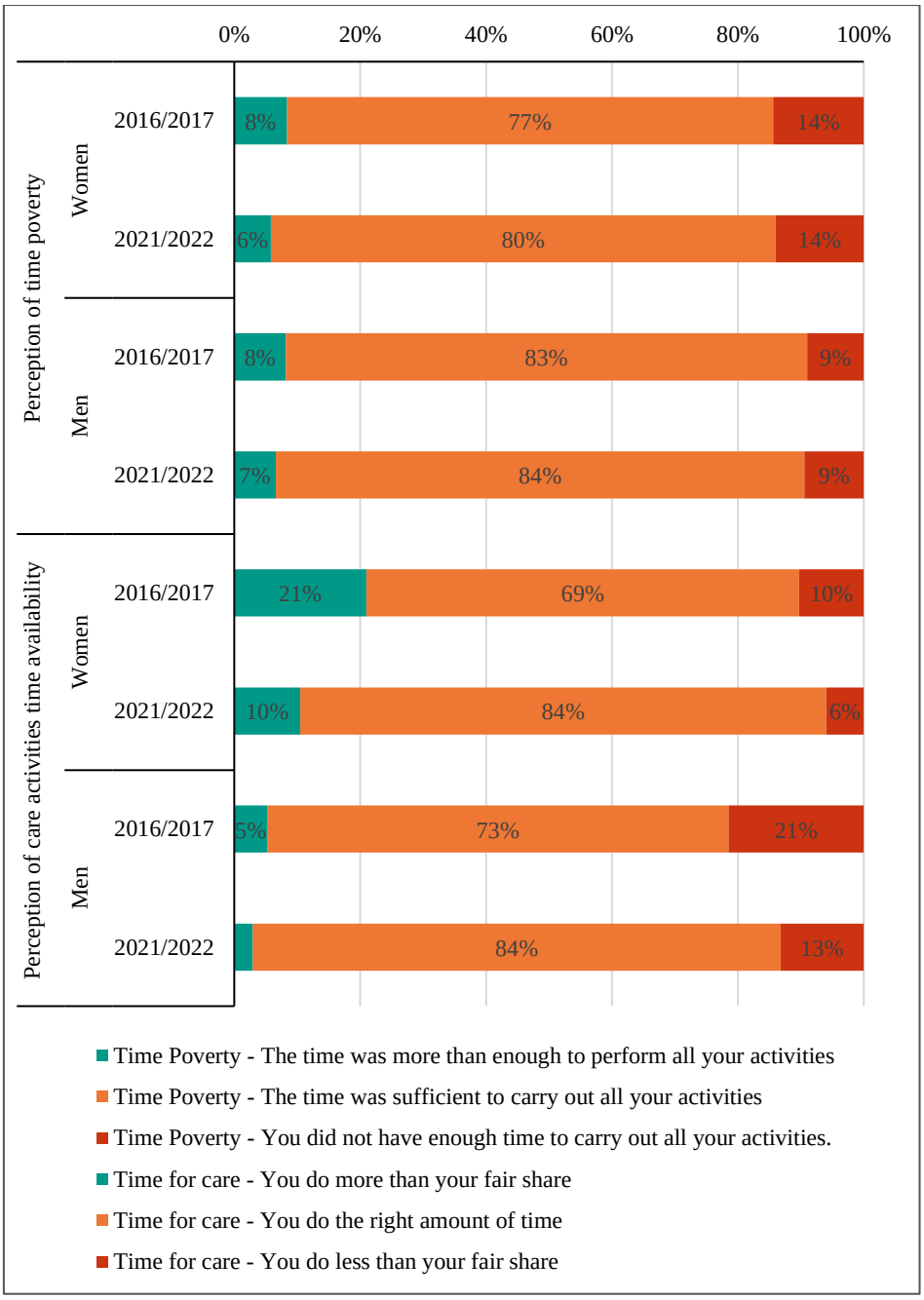


Figure 21 Perception of time poverty and care time availability across sex and age groups

Self-elaboration from data of (Dirección de Metodología y Producción Estadística - DIMPE and Dirección de Censos y Demografía - DCD, 2021)

The interest in understanding women as workers in Bogotá is more relevant when considering how they can spend their time. As evidenced in Figure 21, women are more concerned about their time availability. They mention their inability to have all their activities done during the day in a bigger proportion than men. And when the question is directed at activities of care, they also mention in a lower proportion that they do not do enough activities of care. Consequently, finding if the transport system is to blame for their lack of time is of special relevance.

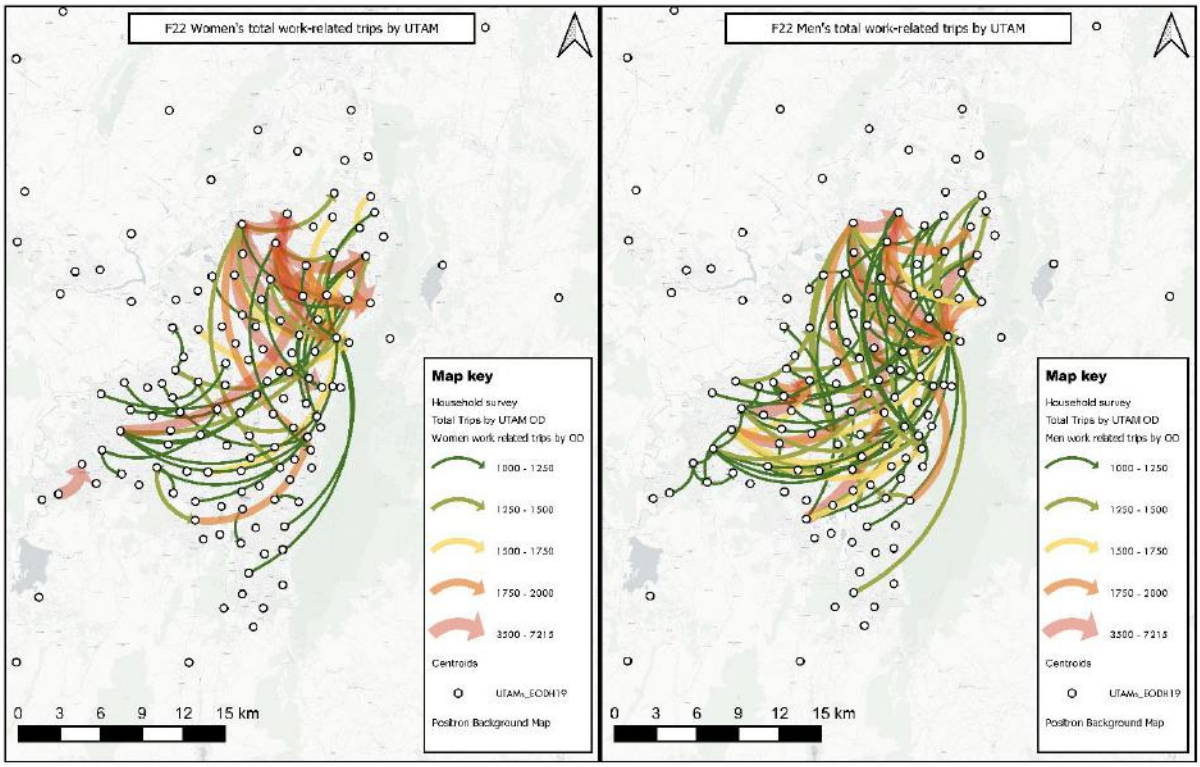


Figure 22 Total work-related trips by UTAM classified by gender

Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

When additional attention is raised to how women make their trips across the city compared to men, the need for generating a model that can address the different needs of each gender with indicators owned to each one becomes more relevant. It is evident how female work-related trips are more concentrated in the city center. By contrast, men's trips are more dispersed and directed to more diverse locations around the urban area, as evidenced in Figure 22. On top of that, when attention is given to how the times of those trips differ between genders, it is clear that for similar routes and destinations, times for women (left) are higher than similar trips for men (Figure 23).

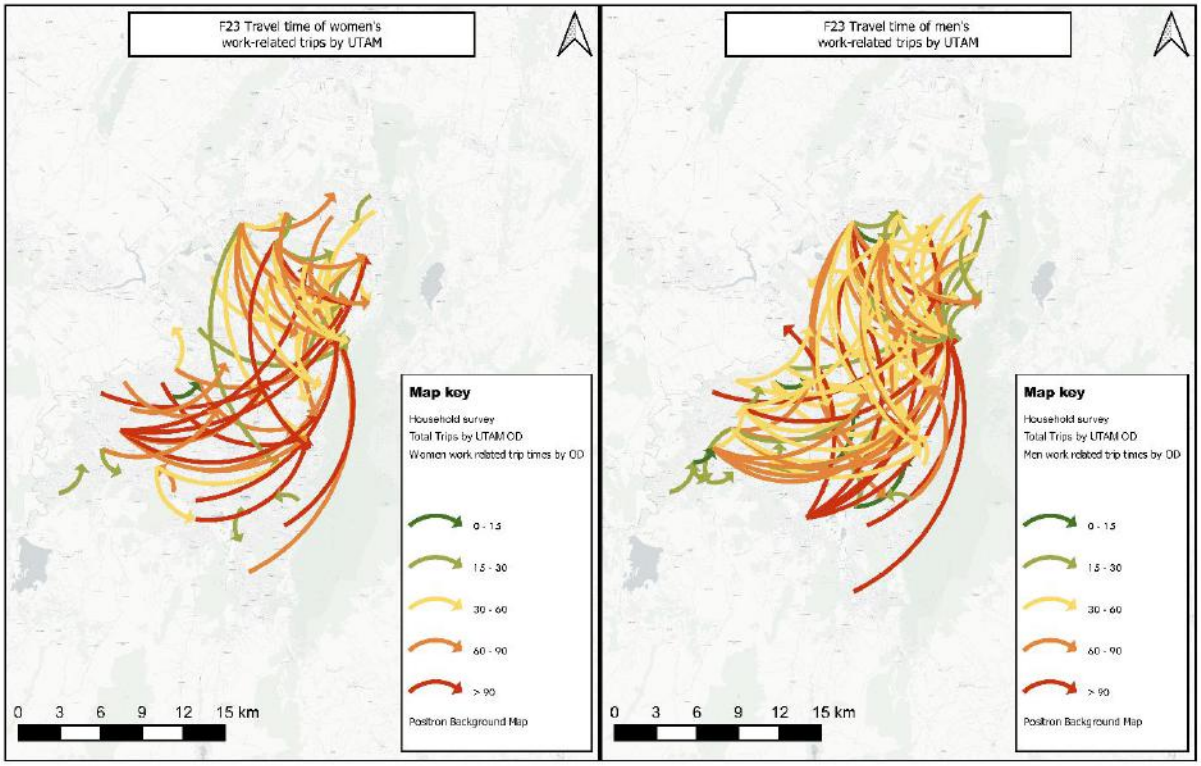


Figure 23 Travel time of work-related trips by UTAM classified by gender

Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

A particular case worth underlining is Montoya-Robledo and Escovar-Alvarez's work regarding how domestic workers are particularly segregated by how the transport system is set up in Bogotá (Montoya-Robledo and Escovar-Álvarez, 2020). They start by demonstrating how domestic workers have the longest commutes of workers in urban Bogotá based on information available in the travel survey of 2015; in Table 1, updated information using the 2019 survey supporting this claim is presented. Table 1 Comparison of work-related trips by economic activities and gender according to the 2019 survey. Inside their findings, analyzing the composition of the city where lower income housing is located in the outskirts of the city and higher income housing in the city center, the longer trips are explained by analyzing the lackluster transport system in both last mile segments. She then explores how these workers are forced to use informal transport to account for the lack of adequate transit in their last-mile segments. Also, they explain how transport policies like the available transfer window for commuters in the smart card of the transit system do not allow these domestic workers to make their whole trip without having to pay for two transit tickets.

Economic Activity / Profession	% Of workforce by gender		Average travel time	
	Women	Men	Women	Men
Domestic Workers	5.27%	0.36%	79.3 min	55.8 min
Employees of Private firms	42.32%	39.78%	63.5 min	58.9 min
Employer	1.12%	1.26%	56.7 min	52.5 min
Employees of a Public Entity	8.44%	7.10%	55.5 min	56.4 min
Construction Worker	1.13%	4.55%	55.6 min	66.7 min
Independent Workers	13.35%	18.79%	52.9 min	60.6 min
Farm Worker	0.15%	0.42%	45.9 min	64.6 min
Driver/courier	0.28%	4.29%	88.6 min	62.4 min
Unpaid worker	0.52%	0.30%	51.2 min	78.3 min
Informal seller	1.46%	1.23%	63.2 min	58.6 min
Disabled	0.03%	0.11%	73.8 min	43.8 min
Household chores	2.79%	0.75%	65.5 min	58.3 min
Retired	0.26%	0.61%	55.4 min	47.2 min
Unemployed	0.69%	1.24%	70.8 min	67.7 min
Other activities	1.21%	1.08%	71.6 min	57.7 min
Students	20.98%	18.14%	59.0 min	53.2 min
Average			**61.0 min**	**58.5 min**

Table 1 Comparison of work-related trips by economic activities and gender according to the 2019 survey. Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

Regarding safety concerns in Bogotá's transport system, the work by Quiñones (Quiñones, 2018) characterizing the struggles of women in transport is the lead document found in the literature review. Using mixed methods, she develops a qualitative and quantitative analysis of how Gender Based Violence (GBV) risks are shaping the mobility patterns of women in Bogotá Her work found that perceptions of safety are not the same across socioeconomic levels, evidencing how higher-income women are less likely to suffer GBV. She attributes this to how women of higher incomes tend to use less public transport than the ones in the lower income brackets. Added to that argument, she points out that the lack of alternatives to travel and the decreased access to own vehicles gives lower-income women no choice but to travel with the risk of being victims of GBV in public transport.

Also, by analyzing reports of sexual violence and the mobility survey of 2015, she finds several other determinants that distinguish women's experiences in Bogota's mobility system. Younger women are more at risk of suffering GBV. How overcrowding in stations and buses generates an increased risk for women than for men, how these experiences vary by location, and how bus stops and BRT stations are built. Additionally, they show how the system has failed to account for safe paths going into the stations. She concludes that all these increased risk perceptions result in "non-logical" decisions by women: using more taxis, walking longer but safer paths, avoiding using the BRT system and preferring the local buses, which are usually slower and less frequent.

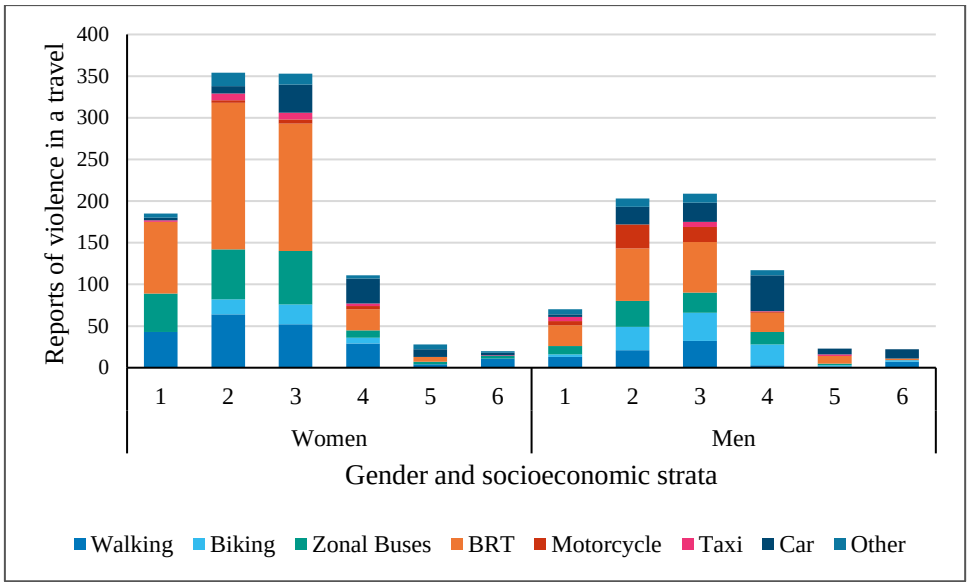


Figure 24 Number of reports of being a victim of violence during one trip by gender and strata according to the mobility survey

Self-elaboration from (Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC, 2019)

The recently created Women's bureau from the mayor's office also has a couple of reports that diagnose the perceptions of women in the city from a local government perspective. In 2017 a baseline analysis by a large-scale survey found that high occupancy is a source of insecurity, with more insecurity perceived at night. They highlighted several public transport stations perceived as more dangerous, coinciding with the findings of Quiñones. And in the same line, interviewees state the intention to change routes to longer routes in local buses to avoid the BRT (Equipo Sistema Violeta, 2017). Then in 2019, a follow-up report was done and added the results from a national survey, where they found that the lowest safety perceptions at a city-wide level are related to the street, public transport and pedestrian bridges (López M. *et al.*, 2019).

> *The stations and places considered most unsafe in the focus groups were: Calle 22, as the most unsafe, Calle 19, Av. Jiménez, Av. Chile, Calle 72, Patio Bonito, Calle 57 and Calle 26. The tunnels that connect some stations also generate a sense of fear: "It is long, and I feel that no one can help me" (interviews and focus groups, December 2017).*
>
> (Traduction from Equipo Sistema Violeta, 2017, p. 54)

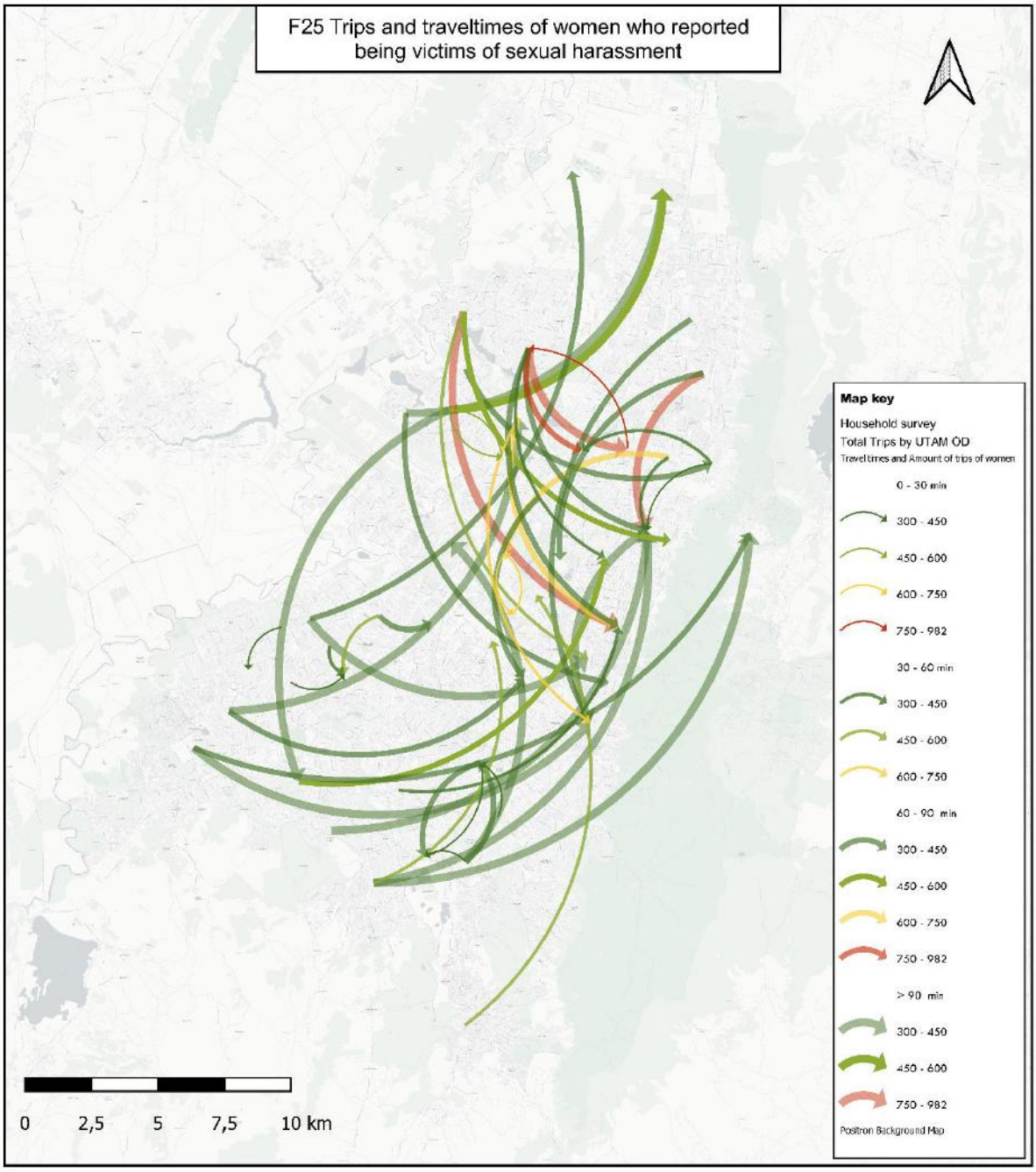


Figure 25 OD map with trips of women who reported being victims of sexual harassment + stations where according to the reports, the violence occurred

Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

4.2 Current status of the 4-step model of the Bogotá metropolitan region

As mentioned at the beginning of this chapter, in order to explore how gender analysis can be integrated into the development of the calibrated model derived from the mobility survey, an in-depth understanding of the 4SM is required. In this case, using the information sent by the SdM in response to a request for public information, the model's baseline and calibrated data are analyzed to understand how the model represents the city's mobility.

To begin, using the data in the geographic file given in the database, the representation of strata by each TAZ was made by analyzing the predominant strata of the households in a given TAZ. As a result, the map in Figure 26 was built, and the clear distribution of lower strata in the south and west peripheries is clear. According to interviewees, this spatial pattern correlated with many considerations of the model and the planning practices surrounding it should not be considered the only factor determining the analysis levels of the model. As explained in the literature review, this means that when considering the Generation and Attraction, Distribution, and Modal choice models, more considerations besides the strata should be made.

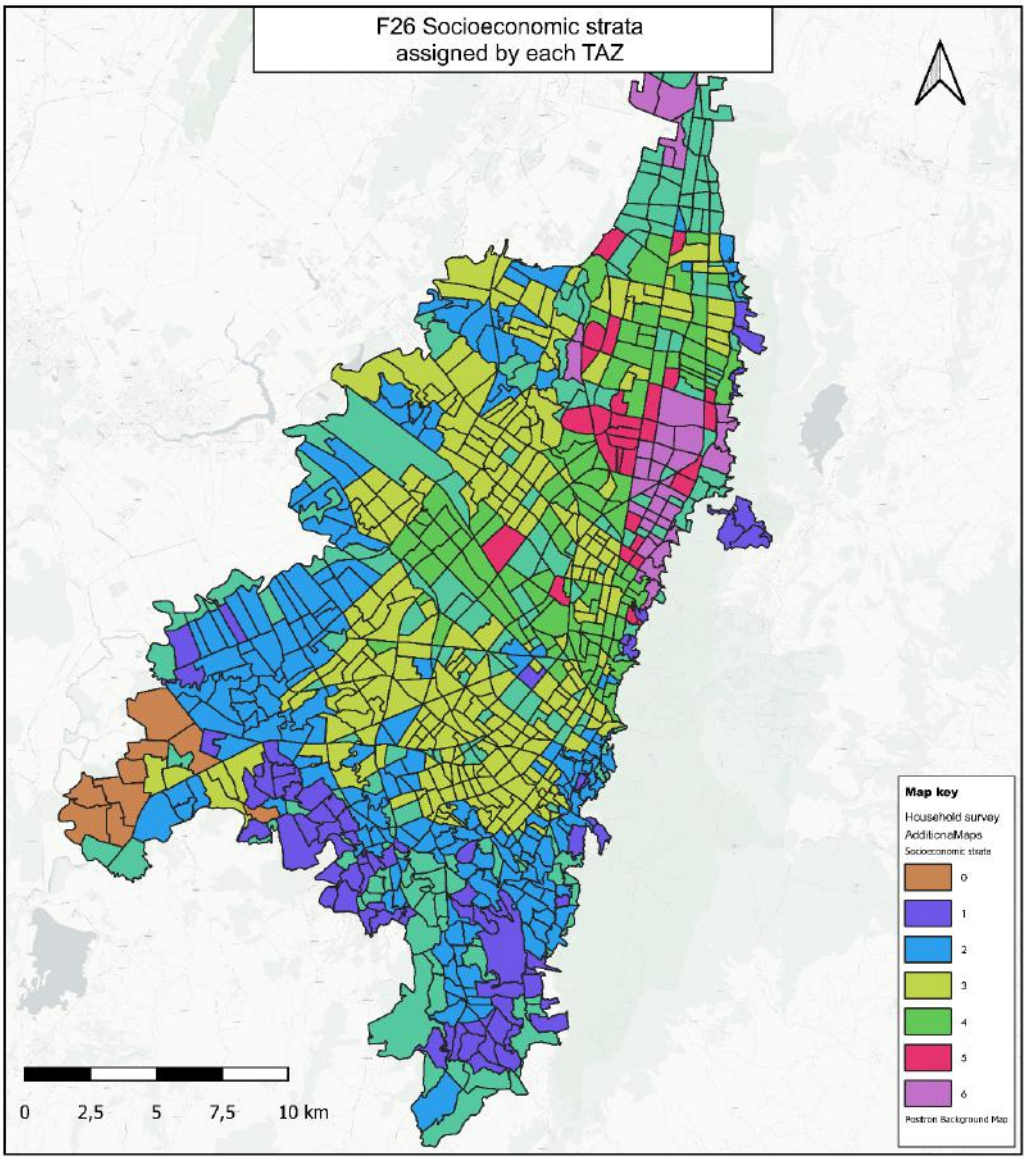


Figure 26 Socioeconomic strata assigned by each TAZ
Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

According to the official report of the model and the data available in the database sent by the bureau, the levels of analysis or demand levels in each of the models are as follows:

1. Model of generation and attraction of trips. For this model 2 groups of functions are developed to represent the number of trips attracted and generated to each zone
    a. For generation: The model estimates trip generation factors to work and non-work activities based on the population of each TAZ and their age group.
    b. For attraction: The model estimates the number of attracted trips with a linear function based on the number of square meters of land used for different activities (Retail, Industrial, Equipment, Educational, Recreational, and Commercial & Services)
2. For the distribution model. The model estimates an Impedance function based on the number of vehicles taking a route, the trip's monetary cost and the time a user has to use to go from one point to another. This function is estimated for work and non-work-related trips. It is different for four segments of income (Strata 1 and 2, Strata 3 and 4, Strata 5 and 6, and people resident in municipalities outside Bogotá).
3. For the modal choice functions, the model uses a combination of the parameters used for the distribution model with the addition of considerations regarding the availability or not of private vehicles (Car and motorcycle). Using that, they developed a logit function that allows them to model the different conditions of a TAZ and the general distribution of modes in the system.
4. For the assignment model, a network assignment is made by each of the segments of the distribution model, with the addition of a layer of modal choice as developed in that model. As a result, the network has a load of passengers and vehicles for different modes and demand strata that tries to represent the conditions of the city.

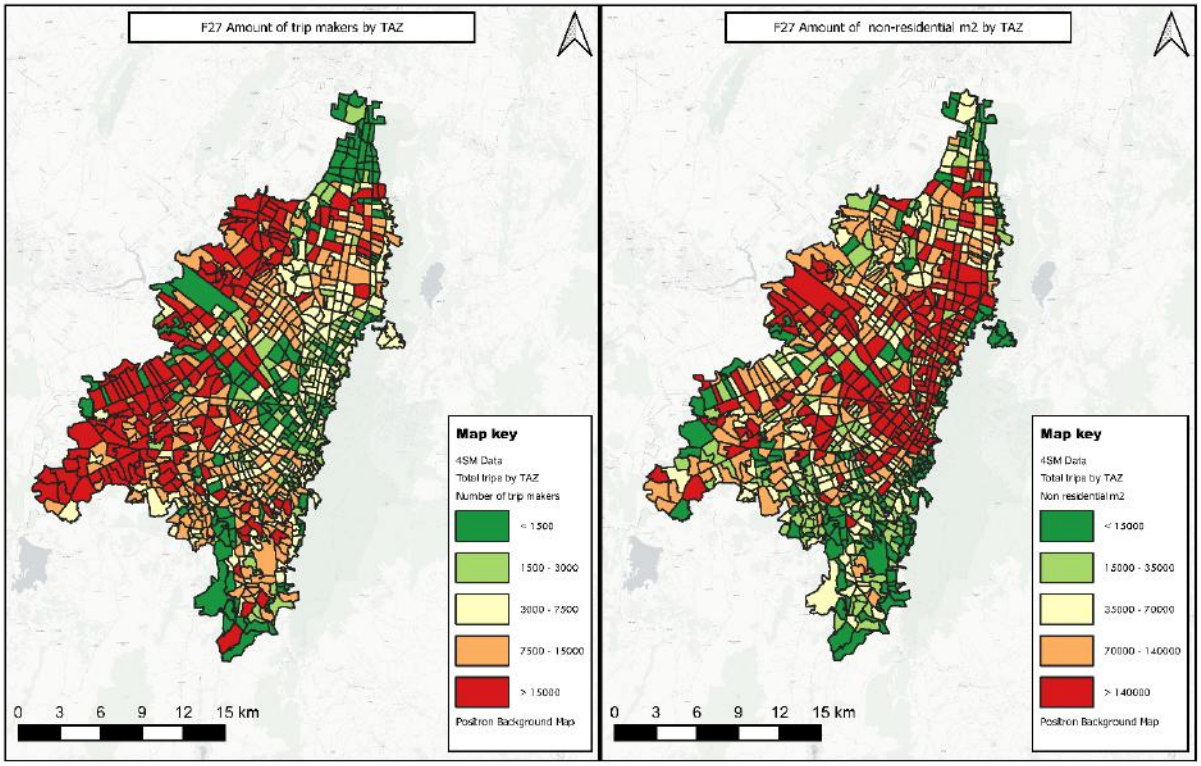


Figure 27 Amount of trip makers (L) and non-residential m^2(R) by TAZ

Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

To reduce the implications of explaining the mathematical models of each step, a series of maps were developed by the author in this chapter using the resulting model data given by the SdM. These maps intend to explain how the model works in the background and how the considerations introduced in it result in a given perspective of the city. It is worth noting again that this model was calibrated in its totality to the morning peak hour, with additional representations of the middle of the day and afternoon peak developed inside the SdM, as mentioned by one of the interviewees. However, he explained that those models are approximations that help to develop short-term measures but should not be analyzed in detail as good representations against the survey.

In the case of Figure 28, the amount of generated and attracted trips is a function of the distribution of people living in the city and the city's land use, as shown in Figure 27. In these four maps, the concentration of the trips represented in the model tends to go from the city's outskirts to the city's geographical center.

Just observing the main areas of generation and attraction of trips in the peak hour contrasts the survey results for the full scope of the trips throughout the day, as shown in Figure 19. This disconnection is a clear example of the implicit biases of analyzing the peak hour, which Madariaga heavily criticizes (Sánchez de Madariaga and Roberts, 2013, chap. 2).

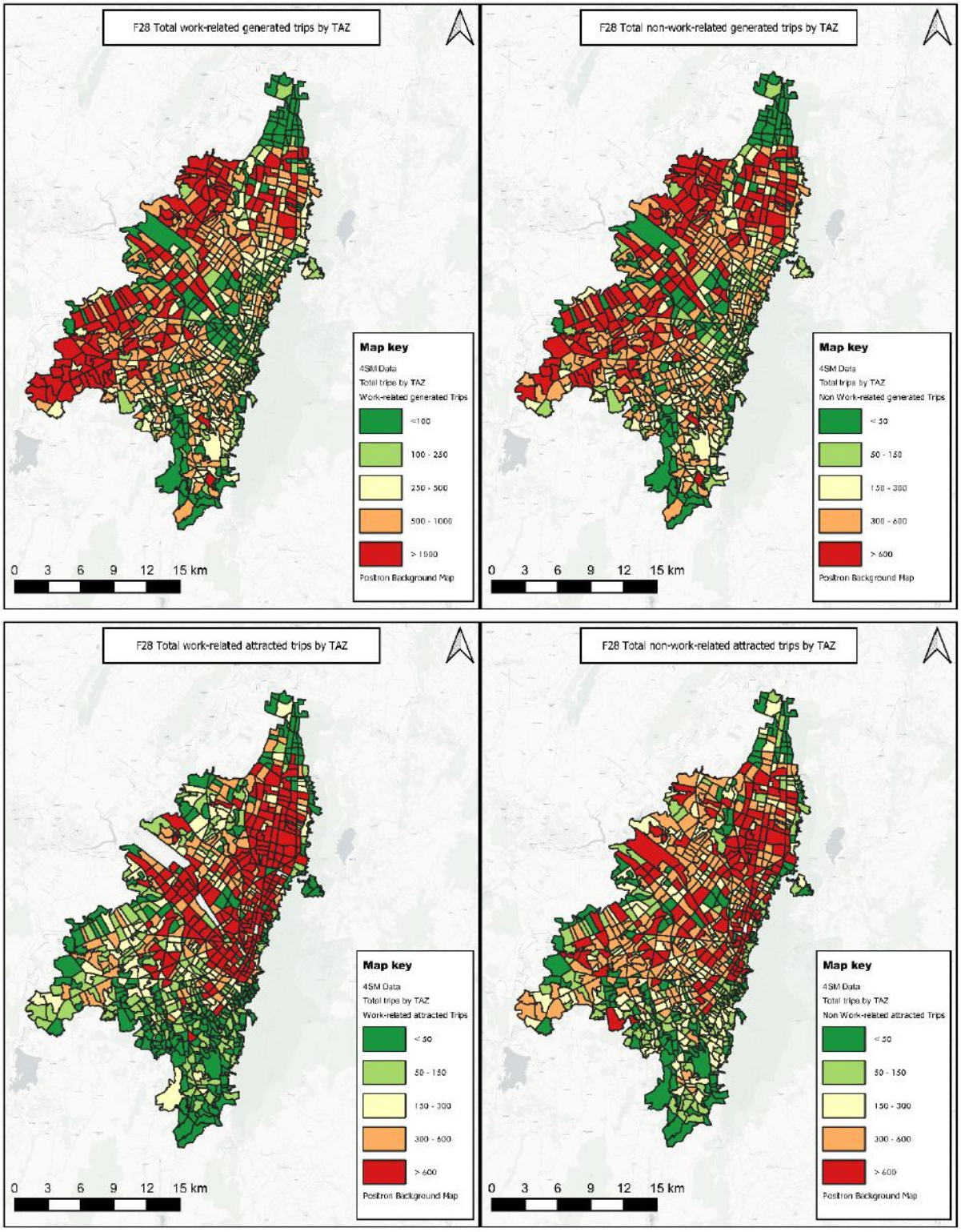


Figure 28 Total work-related(L) and non-work-related(R) generated(U) and attracted(D) trips by TAZ
Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

For the next step, the distribution model uses impedances to estimate the number of trips that go from one TAZ to another. In this case, the maps in Figure 18 represent how easy or not a person can go from a Strata 1 or 2 (left) or a Strata 5 or 6 (right) household to a given zone in the city.

The results given in a non-dimensional number used inside the model explain how the model perceives the uniformity of strata as only one population segment that can access a certain destination. However, as stated before, the differences between women and men play a key role even inside the socioeconomic strata, and the model today cannot represent those differences.

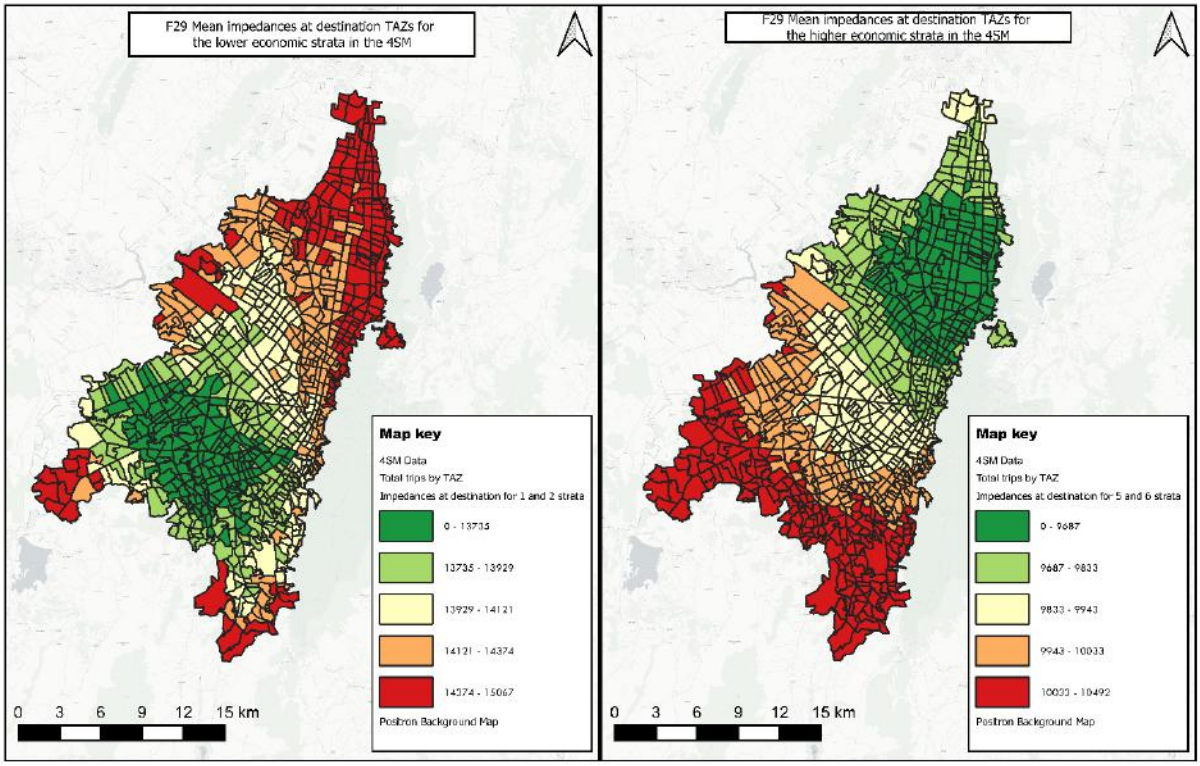


Figure 29 Mean impedances at destination TAZs for lower(L) and higher(R) economic strata in the 4SM
Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

For the modal selection model, the calibration process results in a series of matrices by mode, representing how many users will choose a given mode in the peak hour. Figure 19 shows the results of the major OD pairs for private (left) and public transport (right). In the same way as before, the model results show how different the private and public transport patterns between strata (based on location) are. In this case, seeing how there is a great concentration of transit trips coming to the city center from the outskirts is against a disorganized set of travels of private users from the city center (where there are more high-income households) to the city borders.

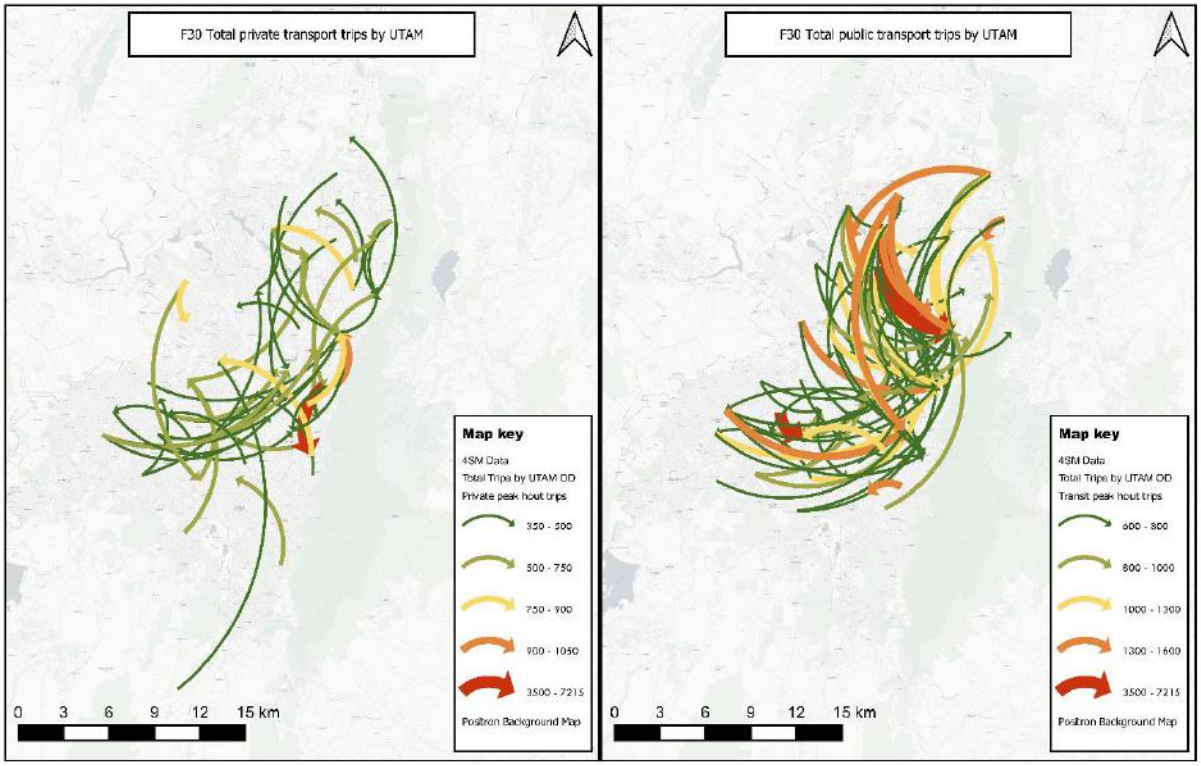


Figure 30 Total private transport and public transit trips by UTAM

Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

At last, a complete representation of the assigned trips is shown in Figure 31, where the influence of the amount trips made in transit tends to match the representation of the trips assigned in the network. It is worth noting that, as discussed with several interviewees, the calibration data for this step is the hardest to collect by gender. Contrasting with the previous steps, where calibration data comes from the mobility survey or additional onboard surveys, it is almost impossible to count how many women and men are driving on a highway or riding a bus. Thus, as one discussion of the interviews suggested, an increased focus on developing a segregated 3-step model should be carried out, and then improve the process made in the four steps.

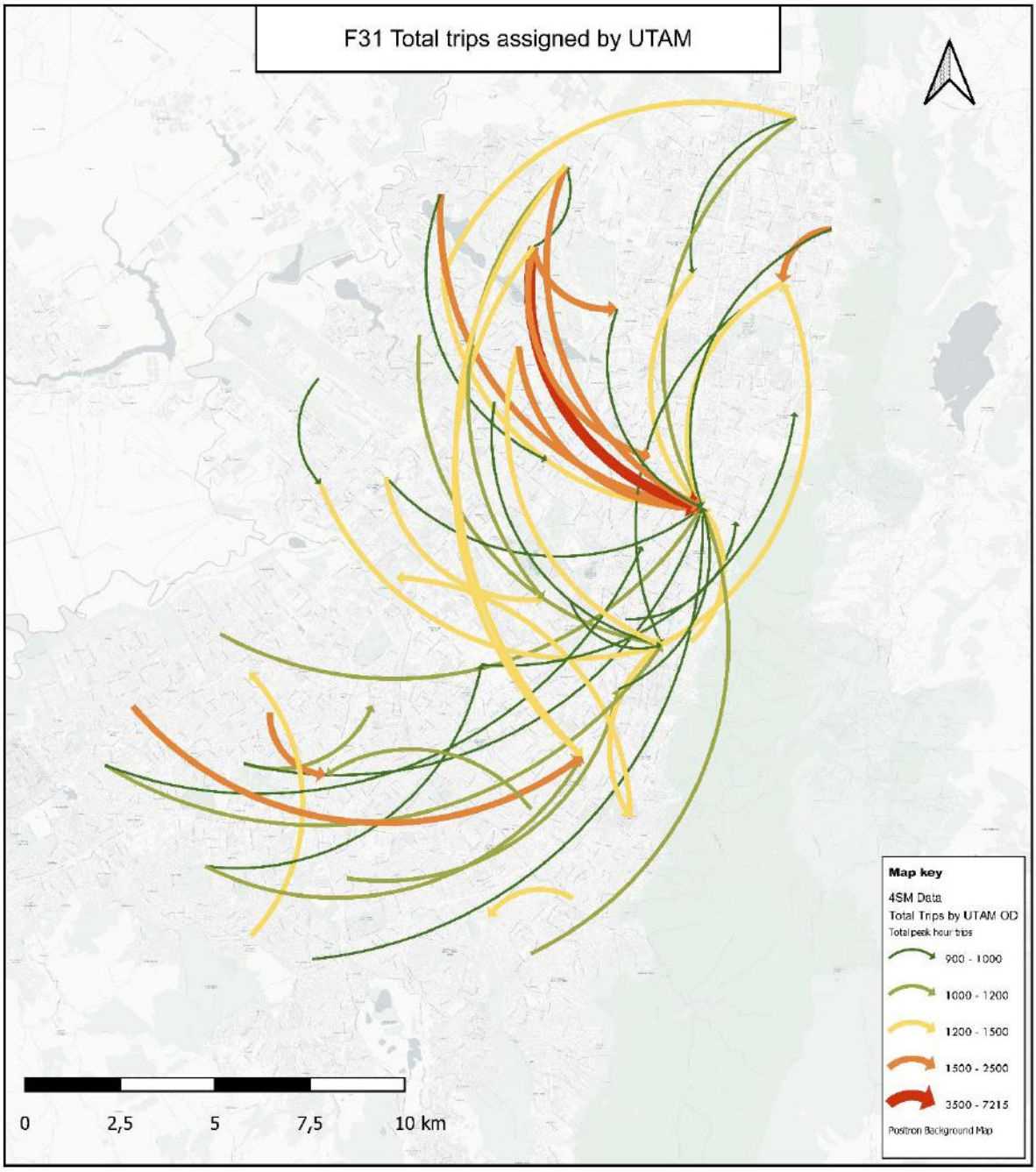


Figure 31 Total trips assigned by UTAM

Self-elaboration from (Secretaría Distrital de Movilidad, 2022)

4.3 Interviews with key actors

As explained before, this section will use an inductive approach to the topics covered in the interviews. This is also useful to understand how different visions of knowledge contrast in each topic, from the researchers and practitioners in gender to the ones working with modeling and consulting.

4.3.1 Gendered mobility in Bogotá:

Generally, professionals from both practices coincide in the need to understand women's mobility in Bogotá. Important remarks from a government employee mention how there has been a shift in the vision of mobility, from a planning approach of efficiency of motorized travel to a more inclusive perspective in transport planning. According to him, this change has come from a vision of inclusion where people with motor disabilities were given the main priority when designing physical spaces to visions where a more holistic perception of inclusion is achieved by understanding users' needs at a macro scale, satisfying those needs. In this sense, his remarks coincide with the consensus among the interviewees on the need to improve how planning for women has to be done.

All of the interviewees who claimed to have analyzed the differences in mobility behavior between women and men in Bogotá agree that there are significant differences. The most recurring comment revolves around the different experiences of men and women in public transport. The responses tend to agree on how women are more vulnerable to GBV in transit and how this risk drives their decisions about mode, route, and desire to travel. The women interviewed spoke from personal experience and the results of their research, expressing how consistently women prefer to take longer bus routes in exchange for less walking in the first and last mile or to avoid transfers at BRT stations. In all the responses, the aspect of high occupancy as a determinant of the time to travel is a recurring theme, as is the fact that the unreliable timetables of buses (both BRT and zonal buses) are an additional constraint on women's travel. Due to uncertain frequencies, they mentioned the need to ask for companions when traveling late at night or early in the morning, making them dependent on these companions. Finally, some interviewees commented on the importance of considering how women are captive users of public transport due to their lack of vehicle access or inability to use other means. They mentioned how this means that when demand models are estimated based on the price, they are willing to pay for transit, the results can indicate a high availability of payment even if they have lower budgets than the average.

On the other hand, not all respondents mentioned gender differences when talking about women as private transport users. Responses on this aspect led to comments on the need to take a broader approach to gender and economic status. They mentioned how lower-income women have more access to motorcycles and higher-income women have more access to cars. However, citing road safety analysis, they agree that women are less involved in accidents as the cause of the accidents agrees in how they have a safer driving style than men. Finally,

when active transport is mentioned, the responses coincide in the fact that women make fewer trips because of safety concerns, lack of focused infrastructure development, and chained commutes that do not allow them to make trips on bicycles, for example.

In conclusion, it is worth highlighting a comment made by one modeler about how these intrinsic choices can be added to the modeling process. He mentioned how the traditional approach to modeling behavior in the four steps is based on models that try to explain travel choices based on an abstraction of cost as a function of time and money spent. He mentioned how these formulas tend to have an additional parameter that tries to explain aspects outside of this parameter and others often used, such as the number of transfers, cost of transfers and accessibility. He notes how he has noticed a tendency to have this additional parameter as more and more relevant in the decision models. He suggested, from his intuition, that additional research needs to be done to have this parameter studied to determine if it explains women's decisions around safety, comfort and accessibility.

4.3.2 The use of the 4-step model in Bogotá

Contrary to what was found in the discussions around gender, most interviewees who specialized in gender were unaware of how the 4SM works and how it is used in Bogotá. For example, one researcher mentioned an encounter with an academic who disregarded the need to explain the model, calling her to understand that mathematics was too complex and should be trusted blindly. Another recalled some government officials and experts from the local government's inability to explain the model's functioning. Another professional mentioned that it is useful to "know how many people will use a transport system." This general disconnect is a reflection of the larger problem with using the model as a way to legitimize policy, the inability to explain it and making an effort to improve it with the views of other experts.

In the case of the professionals with knowledge of the model, the responses about how it works and how it is used are consistent with the data available in the model's reports. They all mentioned the importance of a well-done survey to enable the construction of an accurate model. The consensus on the usefulness of stratifying the model's demand into work and non-work trips, in addition to using socio-economic strata, is consistent with building and using the model according to traditional practices. When discussing the calibration process, conflicting opinions emerged. While some mentioned the correct use of the survey to calibrate the model to current conditions accurately, others raised concerns about the extreme reliance

on the SdM in the assignment model results as a measure of validity. From their experience, they mentioned how putting so much attention on this model can force the process not to be represented in the previous steps to meet the assigned volumes.

Neither had worked with, heard of, or even attempted to use alternative ways of understanding demand needs in the model, and neither had attempted to use gender to classify trips. Regarding uses of the model, respondents tended to agree on evaluating projects based on corridor ridership, overall time savings, and speed in the case of private transport. They all mentioned using the model's results for additional calculations, with pollution estimates being the most common case. When discussing access times as a proxy for understanding low-distance activities (such as care activities), the models tended to agree in explaining the model's shortcomings. They mentioned that, given the scale of the model, it is not feasible to accurately represent short-distance trips for the city.

4.3.3 Gender and planning in Bogotá

Finally, when discussing the current situation of transport planning for women, the interviewees gave different concepts, mainly based on the areas of expertise of each interviewee. On the one hand, the modelers interviewed mainly agree that if the model aims to understand women better, the best way forward is to develop a separate 3-step model for them and mix it with the male model in the allocation process. They added that, in their experience, this could add cost and time to the model, so it should be considered when developing the bidding process for the periodic update. One modeler also suggested implementing an improved multiresolution analysis compared to what is done today with the model. He suggests that improving how the network of the 4SM is done can result in an easier and more precise way to develop mesoscopic or microscopic models[8].

In contrast, the gender researchers agreed with the need to not only rely on direct data from the model; they mentioned the need to include local travel in some way when explaining the model. They mentioned how misleading it could be for authority figures such as modelers to ignore these trips and how this could work against the goal of planning for women. Another point of criticism was related to gender and socio-economic strata; as mentioned above, there is a clear difference between genders in different strata. They ask that the

[8] Mesoscopic and microscopic models are also transportation models that use a smaller scale to represent mobility patterns. Depending on the scale, this can result in the representation of flows or even individual agents (vehicles or pedestrians) to analyze networks, intersections, or even transit stations in detail.

modelers at least try to find ways to account for these differences when creating the demand segments of the model.

Finally, they all agree that the survey needs better gender-disaggregated data. An example of this is the way gender is coded in the EODH-19. Even though adding the gender question improved over the EODH-15, correcting for missing information based on respondents' names could lead to misleading data, as one of the interviewees mentioned. This is consistent with the literature collected for this thesis, which consistently calls for improved data to analyze differences between women and men correctly. In this sense, one modeler clearly stated the need to have better data in order to be able to focus on key differences and justify projects based on these differences and correctly measure their impact by gender.

5 Discussion of results

Using the words of Madariaga, "Gender-aware planning calls for a contrast between competitiveness and social cohesion and the social function of transport. In that regard rethinking how we measure and define impacts in the model should be addressed to develop more inclusive policy inputs" (Sánchez de Madariaga and Roberts, 2013, p. 94). This chapter proposes three strategies, based on the findings of the previous chapter, that allow practitioners to rethink how 4SMs are developed to measure and address gender-sensitive policies through modeling. As the evidence presented in the previous chapter shows, the findings of various scholars on the differences between women and men in transport are also visible in Bogotá.

This section is divided into four parts, consisting of three approximations of new ways of understanding the practice of doing 4SM while considering gender-responsive policies and a probable path to implement these solutions in Bogotá. These three approaches arise from the concern expressed by the interviewees about the cost and time required to redevelop the 4SM, including gender as a key step in the process. Consequently, this chapter is organized to allow for the gradual incorporation of gender into modeling practices. First, it proposes a set of indicators and strategies for using the model as it is currently constructed. Next, a proposal for how gender should be used in a parallel 3-step model is presented. Finally, a brief discussion of how future models should be considered if a deeper understanding of gendered mobilities is desired from the modeling process.

5.1 How different are the mobility behaviors of women and men?

The results presented in the previous section evidence a coherence between the discourses of researchers in the literature review and the way women travel in Bogotá. As presented, there is a clear distinction between women and men in general and across economic levels. Those differences in travel time, travel distances, purposes, origin and destination zones and stated experiences evidence the need to understand women's and men's mobility planning separately.

In the case of Bogotá, it is clear how women are required to put more effort into traveling in the city. Across strata, they are the ones who are required to make more trips in a day, mainly because of the added amount of non-work trips which they have to make in order to carry out caregiving activities for the household. Their trip patterns tend to differ from men's, as their increased concentration of OD pairs to certain parts of the city makes them

more dependent on robust and reliable transport networks. However, as Bogotá lacks a system with those characteristics, the travel times for women in the periphery tend to be higher than those by men. This condition speaks about the existing spatial segregation against women and the need to plan to reduce it and mitigate its effects.

When the number of trip-chained journeys made by women is considered in contrast to men and their reduced time and monetary budget, it is clear that women who are paid and unpaid workers are in a different situation than men. When analyzing the dynamics and particularities of non-paid-working women, the differences around a reliable and accessible transport system also appear. Their need for a transport network of good quality, to make their trips at a local scale appears as their main difference from men, which tend not to make the same number of local trips. Both conditions reflect the need to plan a network of mobility systems that allow women to reduce the existing gaps in access to opportunities and the city itself. To do that, it is necessary to have a planning process that can focus its solutions on their needs.

Those differences signal the need to understand their differences by themselves. However, physical experiences are also a key determinant. Not only in the literature but also the interview process and data gathering process, the conditions of physical and personal safety of women appear as a key determinant in Bogotá. During the writing of this thesis, an increasing number of GBV acts have been reported in Bogotá. The inaction of the government and the transit authority to prevent those acts has been highlighted as a key policy flaw (‘Revictimización y fallas estructurales. El caso de Hilary Castro’, 2022). The policies in this field should aim to provide safer, more reliable transport systems to tackle this problem.

In the voice of the experts interviewed for this thesis, women express their mobility preferences in Bogotá radically differently than men.

5.2 How are 4SMs currently being developed?

The available data allows for a differential approach in policymaking at all transport planning and management levels. However, to do that, the tools designed to develop policies, and even more gender-inclusive policies, should be able to evaluate those differential needs.

However, as demonstrated in the previous chapter, the model today is still using a classic approach to transport, in which a mean user represents a wide segment of the population living in a given area; as stated before, in light of the currently available data, that is no longer a valid approach. The average traveler concept introduced in the 4SM classic

framework states a cohesive and similar population structure in each of the TAZs of a model. In the case of Bogotá, these areas resemble neighborhoods, and the model is calibrated at this level using data from the transport survey. This calibration involves an abstraction of so-called typical behaviors of the habitants of these TAZs in an aggregate manner. Then using mathematical models that represent only socioeconomic levels, the model abstracts how people travel around the city. At last, using a base-line model from the current situation, the local government uses the model to estimate the future demand for transport systems in the city.

Even if the 4SM can correctly represent an aggregation of the city's travel behavior, it lacks a vision of a fairer transport system. The official reports and the interviews coincide in the way in which the model is used today as a way to identify aggregate future demand and travel times. However, today the model is not used to analyze the impacts and benefits of projects in a targeted way. Bogota's 4SM is evidence of how even complex models, which have evolved to represent socio-economic conditions accurately, can be used to develop policies with a blind approach to current inequities. There is a lack of understanding of how different users of the existing system are affected by policy interventions and infrastructure projects. Additionally, aggregate indicators can result in dissolved positive impacts of projects and distorted decision-making derived from using the model.

An additional aspect of this approach is the future scenario development used in the model. As expressed by the interviewees, this is a process made on a project-to-project basis. However, the structure of the model gives a guide in how this process can also have problems derived from its construction as it uses statistical data aggregated using the same classification system used for calibration. Future scenarios combine management policies and changes in infrastructure with expected future demand. However, using existing data as the basis for this future demand estimation can result in replicating existing inequalities. As behavior patterns diverge inside the population segments, expecting a reliable estimation of demand can be deceiving.

5.3 Introducing gender in 4SM

Moving forward, the challenge of combining the need for an improved representation of gender in transport planning and the well-established process of the 4SM is not easy. On one side, as building a 4SM is expensive and time-consuming, governments should be convinced of its cost-effectiveness to assign the resources needed. In that order of ideas, the

process to revolutionize the 4SM of Bogotá, including gender criteria, should be a progressive and escalated process. This approach will allow transport planners to demonstrate the benefits of using this gendered data in policy-making and convince politicians to invest more resources into the model to improve its data. This thesis advocates for a 3-stage approach in the short, medium and long term, from which it is expected that the already consolidated process of improving the model benefits from including gender-sensitive data.

In the short term, an improved data collection process is needed for the next model to be developed. As reflected in the previous chapter, the problems with the data imputation of the gender attribute of the survey make the decision-making a more nebulous process. Building a model using this kind of artificial data can result in models that are not statistically significant or easily calibratable. Additionally, being able to collect more reliable data regarding gender, as suggested by Moscoso and Quiñones (Quiñones and Moscoso, 2022), can also help to develop analyses outside the process of the model. And as is suggested in detail in the next section, it can be done practically. Finally, considering there is already a contract regarding the new transport survey and model, the easiest path forward is to continue to use the model today and explore the gender perspective from an external approach using the survey.

In the medium term, this approach is not acceptable. It is expected that the survey and model to be developed in 2027 will require the generation of a 3-step model only for women. The evidence is clear of the need to develop more accurate and precise policies for women, and the model as it is today cannot do that, nor with the suggested short-term changes. There is a need to estimate accurately and model women's mobility in the long term, and even more, if the subsequent models will be used to shape the next master plan of the city[9]. The SdM can use the additional time to secure the resources needed to hire a contractor that can develop an accurate 4SM, including gender, from its conception. The need for robust historical data regarding mobility and gender when the next master plan is discussed cannot be undermined. In addition, there is also a longer description of why and how a 3-step model can be developed in the next sections.

At last, it is suggested in the long term to revise the use of 4SM models as the main transport planning policy tool. A recent discussion raised by Willumsen (Willumsen, 2023) around this topic is becoming more relevant by the day: As we collect more precise data about

[9] The model and survey contract are awarded every 4 years, while a new masted plan is evaluated every 12. Given that the last master plan was enacted in 2021, it is expected for the 2027 or the 2031 models are going to be the input of the plan.

the inhabitants of urban areas, it is expected that aggregated models as the 4SM become reveal even more of its weaknesses. The last section of this chapter discusses a proposed long-term discussion about the future of the modeling process as it is being carried out in Bogotá and the possibility of starting the discussion of building a new strategic model for the city.

5.3.1 Current structure and opportunities

Reflecting on how the calibration is done, it is necessary to rethink how different aspects are considered when calibrating the model. Based on the comments of the interviewees and the results presented in the previous chapter, a call is made to practitioners and the SdM to take a better look at how the first three steps are calibrated. In this sense, I propose comparing the total number of trips by zone, as is done today, and looking at the trips by zone by gender. Look for the zones where women have more trips and ensure these zones maintain these conditions, as sometimes the calibration process can reduce them. Another condition can be related to how the model's pivot is programmed to allow for the modification of the matrices. This happens because the model can change the number of trips generated and attracted to a zone during iteration. Thus, it is suggested that in this step, a consideration of how much certain zones can vary can be introduced to minimize the disappearance of trips in zones or OD pairs where women represent a greater proportion.

Once the calibration is done, additional analysis can be done. The literature review and data for Bogotá showed that the current system's conditions negatively affect women. Asking modelers to go beyond presenting data on passengers per corridor or aggregate times is a first step forward. As the example given by Martens (Martens, 2017) in the literature review explained, using aggregate data can be misleading when doing a cost-benefit (C/B) analysis. For the current 4SM, using disaggregated data by strata is a first step in explaining how, even if a measure results in a lower C/B result, just selecting solutions aimed at lower-income populations can have a positive impact on women.

Additionally, always including parameters such as experimented occupancy, frequencies, and transfer times by ZAT or OD can be a way to provide a more focused solution. Understanding how these parameters can negatively affect women in public transport, with the overall understanding that more women in lower income brackets use transit, can help develop policies that target good conditions for women. Using parameters such as these when considering citywide solutions can improve women's perceptions of safety, quality of life, and economic mobility.

When thinking in terms of last-mile connectivity, other sets of indicators can also be used. Evaluating scenarios based only on aggregated results can minimize the impact of small-scale mobility. Using filters of nearby zones when evaluating travel times and demand can also help evaluate scenarios with a gender focus. Understanding how long-distance but low-frequency routes can improve operational efficiency at the city scale but reduce the availability of local-scale mobility is key to understanding this proposed change. This is especially important considering that women, as discussed before, are most affected by the loss of transit service in neighborhoods and places near their homes.

Building on the work of Montoya (Montoya-Robledo and Escovar-Álvarez, 2020), a clear example emerges of how geographical relations influence women's travel. In this sense, the evidence of the previous chapter showed how there are certain zones and OD pairs that women mainly do. Understanding this phenomenon can help modelers extract information about these elements in the baseline situation and in proposed scenarios to focus on the impact of certain projects. In addition, as has also been shown, the soon-to-be-implemented care system will focus its developments in certain city zones. If the modelers are aware of these zones, they can filter the results in these zones to understand the transport system's impact on the care system. In this regard, if additional effort is made in estimating the differential impact of the care economy in the general economy, it is clear that benefiting these areas can have a differential impact on the city. Consequently, adding these considerations to the B/C analyses, or I/C analyses, made by modelers can also be a way to plan for women using the current model.

Additionally, using already developed solutions such as modeling hours of the day outside of the morning peak hour can also be a way to focus on the impact of transport on women's mobility. As mentioned in the interviews and reported in the official data, additional model hours exist, but they are not as well calibrated as the morning peak hour. Efforts to better understand how the city moves at night, or how connectivity is offered in the middle of the day, in conjunction with the morning peak results, can also be a way for modelers to improve the way they offer analysis on the model's results. Combining the previous considerations with additional perceptions of the day can give a better perspective of how certain projects may positively or negatively affect women.

Finally, all these solutions can be summarized as a call to modelers better to understand the models beyond the commonly used indicators. Beyond the case of Bogotá, the key to this first strategy is to have modeling teams trained in gender dynamics, understand the shortcomings of current systems, and are willing to challenge established practices. As evidenced in some

of the interviews, modelers are not always aware of the outcomes and dynamics behind the indicators that a citywide average can hide.

5.4 Additional parameters and additional survey data

The evidence presented in Chapter 4 is clear: there is an important difference in how women and men use the transport network in cities, specifically in Bogotá. These differences are marked when looking at the data of the survey. However, given the tradition behind the model, using only strata can minimize the impact of these differences in evaluating policies based on this instrument. For this reason, this section argues for rethinking the 4SM at different scales. One scale is to add gender as a key variable determining how trips are estimated in the first three steps of the model, their impacts, costs and benefits. The next scale is how to adapt the model in the case of Bogotá to reflect better key aspects that affect women that are not currently available in the model and can minimize the way policies are made using the model. Finally, a discussion on the structure of the network is done, where the need to develop a more flexible network that allows a better interaction of multi-resolution models is also developed.

Rethinking the demand layers for the models, including a gender classification of trips, is the next obvious step in developing the model. As expressed by the interviewees consulted for this thesis, and the evidence gathered from different sources, if a complete understanding of the implications of policies in mobility is wanted, adding a layer for understanding the generation and attraction, distribution and mode choice is mandatory in the model. This thesis advocates the inclusion of these three steps in a separate way in the model segregating women and men due to the data presented in chapter 4. It is clear how women and men experience mobility differently in Bogotá.

The evidence shows how women's and men's trips differ significantly in origin and destination patterns. This indicates that the model's first three steps should be considered separately for women and men. According to the experts consulted, doing so would allow modelers and transport planners to understand not only the origins and destinations of trips made by women but also the ability to develop unique functions for the generation and attraction process, the distribution step, and modal choice that would allow a better representation of their behavior.

However, this would require additional effort on the part of modelers to correctly estimate these functions, which would require better network characterization. As a result,

additional effort would be needed to understand how the built environment affects women's behavior. For example, if a night period were to be modeled, given the additional importance women place on well-lit streets, it would be necessary to include an index of street lighting coverage on sidewalks as the one developed by the Women's secretariat (Montoya *et al.*, 2021). While this is an extreme example, it is useful in understanding the potential added complexity of adding more layers to the 4SM.

As explained in the model documentation, improving the characterization of the network would not be the only aspect to consider if this is the type of change proposed to the model. If there is a full three-stage model for women and men, this would also imply the need to have a larger sample in the transport survey. According to the interviewees, this may be the biggest obstacle to implementing this change. Some interviewees cited the already complicated process of accessing sufficient funding for the survey as it is today. In addition, the information available for the EODH 23 indicates that the process could not be contracted at the first attempt due to a high requirement on the part of the SdM to reduce the margin of error. According to these records, the interested companies mentioned the challenges of surveying with this increase in surveys with the given amount of money. Consequently, if the SdM decides to do a gender model, it will need to acquire additional resources to fund the project and allow companies to bid fairly and sufficiently.

This thesis argues that even though this change requires an increased investment of resources, the effort is worth every penny. As noted in the literature review and evidenced by the data analyzed, there is an urgent need for better planning for women. The city's current transport system discriminates against women, but it discriminates even more in the lower income brackets. It is important to have robust and useful tools to measure the positive impact of developing transport systems for these communities. A separate three-tier model will allow for a better understanding of the benefits to women when doing B/C analysis. Accurately measuring women's impacts can also replace a general time price for users, as is currently used, and can better account for the value generated by women, especially women who also perform care activities.

In order to do so, key aspects besides the input surveys are also required to be added to the model. Already available open data built up by the Planning Secretariat (SdP) is standardized. As mentioned in this thesis, the local government constantly maintains and updates databases with information regarding existing road networks, sidewalks, bike paths, and other network data. This information can be coded into the model to add the parametrization of accessibility and connectivity in zones. This can result in a better

representation of conditions key to understanding the impacts on women's mobility; for example, changes in the network, like improving the representation of roads and the configuration of zones, have already been made. Improving the model's resolution is done regularly, as evidenced when evaluating the surveys and models of 2015 and 2019. In consequence, adding already available data is possible. Additional data regarding the bus network is also available from the transit operator who publishes real-world data regarding frequencies and quality of service of the current model in GTFS format.

An additional benefit of this is the last step suggested to analyze women's mobility and is the use of multiresolution modeling to understand the local scale trips or the intrazonal trips. As a result of the interviews and after careful consideration of the structure of the model, it is clear that including these trips in the model is not practical. Also, in a wider discussion, where this model is used to understand metropolitan and large-scale projects, evaluating the local trips at a high level of detail may not be useful for decision-makers. Understanding the scales of different models is essential to develop them correctly. As one of the modelers interviewed mentioned, it is better to represent these trips in smaller models. The detailed explanation of mesoscopic or microscopic models' inner workings is beyond this thesis's scope. However, as Órtuzar and Willumsen (Ortúzar and Willumsen, 2011) describe them in their work, they can better represent the interactions at a road or intersection level. And in that regard, it is highly suggested that a step in the 4SM is to improve the way the network's topology is built to facilitate the export to other models. That will allow even for an iterative process where smaller models can even feed traffic conditions of the 4SM, like improving the Speed-Flow curves or estimating better the accessibility characteristics assigned to connectors of zones and the network.

5.5 The case for starting from scratch

Another aspect to consider is the limitations of the 4-Step Modeling framework, which prevents the information gathered in the survey from adequately representing women's dynamics in transport. Several interviewees pointed out that the 4SM cannot properly represent macro-scale trips and their last-mile connections. They mentioned alternative modeling methods, such as activity-based or full metropolitan-scale agent simulations. Since these methods are outside the scope of this thesis, it is not worth discussing them in this chapter. However, it is worth discussing how the 4SM lacks some analytical capabilities that these methods do not have at first glance.

The first criticism is the abstraction itself; as one of the interviewees mentioned, some characteristics are missing whenever a statistical or mathematical model is used to represent a population. In this sense, using econometric models to represent behaviors is a limitation. Based on the intrinsic complexity of modeling the choices of more than eight million people living in the city, this limitation is a condition that many models and measurement strategies can have. However, the classification and rigidity of using only one set of attributes to explain the behavior of a population can be particularly misleading. In contrast, modeling techniques that use stochastic approaches to simulate behavior can better explain individual decisions at the cost of more complex and computationally intensive models.

Similarly, the classification used at a spatial level can be misleading. Even if the use of TAZs and UTAMs to spatially aggregate the population can be a valid alternative for modeling. As presented in the past two sections, this aggregation limits the possibility of evaluating in-neighborhood trips. This condition is particularly negative against women, which are the ones who make the most of those trips. Again, more granular and disaggregated models can be an alternative to correct this. However, as the experience suggests, increasing the number of analysis zones can exponentially increase the time and size of the computational needs required to develop these models. In this sense, a proper balance between granularity and practicality is needed. An alternative to this approach can be a series of multiple 4SMs, for the metropolitan region and others for bigger city zones. Even if this can represent a bigger data management effort, having coordinated and “zoomed-in-and-out”, models can be a compromise in which local dynamics can be evaluated in conjunction with macro activities.

Finally, the evaluation of only one hour of modeling is one of the main points of contention between gender-aware planning and traditional planning practices. This condition of the model, which is specific to each of the models evaluated, limits the possibility of analyzing trips with durations longer than one hour, which in turn reduces the possibility of better analyzing the chaining of trips, the effect of longer transfer times, or the impact on travel budgets derived from unrelated care activities amenities. As noted above, these unmeasured conditions primarily affect women and might be misrepresented in traditional models. The modelers interviewed for this thesis mentioned an alternative using longer time windows for the model. However, they expressed concern about recalibrating functions already adapted to hourly models, such as volume delay functions. On the other hand, other regional models in the literature express the possibility of modeling even whole days if the model requires it. In this case, it is a matter of understanding the real conditions of the area

and, again, making the necessary investments in time and resources to apply this type of solution in a newly developed model.

Here is important to insist that using a new modeling approach, either one of the mentioned or another, is an incredibly big task. It is not practical to start a new model from scratch and hire a process to develop it. As the tradition in many cities, and as it is in Bogotá, modeling tools are built over time. They require continuous effort to improve and build on existing experiences. It is suggested that the SdM internally explore alternatives to 4SM models and invite the academia, consultancies and other interest groups to a long process of deliberation and development of a new tool in the long term.

6 Conclusions and recommendations

6.1 Conclusions

After reviewing the characteristics of trips in Bogotá, especially considering the particularities of trips of women against men's trips, this thesis proposes a staged process to include gender focus in the development and planning of transport models. Using the example of Bogota's 4SM, I propose short, medium and long-term solutions to include gender using the 4-step model.

This thesis synthesizes the criticisms several authors raised in the literature review against traditional planning practices and then explores a case study to understand how this criticism can be localized and evaluated in a particular scenario. Using the information collected about the 4SM general structure and its implementation in Bogotá, a comparison was made between city-wide characteristics of women's and men's trips and how the model represents the trips of a "standard traveler". This exercise evidenced how for Bogotá, using this assumption leads to unequal transport planning due to the differences in travel behaviors of women and men, as the key actors interviewed for the thesis signaled the results.

This thesis proposes strategies to improve the models' evaluation progressively. As evidenced in the fourth chapter of this thesis, these strategies focus on finding how traditional practices translate into modeling biases and how they can be overcome. It is worth highlighting how the intuitive comments made by several interviewees can be evidenced when looking at the data from the transport survey. Also, this process will only be successful if it is part of a wide process of policy-making centered around data and where local governments invest in developing tools that allow for a robust and trustful generation of data.

The data collected and the analysis carried out in this thesis are sound evidence of how women's trips have various characteristics that should be considered when doing transport models or evaluating their results. The structural economic inequities of cities affect more women as they usually take care of activities in the household, reducing the time they have to travel in the city. On top of that, the additional set of activities they make means a series of chaining of trips, which they tend not to do. Also, structural inequities as the gender pay gap, mean less access to resources to travel. Consequently, a bigger impact on them is caused when policy decisions are developed using monetary instruments, such as price increases or price schemes and integrations, to change behaviors. At last, women's experiences are shaped by gender-based acts of violence almost daily. These four characteristics should be considered

when building and evaluating transport models if it is expected to develop gender-inclusive policies from the results of those models.

In the case of Bogotá, academic literature is available, and the analyses presented in this thesis support this need. Women in Bogotá have smaller financial and time budgets than men, and at the same time, they tend to spend more time doing activities of care. Added to this, the concentration of workplaces across the city, where women have a bigger participation in the workforce, tend to be more concentered than men's ones. They express more discomfort and push against the policies resulting in non-resilient, unsafe transit systems, as evidenced by the protest against gender-based violence that occurred while this thesis was written. Consequently, they have developed strategies to avoid certain transport system elements or have travel behaviors that differ radically from men to avoid gender-based violence.

The information collected for this thesis and the interviews conducted with expert users of the model allowed me to explain the operation of 4SM using Bogotá as a typical example of the classic 4SM process. The model is structured around balancing the supply and demand of a transportation network using a calibrated mathematical model for Bogotá. Also, the model can use a series of forecasts to evaluate how changes in demand will affect proposed policies and infrastructure. However, as was evidenced, today's model can only represent the aggregated demand by economic strata but not by gender or any other demographic characteristics.

For the case of Bogotá, this model is updated every four years and uses the mobility survey as its main input and database of information regarding the city's transport infrastructure and transit system. The process, as of today, does not include an evaluation of gender inside the model or its results in a consistent way. Experts suggest that these gender-based analyses are carried out depending on the project, but there is no consensus on how they should be developed. The practices around evaluating fair and equitable transport systems using the model are limited to using cost-benefit analyses. However, as the literature review shows, no consensus in the valuation of gender differences exists that allows to development of a fully-fledged gender analysis using gender characteristics.

The main line of strategies in the current practices are aimed at improving accessibility and quality of service of the transport network for users of private, public or active transportation. The policy goals, when there is an intention of developing gender equitable systems, are aimed to satisfy the needs of women while reducing the inequities of existing systems. However, in the planning stages, measuring impacts to develop the governance

procedures that allow the investments to carry them out is not easy. This thesis proposes the inclusion of gender equity criteria in 4SM as a way to introduce gender equity criteria in the evaluation of transport projects in cities.

The main strategy proposed is to improve the process of obtaining data from the 4SM when evaluating different scenarios of transport policy and infrastructure. In order to do so, it is necessary to improve how 4SM is developed. This thesis proposes a staged process that will allow policy-makers to do that in the short, medium and long term. Using the example of Bogotá, it is clear that improving how data regarding gender is gathered in mobility surveys can be a short-term solution. Then, with more time to improve the governance structures and process around the hiring and funding of surveys and models, the introduction of an additional 3-step model differentiated by gender is suggested.

At last, in the long term, there is a need to begin an open discussion about the possibility of leaving behind the 4SM framework as more robust and precise models appear. The change in modeling practices is already being developed by many actors and cities around the globe, and it is key for cities like Bogotá not to wait a long to start changing too. However, it is very important to do a gradual process as described to maintain the confidence and trustworthiness that the transport modeling practice has built around the 4SM framework and, consequently, around policy decisions based on it.

6.2 Recommendations

A series of comments and recommendations are made as a concluding argument. As stated before, the use of the Bogotá 4SM is heavily influenced by how the socioeconomic strata attribute and its definitions are spread around the city. According to one of the interviews, the self-correlation of space and strata dissolves the possibility of accounting for different income levels in similar city zones. However, it is not only the definition that results are problematic; the lack of accounting for gender between strata is the biggest issue.

As shown with the characterization of the different indicators by strata and gender, the history of neglecting the particularities around gender has been transferred to modeling. Not recognizing the social constructions around gender and how it shapes the number of trips, the purpose of the trips and the absolute time budget available, and thus the tolerance or impedance to certain variables of the model, is a clear heritage of traditional gender-blind transport planning taken to the modeling practices.

Along the same line, the limitations of the 4SM approach to represent chained trips are a roadblock in implementing a more gender-aware approach to planning and modeling. As Madariaga rightfully mentions, the problem with considering only one hour of analysis goes beyond the impossibility of understanding what happens outside of that hour. How different perceptions of security and comfort are for women across the day. Since the hour of analysis is not at night, fear and security concerns are not addressed (Sánchez de Madariaga and Roberts, 2013, p. 49). One of the modelers interviewed mentioned that every time he uses a new modal choice survey, the parameters outside Time and Cost are more important in the calibrated functions, and the practice with the model has not evolved to account for that. The SdM and the academia should do additional research and development to develop choice and assignment models that represent these choice factors. These factors can represent all aspects that influence, for example, women's travel behavior at night.

The classic 4SM framework finds its biggest issue when trying to account for activities of care or generally chained activities in which women do more when trying to represent the chaining of trips. Even if the 4SM allows for a representation of Non-Home-Based trips, which can be considered chained trips, they are considered by themselves, but the additional burden of doing transfers or having added waiting times cannot be considered under the current conception of the model. Because women usually do more of those chained trips, this omission is especially gruesome against them.

These two criticisms collide in how it is important to abolish the average user concept, which is considered the unit of an average passenger inside modeling, as part of the discussions with modelers, a recurring conception of improving how this average user is characterized appeared. In this line, the work of Bocarejo and Lecompte for Bogotá is highly relevant (Lecompte and Bocarejo S., 2017, p. 4255). They find how parameters outside cost and time influence decisions around traveling itself, modal choice and route choice.

As a closing remark of this thesis, it is important to reflect on its analysis's positioning and limitations. As a cisgender man working in a traditionally men-governed profession, views around gender entering this thesis and how to include gender visions into everyday modeling practices were unclear. I have had to challenge traditional teachings, given mainly by other cisgender men in the area. Additionally, as the author of this thesis, I am not related to the everyday experiences of women in transport. That is why this thesis had to rely heavily upon an impressive and excellent academic background of hundreds and hundreds of researchers that have analyzed the intersection and transport planning. And after getting to know all of these experiences and being highly inspired by Chant (Chant, 2013), this thesis's

last conclusion is the urge for men to take an active role in improving women's transport conditions. I expect with this thesis to bring more male colleagues into this transcendental discussion.

List of references

Alcaldía Mayor de Bogotá, D.C. (2021) 'Plan De Ordenamiento Territorial, Bogotá Reverdece 2022-2035. Decreto 555 de 2021'. Available at: https://www.sdp.gov.co/sites/default/files/generales/pot_digital.pdf (Accessed: 16 January 2023).

Chant, S. (2013) 'Cities through a "gender lens": a golden "urban age" for women in the global South?', *Environment and Urbanization*, 25(1), pp. 9–29. Available at: https://doi.org/10.1177/0956247813477809.

Dirección de Censos y Demografía - DCD (2018) *Microdatos Censo Nacional de Población y Vivienda - CNPV - 2018*. DANE-DCD-CNPV-2018. Departamento Administrativo Nacional de Estadística. Available at: https://microdatos.dane.gov.co/catalog/643 (Accessed: 6 November 2022).

Dirección de Metodología y Producción Estadística - DIMPE and Dirección de Censos y Demografía - DCD (2017) *Microdatos Encuesta Nacional de Uso del Tiempo - ENUT - 2016-2017*. National time use survey DANE-DIMPE-ENUT-2016-2017. Colombia: Departamento Administrativo Nacional de Estadística. Available at: https://microdatos.dane.gov.co/catalog/552 (Accessed: 6 November 2022).

Dirección de Metodología y Producción Estadística - DIMPE and Dirección de Censos y Demografía - DCD (2021) *Microdatos Encuesta Nacional de Uso del Tiempo - ENUT - 2020-2021*. National time use survey DANE-DIMPE-ENUT-2020-2021. Colombia: Departamento Administrativo Nacional de Estadística. Available at: https://microdatos.dane.gov.co/catalog/729/study-description (Accessed: 2 November 2022).

Dobbs, L. (2007) 'Stuck in the Slow Lane: Reconceptualizing the Links between Gender, Transport and Employment', *Gender, Work & Organization*, 14(2), pp. 85–108. Available at: https://doi.org/10.1111/j.1468-0432.2007.00334.x.

Drăguțescu, A., Land, P. and Meskovic, E. (2020) *Addressing Gender Equity and Vulnerable Groups in SUMPs*. ICLEI European Secretariat.

Equipo Sistema Violeta (2017) *Acoso sexual contra mujeres en el transporte público. Caso TransMilenio.* 2. Bogotá D.C., Colombia: Secretaría Distrital de la Mujer, p. 69.

European Commission. Directorate General for International Partnerships (2022) *Estrategia Nacional de Movilidad Activa con enfoque de género y diferencial: ENMA.* LU: Publications Office. Available at: https://data.europa.eu/doi/10.2841/954501 (Accessed: 29 September 2022).

Gauvin, L., Tizzoni, M., Piaggesi, S., Young, A., Adler, N., Verhulst, S., Ferres, L. and Cattuto, C. (2020) 'Gender gaps in urban mobility', *Humanities and Social Sciences Communications*, 7(1), p. 11. Available at: https://doi.org/10.1057/s41599-020-0500-x.

Halsall, D. (2001) 'Transport and Travel: Better for Women?', *Geography*, 86(1), pp. 79–81.

Lättman, K., Friman, M. and Olsson, L.E. (2016) 'Perceived Accessibility of Public Transport as a Potential Indicator of Social Inclusion', *Social Inclusion*, 4(3), pp. 36–45. Available at: https://doi.org/10.17645/si.v4i3.481.

Law, R. (1999) ‘Beyond “women and transport”: towards new geographies of gender and daily mobility’, *Progress in Human Geography*, 23(4), pp. 567–588. Available at: https://doi.org/10.1191/030913299666161864.

Lecompte, M.C. and Bocarejo S., J.P. (2017) ‘Transport systems and their impact con gender equity’, *Transportation Research Procedia*, 25, pp. 4245–4257. Available at: https://doi.org/10.1016/j.trpro.2017.05.230.

Levin, L. and Faith-Ell, C. (2019) ‘How to Apply Gender Equality Goals in Transport and Infrastructure Planning Lena Levin and Charlotta Faith-Ell’, in C.L. Scholten and T. Joelsson (eds) *Integrating Gender into Transport Planning: From One to Many Tracks*. Cham: Springer International Publishing, pp. 89–118. Available at: https://doi.org/10.1007/978-3-030-05042-9.

Levy, C. (2013) ‘Travel choice reframed: “deep distribution” and gender in urban transport’, *Environment and Urbanization*, 25(1), pp. 47–63. Available at: https://doi.org/10.1177/0956247813477810.

Liu, C., Tapani, A., Kristoffersson, I., Rydergren, C. and Jonsson, D. (2020) ‘Development of a large-scale transport model with focus on cycling’, *Transportation Research Part A: Policy and Practice*, 134, pp. 164–183. Available at: https://doi.org/10.1016/j.tra.2020.02.010.

López M., L.M., Correa B., T., Ramírez C., Y.M., Echeverry S., J.A. and Castañeda E., J.P. (2019) *Experiencias de las mujeres en el espacio y el transporte públicos*. Boletín informativo 13. Bogotá D.C., Colombia: Secretaría Distrital de la Mujer, p. 31. Available at: https://omeg.sdmujer.gov.co/index.php/mediciones/publicaciones/boletin?download=562:boletin-mujer-es-en-cifras-16-experiencias-de-las-mujeres-en-el-espacio-y-el-transporte-publicos.

Martens, K. (2017) *Transport justice: designing fair transportation systems*. New York, NY: Routledge, Taylor & Francis Group.

McCray, T. and Brais, N. (2007) ‘Exploring the Role of Transportation in Fostering Social Exclusion: The Use of GIS to Support Qualitative Data’, *Networks and Spatial Economics*, 7(4), pp. 397–412. Available at: https://doi.org/10.1007/s11067-007-9031-x.

McNally, M.G. (2000) ‘The Four Step Model’, *UC Irvine: Center for Activity Systems Analysis*, p. 19.

Montoya Robledo, V., Montes Calero, L. and Bernal Carvajal, V. (2021) *Decálogo para planes de movilidad urbana sostenible sensibles al género*. Inter-American Development Bank. Available at: https://doi.org/10.18235/0003423.

Montoya, V., Montes, L., Bernal, V., Camós, G., Bertossi, F., Orozco, Á.M., Arístide, E., Roldán, J.D., Angel, S., Lozano, D. and Pinilla, P. (2021) *ABC Género y Transporte*. Inter-American Development Bank. Available at: https://doi.org/10.18235/0003772.

Montoya-Robledo, V. and Escovar-Álvarez, G. (2020) ‘Domestic workers’ commutes in Bogotá: Transportation, gender and social exclusion’, *Transportation Research Part A: Policy and Practice*, 139, pp. 400–411. Available at: https://doi.org/10.1016/j.tra.2020.07.019.

Moscoso, M., López, S., Montoya, V., Quiñones, L.M., Gomez, L.D., Lleras, N. and Adriazola-Steil, C. (2019) 'Mujeres y transporte en Bogotá: las cuentas'. Bogotá. Available at: https://www.despacio.org/portfolio/las-mujeres-y-el-transporte-en-bogota-las-cuentas/.

Nasrin, S. and Bunker, J. (2021) 'Analyzing significant variables for choosing different modes by female travelers', *Transport Policy*, 114, pp. 312–329. Available at: https://doi.org/10.1016/j.tranpol.2021.10.017.

National Academies of Sciences, Engineering, and Medicine (2010) *Advanced Practices in Travel Forecasting*. Washington, D.C.: Transportation Research Board, p. 22950. Available at: https://doi.org/10.17226/22950.

Ortúzar, J. de D. and Willumsen, L.G. (2011) *Modelling transport*. 4. ed. Chichester: Wiley.

Quiñones, L. and Moscoso, M. (2022) 'Recomendaciones Para Una Encuesta De Movilidad Sensible Al Enfoque De Género E Interseccional – Bogotá 2023', *Noticias Despacio*, 19 June. Available at: https://www.despacio.org/2022/07/19/recomendaciones-encuesta-de-movilidad-enfoque-genero-bogota-2023/ (Accessed: 1 September 2022).

Quiñones, L.M. (2018) *Sexual Harassment in Public Transport in Bogotá / Acoso sexual en el transporte público en Bogotá*. Thesis. The London School of Economics and Political Science. Available at: https://babel.banrepcultural.org/digital/collection/p17054coll23/search/searchterm/PDF/field/format/mode/exact/conn/and.

'Revictimización y fallas estructurales. El caso de Hilary Castro' (2022) *Presunto Pódcast*. Available at: https://open.spotify.com/show/07H1d02UXSbKcQ8NQPn9h7 (Accessed: 31 January 2023).

Roberts, M. (2013) 'Gender, Fear and the Night-time City', in I. Sánchez de Madariaga (ed.) *Fair shared cities: the impact of gender planning in Europe*. Burlington: Ashgate Pub. Company.

Rodriguez-Valencia, A., Rosas-Satizabal, D., Unda, R. and Handy, S. (2021) 'The decision to start commuting by bicycle in Bogotá, Colombia: Motivations and influences', *Travel Behaviour and Society*, 24, pp. 57–67. Available at: https://doi.org/10.1016/j.tbs.2021.02.003.

Rouhanizadeh, B. and Kermanshachi, S. (2021) 'A gender-based analysis of workforce promotion factors in U.S. transportation agencies', *Transportation Research Interdisciplinary Perspectives*, 12, p. 100457. Available at: https://doi.org/10.1016/j.trip.2021.100457.

Sánchez de Madariaga, I. and Roberts, M. (2013) *Fair shared cities: the impact of gender planning in Europe*. Burlington: Ashgate Pub. Company.

Secretaría Distrital de Movilidad (2019) *Mujeres trabajo y movilidad sostenible. Estudio de caso y recomendaciones para las organizaciones.* Bogotá D.C., Colombia: Secretaría Distrital de Movilidad, p. 106. Available at: https://www.simur.gov.co/sites/www.simur.gov.co/files/2022-04-12/biblioteca/20220412-1251-650.pdf.

Secretaría Distrital de Movilidad (2022) 'RESPUESTA AL RADICADO 202261203507952 - Solicitud de información modelo de 4 etapas'.

Secretaría Distrital de Movilidad and Unión Temporal Steer - CNC (2019) *Microdatos Encuesta de Movilidad Bogota D.C. 2019*. Transportation domestic survey. Bogotá D.C., Colombia: Secretaría Distrital de Movilidad. Available at: https://datosabiertos.bogota.gov.co/dataset/encuesta_movilidad_bogota (Accessed: 4 November 2022).

The Australian Department of Infrastructure, Transport, Regional Development, Communications and the Arts (2017) *Australian Transport Assessment and Planning: Tools and Techniques, Australian Transport Assessment and Planning*. Available at: https://www.atap.gov.au/tools-techniques/index (Accessed: 13 January 2023).

Turner, J. and Grieco, M. (2000) 'Gender and Time Poverty: The Neglected Social Policy Implications of Gendered Time, Transport and Travel', *Time & Society*, 9(1), pp. 129–136. Available at: https://doi.org/10.1177/0961463X00009001007.

UK DfT (2022) *Demand responsive transport, Demand responsive transport: local authority toolkit*. Available at: https://www.gov.uk/government/publications/demand-responsive-transport-local-authority-toolkit/demand-responsive-transport-local-authority-toolkit (Accessed: 17 January 2023).

Unión Temporal Steer - CNC (2019) *Actualización del modelo de transporte – Encuesta de Movilidad de Bogotá 2019*. Informe etapa IV. Bogotá D.C., Colombia: Secretaría Distrital de Movilidad, p. 101.

Wankiewicz, H. (2013) 'European Regional Development Programmes for Cities and Regions: Driving forces for Gender Planning?', in I. Sánchez de Madariaga and M. Roberts, *Fair shared cities: the impact of gender planning in Europe*. Burlington: Ashgate Pub. Company.

Willumsen, L.G. (2023) 'When the future changes do I adapt or do I change my models?', *LinkedIn*. Available at: https://www.linkedin.com/pulse/when-future-changes-do-i-adapt-change-my-models-luis-willumsen/ (Accessed: 30 January 2023).

Annex A: Key interviewee list and topic covered

Key actor list:

Name	Gender	Age	Affiliation	Role and tasks
Vanessa Ferro	F	26	GIZ (International Cooperation)	Develops projects of international cooperation, including gender equity criteria and developing project-wide strategies to include gender visions
Gonzalo Guerra	M	34	Steer (Transport Consultants)	Develops and analyzes models to evaluate transport systems. Has worked extensively with 4SM in its calibration and evaluation of several projects in the city
Valentina Montoya	F	36	IDB (International Cooperation)	Develops research and government assistance projects in gender and transport. Her main line of research is in the mobility of domestic workers in Latam
Maximiliano Bernal	M	29	CyM (Transport Consultants)	Develops and analyzes models to evaluate transport systems. Has worked extensively with the 4SM in projects like the First Metro Line, the regional trains and others using programming
Cristian Quintero	M	36	SdM (Mobility Secretariat)	Leads the team in charge of maintaining the 4SM and doing additional analysis of demand and congestion to help decision-makers at the local government
Miguel Castillo	M	33	CyM (Transport Consultants)	Leads and develops transport projects at CyM. He is in charge of the planning and technical coordination of projects. Reviewing methodologies and development of the projects. Technical supervision from inside the company
Ana Sepulveda	F	38	Metro Bogotá (Metro agency)	4-Step Modeler at Empresa Metro. Works in the planning and evaluation of future metro projects. Reviews and validates models and reports from consultants
Paola Castañeda	F	31	UniAndes University)	Feminist geographer professor and researcher at Uniandes. Teaching and researching in geographies of gender and inequities.
Lina Quiñones	F	31	Despacio (NGO)	Project manager for Despacio (NGO), former Director for Intelligence for Mobility at SdM. Develop and coordinates teams working on gender and mobility
Jessica Buriticá	F	34	Steer (Transport Consultants)	Modeler and project coordinator at Steer (USA, previously in Bogotá). She leads and coordinates modeling teams to develop projects. Also develops packages to use inside the software to improve modeling practices.

Interview structure:

In this section, a complete explanation of the topics covered throughout the interview is made. The questions were framed inside an unstructured conversation with the interviewees, but the order of the questions was as follows:

Gender and transport: In this section, a baseline of concepts around gender was done to review the concepts of gender gathered in the literature review with the gender researchers. And to form a common baseline of gender topics with the modelers interviewed.

- How would you describe the differences between gender and sex?
- How do you think that men experience public and private transport? By contrast, how do you think women experience public and private transport?
- In your professional practice, have you used gender as a defining factor? How? In modeling? Why? Why not?

Gender issues in Bogotá's transport: With the common ground around gender and transport at a general level, the interviewees were then asked to comment on particular issues about how those dynamics can be seen in Bogotá.

- What do you know about women's experiences with transport in Bogotá?
- Which travel patterns are mainly made by women in Bogotá?
- Where is a special concentration of women's trips in the city?
- What are the biggest problems for women in transport in Bogotá?

Modeling and Planning: Similarly, as it was done with gender, now modelers were asked about the literature review findings in this aspect. And for gender researchers, a brief framework was laid out, and some related questions were done about planning processes in Bogotá.

- Do you know about the 4-step model?
- How is the model used in Bogota's transport planning process?
- What are your experiences with projects when the 4-step model is being used? (Which parameters are observed in the mobility system? Which parameters are optimized for?)
- How is the model calibrated? Which cross-validation measures are being used?
- Does the model represent the waiting times observed in the survey?

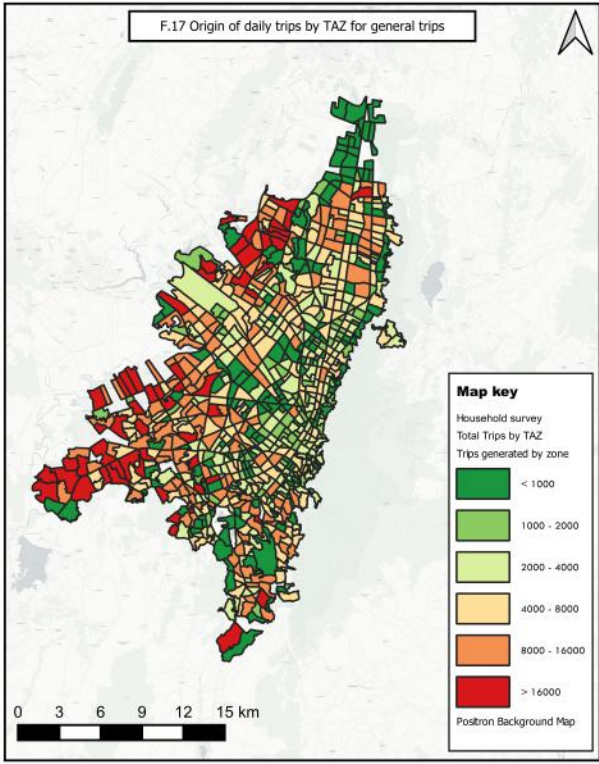
Planning for women: After the previous three questions, the interviews were pushed to discuss how modeling planning processes can be transformed to use gender in modeling.

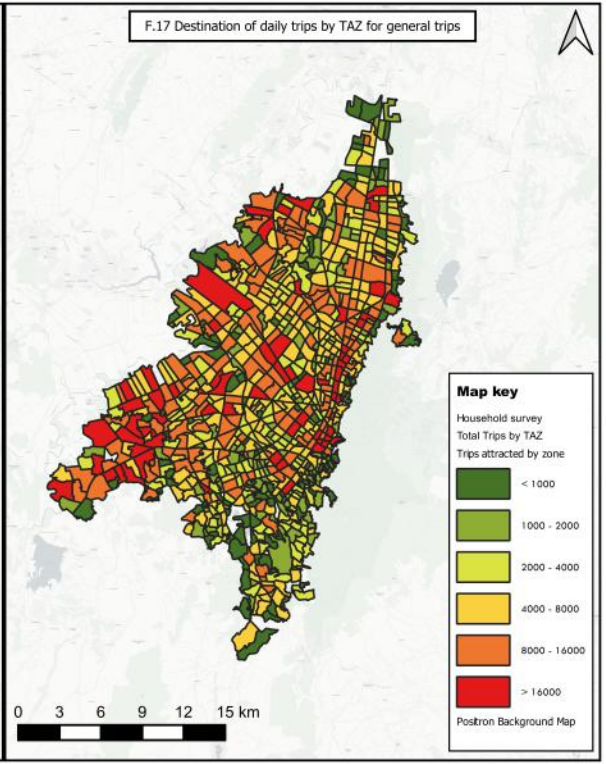
- How do you imagine a process of planning that targets women positively?
- How can the survey + 4-step model be adapted to better account for women?
- Is Bogotá planning for women's transport?

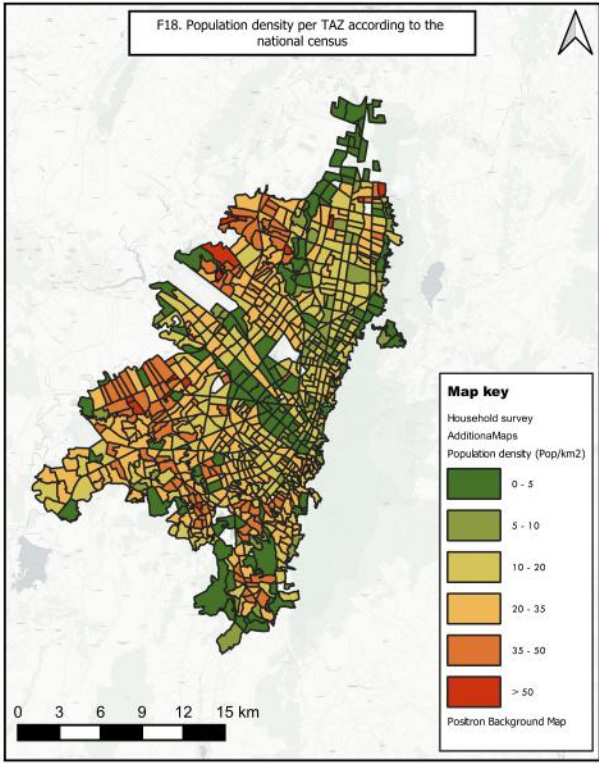
Transversal issues: In addition to the questions that were carried out in the structure of the thesis, other questions were made to gather relevant aspects highlighted by the interviewees and their perspective about the modeling environment and how its workforce is shaped or not by gender stereotypes.

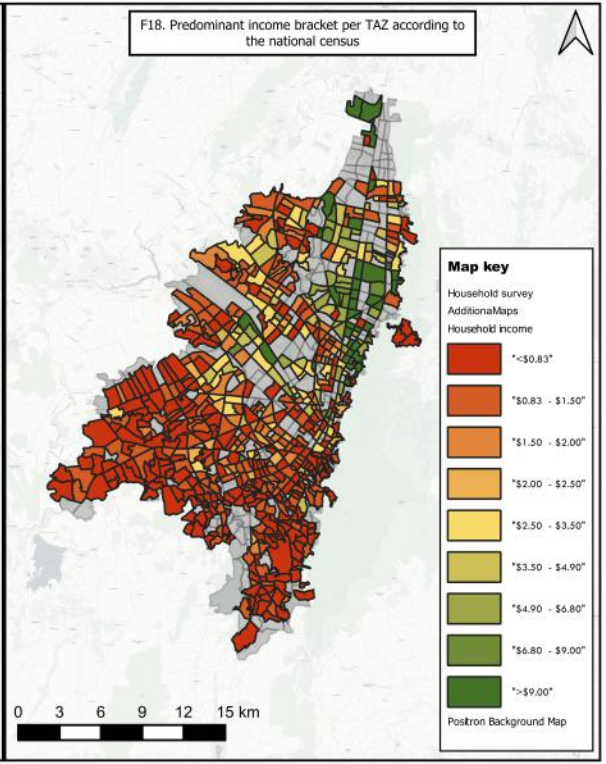
- Do you know women that work with the 4-step model?
- How do you imagine those gender criteria can be used to evaluate 4-step models?
- Additional Remarks raised in the interview.

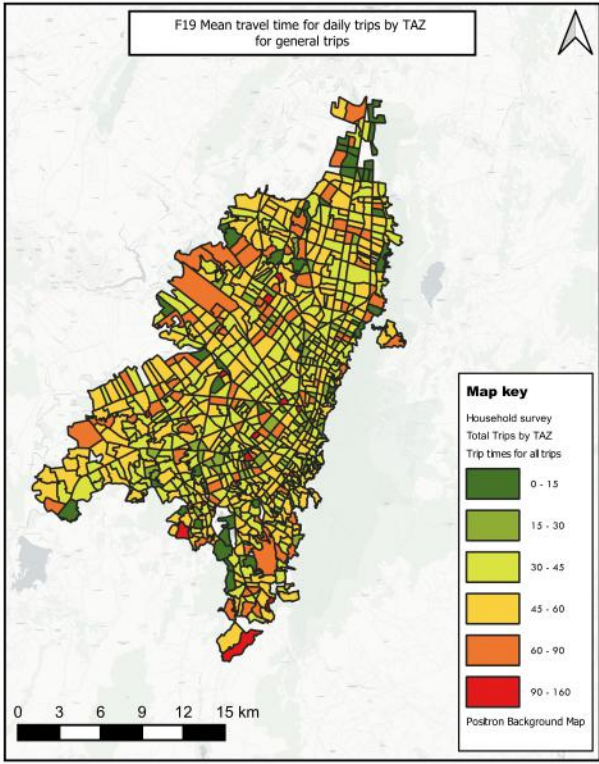
Annex B: Maps

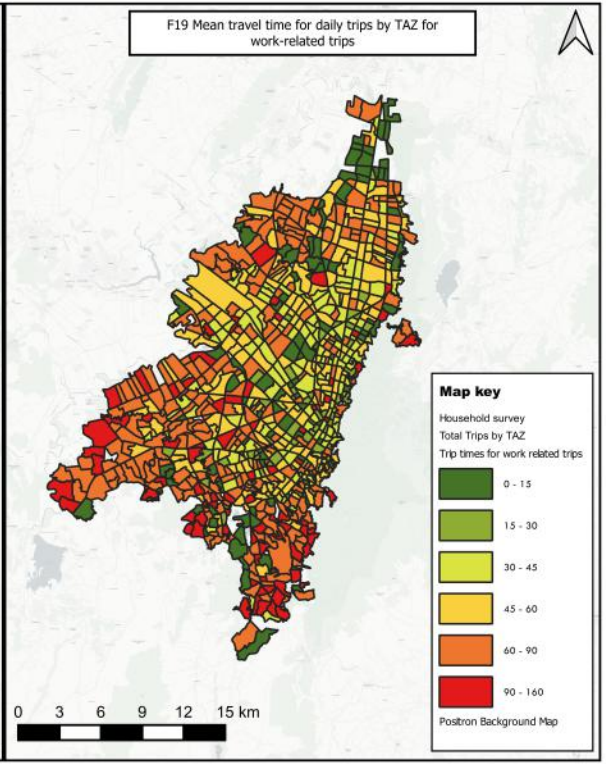

F.17 Origin of daily trips by TAZ for general trips
Map key
Household survey
Total Trips by TAZ
Trips generated by zone
< 1000
1000 - 2000
2000 - 4000
4000 - 8000
8000 - 16000
> 16000
Positron Background Map
0 3 6 9 12 15 km

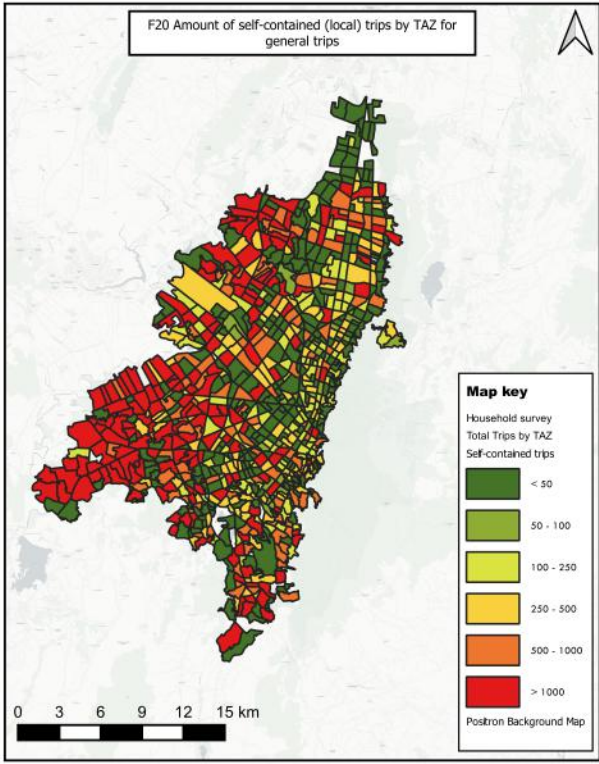

F.17 Destination of daily trips by TAZ for general trips
Map key
Household survey
Total Trips by TAZ
Trips attracted by zone
< 1000
1000 - 2000
2000 - 4000
4000 - 8000
8000 - 16000
> 16000
Positron Background Map
0 3 6 9 12 15 km

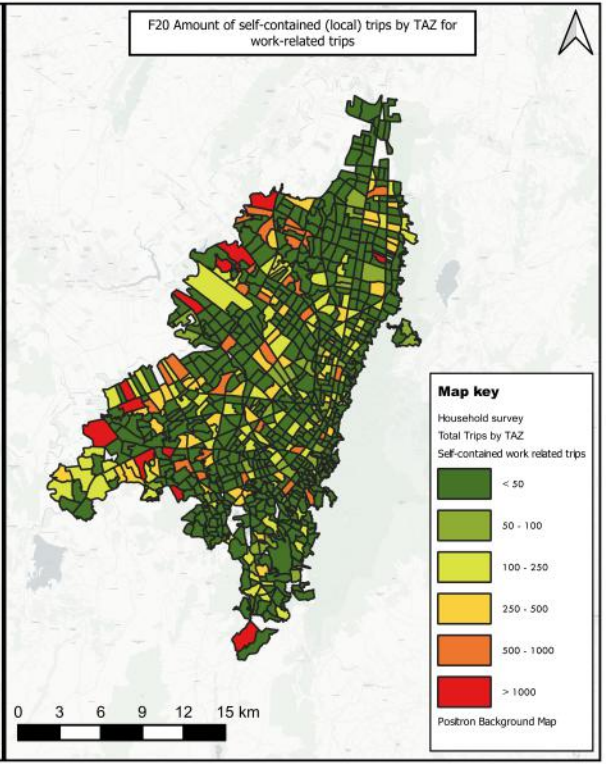

F18. Population density per TAZ according to the national census
Map key
Household survey
AdditionaMaps
Population density (Pop/km2)
0 - 5
5 - 10
10 - 20
20 - 35
35 - 50
> 50
Positron Background Map
0 3 6 9 12 15 km

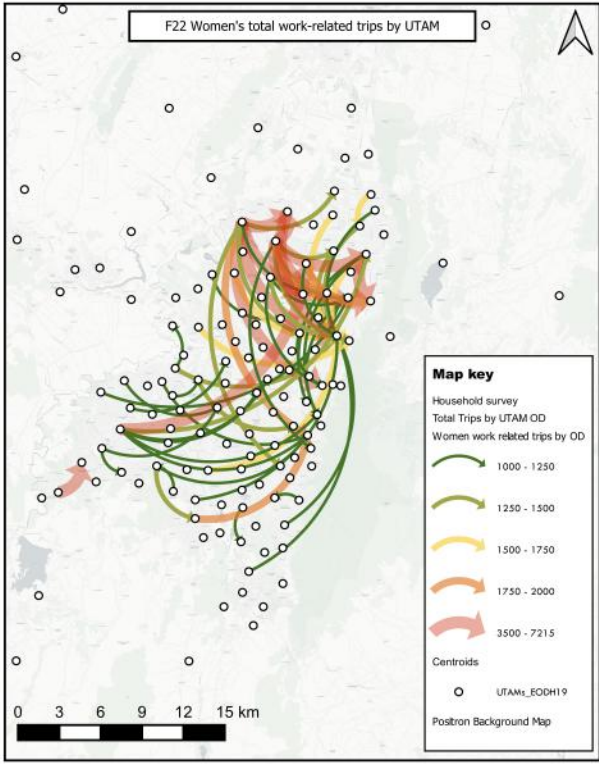

F18. Predominant income bracket per TAZ according to the national census
Map key
Household survey
AdditionaMaps
Household income
"<$0.83"
"$0.83 - $1.50"
"$1.50 - $2.00"
"$2.00 - $2.50"
"$2.50 - $3.50"
"$3.50 - $4.90"
"$4.90 - $6.80"
"$6.80 - $9.00"
">$9.00"
Positron Background Map
0 3 6 9 12 15 km

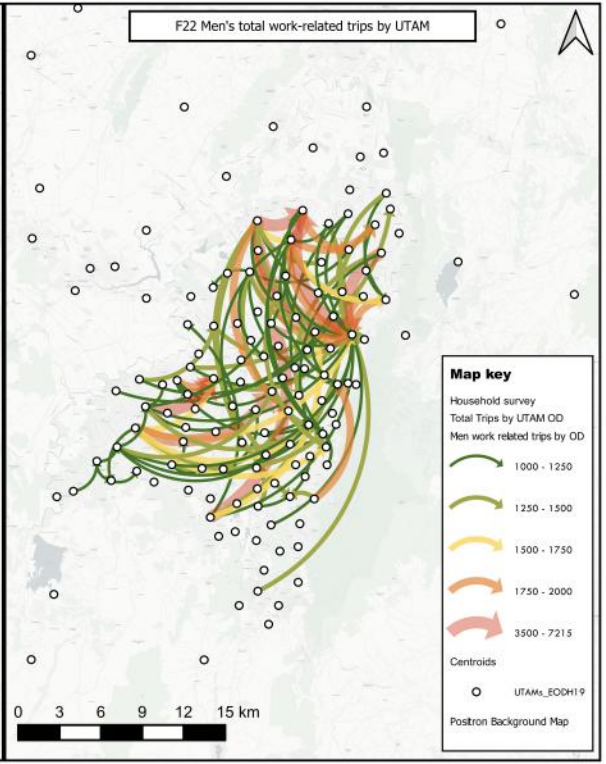

F19 Mean travel time for daily trips by TAZ
for general trips
Map key
Household survey
Total Trips by TAZ
Trip times for all trips
0 - 15
15 - 30
30 - 45
45 - 60
60 - 90
90 - 160
Positron Background Map
0 3 6 9 12 15 km

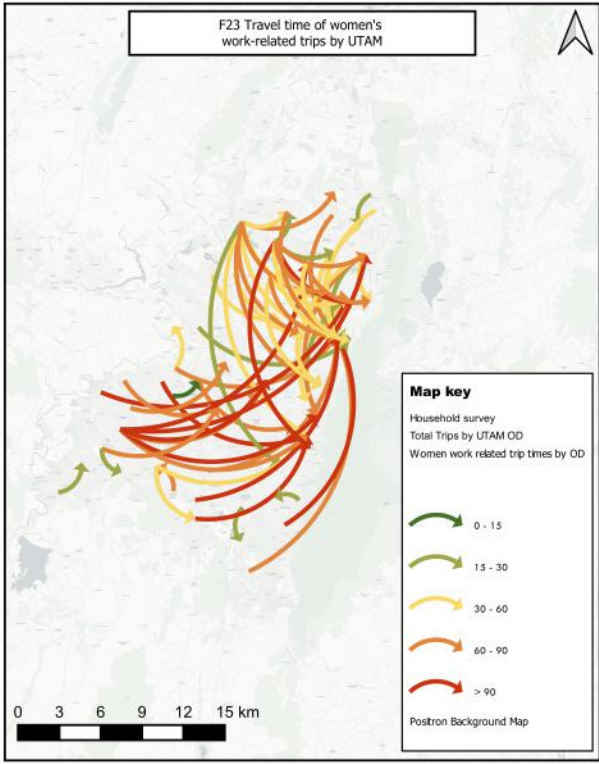

F19 Mean travel time for daily trips by TAZ for
work-related trips
Map key
Household survey
Total Trips by TAZ
Trip times for work related trips
0 - 15
15 - 30
30 - 45
45 - 60
60 - 90
90 - 160
Positron Background Map
0 3 6 9 12 15 km

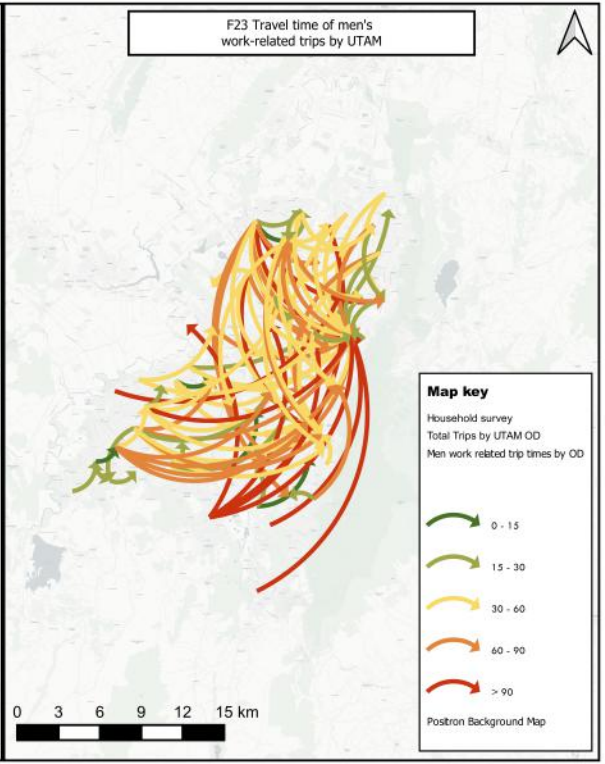

F20 Amount of self-contained (local) trips by TAZ for general trips
Map key
Household survey
Total Trips by TAZ
Self-contained trips
< 50
50 - 100
100 - 250
250 - 500
500 - 1000
> 1000
Positron Background Map
0 3 6 9 12 15 km

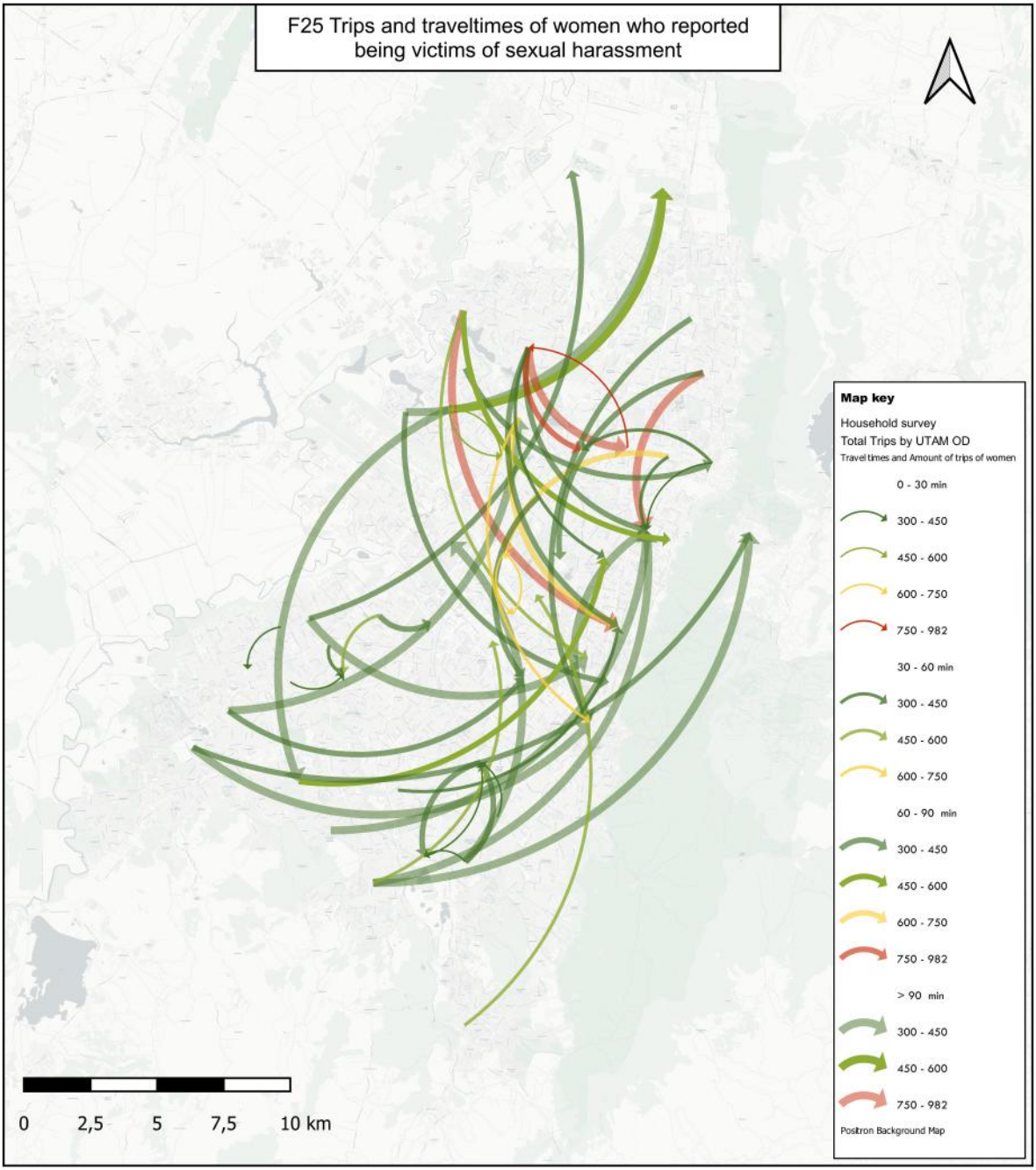

F20 Amount of self-contained (local) trips by TAZ for work-related trips
Map key
Household survey
Total Trips by TAZ
Self-contained work related trips
< 50
50 - 100
100 - 250
250 - 500
500 - 1000
> 1000
Positron Background Map
0 3 6 9 12 15 km

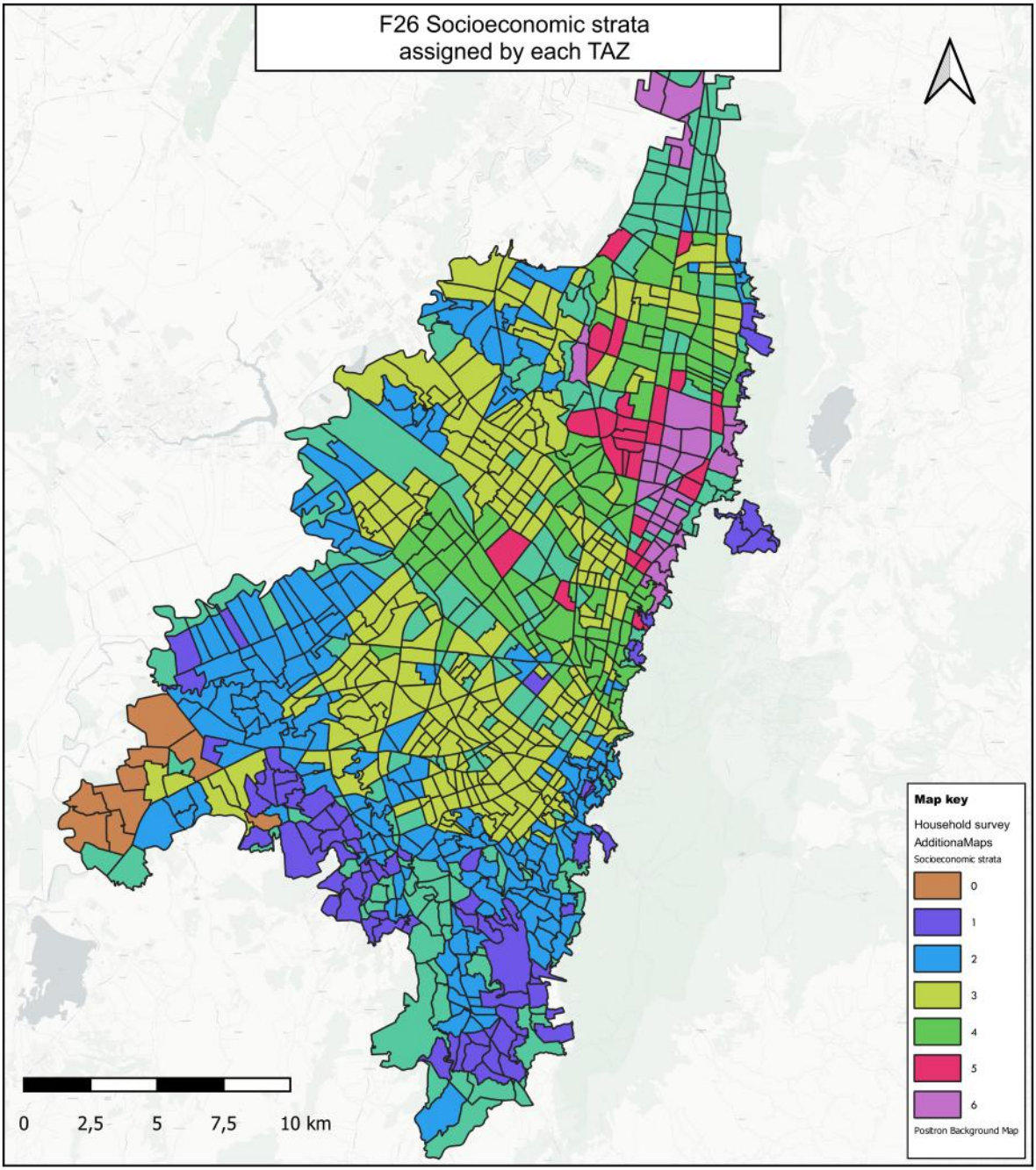

F22 Women's total work-related trips by UTAM
Map key
Household survey
Total Trips by UTAM OD
Women work related trips by OD
1000 - 1250
1250 - 1500
1500 - 1750
1750 - 2000
3500 - 7215
Centroids
UTAMs_EODH19
Positron Background Map
0 3 6 9 12 15 km

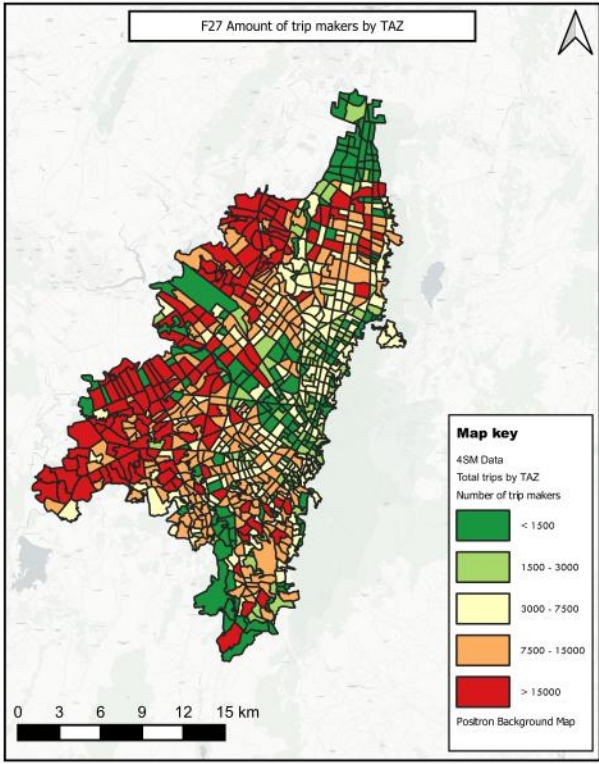

F22 Men's total work-related trips by UTAM
Map key
Household survey
Total Trips by UTAM OD
Men work related trips by OD
1000 - 1250
1250 - 1500
1500 - 1750
1750 - 2000
3500 - 7215
Centroids
UTAMs_EODH19
Positron Background Map
0 3 6 9 12 15 km

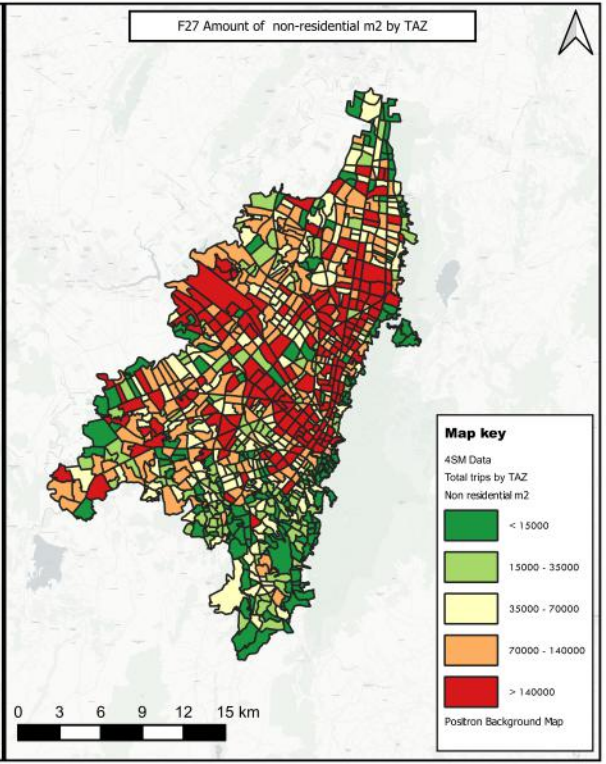

F23 Travel time of women's
work-related trips by UTAM
Map key
Household survey
Total Trips by UTAM OD
Women work related trip times by OD
0 - 15
15 - 30
30 - 60
60 - 90
> 90
Positron Background Map
0 3 6 9 12 15 km

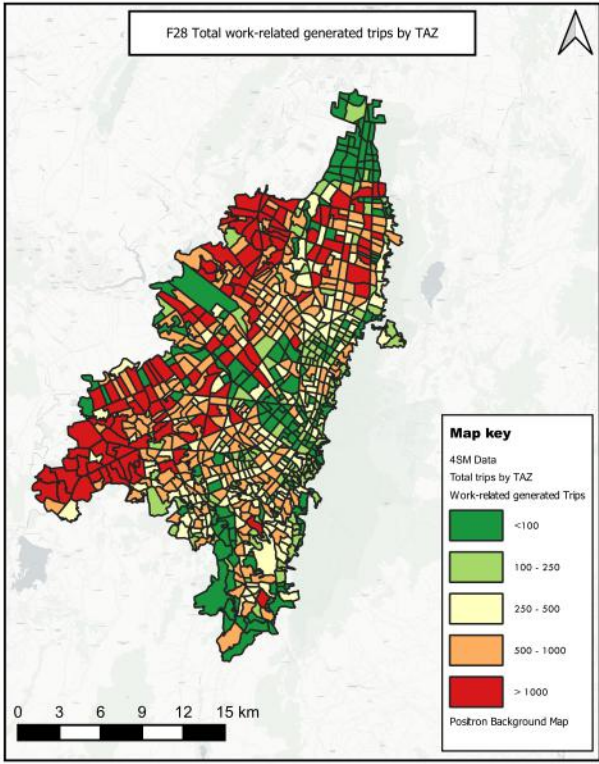

F23 Travel time of men's
work-related trips by UTAM
Map key
Household survey
Total Trips by UTAM OD
Men work related trip times by OD
0 - 15
15 - 30
30 - 60
60 - 90
> 90
Positron Background Map
0 3 6 9 12 15 km

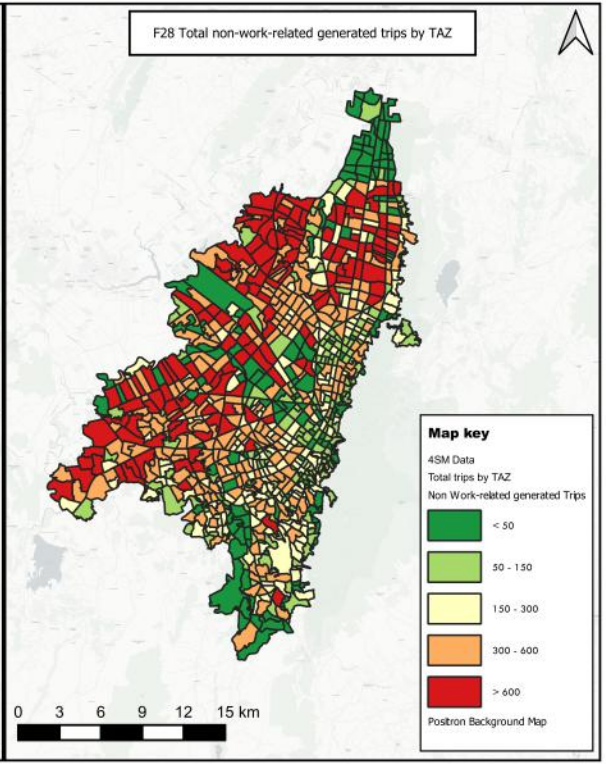

F25 Trips and traveltimes of women who reported being victims of sexual harassment
Map key
Household survey
Total Trips by UTAM OD
Travel times and Amount of trips of women
0 - 30 min
300 - 450
450 - 600
600 - 750
750 - 982
30 - 60 min
300 - 450
450 - 600
600 - 750
60 - 90 min
300 - 450
450 - 600
600 - 750
750 - 982
> 90 min
300 - 450
450 - 600
750 - 982
Positron Background Map
0
2,5
5
7,5
10 km

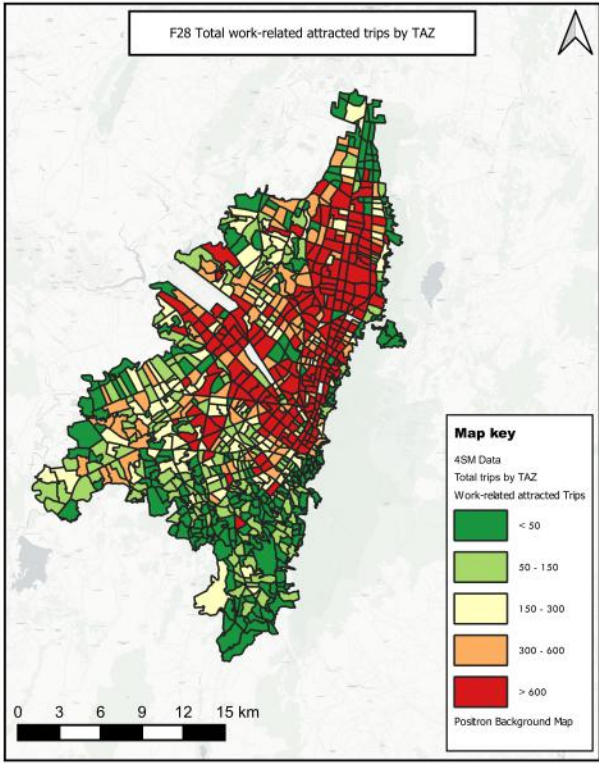

F26 Socioeconomic strata
assigned by each TAZ
Map key
Household survey
AdditionaMaps
Socioeconomic strata
0
1
2
3
4
5
6
Positron Background Map
0
2,5
5
7,5
10 km

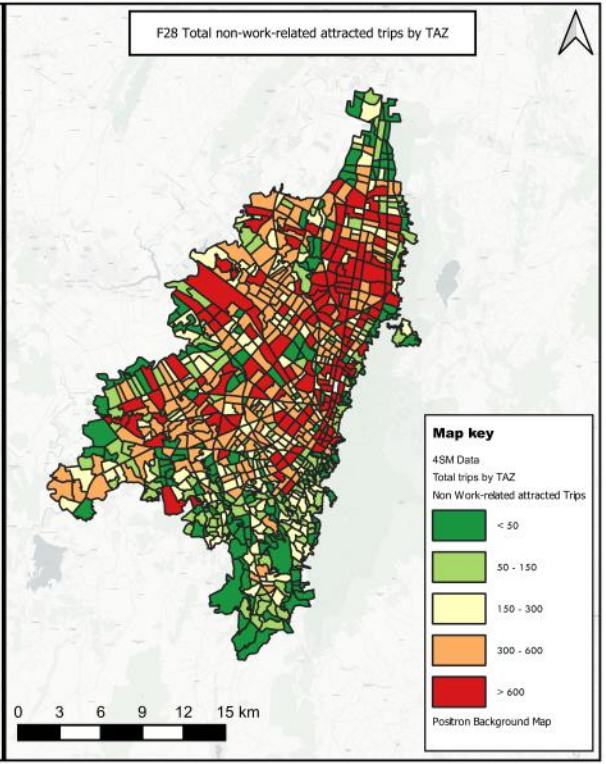

F27 Amount of trip makers by TAZ
Map key
4SM Data
Total trips by TAZ
Number of trip makers
< 1500
1500 - 3000
3000 - 7500
7500 - 15000
> 15000
Positron Background Map
0 3 6 9 12 15 km

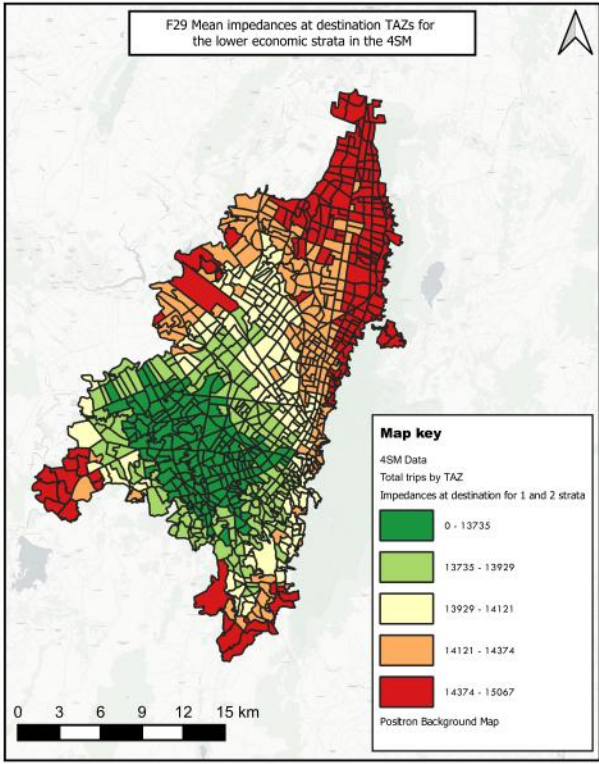

F27 Amount of non-residential m2 by TAZ
Map key
4SM Data
Total trips by TAZ
Non residential m2
< 15000
15000 - 35000
35000 - 70000
70000 - 140000
> 140000
Positron Background Map
0 3 6 9 12 15 km

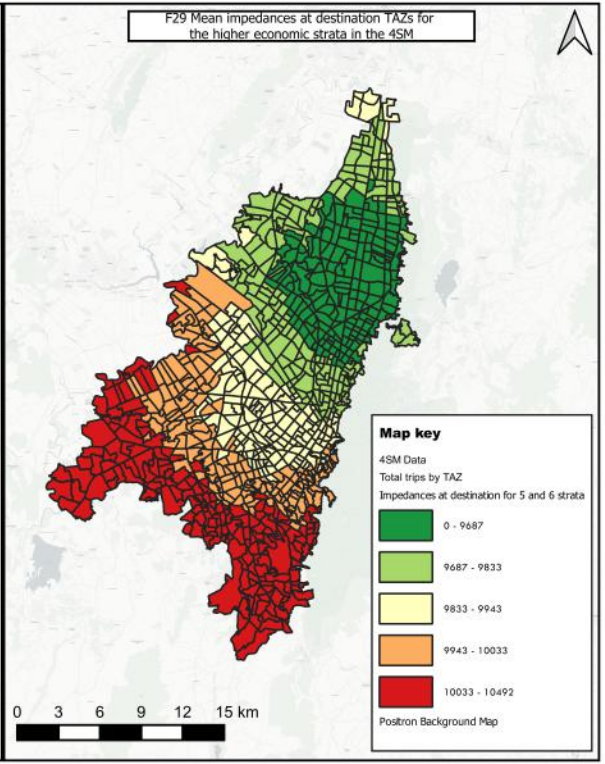

F28 Total work-related generated trips by TAZ
Map key
4SM Data
Total trips by TAZ
Work-related generated Trips
<100
100 - 250
250 - 500
500 - 1000
> 1000
Positron Background Map
0 3 6 9 12 15 km

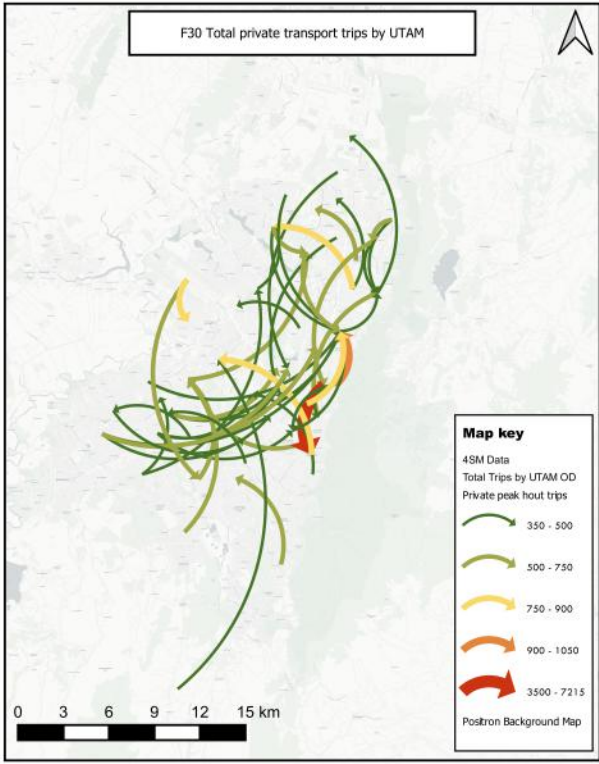

F28 Total non-work-related generated trips by TAZ
Map key
4SM Data
Total trips by TAZ
Non Work-related generated Trips
< 50
50 - 150
150 - 300
300 - 600
> 600
Positron Background Map
0 3 6 9 12 15 km

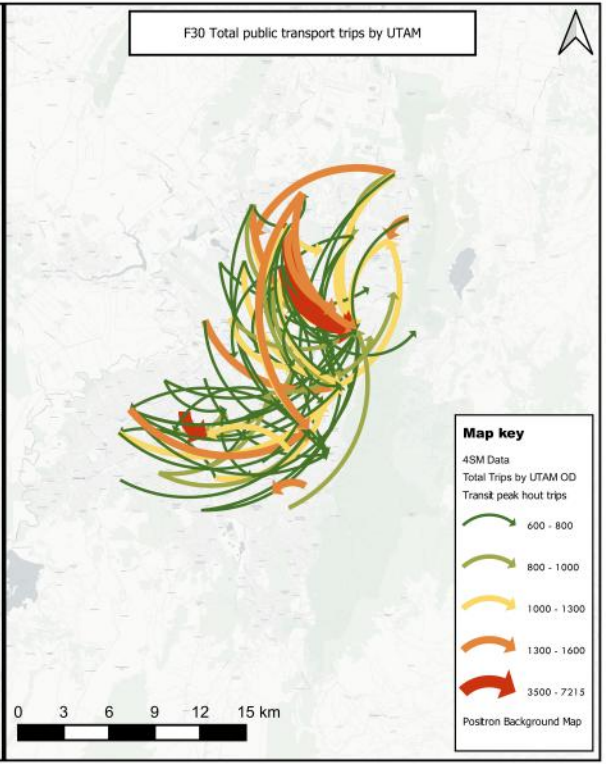

F28 Total work-related attracted trips by TAZ
Map key
4SM Data
Total trips by TAZ
Work-related attracted Trips
< 50
50 - 150
150 - 300
300 - 600
> 600
Positron Background Map
0 3 6 9 12 15 km

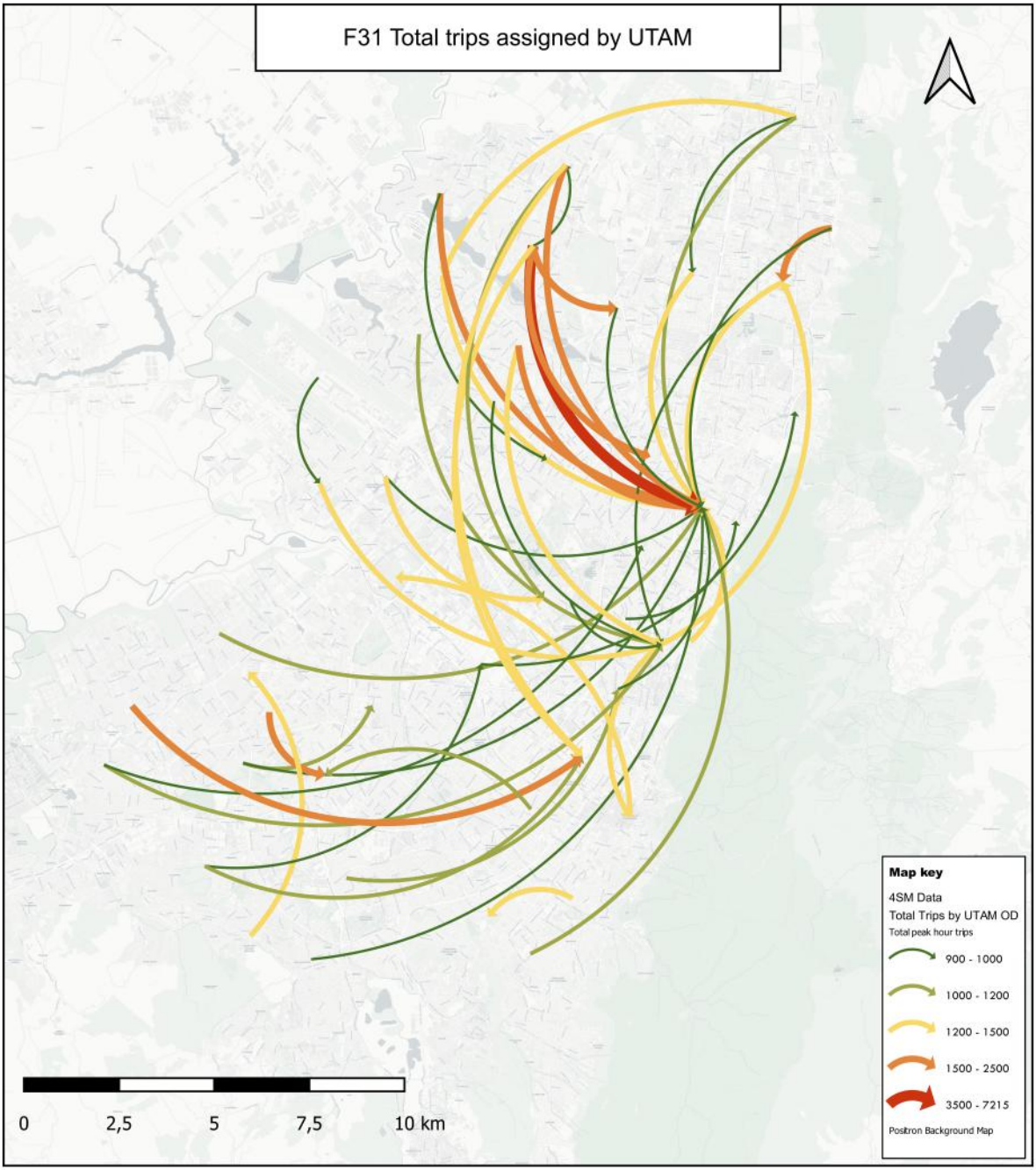

F28 Total non-work-related attracted trips by TAZ
Map key
4SM Data
Total trips by TAZ
Non Work-related attracted Trips
< 50
50 - 150
150 - 300
300 - 600
> 600
Positron Background Map
0 3 6 9 12 15 km


F29 Mean impedances at destination TAZs for the lower economic strata in the 4SM
Map key
4SM Data
Total trips by TAZ
Impedances at destination for 1 and 2 strata
0 - 13735
13735 - 13929
13929 - 14121
14121 - 14374
14374 - 15067
Positron Background Map
0 3 6 9 12 15 km


F29 Mean impedances at destination TAZs for the higher economic strata in the 4SM
Map key
4SM Data
Total trips by TAZ
Impedances at destination for 5 and 6 strata
0 - 9687
9687 - 9833
9833 - 9943
9943 - 10033
10033 - 10492
Positron Background Map
0 3 6 9 12 15 km


F30 Total private transport trips by UTAM
Map key
4SM Data
Total Trips by UTAM OD
Private peak hout trips
350 - 500
500 - 750
750 - 900
900 - 1050
3500 - 7215
Positron Background Map
0 3 6 9 12 15 km


F30 Total public transport trips by UTAM
Map key
4SM Data
Total Trips by UTAM OD
Transit peak hout trips
600 - 800
800 - 1000
1000 - 1300
1300 - 1600
3500 - 7215
Positron Background Map
0 3 6 9 12 15 km


F31 Total trips assigned by UTAM
Map key
4SM Data
Total Trips by UTAM OD
Total peak hour trips
900 - 1000
1000 - 1200
1200 - 1500
1500 - 2500
3500 - 7215
Positron Background Map
0
2,5
5
7,5
10 km