Agent-Based Modeling of Female Mobility: Informing Transport Policy Through Gender-Informed Approaches in Pakistan

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By

Amina Haider ***Roll No: 24100205***

Mehreen Naveed ***Roll No: 23100165***

Advisor: Dr. Talha Manzoor
Assistant Professor, EE.

Co-Advisor(s): Dr. Momin Uppal
Associate Professor, EE.

Department of Electrical Engineering,
Syed Babar Ali School of Science and Engineering,

Lahore University of Management Sciences, Pakistan

PROJECT ABSTRACT

Female mobility has always been a significant issue in Pakistan. While public transport infrastructure exists in major cities, concerns of safety, socio-cultural norms, comfort, and awareness remain as top concerns for women. On multiple instances, policies introduced to improve female-mobility have not been able to bring about the desired effect. The objective of our project is to evaluate the current state of public transportation in Lahore and evaluate the impact of potential gendered transport policies both separately and in tandem. An agent-based mobility model is created in NetLogo to simulate situations in which potential transport policies such as gender-segregated services are implemented in the Lahore Bus Rapid Transit (BRT). The aim of this project is to assess the impact of implemented policies on female mobility. The results from these simulations are used to create a policy library which can be used as a reference to make informed policy changes to improve female mobility in Lahore.

ACKNOWLEDGMENTS

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ORIGINALITY CERTIFICATE

"We the undersigned certify that this submission is the original work of members of the group and meets the Faculty's Expectations of Originality":

1. ***Amina Haider [2024-10-0205]***
   Signature: ____________________ 24100205@lums.edu.pk

2. ***Mehreen Naveed [2023-10-0165]***
   Signature: ____________________ 23100165@lums.edu.pk

Advisor (Name and Signature)

____

talha.manzoor@lums.edu.pk

Co advisor(s) (Name(s) and Signatures(s))

____

momin.uppal@lums.edu.pk

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Chapter 1

INTRODUCTION

1.1: MOTIVATION

Transport is fundamental towards driving economic and social development – connecting individuals and providing them with access to work, education, and healthcare. However, the transportation sector's share of global carbon dioxide emissions is 20.2%, making it the second-largest carbon-polluting sector in the world [1]. These emissions are mainly from the burning of petroleum-based fuels, such as diesel and gasoline, in the internal combustion engines of vehicles. As populations and economies continue to grow, it is imperative to shift towards sustainable transport systems. One aspect of sustainable transport systems is the provision of intra-city public transport. However, when designing public transport systems, gender sensitive aspects are rarely taken into consideration. There are inherent differences in the mobility needs of men and women within a community, and transport policy should address all of these needs.

In Pakistan, as in many other developing countries, female mobility is intricately intertwined with deeply rooted socio-cultural norms and structural constraints. Unequal access to transportation resources not only limits womens' ability to participate in the workforce and access essential services, but also continues to propagate gender disparities across various facets of society. Although women in Pakistan travel less than men, as a proportion of non-walking trips, they are significantly more dependent on public transport modes than men. However, concerns over safety, harassment, and social reputation pose significant challenges for women when it comes to using public transport [2]. In a study aiming to assess the safety concerns of women and girls using public transport in Lahore, it was found that "about 90% of women report experiencing sexual harassment on buses" [3]. The situation is equally dire across the country. In attempts to improve female mobility in Lahore, women-only bus services were introduced, however, due to limited geographic coverage, restricted timings, and lack of publicity, these services only benefitted a small proportion of the city's female population before being discontinued in 2014 [2]. Similar public and private women-segregated transport initiatives continue to spring up across the country from time to time on a limited scale. However, while such initiatives do work as short-term solutions to improve female mobility, it is extremely important to consider the long-term consequences of strengthening the notion that men and women require separate spaces [4].

Given the current public transport situation in Lahore, specifically for women from lower socio-economic backgrounds that do not have access to private vehicles, we aim to look at the short and long-term impacts of improving public transport in terms of female mobility and the introduction and wide-scale adoption of women-segregated transportation services before advising policy changes. We also aim to factor in psychological decision-making in women in regards to mobility when modelling these scenarios.

1.2: PROBLEM STATEMENT

Female mobility has always been a significant issue in Pakistan, particularly within certain segments of the population. Through this project, we aim to use agent-based modelling, to depict multiple scenarios restricted to the Lahore Bus Rapid Transit (BRT). Both gender-inclusive and gender-segregated transport policies are explored, with focus on assessing the short- and long-term impacts on female mobility. Based on our findings, we create a policy library with simulated results, and based on these, propose relevant reforms to transport policy in Lahore.

1.3: GENERAL BLOCK DIAGRAM

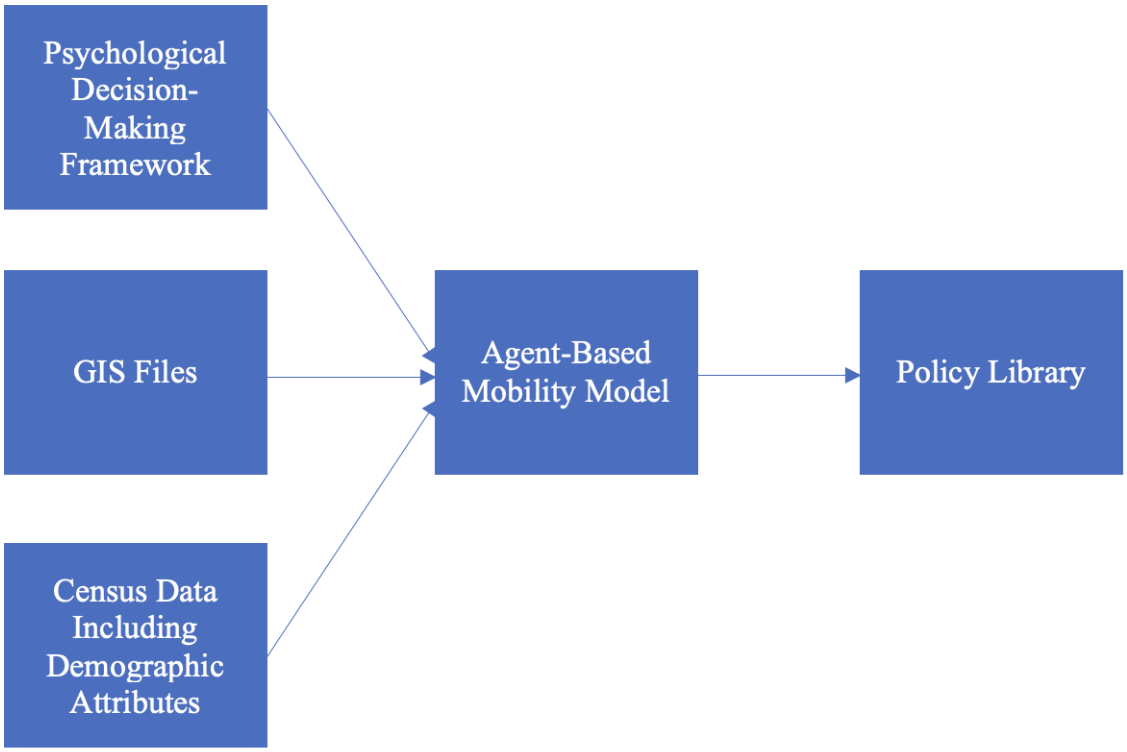


Fig. 1 General Block Diagram for the Project

As depicted in figure 1, three elements will go into making the agent-based mobility model : the psychological decision-making framework, GIS files for the Lahore BRT, census data and demographic attributes such as the gender distribution of Lahore. After creating the model, predictive scenarios will be run on the final model and a policy library based on simulation results will be created.

1.4: SOCIAL BENEFITS AND RELEVANCE

Adopted by all UN Member States in 2015, the Sustainable Development Goals (SDGs) are a set of 17 interconnected goals designed to act as a blueprint towards a better and more sustainable future. SDG 5, Gender Equality, aims to achieve gender equality and empower all women and girls. Target 5.a of the SDGs is to "undertake reforms to give women equal rights to economic resources, as well as ownership and control over land and other forms of property, financial services, inheritances and natural resources, in accordance with national laws" [5]. SDG 11, Sustainable Cities and Communities, aims to make cities and human settlements inclusive, safe, resilient and sustainable. Target 11.2 states that "by 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons" [6].

This project focuses on tackling the problem of female mobility in Lahore, which is both a gendered issue and one of sustainable transport. The findings of this project will help advise policy changes to existing transport law in Pakistan, identifying the most impactful mechanism in gender-informed transport design while taking into account female mobility impacts in the short- and long- term. The benefit of increasing female mobility is two fold: first, it will allow for women, especially from lower-socioeconomic backgrounds, to have improved access to work, education, healthcare, and other economic resources – working towards improving gender equality – and second, increased female mobility will lead to economic growth in the country, as more women enter the workforce and participate in the economy. These benefits become particularly relevant in Pakistan, where deeply ingrained social and cultural norms greatly inhibit a woman's freedom and ability to take space in the public sphere.

Furthermore, while some survey-based research has been done on the problems faced by women using Lahore's public transport [7], the question of whether the gender-segregated or gender-inclusive approach is more suitable for addressing the transport needs of Lahore – and as an extension Pakistan – has largely gone unanswered. Our research takes a gendered-approach towards activity-based travel demand and supply, using an agent-based model to design a predictive simulation which captures both female decision-making phenomenon and real-time data about Lahore's BRT and Metro System to run multiple scenarios and identify the most impactful one. This approach is entirely novel in the scope of Pakistan's transport systems.

1.5: GOALS

The goal of our project is to determine the best way forward for improving female mobility. The scope of this research project is limited to the specific case of BRT in Lahore, Pakistan. We aim to look at psychological decision-making in women, and address the impacts of multiple gendered-transport policies in attempts to improve female mobility.

1.6: OBJECTIVES

We have identified a gap in the literature which does not address gender-based mobility in Pakistan. We intend to focus on why there is gender discrepancy in public transportation usage and how we can suggest policy changes to make the environment more conducive to both genders. Our objective is to evaluate the current state of public transportation, specifically the BRT and Metro and women-segregated services in Lahore, using an agent-based modelling approach. This will help understand the dynamics of safety, accessibility, and efficiency for female users, especially those from lower socio-economic backgrounds.

We aim to measure the psychological impact of these transportation modes on women's decision-making by employing a psychological model. The model will focus on perceived safety, comfort, cultural stigmas, awareness, and affordability among other factors. We will use the model to provide insights into the mental processes women undergo when choosing a mode of transportation.

Using agent-based modelling to depict the scenarios, the model will look at the benefits and challenges of public transportation and women-segregated services. This comparison will identify areas of improvement and potential integration. Through this, we aim to gain a comprehensive view of the transportation landscape for women in Lahore.

Finally, we intend to propose evidence-based transport policy changes by the end of the project timeline. These changes will be tailored to enhance female mobility in Lahore, with a special emphasis on addressing the needs of women from lower socio-economic backgrounds. They will be informed by the insights gained from the previous objectives.

1.7: OUTCOMES

The first outcome we aim to achieve is an enhanced understanding of female mobility. Evaluating current transportation modes and the psychological impact on women's decision-making will lead to a deeper understanding of the challenges and preferences of female commuters in Lahore, especially those from lower socio-economic backgrounds.

Further, the agent-based modelling will provide stakeholders with a comprehensive view of the transportation landscape for women in Lahore. This will aid in identifying gaps and areas of potential integration between public transportation and women-segregated services.

The project will also produce a set of policy recommendations grounded in empirical data. These policies, when implemented, are expected to bring about significant improvements in female mobility in Lahore.

Due to these proposed policy changes and recommendations, we intend to increase awareness of female commuters' issues, especially those from lower socio-economic backgrounds. We anticipate long-term improvement in the safety, accessibility, and efficiency of transportation modes for women in Lahore.

1.8: DELIVERABLES (OUTPUTS)

1. Agent-Based Mobility Simulation Model for Female Commuters in Lahore: To provide a visual representation of the transportation landscape for women in Lahore, considering various factors that influence their mobility choices.

Deliverable: Interactive Agent-Based Simulation Tool: This tool will employ agent-based modelling to depict the transportation landscape for women in Lahore. Users can view the movement and decisions of individual agents (representing female commuters) within the simulation environment. The tool will have features like:

- What-if Scenarios: Users can test different scenarios, such as changes in transportation availability, safety measures, or socio-economic factors.
- Visualisation Dashboard: A user-friendly interface that displays the results of the simulation in real-time, using graphs, charts, and maps.
- Parameter Modification: Stakeholders can adjust certain parameters to understand the potential impact of different interventions on female mobility.

2. Policy Library: To compile existing policies related to female mobility in Lahore and identify gaps or areas of improvement.

Deliverable: Comprehensive Policy Library Document: This document will list all existing policies, regulations, and guidelines related to female mobility in Lahore. It will also highlight areas where current policies may be lacking or where improvements can be made. The library will serve as a reference point for policymakers and stakeholders.

1.9: TIMELINE AND DISTRIBUTION OF WORK

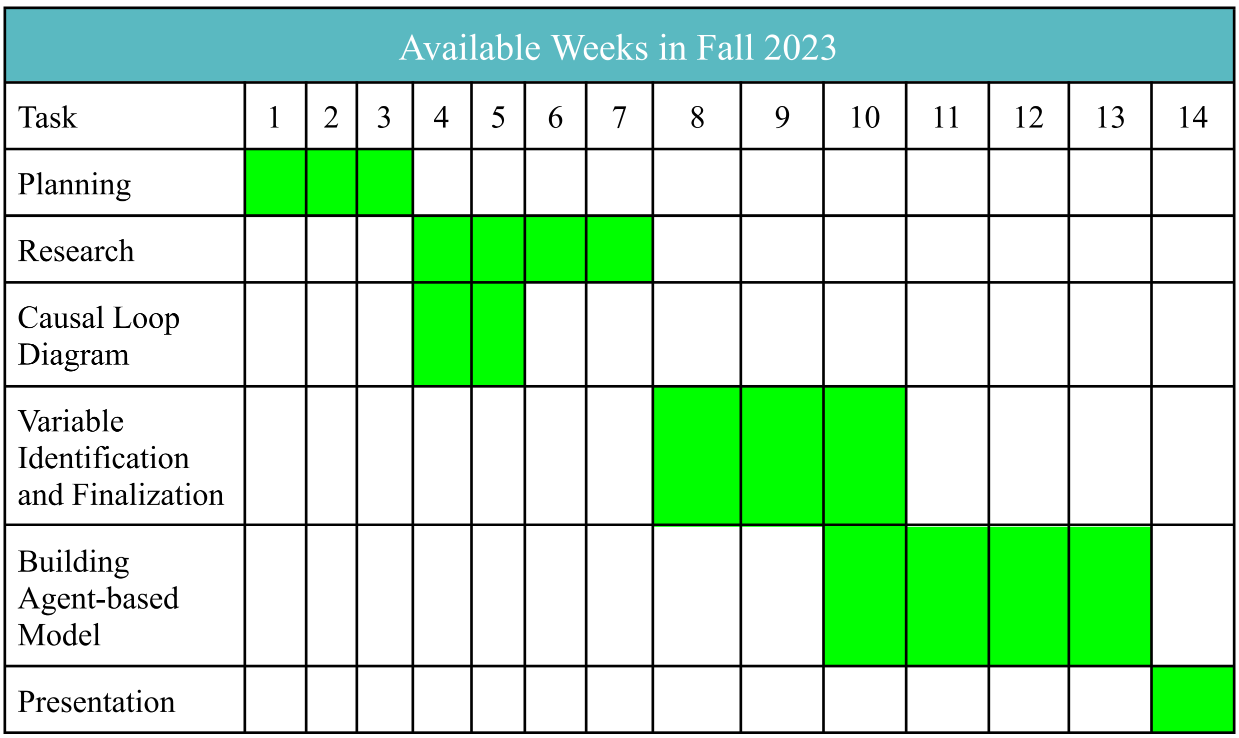
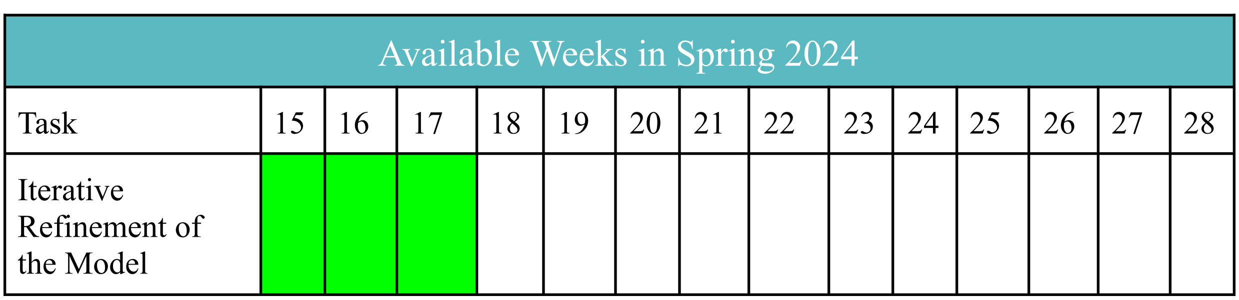


Fig. 2 Gantt Chart for Fall 2023



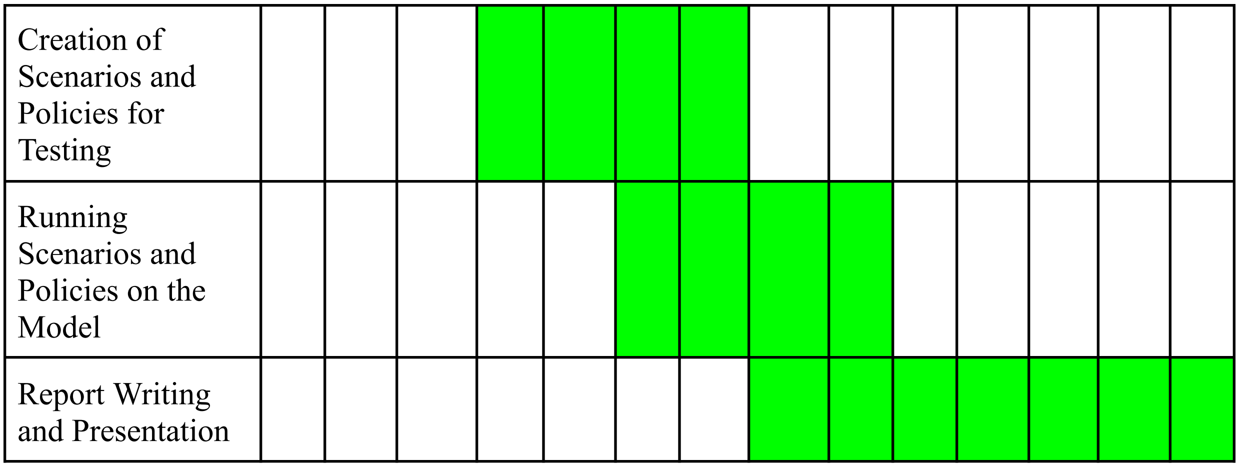


Fig. 3 Gantt Chart for Spring 2024

Table 1 DISTRIBUTION OF WORK

Task	Responsible Person	Planned Duration
Planning	Amina and Mehreen	3 weeks
Research		4 weeks
Causal Loop Diagram		2 weeks
Variable Identification and Finalisation		3 weeks
Building Agent-Based Model		4 weeks
Presentation		1 week
Iterative Refinement of the Model		3 weeks
Creation of Scenarios and Policies for Testing		4 weeks
Running Scenarios and Policies on the Model		4 weeks
Report Writing and Final Presentation		7 weeks

Chapter 2

BACKGROUND

2.1: LITERATURE REVIEW

The literature review is divided into two sections. In the first section, we examine the causes and the short/long-term impact of low female mobility in Pakistan and look at the gender-segregated transport policies implemented by the Pakistani government. The second section focuses on computational modelling. We review existing models in the literature to understand how to create an accurate model to identify patterns, predict outcomes, and simulate female mobility in Pakistan.

2.1.1: FEMALE MOBILITY IN PAKISTAN

Understanding why female mobility is low in Pakistan requires an in-depth explanation of the socio-cultural and economic causes and infrastructural limitations.

2.1.1.A: SOCIO-CULTURAL FACTORS

The literature determines that mobility in Pakistan is influenced by traditional gender norms. Pakistani men are allowed to freely access the public sphere, but women are expected to minimise movement beyond their homes, which is seen as inappropriate [9]. Furthermore, 56% of Pakistani women claimed to dedicate 8+ hours to domestic chores versus 23% of men [10]. Therefore, the majority of Pakistani women do not have the time to travel outside their homes. Moreover, due to common crimes/violence against women in Pakistan, safety concerns limit female mobility. For example, 80% of women surveyed in Karachi declared public transport as "highly unsafe" [10]. Additionally, a 2014 report by the Asian Development Bank (ADB) states that 70% of Pakistani women reported experiencing harassment while using public transportation. As a result, women are less likely to use public transport, as is evident by the fact that only 31% of female students, 23% of working women, and 20% of homemakers use public transportation [1].

2.1.1.B: ECONOMIC FACTORS

Economic factors decrease women's mobility. Most Pakistani women do not have the money to purchase private vehicles, such as cars, which are a relatively safer option. Furthermore, gender norms discourage women from using cycles/motorbikes, which are cheaper, leaving them no option but to use unsafe public transportation [10].

Women's mobility is also reduced by poverty as many Pakistani women cannot afford public transportation. Furthermore, due to gender-roles and the patriarchy, many families choose to prioritise men's transportation needs [10] over women's.

This creates a cycle. Low female mobility prevents women from accessing economic opportunities and reduces female labour-force participation. This results in decreased financial resources (and an increased dependence on men), which in turn further limits women's mobility.

2.1.1.C: TRANSPORT INFRASTRUCTURE

Limited and poor infrastructure lowers female mobility in Pakistan. The literature states that poor infrastructure, such as litter and dimly-lit streets and transportation stations make women feel unsafe [11]. This is known as Defensible Space Theory, which argues that "poor design enables conditions for crime" [12]. Furthermore, transport stations are located far from residential areas, requiring women to walk long distances. Pedestrian infrastructure (e.g. footpaths, crosswalks, etc.) is either non-existent or poorly-maintained [9]. Lastly, women often have to travel in overcrowded vehicles with limited seating (if any) reserved for them, which is often occupied by men. [10].

2.1.1.D: GENDER SEGREGATED INITIATIVES

The Pakistani government has started many gender-segregated initiatives to improve female mobility, like the Pink Buses Project in Lahore [11]. Women-only transport services are likely to be safer and more culturally-acceptable for Pakistani women. However, it is unknown if they are sustainable or even helpful in the long-run.

2.1.2: COMPUTATIONAL MODELING

In order to make a computational model which can simulate the Lahore BRT, we thoroughly review the existing literature and learn about which methodologies, tools, and strategies have been successful for similar projects.

Women's mobility patterns in developing countries are highlighted by Nadimi, Sangdeh, and Amiri in *"Deciding about the Effective Factors on Improving Public Transport Popularity among Women in Developing Countries"* . They used structural equations modelling (SEM) and interviewed women in Tehran, Iran to determine what affects the popularity of local public transportation methods such as regular buses (RB), Tehran Bus Rapid Transit (BRT), and Metro. The results indicate that as income, education, and car ownership increase, women's preference for regular buses (RB) decreases. Moreover, we can see that higher costs and increased waiting times reduce use of the Tehran Bus Rapid Transit (BRT), and Metro [13]. The use of Structural equations modelling (SEM) stood out as a possible approach for our project.

We looked at a few studies on urban mobility as well. These were helpful as the methodology could be modified for our project. For example, *"Effects of Street Pattern, Traffic, Road Infrastructure, Socioeconomic and Demographic Characteristics on Public Transit Ridership"* focused on how *"different street patterns, traffic, infrastructure, and socio-demographic factors"* affect public transport use in Calgary, Canada. The study used the Ordinary Least Square Regression Model. The results show that *"an increase in commercial areas, expressways/highways, and train stations"* is positively correlated with increased public transport use [14]. Similarly, *"Factors Affecting Modal Choice in Urban Mobility"* by Y. Tyrinopoulos and C. Antoniou looks at what affects the "modal choices of commuters" in Greece. By using Probit, structural equations modelling (SEM), and statistical analysis, the study concluded that an increase in the use of passenger vehicles is caused by the availability of parking space and public transportation use decreases due to overcrowding [15].

The most useful paper we found is titled *"Fully Agent-based Simulation Model of Multimodal Mobility in European Cities"* by M. Certicky, J. Drchal, M. Cuchy, and M. Jakob. They developed a "large-scale activity-based" model which simulated millions of inhabitants across

Europe cities as “autonomous, self-interested agents which schedule and execute their activities and trips in time and space” [16]. The work by Certicky et al. demonstrates the potential of agent-based modelling in transportation research.

2.1.3: NEED FOR THE STUDY AND MODELLING

The Pakistani government has launched many women-only transport initiatives to improve female mobility. However, we do not know the long-term impact of such initiatives.

Additionally, no prior studies have used agent-based modelling to analyse female mobility in Pakistan. Agent-based modelling considers individuals as independent agents who make their own real-time decisions. Therefore, it can be used to simulate female mobility, especially use of the Lahore BRT to determine the impact of transportation policies such as gender-segregated buses and create a policy library which suggests policy recommendations to the Pakistani government to improve female mobility, and thus, Pakistani women’s economic well-being and overall quality of life.

Chapter 3

METHODOLOGY AND TOOLS

3.1: SYSTEM LEVEL DESIGN

A model is an abstracted description of a process, object, or event in order to answer a question. Our project aims to analyse the factors which affect female mobility in Pakistan and simulate gender-segregated policies in the Lahore BRT system – both separately and in tandem – to predict their impact. Since this problem involves a complex system and decision-making at the individual level, a bottom-up modelling approach is used to identify patterns from the local interactions and decision-making of individuals using the Lahore BRT, as depicted in fig. 4.

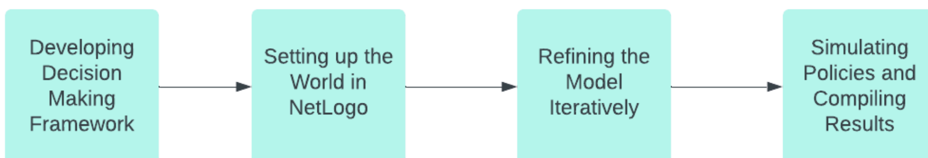


Fig. 4 Process to Create the Final Agent-based Mobility Model

As initially described in fig.1, several elements come together to create the final agent-based mobility model including a decision-making framework i.e., a psychological model, transport networks, map database, and demographic attributes. At a system level, the process can be categorised into four main blocks: collection of data, creating the psychological framework, setting up the world, and iteratively refining the model (refer to fig. 5).

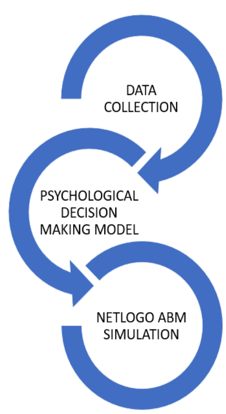


Fig. 5 System Level Design

3.1.1: DATA COLLECTION

For our project, we collected data from several reliable sources. Our approach was influenced by the techniques in *"Fully Agent-based Simulation Model of Multimodal Mobility in European Cities"* which provided us with a general framework on the types of data we needed to collect, specific to the city of Lahore, Pakistan [16]. To ensure high accuracy and reliability of our model, we collected comparable data in terms of quality and type.

The primary source of the demographic data of Lahore was the website of the Pakistan Bureau of Statistics, run by the Government of Pakistan [17], which hosts the latest census data. The data collected included population, age, and other demographic factors for Lahore and the urban localities (districts or *mohallas*) within the city. This data will be essential to the accuracy of the representative agents, i.e. the Lahori population, in our model.

For geographical and infrastructural data, the *CITY@Lums*[1] group at the Lahore University of Management Sciences, provided us with GIS shapefiles of Lahore and its public transport system, including the BRT and Orange Line. These files are required for accurately visualising the Lahore BRT network and surrounding districts (*mohallas*) within our model.

For the psychological model, we utilised survey data from the doctoral dissertation of Dr. Muhammad Aamir Basheer and *Urraan*[2], which was made available to us by *CITY@Lums*. Detailed information about this can be found in section 3.1.2.

Lastly, we obtained the timetable, routes, station names, and other relevant information about the Lahore Metrobus System from the Punjab Mass Transit Authority website, run by the Punjab government [18]. Data regarding the operation of the BRT is essential for accurately modelling the operation of the BRT line in our simulation.

[1] https://city.lums.edu.pk/
[2] https://uraan.com.pk/

3.1.2: PSYCHOLOGICAL DECISION-MAKING FRAMEWORK

3.1.2.A: LITERATURE REVIEW

Our literature review was divided in two sections: the first aimed to identify variables for our psychological model and the second focused on the framework for analysis, namely the Theory of Planned Behavior.

3.1.2.A.A: IDENTIFYING THE VARIABLES IMPACTING PUBLIC TRANSIT USE

We conducted a literature review to identify and analyse various factors influencing an agent's decision to use the Lahore BRT. These factors include safety perceptions, awareness, comfort levels, the preference for private versus public vehicles, socio-cultural norms, the quality of transport infrastructure, security measures, and the overall layout of the transit environment.

From our investigation, the following variables stood out due to their significant impact on the use of public transport.

3.1.2.A.B: GENDER

According to Nadimi, Sangdeh, and Amiri, the impact of gender on decision-making in the context of public transport is significant in developing countries including Pakistan [13]. Additionally, as per the World Bank, Pakistan's female labour force participation is a low 20%, a figure which highlights the substantial gender gap in the country [14]. Limited access to employment for women results in limited mobility, affecting their use of public transport services. By incorporating gender as a variable in our model, we acknowledged the complex interplay of social, economic, and cultural factors which shape public transport usage patterns, ensuring our model accurately reflects the gender-specific nuances of decision-making.

Our model treats agents as either male or female, using the gender distribution data from the 2017 Pakistan Census to ensure an accurate reflection of Lahore's population composition and understand the gender-specific nuances of transportation mode choice.

3.1.2.A.C: PT ATTITUDE

"PT Attitude" measures a passenger's overall feeling about using public transportation. We know from a study conducted in Calicut, India titled "Influence of Psychological Factors in Mode Choice Decision Making: A Structural Equation Modelling Approach" that there exists a relationship between attitude towards public transport ("PT Attitude") and the frequency of use [20]. Given the shared history of Pakistan and India, there are many similarities in the public transit environments of Calicut and Lahore. Therefore, we take into account the impact of "PT Attitude" in our psychological model to see how the preference for public over private transport, individual comfort requirements, and affordability can impact public transportation use.

To measure a respondent's opinion, it is best to use a psychometric rating scale. The Calicut paper measures "PT Attitude" using the Likert scale which specifies a respondent's level of agreement or disagreement by assigning a score to each agent which ranges from -2 to 2. -2 represents strong disagreement and 2 represents strong agreement. The statements evaluated included:

- "I enjoy travelling by public transit" [20].
- "I prefer public transit to driving" [20].
- "I find the facilities of public transit comfortable" [20].
- "Public transit is affordable" [20].

Agents in our model will be assigned scores accordingly to quantify their "PT Attitude".

3.1.2.A.D: PV ATTITUDE

"PV Attitude" measures a passenger's overall feeling about using private transportation. We know from a study conducted in Calicut, India that there exists a relationship between attitude towards private transport ("PV Attitude") and usage patterns of public transportation [20]. Given the shared history of Pakistan and India, there are many similarities in the examined public transit environments of Calicut and Lahore. Therefore, we have accounted for "PV Attitude" in our psychological model to see how the preference for private over public transportation, safety concerns, and the prestige associated with private vehicle ownership can impact the frequency of use of public transportation.

The Calicut paper measures “PV Attitude” using the Likert scale, assigning a score specifying a respondent’s level of agreement or disagreement to each agent ranging from -2 to 2. The statements evaluated included:

- “I prefer private vehicles over public transit due to convenience” [20].
- “Private vehicles are safer than public transit” [20].
- “Private vehicles are a sign of prestige” [20].

Agents in our model will be assigned scores accordingly to quantify their “PV Attitude”.

3.1.2.A.E: FEELING OF SAFETY

“Feeling of Safety” captures passengers’ perception of personal safety or security while using public transportation and is influenced by crime, violence, and/or harassment. Compared to male agents, safety concerns are more significant for female agents as demonstrated by research conducted by United Nations Women Pakistan and the Asian Development Bank. These studies highlight significant concerns about sexual harassment on public transit systems. For instance, 80% of women surveyed in Karachi described public transport as "highly unsafe" [10] while a survey by the Asian Development Bank found that 70% of Lahori women who use public transport have experienced sexual harassment [1]. These findings are corroborated by Gardner [12] and the results of the *Urraan* survey, demonstrating the relationship between “Feeling of Safety” and transport choices. Therefore, we have incorporated the variable “Feeling of Safety” to our decision-making model to observe its impact on the frequency of use of public transportation.

“Feeling of Safety" is quantified using the Likert Scale to capture a variety of safety perceptions among public transport users, with scores ranging from "Very Safe" [2] to "Very Unsafe" [-2]. Analysis of the *Urraan* survey data revealed the primary factors influencing women's feeling of safety on public transport, such as theft, harassment, lack of security measures, prolonged waiting times, and a lack of seating for women. These factors have been incorporated into the model for female agents. For male passengers, we did not incorporate the “gendered” variables that disproportionately affect women, focusing instead on theft, lack of security, and long waiting times. This approach ensures the model accurately captures the different safety concerns and experiences of all public transport users.

To model the distribution of “Feeling of Safety” among our agents, we incorporated a methodologically-sound approach to reflect variability in perceptions' of safety and the subsequent impact on public transport choices. We assign values to agents based on a Gaussian distribution as many studies indicate that perceptions of safety among a sample of individuals follow a normal distribution [21]. We are assuming this holds true for our sample. This assumption is applied to our sample, ensuring that our model realistically represents the range and impact of safety concerns on public transport usage.

3.1.2.A.F: COMFORT

Comfort refers to the degree to which passengers find the public transportation environment both physically and psychologically pleasing. According to Friman, Lattman and Olsson, the significance of comfort in influencing decision-making can lead to more enjoyable and safe travel experiences, especially for women [22]. Many studies, including the findings from the *Urraan* survey, have shown that a lack of proper facilities can significantly discourage people from using public transport, especially women. In Lahore, the lack of seating reserved for women, alongside overcrowded conditions and insufficiently secure waiting areas, highlights these shortcomings which reduce the appeal of public transport, cause discomfort, and introduce safety risks, affecting women’s transport mode choices.

To quantify comfort, we used the Likert Scale with scores ranging from "Very Comfortable" [2] to "Very Uncomfortable" [-2], allowing for a nuanced assessment of passengers' perceptions. Next, we used the *Urraan* survey data to identify the primary factors that influence passengers' comfort levels on the Lahore BRT, such as disruptive behaviour, lack of amenities, unhelpful or unfriendly staff, and operational and infrastructural inadequacies.

To accurately model the feeling of comfort among the agents, we assigned values based on a Gaussian distribution as research suggests that comfort levels among a sample of individuals usually follow a normal distribution [23]. Our approach ensures that our model captures the variability in comfort perceptions among passengers and reflects the interaction of factors that contribute to these perceptions.

3.1.2.A.G: CONFIDENCE

"Confidence" is a variable measuring a passenger's self-assurance in navigating the use of public transport. To identify the factors affecting the frequency of use of public transport, we utilised the Calicut model from the literature, and were able to determine the causal link between "Confidence" and decision-making [20]. This link is strongest for women (or female agents) as supported by findings from the Women's Development Department, Punjab, which show that most Pakistani women who use public transport ignore incidents of violence or harassment and do not report them to the police due to low self-confidence [24].

To quantify confidence, we again used the Likert Scale, with scores ranging from "Very Confident" [2] to "Very Unconfident" [-2]. To accurately model the relationship between confidence and the frequency of use of public transportation, the agents were assigned random values from a Gaussian distribution. This was done to align with the previously discussed Calicut model, which showed that confidence levels among a sample of people followed a normal distribution [20].

3.1.2.A.H: AWARENESS

"Awareness" is a variable that represents the extent of a passenger's understanding of the Lahore BRT system, including routes, schedules, and fares. A survey from *Urraan* showed that the level of "Awareness" in the context of the Lahore BRT can influence the frequency of use. According to the Women's Development Department, Punjab, 98% of Pakistani women are not aware of any emergency helplines or mobile applications that could be used to report criminal activity on public transport (such as violence or harassment) [24]. This lack of awareness leaves women in a vulnerable position, thereby discouraging the use of public transport.

To assess the level of awareness among passengers, we utilise a modified Likert Scale, with the following scores: "Very Aware" [2], "Neither Aware or Unaware" [0], and "Very Unaware" [-2] to quantify the extent of passengers' knowledge about the Lahore BRT system. The demographic breakdown is obtained from the *Urraan* survey data to better align with the experiences of those who use the Lahore BRT regularly.

3.1.2.A.I: URGENCY

"Urgency" is the importance of a trip, affecting the choice of transport mode, particularly influenced by factors like the nature of the trip, time sensitivity, and the traveller's employment status. Intuitively, "urgency" in the context of trip making is a significant factor influencing the choice of transport mode, especially for female travellers. According to prior work, female travellers are often more flexible in their mode of transport compared to their male counterparts thus making "urgency" more likely to have an impact on choice of transport [13]. This flexibility stems from the nature of their trips, which tend to vary in time, purpose, and duration. Furthermore, the employment status of women directly impacts their public transit usage [25]. Given the differences in labour-force participation and trip flexibility between genders, we incorporated "Urgency" as a variable in our model to ensure we accurately simulate the dynamics affecting public transit usage.

For modelling purposes, we quantify the concept of urgency using a binary Likert scale with either "High Urgency" [2] or "Low Urgency" [-2]. To accurately reflect the demographic specifics, we incorporated the results from "The Case of Bus Rapid Transit Lahore Pakistan" by Dr. Muhammad Aamir Basheer of Ghent University in Belgium.

3.1.2.A.J: PV OWNERSHIP

"PV Ownership" is a binary variable which classifies agents based on whether they own a private vehicle or not. Based on the study conducted in Calicut, India, private vehicle (PV) ownership (or lack thereof) is a convenient and safe alternative to public transport and thus affects the frequency of use of public transport [20]. Furthermore, the impact of PV ownership on a passenger's choice between public and private transport is significant for women in Pakistan, where 80% of the women surveyed reported public transport as "highly unsafe" [10]. Therefore, we have added PV ownership to our decision-making model to simulate the impact on mode choice, especially among women.

3.1.2.B: THE THEORY OF PLANNED BEHAVIOR

We examined many decision-making frameworks to find the best approach for our model. The Theory of Planned Behavior (TPB) by Icek Ajzen was a good choice as it has been used as a decision-making framework throughout the literature, especially for modelling transport mode-choice [26].

According to the TPB, an individual's behaviour will depend on their intention, which is affected by three factors: "attitude", "subjective norms", and "perceived behavioural control" (refer to fig. 6) [26].

- Intention refers to the level of willingness of an individual to perform a specific behaviour [26].
- Attitude measures an individual's opinion and is determined by behavioural beliefs [26]. In our decision-making model, we have measured attitude using two variables: "PT Attitude" and "PV Attitude".
- Subjective norms indicate the perceived societal pressure to perform or not perform a behaviour which is influenced by cultural and social norms [26]. According to a survey conducted in Lahore, more than 70% of male respondents discourage female family members from using public transport, resulting in 15% of female commuters staying home [27] – clearly illustrating the impact of subjective norms on transport mode choice for women, necessitating their inclusion in our decision-making model.
    - To measure Subjective Norms (SN), we use the Likert scale, assigning scores from -2 to 2. The statement evaluated was: "most people who are important to me would support me using public transport" [20]. Although the Calicut model attributed a weight of 0 to this variable, we include it in our analysis for a comprehensive sensitivity analysis.
- Perceived behavioural control refers to the perceived ease or difficulty in performing a specific behaviour for an individual, and is determined by control beliefs such as past experiences [26]. To quantify PBC, we also employ the Likert scale. The statement evaluated to gauge PBC was: "I am confident that I can use public transit" [20].

To develop our psychological model, we have adopted the weights quantifying the influence of Perceived Behavioral Control (PBC), Subjective Norms (SN), PT Attitude, and PV Attitude on users' intent to choose public transportation from the Calicut model. Since we were unable to collect our own survey data and due to similarities in the urban environment of Calicut and Lahore, we are assuming the effects of these psychological factors on transportation preferences are similar in both cities. Therefore, we can use the findings of the Calicut model to predict the strength of the associations between these key psychological factors and the intention to use the Lahore BRT. The specifics of these weights are further elaborated in later chapters.

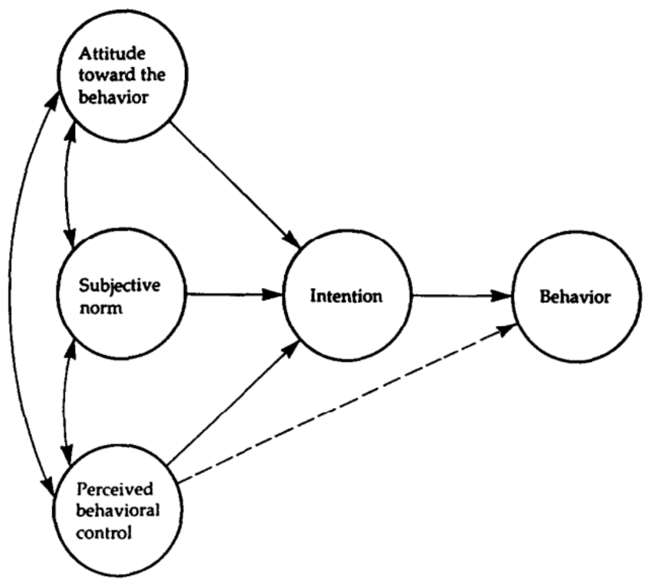


Fig. 6 The Theory of Planned Behavior [28]

In fig 6., we can see that the more positive the attitude, subjective norms, and perceived behavioural control, the stronger an individual’s intention to perform a certain behaviour. The power of attitude, subjective norms, and perceived behavioural control in predicting intention depends on the behaviour and situation [26].

The TPB can be represented by a linear model with the following general equation:

$$Intention = \left(\beta_0 \times Attitude\right) + \left(\beta_1 \times Subjective\ Norms\right) + \left(\beta_2 \times Perceived\ Behavioral\ Control\right) + \varepsilon \quad (1)$$

Where β_0 β_1 and β_2 are regression coefficients representing the weights assigned to each variable which indicate the strength between the predictor variables and intention while ε represents the error. The weights are estimated through statistical techniques such as regression analysis or Structural Equation Modelling (SEM), both of which rely on primary research such as questionnaires [26].

3.1.2.C: ADDITIONS MADE TO THE MODEL

Since conducting primary research to estimate the model coefficients was not feasible due to time and resource constraints, we identified and modified a secondary model from the existing body of literature. The foundation of our model is based on "Influence of Psychological Factors in Mode Choice Decision Making: A Structural Equation Modelling Approach" [20]. This study, conducted in Calicut, India, surveys over 400 people and investigates the decision-making processes of individuals who have a preference for public or private transport by employing Structural Equation Modelling (SEM) to analyse the data collected [20].

Given the cultural and infrastructural similarities between Calicut and Lahore, especially concerning urban dynamics and transportation issues like congestion and rapidly growing vehicle ownership, we are assuming the Calicut model is representative of Lahore and thus serves as an appropriate starting point. However, it is important to acknowledge that despite these similarities, we cannot guarantee that the Calicut model's data will be fully representative of Lahore. Differences in local conditions, policies, and infrastructure developments could lead to distinct transportation mode choice behaviours in Lahore.

We adapted and extended the Calicut model to our context by including additional variables relevant to Lahore's urban environment identified during the literature review and incorporating the challenges faced by women using public transport. Our iteration is based on the survey data collected by *Urraan* in 2023 which details the experiences of over 700 women who use public transport in Lahore. Since most of the questions in the original *Urraan* survey had an open-ended format, we had to first clean the data (show in fig 7.) and convert it into a quantitative framework due to the significant overlap in the responses and to obtain clear insights from the varied and nuanced feedback provided by the participants (shown in fig 8.).

Gender	Usual Mode of Transportation in Lahore	How often do you take public transportation?	What makes you feel unsafe?
Female	Metrobus	Never	Lack of CCTV/security cameras - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	Never	Lack of CCTV/security cameras - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	Once a month	Long waiting times - Careless driving - No segregated compartments for women - Harrassment
Female	Metrobus	Once a month	Long waiting times - Careless driving - No segregated compartments for women - Harrassment
Female	Metrobus	Once a month	Long waiting times - Careless driving - No segregated compartments for women - Harrassment
Female	Metrobus	Once a month	Long waiting times - Careless driving - No segregated compartments for women - Harrassment
Female	Metrobus	4-6 days a week	Lack of security guards or ticketing staff at stops - No segregated compartments for women - Less seating for women - Harrassment
Female	Metrobus	4-6 days a week	Lack of security guards or ticketing staff at stops - Careless driving - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	Everyday	Lack of security guards or ticketing staff at stops - Lack of CCTV/security cameras - Careless driving - Less seating for women
Female	Metrobus	Once a month	Long waiting times - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	1-3 days a week	I don't feel unsafe while using public transport - Inadequate lighting at train or bus stops - Lack of security guards or ticketing staff at stops - La
Female	Metrobus	4-6 days a week	I don't feel unsafe while using public transport - Long waiting times - Careless driving - Fear of theft / bag-snatching
Female	Metrobus	1-3 days a week	I don't feel unsafe while using public transport - Inadequate lighting at train or bus stops - No segregated compartments for women - Fear of tl
Female	Metrobus	Everyday	Inadequate lighting at train or bus stops - Long waiting times - Careless driving - Fear of theft / bag-snatching
Female	Metrobus	4-6 days a week	Lack of security guards or ticketing staff at stops - Lack of CCTV/security cameras - Less seating for women - Fear of theft / bag-snatching
Female	Metrobus	4-6 days a week	Inadequate lighting at train or bus stops - Careless driving - Less seating for women - Harrassment
Female	Metrobus	Everyday	Careless driving - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	1-3 days a week	Careless driving - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	4-6 days a week	Inadequate lighting at train or bus stops - Long waiting times - No segregated compartments for women - Less seating for women
Female	Metrobus	Once a month	Lack of security guards or ticketing staff at stops - Lack of CCTV/security cameras - Long waiting times - Less seating for women
Female	Metrobus	Once a month	Careless driving - No segregated compartments for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	1-3 days a week	No segregated compartments for women - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	4-6 days a week	Inadequate lighting at train or bus stops - Lack of CCTV/security cameras - Long waiting times - No segregated compartments for women
Female	Metrobus	4-6 days a week	I don't feel unsafe while using public transport - Long waiting times - Less seating for women - Fear of theft / bag-snatching
Female	Metrobus	Everyday	Inadequate lighting at train or bus stops - Lack of CCTV/security cameras - No segregated compartments for women - Harrassment
Female	Metrobus	4-6 days a week	Long waiting times - Less seating for women - Harrassment - Fear of theft / bag-snatching
Female	Metrobus	Everyday	Lack of CCTV/security cameras - Long waiting times - Less seating for women - Fear of theft / bag-snatching

Fig. 7 The Urraan Survey Responses After Data Cleaning

How often do you take public transportation?	%
Everyday	29.76
4-6 days a week	30.95
1-3 days a week	23.81
Once a month	11.90
Never	3.57

What makes you feel unsafe?	%
Lack of CCTV/security cameras	9.23
Less seating for women	15.77
Harassment	12.50
Fear of theft / bag-snatching	14.88
Long waiting times	13.99
Inadequate lighting at train or bus stops	4.76
Lack of security guards or ticketing staff at stops	7.44
No segregated compartments for women	7.74
Careless driving	7.74
I don't feel unsafe while using public transport	5.95

For the Simulation

What makes you feel unsafe?	%
Lack of Seating for Women	26.87
Lack of Security	19.05
Harassment	14.29
Theft	17.01
Long Waiting Times	15.99
I don't feel unsafe while using public transport	6.80

What makes you feel uncomfortable?	%
Noisy or ill-behaved passengers	24.80
Badly maintained trains, buses, or stops	12.00
I don't feel uncomfortable while using public transport	7.20
Unhelpful or unfriendly staff	6.80
Lack of general information on bus/train services	10.40
Lack of food or drink options	6.00
People begging	14.80
Lack of amenities (clean bathrooms, seating areas, etc)	7.60

For the Simulation

What makes you feel uncomfortable?	%
Disruptive Behavior	39.60
Lack of Amenities	24.00
Operational and Infrastructure Inadequacies	22.40
Unhelpful/Unfriendly Staff	6.80
I don't feel uncomfortable while using public transport	7.20

Fig. 8 Results After Data Cleaning

We were able to identify and understand the key factors influencing women's transportation choices, which we then integrated into the Calicut model to accurately reflect the concerns of female commuters on the Lahore BRT. For instance, the *Urraan* survey results indicate that women's perception of safety on public transport is impacted by factors such as the prevalence of theft, harassment, and lack of security presence. Similarly, the feeling of comfort was determined by the physical condition of the transit facility, the behaviour of staff and co-passengers, and the availability of amenities. Therefore, in our final iteration of the psychological model (shown below in fig 9.), we introduced specific variables addressing these concerns. For example, we added variables capturing the presence of disruptive behaviour, the helpfulness of staff, and the adequacy of the infrastructure.

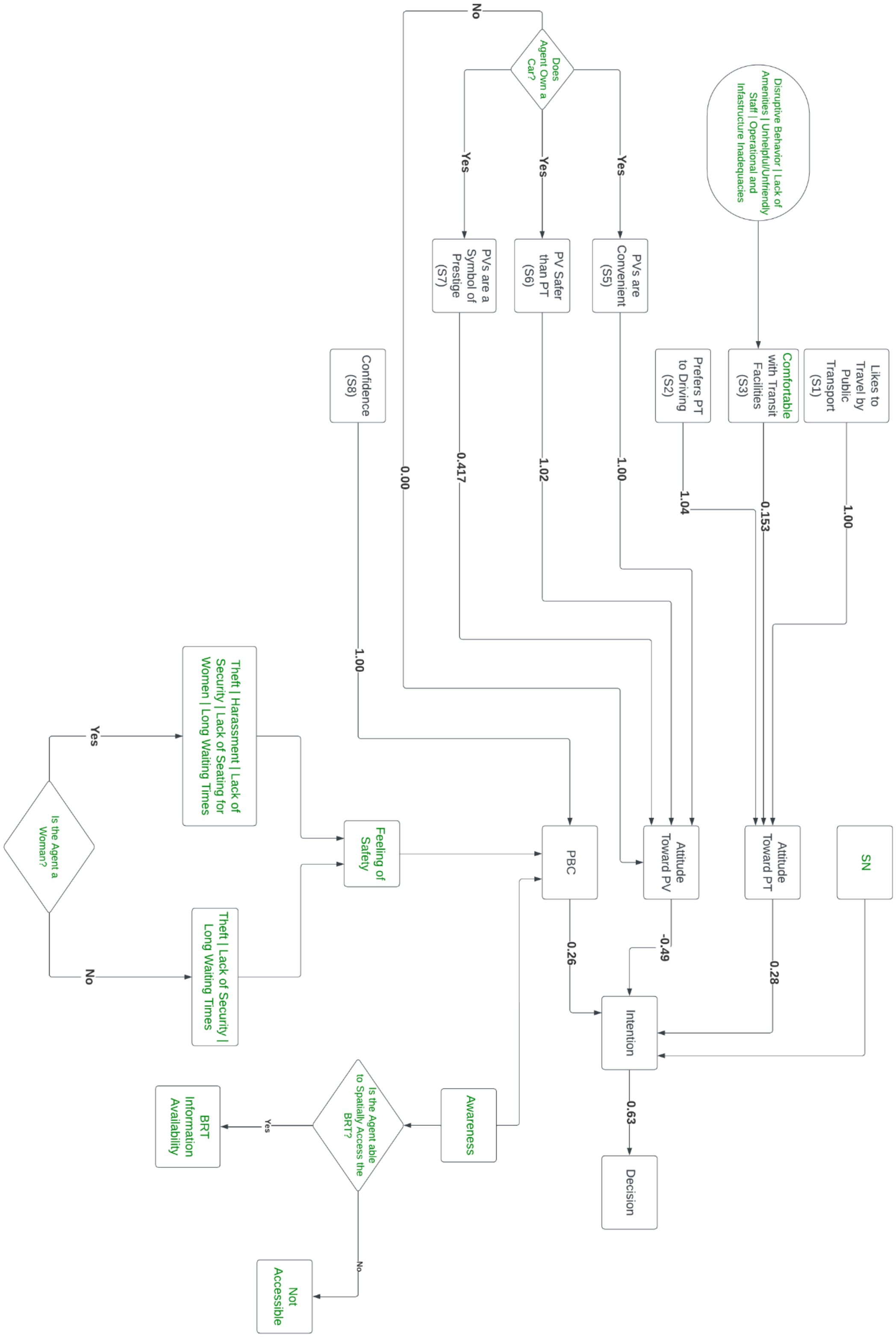


Fig. 9 The Modified Psychological Model

Fig 9. illustrates the final iteration of our modified psychological model. The additions in green text, informed by the Urraan survey, are our contributions to include Lahore-specific factors affecting women's use of public transport. Please note the following:

- The original variables from the Calicut model are shown in black.
- The numbers (shown in bold on each link) represent the weights from the Calicut model, indicating the influence or quantitative strength of each factor in the model.

3.1.3: AGENT ATTRIBUTES

The following table summarises the set of agent attributes created based on the literature review.

Table 2 AGENT ATTRIBUTES

Attribute	**Description**
Gender	1. Agents can be either male or female. 2. The gender breakdown is obtained from the 2017 Pakistan Census.
Age	1. Agents can be either an adult, child, or senior. 2. The age breakdown is obtained from the 2017 Pakistan Census.
Income	1. Agents can either belong to lower, lower-mid, mid, upper-mid, or upper. 2. The age breakdown is obtained from the 2017 Pakistan Census. 3. The demographic breakdown is obtained from "Urban Transition as a Result of Transport Investment: The Case Bus Rapid Transit Lahore Pakistan" by Dr. Muhammad Aamir Basheer.
Employment Status	1. Agents can either be students, unemployed, or employed. 2. The demographic breakdown is obtained from the *Urraan* survey data for women and "Urban Transition as a Result of Transport Investment: The Case Bus Rapid Transit Lahore Pakistan" by Dr. Muhammad

	Aamir Basheer for men.
Car Ownership	1. "Car Ownership" is a binary variable, i.e., agents can either own a car or not own a car.
Comfort	1. Refers to the extent to which passengers find the public transportation environment physically and psychologically pleasing.
Feeling of Safety	1. Refers to the subjective perception of passengers regarding their personal security while using public transport.
Confidence	1. The extent to which passengers feel assured in their ability to navigate and utilise the Lahore BRT system effectively, including understanding routes, schedules, and services.
Harasser?	1. This binary variable indicates whether an agent is a harasser or not. 2. The proportion of agents set as harassers can be set within the simulation.
Urgency	1. "Urgency" refers to the importance of a trip, affecting the choice of transport mode.
Awareness	1. The extent to which passengers are aware of schedules, routes, fares, and services of the Lahore BRT system.
BRT-Use-Score	1. After running the psychological model, an output score, "BRT-use-score", is assigned to each agent which indicates the likelihood of said agent using the Lahore BRT. 2. Quantifies the inclination towards BRT usage based on the modelled psychological factors.
Home-Loc	1. Refers to the specific area within a patch where the agent's residence is based.

	2. Assigned randomly based on the demographic breakdown for each Tehsil in Lahore as per the 2017 Pakistan Census.

3.1.4: NETLOGO ABM SIMULATION

Our decision to develop an agent-based model was inspired by the insights gained from *"Fully Agent-based Simulation Model of Multimodal Mobility in European Cities"* [16]. We recognized the importance of agent-based modelling as we wished for the agents (individuals) in our model to have their own decision-making capabilities in the context of public transport use, thereby realistically representing human behaviour. With this feature being pivotal to our project's aim of modelling the use of the Lahore BRT system, NetLogo emerged as an ideal choice for our project. Its user-friendly interface and capacity to handle large-scale and complex agent-based models would allow us to achieve our objective of accurately simulating the use of the Lahore BRT system.

We started off by successfully importing a GIS shapefile of the Lahore BRT (procured from *CITY@Lums*) in NetLogo using the GIS extension. This allowed us to accurately represent, label, and highlight each bus stop within the Lahore BRT network. Next, we programmed a bus, represented by a mobile agent (turtle), navigating the specified route. The bus moves from one stop to the next, pausing at each stop to simulate passengers boarding and disembarking. Additionally, we created agents representing the Lahori population in the model, who are colour-coded: blue for men and magenta for women. These agents interact with the BRT by boarding the bus at a chosen stop and disembarking at their respective destination. Furthermore, to improve the realism of the model, we programmed the agents to be shown walking to and from the bus station.

The next step involved importing additional GIS shapefiles to visualise the various districts (*mohallas*) within Lahore. We also incorporated the 2023 Lahore census data to determine the number of and types of agents within our model. Type refers to demographic factors such as gender, socio-economic class, occupation, marital status, and others. This demographic information works in conjunction with the psychological model (refer to fig. 9) allowing us to model the behaviours and interactions of the agents with their environment and with each other more accurately.

Moreover, we added additional features to increase the realism of our simulation, such as the maximum capacity of buses. Next, we programmed for and implemented government transport policies, with a special emphasis on gender-segregated policies (such as the Pink Bus) within the model and examined the short and long-term impact of said policies on female mobility. We also look at the effects of the implemented policies on transportation and society. These results form our policy library and the simulation serves as evidence for the effectiveness of these policies.

To validate our model and ensure our model accurately reflects the Lahore BRT, we used existing survey data, especially the results compiled by the Center for Economic Research in Pakistan (CERP) to check if the behaviour and patterns observed in our simulation corresponds to the real-world data. Given the time constraints and large sample size required to obtain meaningful survey results, conducting surveys from scratch was not feasible for us.

Additional details about the project simulation are given in Chapter 4.

3.2: FINAL DESIGN

Based on the methodology discussed above, our final design is an ABM created using NetLogo, on which multiple simulations are run to depict the impact of various gendered-transport policies both individually and in tandem. The data being used includes GIS shapefiles of Lahore and the BRT route, 2023 Lahore census data for the description of demographic attributes in the model, and the Punjab Mass Transit Authority's data for the Metrobus which includes timetable, routes, station names, and other relevant BRT information. The psychological model in Fig. 9 is used to define rules for agents which are all coded into the NetLogo simulation. The world in this simulation serves as an accurate depiction of the current state of the Lahore BRT, with gender-segregated policies being an extra set of rules that may be enforced onto the world in the final simulation.

3.3: TOOLS/INSTRUMENTS

3.3.1:SIMULATION SOFTWARE PACKAGES

NetLogo is a “software, programming language, and integrated modelling environment” developed by Uri Wilensky of Northwestern University’s Center for Connected Learning and Computer-Based Modeling (CCL) in 1999 [29]. NetLogo was the “first software tool specifically designed for agent-based models (ABMs)” which are computational models simulating the actions and interactions of agents to simulate their impact on real-life systems [29]. It is freely available, easy to use, fully-programmable with visualisation in 2D/3D, and comes with online resources, including YouTube tutorials and references created by the developer and users.

Chapter 4

PROJECT SIMULATION

4.1: SIMULATION SETUP

This chapter focuses on the implementation of our final ABM on NetLogo. It combines the data collected from multiple sources with the final decision-making framework designed and discussed in Chapter 3. To create our final ABM, multiple iterations of the model were created in which complexities were slowly introduced to ensure the correct operation of each function. The simulation setup can be divided into two parts: implementation of the psychological decision-making framework and setting up the world. While both of these segments were being implemented simultaneously over multiple iterations, it is useful to approach the two separately for better comprehension.

To begin, it is fundamental to understand the basics of NetLogo. There are three kinds of agents that exist within Netlogo: turtles, patches, and links. Turtles are the basic mobile agents in the model while patches are immobile background objects which exist behind every space of the world defined in the model and links are the network-based attributes of the turtles. The world is defined by the user, and it is the space within which turtles, patches, and links exist and interact. Fig. 10 shows the world settings that the user can change. The world is contained within the black frame seen on the NetLogo interface. The location of the origin can be defined as either a custom point or the centre, corner, or edge of the world. This definition is important as it helps determine the coordinate system of the world. The minimum and maximum coordinates of the patches, as well as the patch size are input by the user to set the size of the frame containing the model and the patch size. World wrapping can be set as on or off, affecting how turtles move in the world. If world wrapping is off, the end of the frames act as boundaries for the turtles and they cannot move beyond it.

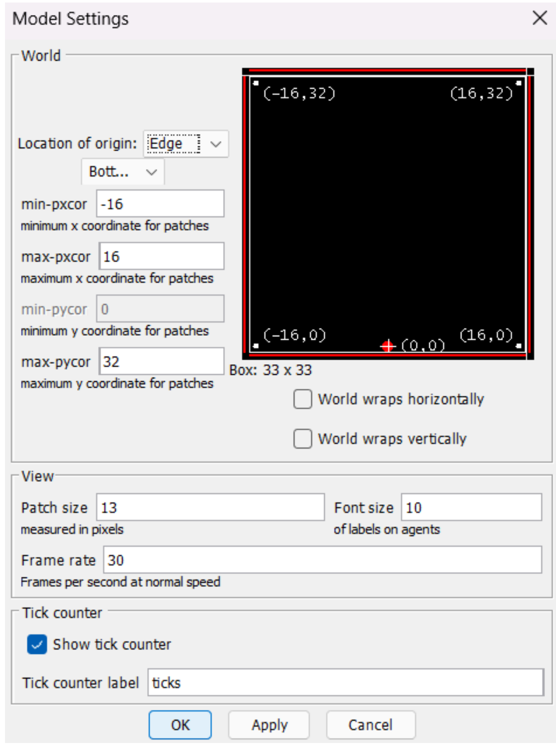


Fig. 10 User Defined World Settings

Fig. 11 shows a simple simulation on NetLogo which visually describes each of the agents while fig. 12 contains the code. As can be seen in fig. 11, the world is coloured black and contained within the white frame. A random patch from the world is selected and the colour is set as magenta. There are two turtles, or mobile agents, in this model that are assigned to random coordinates within the world frame. The white line is the link between the two turtles. As seen from the code in fig. 12, each agent has specific attributes that the user can define and manipulate in functions. Any model must have the setup and go function. The setup function defines the basic parameters of the model (i.e., how many turtles need to be created, starting-point attributes of agents, etc.) and the go function is a loop which runs forever until stopped or a stopping criterion that is coded into it is reached. 'Ticks' keep track of how many times the go function has looped. All other user-defined functions are either called in setup or the go function. It is then up to the user how they define certain rules that agents must follow within the world. To call a function, the user can add buttons to the interface. When clicked, the purple button on the left of the world frame calls the setup function. Similarly multiple buttons may be defined for calling multiple functions. There are different types of interface items that can be added including buttons, sliders, switches, choosers, inputs, monitors, plots, outputs, and notes. The interface items that are used in our ABM model will be discussed wherever they are first used.

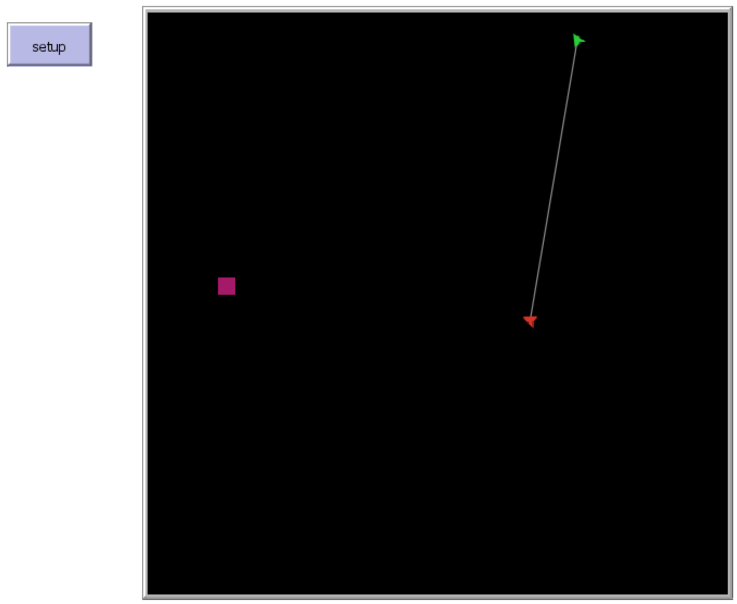


Fig. 11 Example Simulation to Visualise NetLogo Agents

```
to setup
  ca
  create-turtles 2 [
    setxy random-xcor random-ycor
  ]
  ask turtle 0 [create-link-with turtle 1 set color red]
  ask one-of patches [
    set pcolor magenta
  ]
  reset-ticks
end

to go
  tick
end
```

Fig. 12 Code for Example Simulation

Having formed a basic understanding of NetLogo, we can move on to discuss the simulation setup for our ABM.

4.1.1: IMPLEMENTATION OF THE PSYCHOLOGICAL DECISION-MAKING FRAMEWORK

4.1.1.A: GENERATING PEOPLE AND DEFINING PEOPLE VARIABLES

NetLogo allows for the creation of custom 'breeds' or kinds of turtles. This is done to differentiate the behaviour between groups of turtles. Our model has three kinds of breeds specified: people, buses, and stations. As the names suggest, turtles in our model are either people, buses, or BRT stations. This section will explain the "people" turtle whereas section 4.1.2 will describe "buses" and "BRT station" turtles.

All turtles are associated with pre-specified variables that can be set by the user. However, the user can also create custom variables specific to each breed that can be called upon in the code. People breed variables in the NetLogo model that are relevant to the psychological decision-making framework are gender, age, income, employment-status, car-ownership?, comfort, feeling-of-safety, confidence, harasser?, urgency, awareness, BRT-use-score, and home-loc. These are based on the agent attributes described earlier in section 3.1.3. Gender, age, and employment-status are string variables whereas feeling-of-safety, comfort, confidence, and awareness, and urgency are integer variables. On the other hand, car-ownership? and harasser? are boolean variables while home-loc stores a patch which corresponds to the home location of the person. BRT-use-score refers to a decimal value which is the output of the psychological model specific to each person based on their attributes and income is a decimal value between 0 and 1. A summary of these variables is given in Table 3.

The functions "set-people-location [num-tehsil name-tehsil num-women]", "set-internal-vars", and "gender-impact" initialise these variables for the people.

Table 3 DESCRIPTION OF PEOPLE VARIABLES

Variable Name	Data Type	Possible Values
gender	String	"male" or "female"
age		"child", "adult", or "senior"
employment-status		"student", "employed", or "unemployed"
feeling-of-safety	Integer	-2, -1, 0, 1, or 2
comfort		-2, -1, 0, 1, or 2
confidence		-2, -1, 0, 1, or 2
awareness		-2, -1, 0, 1, or 2
urgency		-2 or 2
car-ownership?	Boolean	true or false
harasser?		true or false
home-loc	Patch	patch *patch-no*
income	Floating-point	Decimal value between 0 and 1.0 rounded to 1 d.p.
BRT-use-score		Depending on input data and simulation settings, it could be a negative or positive number rounded up to 1 d.p.

"Set-people-location" is called in the setup function. The arguments of this function consist of the population of a tehsil, the name of a tehsil, and the female population of that tehsil. These values are originally found in the setup function and are based on the Pakistani census data. The census data gives the population density by percentage for each tehsil. Using the "num-people" variable, which is a global-variable set by the user using a slider on the interface tab and the percentages from the census data, the population of each tehsil is found. A gender breakdown is also given for each tehsil by percentage in the Pakistani census data which is used to compute the female population of each tehsil. This is how we have incorporated and scaled the census data for our model. Using .GIS files containing the boundaries of Lahore's tehsils, patches have been assigned a user-defined variable "tehsil" which contains the name of the tehsil the patch falls under. Set-people-location is called for each of the five tehsils – Model Town, Shalimar, Raiwind, Lahore Cantonment, and Lahore City – and populates them with people based on the inputs given. Using a counter it creates men and women separately for each tehsil, initialising all people variables, and defining their ages as per census data.

Once all of the people in the model have been generated, their internal variables for the functionality of the psychological model need to be set correctly. To do this, "set-internal-vars" is called in setup. The first variable that is set is "income". Percentage division of income is taken from data sources as described earlier in section 3.1.3, and the values are normalised by taking each income threshold and dividing it by the maximum income recorded in the data. This results in values between 0 and 1, which are randomly assigned to the agents in the model using the percentage breakdown given in the data (e.g. 19.3% of the population are lower-middle class, and will be assigned a value of either 0.1 or 0.2). Similarly, "employment-status" such as "student", "unemployed", or "employed" is assigned to the agents. Same is the case for all the variables for which data is available as per section 3.1.3. For "confidence" and "comfort", data was not available in the case of Pakistan. To overcome this, a Gaussian random distribution was applied to assign integer values between -2 and 2 for these variables as described in chapter 3.

Finally, to introduce a dynamic element in our model, a harasser-type agent was introduced. Each agent possesses a boolean variable harasser? which may be true or false. A user-defined global variable "harasser-percentage" determines the percentage of the male population that are harassers, assigning them harasser? = true, whereas the remainder of the population has harasser? = false. The impact of this variable will be discussed in section 4.1.1.C.

Moving on to the function "gender-impact", as there was no concrete data available for gendered variables such as "comfort", "feeling of safety", and "confidence" – as determined through the literature review – we scaled down these values for male agents. The scaling was done using a user-defined global variable "gender-impact-disparity". In the business-as-usual scenario, this variable is set to have a value of 0.55 which represents the Gender Gap Index of Pakistan. This value essentially means that the ratio of contribution of women to men in every dimension of life is 0.55:1. Using this ratio, the variables of “comfort”, “confidence”, and “feeling-of-safety” are scaled up for all men and rounded to ensure that the values are integers between -2 and 2.

While these assumptions were made for our model in the case of “comfort”, “confidence”, “feeling-of-safety”, and “harasser-percentage”, it is important to note that if survey data specific to Pakistan is made available and measures these specific variables with questions designed to determine the gendered experience of using public transport, it could be input directly into our model. While information on education was available for both genders, biases in female educational data made it unsuitable for this model.

For further details on how these variables were coded, refer to Appendix A.

4.1.1.B: CODING THE DECISION-MAKING FRAMEWORK

Having populated the world and defined the internal variables of all people as per the data available, the next step was coding the final decision-making framework (as depicted in fig. 9) in NetLogo. As mentioned earlier in chapter 3, the Theory of Planned Behaviour is a linear model and the final output is given through the summation of the product of all variables with their respective weights. While weights for most of the variables were adapted from the literature (refer to section 3.1.2 for details), a few were not available. To tackle this problem, we defined these weights as global variables and added sliders to the interface to allow users to choose any value between 0 and 1. The weights determine the impact each variable has on the final score which is calculated after the decision-making framework is run.

The variables for which weights were not available were “safety”, “urgency”, “social norms”, “income”, and “awareness”. Values set for these weights differ based on the scenarios and policies being implemented. A sensitivity analysis is also conducted by systematically varying these weights. More information can be found in chapter 5. The weights determined from the literature are summarised in table 4.

Table 4 WEIGHTS FOR DECISION MAKING FRAMEWORK

Variable	**Weight**
Comfort	0.153
Confidence	1.00
Attitude Towards Public Transport (APT)	0.28
Attitude Towards Private Vehicle (APV)	-0.49
Perceived Behavioral Control	0.26
Intention	0.63

The decision-making-framework is implemented in the function "calculate-prob-brt". In this, the value for APT was found by summing the values for comfort and income with their respective weights. The value for PBC was found by summing the values for confidence, feeling-of-safety, and awareness with their respective weights. To account for car-owners, only those people with car-ownership? = true would have a value of 1 for APV, the rest would have a value of 0. Once these values were found, APT, PBC, APV, and social norm were multiplied with their respective weights and summed together to find the value for intention. Social norm is a global variable that is determined by the user using a slider at the interface. The final score is calculated by summing together the product of intention and urgency with their respective weights. The weights for social norms and APV are negative, as the higher the value for these, the less likely the person is to use public transport. For further clarity, refer to Appendix A to see the code.

Since the values of the variables being used in the decision-making framework can be both positive and negative (e.g. comfort can be any integer value between -2 and 2), the final score calculated for each person can also be negative or positive. The final score calculated by this framework is rounded to 1 d.p. and stored in the variable BRT-use-score, one of the internal variables for the people-breed, meaning that each person has their own individual score. The function calculate-prob-brt is first called during setup to initialise the variable BRT-use-score at the start of the simulation, and then called each time the go loop is iterated to account for change due to dynamic effects that will be discussed in the next section.

To use the BRT, a person's score stored in the variable BRT-use-score must be equal to or greater than the mean BRT-use-score score of all agents. The implementation of this rule will be discussed in section 4.2.

4.1.1.C: CODING THE DYNAMIC IMPACTS

Since a person's likelihood to use the BRT is not static and varies depending on their experiences with the BRT, two dynamic components were added to show how female mobility can change with time.

Firstly, a harasser impact was considered. As discussed earlier, a user-defined percentage of the population were given the harasser attribute. Similarly the user can also define the impact a harasser has on women, which can be 0, 1, or 2 representing no-impact, moderate impact, or severe impact. In the world, if a harasser is present at the same bus-stop with women, comfort, feeling-of-safety, and confidence of one of the women at the bus-stop will be reduced by the value set as harasser-impact. Over time, these reductions in the specified internal variables of women will result in lower BRT-use-score scores for them, hindering more and more women from using the BRT – consistent with what was found in the literature review.

Secondly, overcrowding was considered. Bus-capacity is introduced as a user-defined global variable that can be set using a slider. Whenever the passenger count (determined by counting the number of links the bus has with people in every iteration of the go loop) of the bus goes above the bus-capacity, the comfort of all women in the bus decreases by 1.

For both of these dynamic impacts, it is ensured that the internal variables impacted do not go below the lower threshold values as given in table 3.

4.1.2: SETTING UP THE WORLD ON NETLOGO

This section focuses on the iterative approach through which the world for our ABM was developed on NetLogo.

4.1.2.A: THE BRT ROUTE

For the first iteration of the model, the world settings defined are depicted in fig. 13. These settings stayed the same for all future runs of the model.

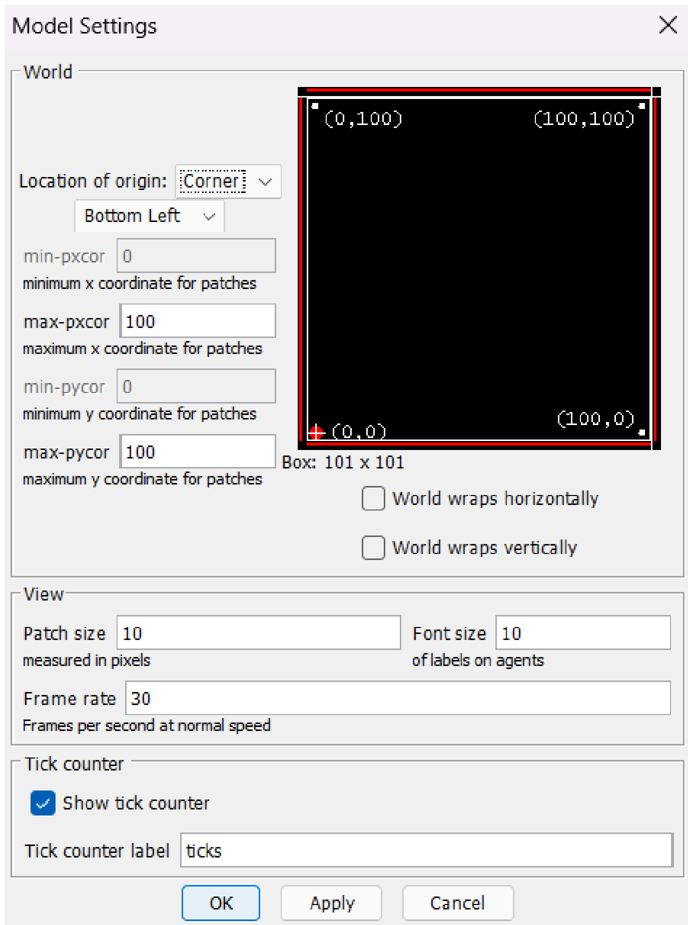


Fig. 13 World Settings for ABM

In this iteration, we successfully imported a GIS shapefile of the Lahore BRT in NetLogo using the GIS extension. From this shapefile we manually identified the coordinates at which the bus-stations existed and created turtles of the breed stations at these coordinates. The station breed was set to have an internal variable name which contained the station name within it. Next, each station was asked to form links with the next one, which represented the route connecting the stations. For the first iteration, we created two agents – one male and one female, colour-coded blue and magenta respectively for visual clarity. The shape was set to 'person'. To represent home and work locations, we programmed some patches near the Katchery station to be the colour green and labelled it ‘house’. Similarly, we created another area with orange coloured patches near the Model Town station and labelled it ‘school’.

A bus breed was introduced and its shape was default. The bus has an internal variable location, which is initialised to contain station 0 in it. It also has a boolean variable reverse? which determines the direction in which the bus is going. In the function move-bus, the new location is set by finding one of the link neighbours of location. Since location stores a station and in creating the BRT route all stations were linked, the link neighbour is just the next stop on the BRT route. Therefore, in this function the bus stores the new location in a temporary variable, and as long as this variable has a value (meaning that the last stop is not reached), the bus will face this new station and then move to the new station. Once the bus has reached the next station, it will update its location to store the next station. If the final stop is reached it will set reverse? = true, and move in the opposite direction, essentially completing a round trip. The bus moves one station each time the go loop is run. For the first iteration, the initial and final station of one agent was given. The person was made to create a link with the bus when the location of the bus was at the station with the label “Katchery” and exit the bus when the location of the bus was at the station “Model Town”. The person was programmed to be shown walking to the bus stop from the home patch, and from the bus stop to the school. Fig. 14 shows the setup of the world for the first iteration. This iteration depicted the basic functionality of what we aimed to do with our ABM.

Fig. 14 Setup of the World in the First Iteration

4.1.2.B: GIS MAP OVERLAY AND BUS FUNCTIONALITY

In the second iteration, GIS shapefiles are used to overlay the map of Lahore in the background to give the users a better visual understanding of where the BRT stations are located. The num-people global variable is introduced which is set by the user, determining total people in the simulation. The bus shape is changed to ‘bus’. The people agents are given three internal variables final-station, nearest-station, and has-arrived?. Nearest-station is the station at which the agent will board the bus, and final-station is the station at which they will disembark. has-arrived? is a boolean variable which determines whether the agent has reached their final destination or not. In setup, people are created as per user-defined num-people. They are given the shape ‘person’ and their original colour is set to white. They are given random x and y coordinates in the world, and final-stations are randomly assigned. has-arrived? is initialised to be false. In the go loop, all people are asked to carry out the function move-to-nearest-station. In this function, if has-arrived? = false, the nearest-station is set to be one of the stations that has the minimum distance from the person's current location. Since each person is asked to carry out this function, the function has access to the internal variables of each individual agent in the model, and sets the nearest-station for each individual accordingly. The people are then made to move towards their nearest-stations, and if the bus passes by the bus-stop and the agent is there, a ‘tie’ or link will be created between the bus and the person at the bus stop. A tie is a type of link in which one agent starts to move with the other agent. This way, the person is shown to be moving with the bus in the code. In untie-people, the link will be removed for people whose final-destination is equal to the location of the bus at any given time. When the link is removed they will set has-arrived? = true and change their colour from white to red. To avoid creating another tie with the bus, their x and y coordinates are randomised again.

This iteration gives a better visualisation of the interaction between the people and the bus, with improved working of how the people move to the nearest stations and disembark on their final-station. It is randomised, but not hard-coded as it was in the first iteration. Fig. 15 shows the output of the second iteration.

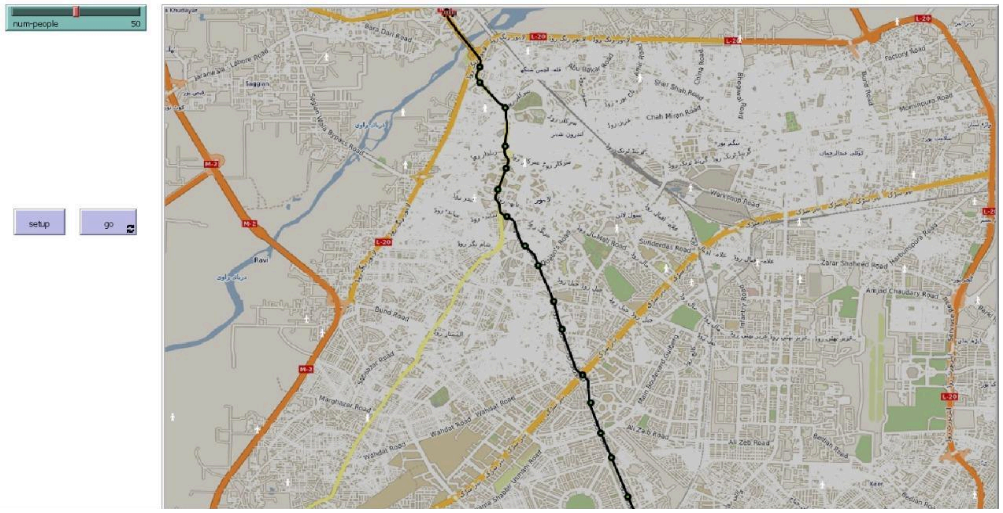


Fig. 15 Setup of the World in the Second Iteration

4.1.2.C: INTRODUCTION OF TEHSILS

For the third iteration, as depicted in fig. 16, we divided the world into segments and generated the population by area. For this percentage-density was used against user-defined num-people, and people were populated within the constraints of the five tehsils whose boundaries were chosen randomly. In fig. 16, the different tehsils are colour coded, and the people populated in each are also colour coded accordingly. Functionality of using the bus is the same as in the previous iteration.

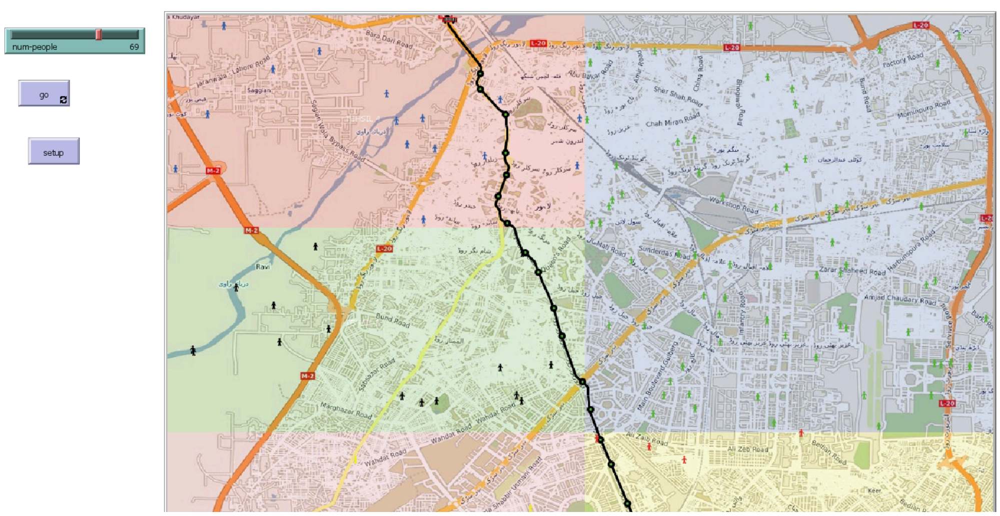


Fig. 16 Populating the World by Tehsils

4.1.2.D: INCORPORATING CENSUS DATA

Having figured out the functionality of populating the arbitrarily defined tehsils in the third iteration, census data is incorporated into the fourth iteration. This includes overlaying GIS files of tehsil boundaries, and populating them as per the percentage-divisions given in census data. The gender and age division as per census data is also added, whose method was described earlier in section 4.1.1. The agents are now coloured based on their gender. Fig. 17 displays the interface for this iteration.

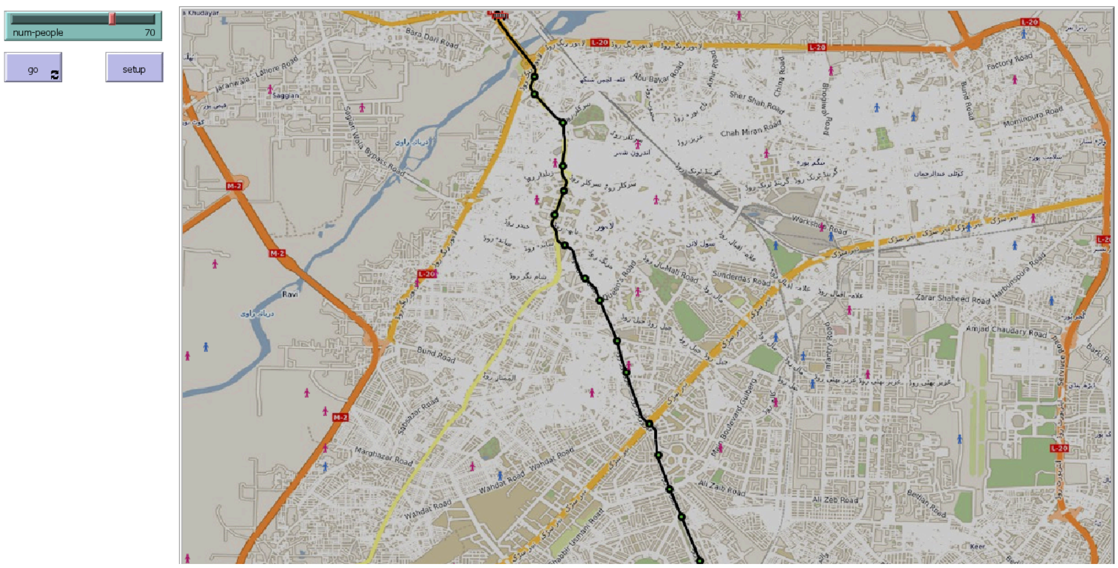


Fig. 17 Fourth Iteration Incorporating Census Data

4.1.2.E: ADDING POINTS OF INTEREST AS FINAL LOCATIONS FOR PEOPLE

In the fifth iteration, the agents are given new internal attributes including home-loc and home-tehsil which contains information about their home locations based on census data. Once an agent is given a home-tehsil based on the percentage division as done in the last iteration, its random location in its home-tehsil is saved as its home-loc. This variable will be used in future iterations to make the person use the BRT to go to their final location and then go back to their home location. In this interest, 122 points of interest (POIs) were added within the model to act as final destination points that the agents can travel to. These POIs were taken from GIS datasets that had mapped out education, food, health, pharmacy, bank, police stations, shops, and supermarkets in Lahore. Since these dataset contained thousands of points, we chose the ones immediately surrounding the Lahore BRT, in the envelope defined as (xmin = 29, xmax = 72, ymin = 0, ymax = 100). 45 ‘work’ POIs, 20 ‘education’ POIs, 21 ‘health’ POIs, and 35 ‘leisure’ POIS were chosen, colour coded and mapped across the world, as depicted in fig. 18. These POIs will serve as the final locations for the agents in the model.

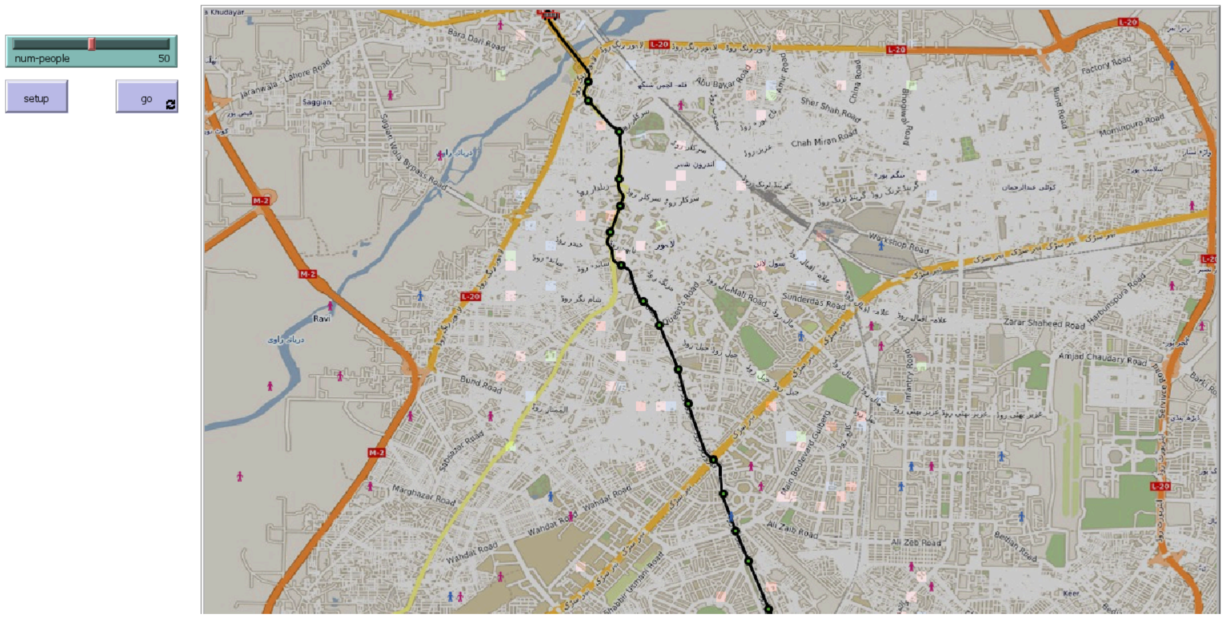


Fig. 18 Fifth Iteration, Adding POIs to the Model

4.1.2.F: IMPROVING BUS USE FUNCTIONALITY

In this iteration, functionality of the bus was improved by setting the final location of the bus as one of the POIs. Here, when the agent uses the bus, they go to their final destination, wait there for a few seconds before setting their new destination as their home location, and continue to use the bus to go back to their home location. This functionality will be continued to be used in future iterations. Counters were also added to show the number of trips completed by men and women, however there were some errors in counting. Sixth iteration is shown in fig. 19.

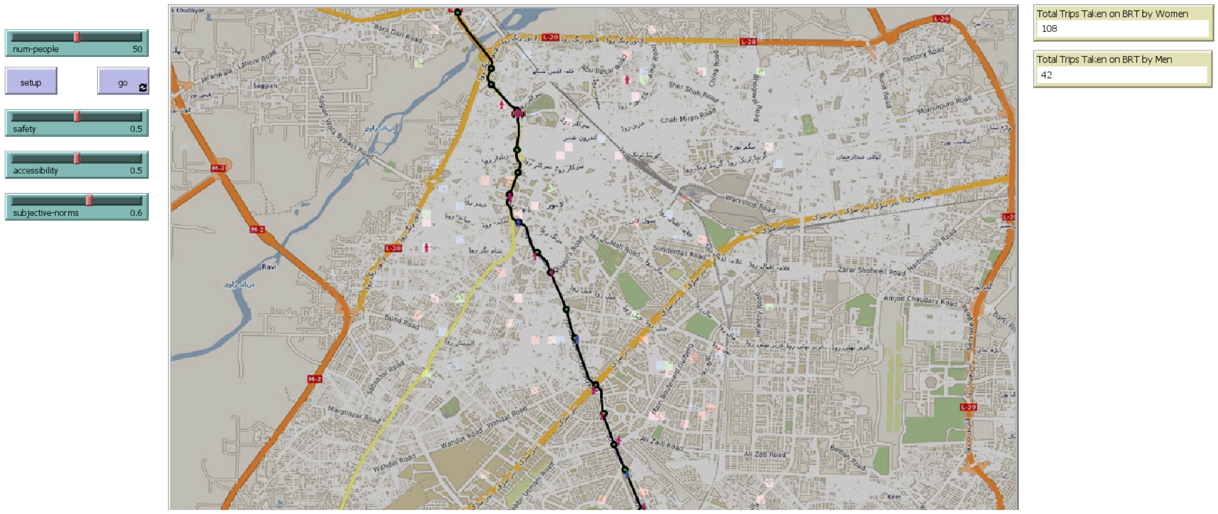


Fig. 19 Sixth iteration, Improving Bus Functionality

4.1.2.G: IMPLEMENTING AN EARLY VERSION OF THE PSYCHOLOGICAL MODEL

In this iteration, we implemented a psychological model, however this was purely based on assumptions. There was no separate function for calculating BRT-use-score scores, and it was determined by feeling-of-safety and confidence of women being above certain thresholds that were also set arbitrarily. Some policy measures were also introduced to increase these internal variables, but since we were not looking at any specific data for these variables (i.e., comfort, feeling-of-safety, confidence, awareness, etc.), they were randomised as values between 0 and 1. We plotted the results that we found, showing what the final simulation results could look like.

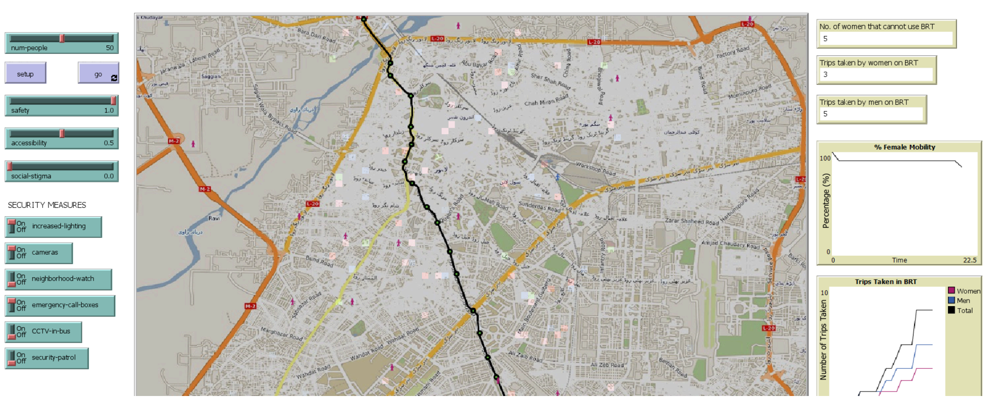


Fig. 20 Seventh Iteration, Plotting Results and Implementing the Psychological Model

4.1.2.H: INCORPORATING TIME AND POLICIES INTO THE MODEL

The final iteration of our NetLogo model contained all available data to populate the simulation, as discussed in previous sections, and the updated psychological decision-making framework, whose implementation was extensively discussed in section 4.1.1. The world settings have been discussed over each iteration, being slowly worked upon and improved. Debugging was done to ensure that all functions work correctly. The final base model allows people to use the BRT to travel between their home and final locations – which could be categorised as work, education, health, or leisure trips. One bus represents all 64 buses that run on a daily basis in the Lahore BRT to reduce the computational burden of the simulation. When the simulation is set up and run initially, the bus begins moving from Shahdara station down to Gajjumata station. Once the bus reaches the final station, it changes direction and continues the route back to Shahdara station. As per data found through bus tracking on Google Maps and what was available on the Punjab Masstransit Authority's website, it was found that it takes 2 hours for a bus to complete a roundtrip from Shahdara to Gajjumata and back to Shahdara. Given that the timings for the Lahore BRT are from 6:00 am to 10:00 pm – a total of 16 hours – one bus can do 8 round trips per day. To incorporate a sense of time into the model, the 'tick' counter in NetLogo was coded so that it would only update once a roundtrip was completed by the bus, and when the tick counter reached 8, a variable 'no-days' would increment by 1 to show that one day had passed.

After introducing the concept of time into the model, it was noticed that the simulation itself was very computationally taxing, and it required a few hours to simulate ten days. Given both technical and time constraints, it was decided to exaggerate the dynamic impacts of overcrowding and harassment to be able to visualise the overall behaviour of the model during project implementation. This will be further discussed in chapter 5.

Having formed the base simulation through world building on NetLogo and a decision making framework, the next step was to incorporate policies that were to be tested through this model. Based on the literature review, four main routes stood out for possible policy intervention. These were the implementation of capacity checks on buses, the introduction of gender-segregated bus services for women, awareness campaigns, and increased safety checks at bus terminals. The reasoning behind each policy and its specific implementation will be discussed below. The policies are added as Boolean values on the interface, that the user can choose to turn on or off at any point in the simulation.

4.1.2.H.A: POLICY 1 – IMPLEMENTING CAPACITY CHECKS ON BUSES

As discussed in section 3.1.2.A.F, comfort is a major factor that women consider when choosing mode of transport. Specifically in the Lahore BRT, lack of reserved seating for women, overcrowding conditions, and insufficient waiting areas are all factors that lead to reduced feelings of comfort.

In section 4.1.1.C, overcrowding in buses was coded as a dynamic element – meaning that at every instance the bus capacity was exceeded, the comfort variable for all women in the bus was decreased by a user-defined variable overcrowding-impact. This decrease in comfort for women then leads to a lower individual BRT use score, thereby limiting the number of women that meet the required threshold to use the BRT over time.

To counter the impact of overcrowding in buses, policy 1 enacts capacity checks on buses. To do this, everytime the bus moves from one station to another, the function 'check-bus-capacity' is run. In this function, the total links of the bus with people are counted. If the number of links are equal to the predefined bus-capacity variable, then no further people are allowed to board the bus. This policy ensures that the comfort score for women is not lowered over time due to overcrowding on buses. The one downside of this policy is that fewer people in the simulation can use the bus services.

4.1.2.H.B: POLICY 2 – GENDER-SEGREGATED SERVICES FOR WOMEN

The second policy that is explored is the introduction of gender-segregated buses for women. This policy is specifically explored as it is a common solution used by governments across the world to increase female mobility, however there is much debate about whether such services actually do more good or harm in the long-term for women. Furthermore, there has been a trend that such initiatives started by the Pakistani government over the last decade usually get shut down after a few years due to varying reasons.

To explore the impact of such gender-segregated services in the Lahore BRT, the bus in the simulation was coded such that it only allowed women to board it. While this choice translates to converting the entire fleet of buses in the Lahore BRT to women-only buses in real-life, modelling such a scenario gives a better perspective of how many women can actually benefit from such services, as compared to the usual policy implementation of reserving a small proportion of buses as gender-segregated. Furthermore, instead of using the mean BRT-use score for all people in the simulation as the threshold value, the mean BRT-use score for women was used as the threshold to board the bus instead.

As per the literature review, it was found that women-only services are more likely to be safer and socially acceptable means of transportation for high social stigma regions. To show this effect in our simulation, a few changes were made. Firstly, the chances of running into a harasser are halved. In the base simulation, the harasser-percentage is defined by the user at setup, and everytime a harasser is waiting at a station where women are present, one woman agent is randomly chosen from the station and her internal variables feeling-of-safety, comfort, and confidence are decreased by the user defined variable harasser-impact. When policy 2 is on, there is a 50-50 chance that harassment occurs or doesn't occur, thereby reducing the dynamic impact of harassment.

Moreover, at setup the feeling-of-safety and confidence of all women agents in the simulation is increased by 1. During the calculation of BRT-use score, the impact of social norms is the same on women as it is for men in the base simulation. Normally, the impact of social norms is increased given the gender-impact-disparity set for the world at setup, however, since the services are gender-segregated, women do not have an increased weightage of social norms influencing their final decision-making when the policy is implemented.

Therefore, the implementation of this policy has both static effects at setup, and dynamic effects as the simulation continues to run.

4.1.2.H.C: POLICY 3 – AWARENESS CAMPAIGNS

Policy 3 focuses on increasing awareness regarding the Lahore BRT service offerings among the population. As discussed in 3.1.2.A.H., the awareness variable captures a passenger's understanding of the Lahore BRT system. This includes understanding of the service, knowledge about routes and timings, and how easily accessible this information is. Therefore, the more awareness a passenger has about the Lahore BRT, the easier it is for them to use it, and so they are more inclined to use it.

To implement awareness campaigns in our model, every day, as counted through the variable no-days, 10% of the population at random were selected and asked to increase their internal awareness variable by 1.

4.1.2.H.D: POLICY 4 – INCREASED SAFETY MEASURES AT BUS TERMINALS

One major issue that comes across in the literature review as a hindrance for women using public transport is safety concerns. While there are measures in place in the Lahore BRT to increase a feeling of safety such as the presence of security cameras, guards at bus stations, helplines posted in the buses, and lighting at night, women can still feel unsafe using the BRT as they are susceptible to crime and harassment on their way from their initial locations to the bus stations. Therefore, this policy focuses on increasing the overall safety of the world for women such as increased street lighting at night and more secure bus stations for the feeder routes that go into the main Metroline. From site visits, it was found that the safety measures at feeder bus stations were nonexistent, and many women use the feeder buses with the main Metroline to get from their initial destinations to their final destinations.

There is no data available as of yet which categorises what safety measures have the most impact, therefore we have used a general umbrella term of safety-checks to encompass the different initiatives that can be taken to increase the safety of the world.

This policy has a static impact during setup, in which it increases the feeling-of-safety of all women in the world by either 1 or 2 on a random basis. This increase in the feeling-of-safety variable leads to an overall higher BRT-use score for women initially.

4.2: SIMULATION RESULTS

The final simulation contains all of the elements and changes that were introduced iteratively as discussed in sections 4.1.1 and 4.1.2 – specifically the psychological decision-making framework, bus functionality, home locations for all agents, final destinations categorised by type of trip, incorporation of demographic data, and policy implementation capabilities. The final model contains the base simulation which is meant to represent the Lahore BRT in its current state, with the option of implementing four policies – capacity checks, gender-segregated services, awareness campaigns, and safety checks – individually or in tandem. The policies are designed to target specific variables of the agents that are mentioned frequently as key decision-making variables in existing literature. The policies are designed in such a way as to have both static impacts at initialization and dynamic impacts that can be measured as the simulation is allowed to run.

4.3: RESULT ANALYSIS AND OUTLOOK

Fig. 21 depicts the final simulation result for the final model described in section 4.2. A histogram on the interface tab gives a breakdown of the overall BRT-use score distribution in black as well as one for just women in pink. This histogram continues to update with time, showing the dynamic changes in overall and women BRT-use scores as the simulation is run. The user-defined variables are given on the left. These variables include the number of people in the world, social stigma, gender impact disparity, bus capacity, harasser population, harasser impact, and overcrowding impact. The user-defined weights for the psychological model are given on the right side of the world. Below the weights, the policies are given as boolean values that can be switched on or off at any point while the simulation is running. Result analysis and policy implementation will be discussed in detail in chapter 5.

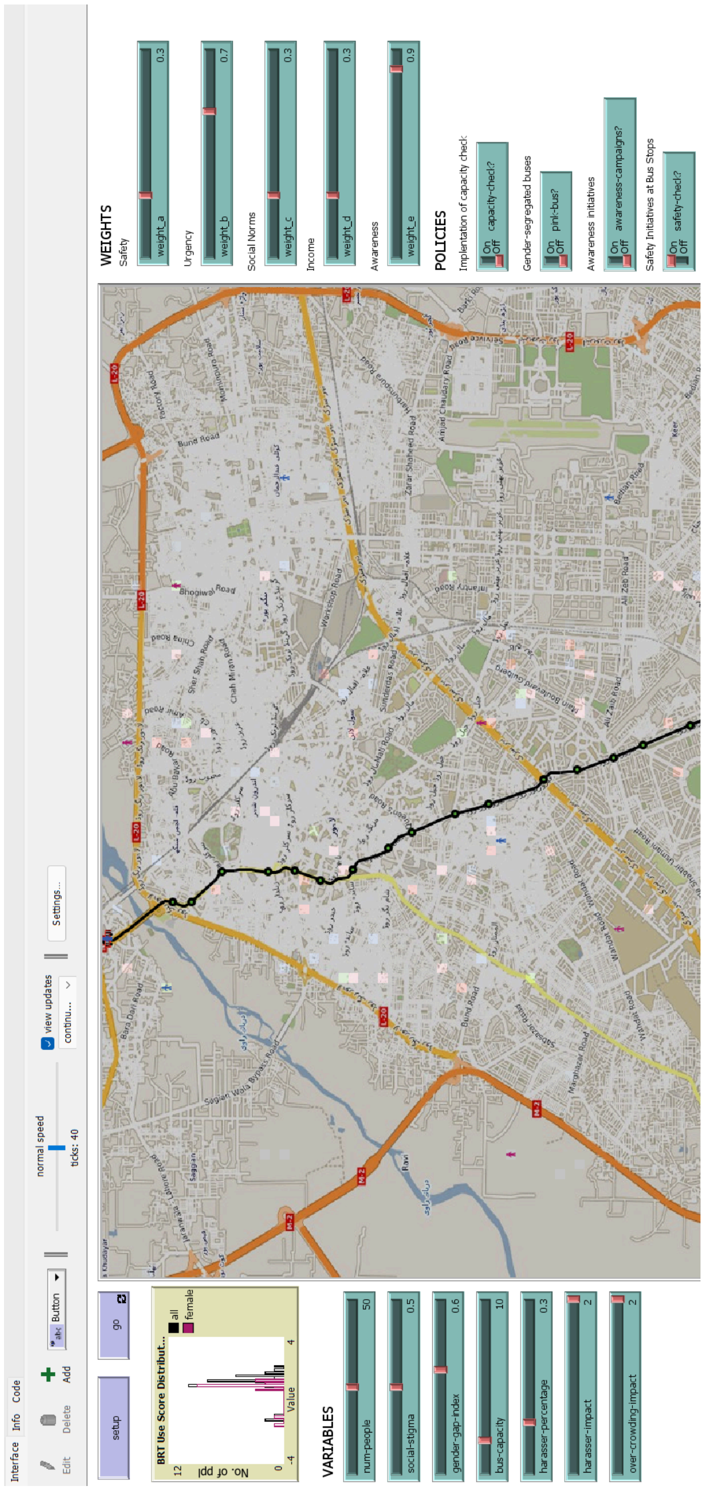


Fig. 21 Final Simulation of Base Model

Chapter 5

PROJECT IMPLEMENTATION

5.1: HARDWARE SETUP

N/A

5.2: EXPERIMENTAL PROCEDURE

In order to conduct a policy analysis using the final simulation setup on NetLogo, three scenarios and a total of 15 policy combinations were used. Scenarios were created by varying world settings at the initialization stage. The three scenarios are (i) business-as-usual, (ii) high awareness, low crime, and (iii) increased gender parity, low social stigma. Scenario definitions are given in sections 5.2.2 – 5.2.4.

To conduct a scenario and policy analysis, it is vital that the agentset being used for each case is identical. To do this, the "random-seed" function is called in setup to initialise a pseudo-random number generator which generates a sequence of numbers with properties approximate to that of a sequence of random numbers. Incorporating this line of code into the model ensures that every time random numbers are generated in the model, they follow the same sequence and ensure that the agentset at initialization will always have the same attributes.

In our final model, there are four policies that can be implemented. These policies can be implemented alone or in combination with one another. There are 15 possible combinations for these four policies as listed in table 5. All 15 policy combinations will be run on the business-as-usual scenario to determine how different policies interact with one another. However, for the other two scenarios, only the standalone four base policies will be implemented due to computational and time constraints.

To run the model for all scenarios and policy combinations, BehaviorSpace will be used. More details are given in the following section.

Table 5 POLICY COMBINATIONS

Policy No.	Policy Combination
P1	Capacity-check
P2	Gender-segregated Buses
P3	Awareness-campaigns
P4	Safety-check
P5	Capacity-check, Gender-segregated Buses
P6	Capacity-check, Awareness-campaigns
P7	Capacity-check, Safety-check
P8	Gender-segregated Buses, Awareness-campaigns
P9	Gender-segregated Buses, Safety-check
P10	Awareness-campaigns, Safety-check
P11	Capacity-check, Gender-segregated Buses, Awareness-campaigns
P12	Capacity-check, Gender-segregated Buses, Safety-check
P13	Capacity-check, Awareness-campaigns, Safety-check
P14	Gender-segregated Buses, Awareness-campaigns, Safety-check
P15	Capacity-check, Gender-segregated Buses, Awareness-campaigns, Safety-check

5.2.1: BEHAVIORSPACE

NetLogo's BehaviorSpace is designed to conduct experiments within NetLogo's modelling framework. We will be using BehaviorSpace to observe the model's behaviour by parameter sweeping, i.e., conducting a sensitivity analysis to assess the impact of varying parameters on the model outputs and identify parameters which significantly impact agent behaviour.

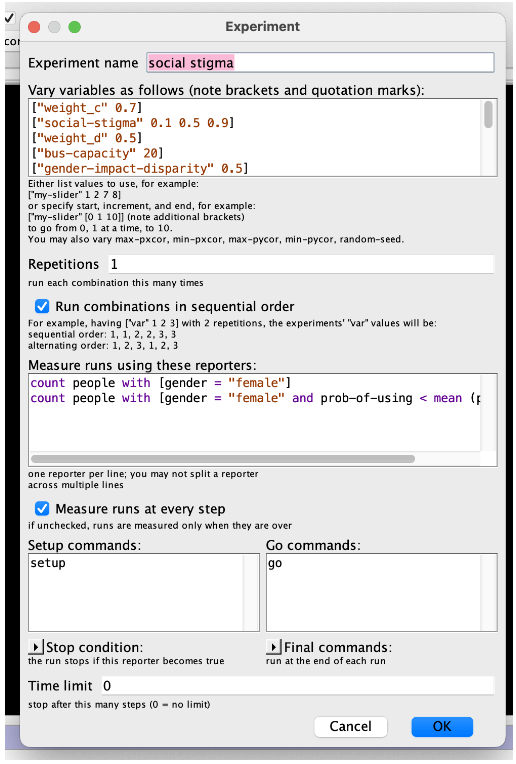


Fig. 22 BehaviorSpace in NetLogo

The parameters that will be changed for each scenario are described in the following sections. BehaviorSpace records the values of specified variables at each time step. These variables can then be recorded and compared across different scenarios and policy combinations. To measure the change in "female-mobility" over time, the following variables were recorded using BehaviorSpace: "no-days", "total-trips-women", "total-trips-men", "women-stopped", and "women-intention". "Women-stopped" refers to the number of women who wished to use the BRT at any time but could not do so as their BRT-use score was below the threshold. "Women-intention" records the total number of women who wished to use the BRT at any time. Using these two variables, a percentage (female mobility) is calculated and then visualised with time.

Fig. 22 shows the interface of BehaviorSpace when defining a new experiment. For each policy or scenario combination, a new experiment needs to be defined. A total of 26 experiments were conducted – three base case scenarios, 15 policy combinations for the business-as-usual scenario, and four policy combinations each for the “high awareness, low crime” and “increased gender parity, low social stigma” scenarios.

5.2.2: BUSINESS-AS-USUAL SCENARIO

The business-as-usual scenario aims to model the Lahore BRT as accurately as possible and establish a baseline against which potential improvements brought by policy changes can be measured. This simulation is designed according to the literature review.

The parameters for the business-as-usual scenario are shown in table 6. The variables below are carefully assigned values to balance model accuracy and computational feasibility. We will be running all fifteen combinations of the policies discussed in chapter 4 to determine which are the most successful in improving female mobility.

- Number of People (num-people): As per the Punjab Mass Transit Authority, 135,000 commuters use the Lahore BRT daily on average [30]. To reduce the computational load of the simulation, we have scaled down this value using a ratio of 1:0.00037. Therefore, num-people is set to 50, which represents 135,000 people.
- Simulation Duration (no-days): The duration of the simulation is set to 5 days to minimise the computational load, observe trends, and record meaningful data.
- Bus Capacity (bus-capacity): The Lahore BRT system consists of 64 buses, each with an approximate capacity of 150 passengers [18]. In the simulation, this is scaled down to a single bus using the ratio 1:0.00037. Therefore, the bus-capacity is set as 4 and represents a scaled version of the total capacity of 9,600 passengers.
- Social Stigma (social-stigma): Social stigma can impact public transport usage and female mobility, particularly among women in countries with conservative social norms, such as Pakistan. Classifying Pakistan as a high social stigma area, “social-stigma” is set as 0.8 which captures the impact of societal barriers on public transport use amongst women.
- Gender Gap Index (gender-gap-index): Gender-gap-index is assigned a value of 0.6 since Pakistan has a Gender Gap Index of 57.5% according to the World Economic Forum’s Global Gender Gap Report 2023 [31].

- Harassment Prevalence (harasser-percentage): Harasser-percentage is set at 70% to observe noticeable changes and trends within five days and since 70% of Pakistani women using public transport report daily harassment [1].
- Harasser Impact (harasser-impact) and Overcrowding Impact (over-crowding-impact): Harasser-impact and over-crowding-impact are set at 2 (the maximum value) to see the maximum impact in the simulation and ensure meaningful trends are visible within five days.
- Safety Weight (weight_a): According to the *Urraan* survey, safety is the most important concern for women using the Lahore BRT. Therefore, weight_a is set as 0.8 to obtain meaningful results within 5 days and due to prevalent safety concerns among women in Lahore, where crimes against women are common and legal accountability is often lacking.
- Urgency Weight (weight_b): Weight_b is set at 0.5, i.e., the middle point, due to a lack of data related to the urgency of travel needs among those who use the Lahore BRT.
- Social Norms Weight (weight_c): Weight_c is set as 0.8 due as the *Urraan* survey demonstrates the strong influence of social norms on behaviour in Pakistan, especially in the context of gender roles and public presence.
- Income Disparity Weight (weight_d): Weight_d is set as 0.3 to incorporate the impact of income inequality within the Lahore BRT system. It is based on the GINI Index for Pakistan, which was projected to be 30.7% for 2022-23 according to The World Bank [32].
- Awareness Weight (weight_e): Weight_e is assigned a value of 0.5 indicating moderate levels of public awareness. This is due to low literacy rates in Pakistan [33] and inaccessibility of information regarding routes, times and other details of the Lahore BRT as ascertained by the *Urraan* survey.

Table 6 PARAMETER VALUES FOR BUSINESS-AS-USUAL

Parameter	**Value**
num-people	50

no-days	5
bus-capacity	4
social-stigma	0.8
gender-impact-disparity	0.6
harasser-percentage	0.7
harasser-impact	2
over-crowding-impact	2
weight_a (safety)	0.8
weight_b (urgency)	0.5
weight_c (social norms)	0.8
weight_d (income)	0.3
weight_e (awareness)	0.5

5.2.3: HIGH AWARENESS, LOW CRIME SCENARIO

The "High Awareness, Low Crime Scenario" simulates the Lahore BRT given increased awareness among women about public transport and reduced crime. This scenario is inspired by Tokyo's Toei Bus System and most parameters have been set accordingly to explore the consequences of Lahore evolving into a socio-economic and cultural context similar to that of Tokyo. This scenario will be compared against the business-as-usual scenario to see how women's mobility patterns change as awareness increases and crime decreases.

Parameters for the "High Awareness, Low Crime Scenario" are given in table 7. The variables below are carefully assigned values to balance model accuracy and computational feasibility, drawing inspiration from but not directly copying the Tokyo case. We will be running all four policies individually to determine which are the most successful in improving female mobility.

- Number of People (num-people): As per Statistica, 195.37 million people used the Toei

Bus in 2021 [34]. This comes to approximately 535,260 people per day. To reduce the computational load of the simulation, we have scaled down this value using the ratio 535260:50 and set num-people to 50 in our simulation.

- Simulation Duration (no-days): The duration of the simulation is set to 5 days to minimise the computational load, observe trends, and record meaningful data.
- Bus Capacity (bus-capacity): The Toei Bus System consists of 1400 buses, each with an approximate capacity of 78 passengers [35], and total capacity of 109,200 people per day. In the simulation, this is scaled down to a single bus using the ratio 535260:50. Therefore, the bus-capacity is set as 10 and represents a scaled version of the total capacity.
- Social Stigma (social-stigma): Social stigma can impact public transport usage and female mobility. We classify Tokyo as having medium social stigma due to cultural norms which emphasise conformity and traditional gender roles, impacting women's behaviour and perceptions in public spaces. Therefore, social-stigma is set as 0.5 in this scenario.
- Gender Gap Index (gender-gap-index): Gender-gap-index is assigned a value of 0.6 since Japan has a Gender Gap Index of 64% according to the World Economic Forum's Global Gender Gap Report 2023 [31].
- Harassment Prevalence (harasser-percentage): Harasser-percentage is set as 0.3 to observe noticeable changes and trends within five days and since 30% of women in Tokyo have expressed safety concerns about travelling on public transport [36].
- Harasser Impact (harasser-impact) and Overcrowding Impact (over-crowding-impact): Harasser-impact and over-crowding-impact are set at 2 (the maximum value) to see the maximum impact in the simulation and ensure meaningful trends are visible within five days.
- Safety Weight (weight_a): In this scenario, weight_a is set as 0.3, lower than the value in the business-as-usual scenario to identify meaningful trends over five days and since most women in Tokyo do not consider sexual harassment on public transport as a significant issue [36].
- Urgency Weight (weight_b): Weight_b is set as 0.7 due to high levels of labour force

participation rates among both men and women in Tokyo [37]. This setting contrasts with Lahore, where labour force participation rates and consequently the urgency associated with commuting is lower.

- Social Norms Weight (weight_c): Weight_c is set as 0.3, reflecting the minimal impact of social norms on behaviour in Tokyo where low crime rates and a robust public transport infrastructure significantly enhance women's mobility [38].
- Income Disparity Weight (weight_d): Weight_d is set as 0.3 to incorporate the impact of income inequality within the Toei Bus System. It is based on the GINI Index for Japan, which is projected to be 30.1% for 2024 [39].
- Awareness Weight (weight_e): Weight_e is set as 0.9 indicating high levels of public awareness in Tokyo. This is due to high literacy rates in Japan and the widespread availability of information regarding routes, times, and other specifics of the Toei Bus System [40].

Table 7 PARAMETER VALUES FOR HIGH AWARENESS, LOW CRIME

Parameter	**Value**
num-people	50
no-days	5
bus-capacity	10
social-stigma	0.5
gender-impact-disparity	0.6
harasser-percentage	0.3
harasser-impact	2
over-crowding-impact	2
weight_a (safety)	0.3
weight_b (urgency)	0.7
weight_c (social norms)	0.3

weight_d (income)	0.3
weight_e (awareness)	0.9

5.2.4: INCREASED GENDER PARITY, LOW SOCIAL STIGMA

The "Increased Gender Parity, Low Social Stigma" simulates the Lahore BRT given increased gender parity and reduced social stigma. This scenario is inspired by New York City's Metropolitan Transit Authority (MTA) Bus System and most parameters have been set accordingly to explore the consequences of Lahore evolving into a socio-economic and cultural context similar to that of New York City. This scenario will be compared against the business-as-usual scenario to see how women's mobility patterns change as gender parity increases and social stigma decreases.

Parameters for the "Increased Gender Parity, Low Social Stigma" are given in table 8. The variables below are carefully assigned values to balance model accuracy and computational feasibility, drawing inspiration from but not directly copying the New York City case. We will be running all four policies individually to determine which are the most successful in improving female mobility.

- Number of People (num-people): As per the Metropolitan Transportation Authority (MTA), 1.4 million people used the New York City Bus daily in 2022 [41]. To reduce the computational load of the simulation, we have scaled down this value using the ratio 1:50 and set num-people to 50 in our simulation.
- Simulation Duration (no-days): The duration of the simulation is set to 5 days to minimise the computational load, observe trends, and record meaningful data.
- Bus Capacity (bus-capacity): The MTA has 5,840 buses which are run multiple times per day with a capacity of 57 per bus, which comes to a total capacity of 332,880 [42]. Using the ratio of 1,400,000:50, the bus-capacity set in this simulation is 12.
- Social Stigma (social-stigma): Social stigma can impact public transport usage and female mobility. We classify New York City as having low social stigma due to minimal emphasis on traditional gender roles. Therefore, social-stigma is set as 0.2 in this

scenario.

- Gender Gap Index (gender-gap-index): Gender-gap-index is assigned a value of 0.8 since the U.S. has a Gender Gap Index of 77.3% according to the World Economic Forum's Global Gender Gap Report 2023 [31].
- Harassment Prevalence (harasser-percentage): Harasser-percentage is set as 0.7 to observe noticeable changes and trends within five days. Furthermore, this allows for a comparison with the business-as-usual scenario, helping to isolate and evaluate the effects of increased gender parity and reduced social stigma on female mobility.
- Harasser Impact (harasser-impact) and Overcrowding Impact (over-crowding-impact): Harasser-impact and over-crowding-impact are set at 2 (the maximum value) to see the maximum impact in the simulation and ensure meaningful trends are visible within five days.
- Safety Weight (weight_a): In this scenario, weight_a is set as 0.2, lower than the value in the other two scenarios as the New York Public Transport System is considered to be the safest in the world for women [43].
- Urgency Weight (weight_b): Weight_b is set as 0.7 due to high levels of labour force participation rates among both men and women in New York City [44]. This setting contrasts with Lahore, where labour force participation rates and consequently the urgency associated with commuting is lower.
- Social Norms Weight (weight_c): Weight_c is set as 0.1 since the majority of bus riders in New York are female [45] which indicates low societal pressure discouraging the use of public transport.
- Income Disparity Weight (weight_d): Weight_d is set as 0.5 to incorporate the impact of income inequality within the New York City Bus System. It is based on the GINI Index for the U.S., which is projected to be 47% for 2024 [46].
- Awareness Weight (weight_e): Weight_e is set as 1.0 indicating high levels of public awareness in New York City. This is due to high literacy rates in the U.S. and the widespread availability of information regarding routes, times, and other specifics of the New York City Bus System [47].

Table 8 PARAMETER VALUES FOR INCREASED GENDER PARITY, LOW SOCIAL STIGMA

Parameter	**Value**
num-people	50
no-days	5
bus-capacity	12
social-stigma	0.2
gender-impact-disparity	0.8
harasser-percentage	0.8
harasser-impact	2
over-crowding-impact	2
weight_a (safety)	0.2
weight_b (urgency)	0.7
weight_c (social norms)	0.1
weight_d (income)	0.5
weight_e (awareness)	1.0

5.3: IMPLEMENTATION RESULTS

All scenarios were simulated for five days within NetLogo's BehaviorSpace to demonstrate the transient and steady-state behaviours of the system when different policy conditions were applied. The timeframe was chosen because running the simulation for longer would have significantly increased the computational load. As shown in the graphs below, five days are sufficient to effectively observe the system's response to various policies. Small lines on the horizontal axes represent each time-period and can be used to analyse changes as time passes.

Due to computational constraints, certain variables are set to their maximum values to ensure changes could be observed within the simulation period. It is important to note that while a five-day timeframe is sufficient for demonstrating noticeable changes in the output, real-life policy impacts might not be as immediate.

5.3.1: BUSINESS-AS-USUAL SCENARIO RESULTS

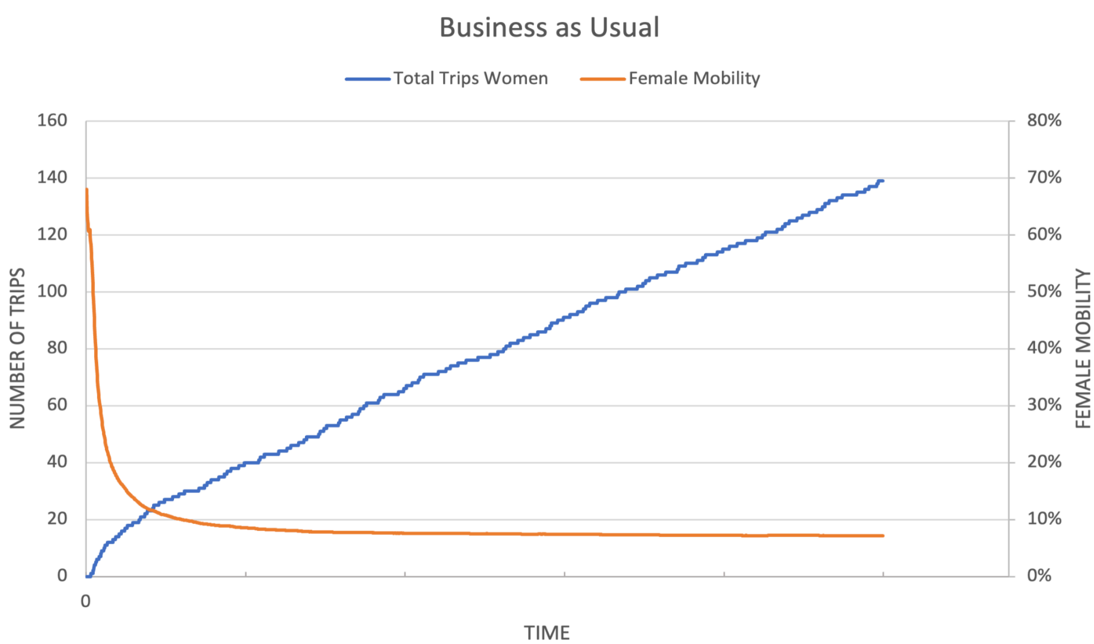


Fig. 23 Business-as-Usual Case with No Policies

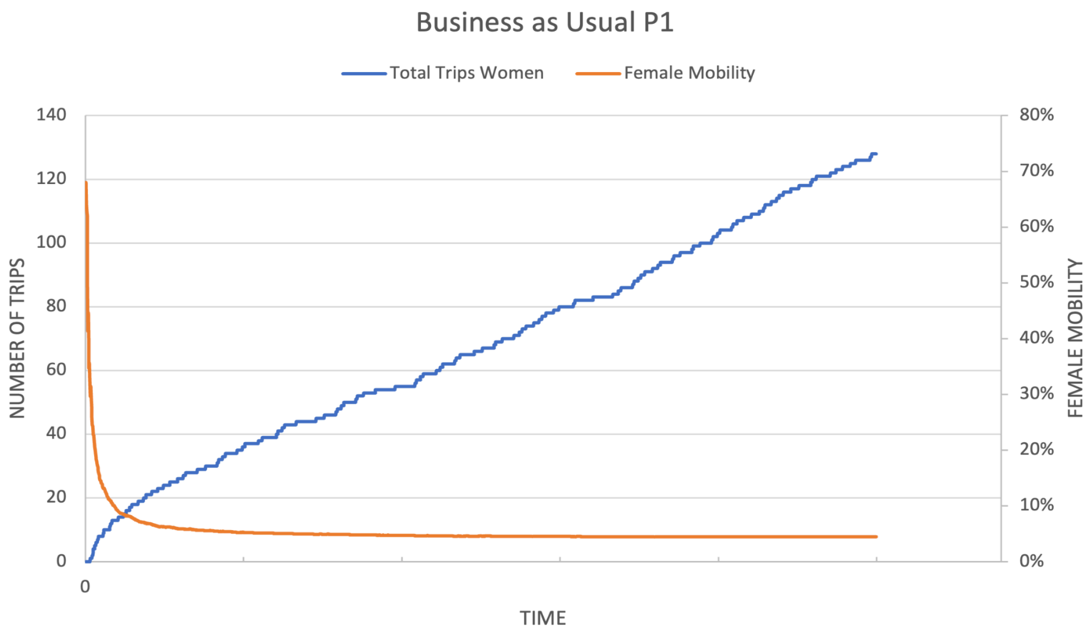


Fig. 24 Business-as-Usual Case with P1

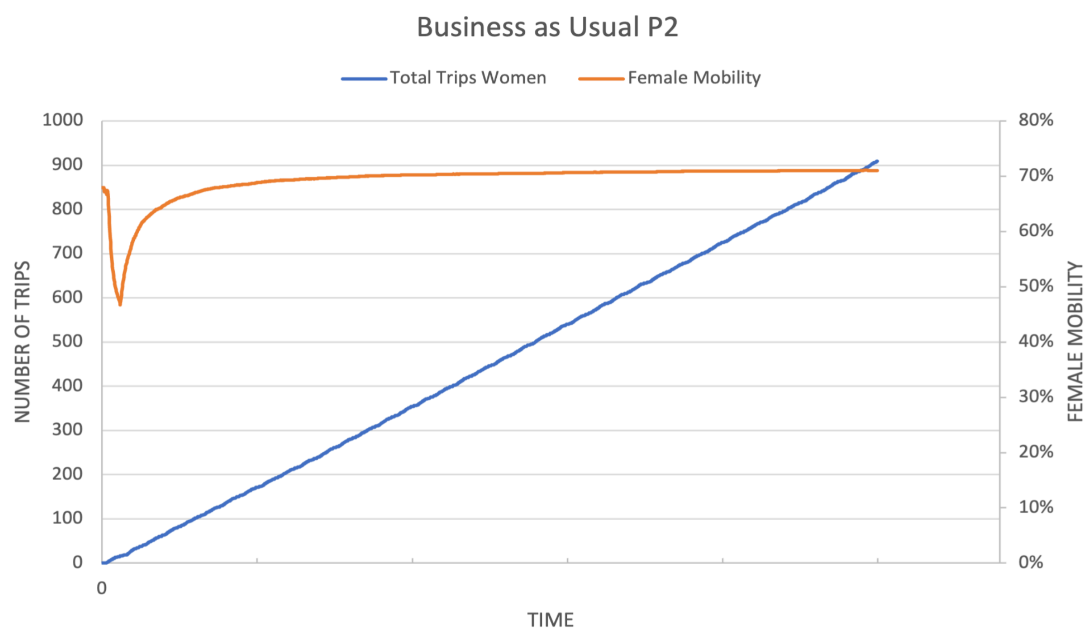


Fig. 25 Business-as-Usual Case with P2

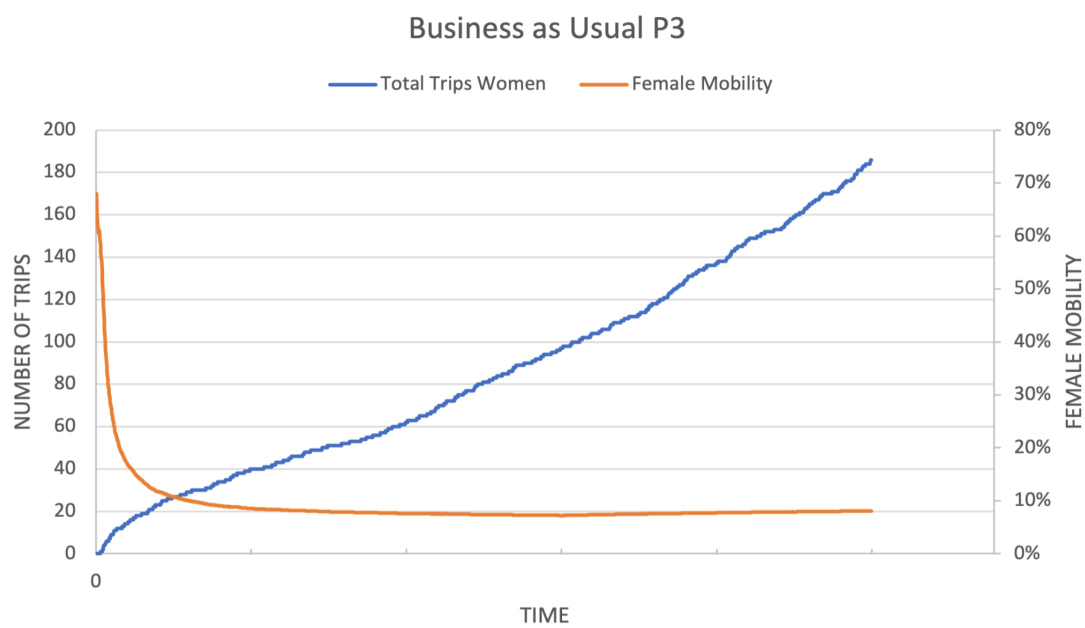


Fig. 26 Business-as-Usual Case with P3

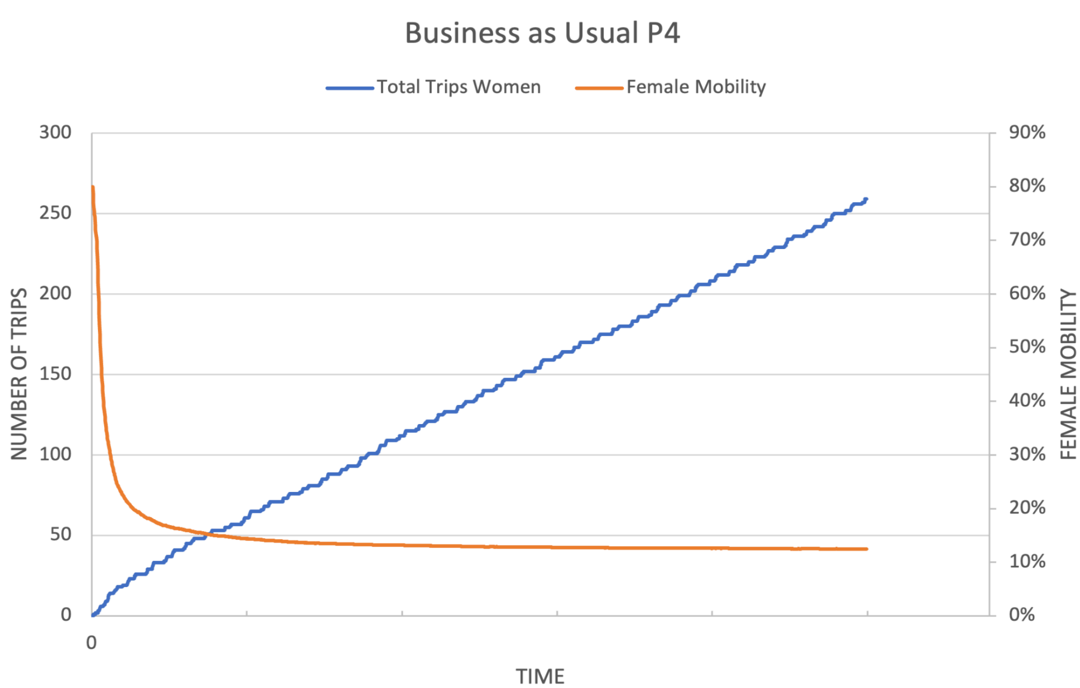


Fig. 27 Business-as-Usual Case with P4

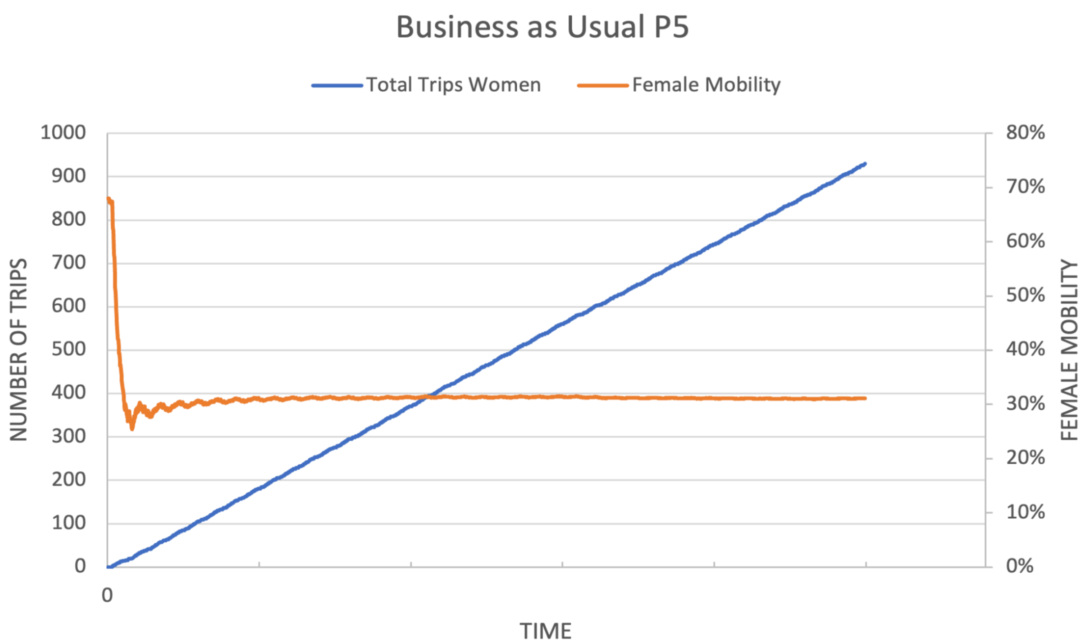


Fig. 28 Business-as-Usual Case with P5

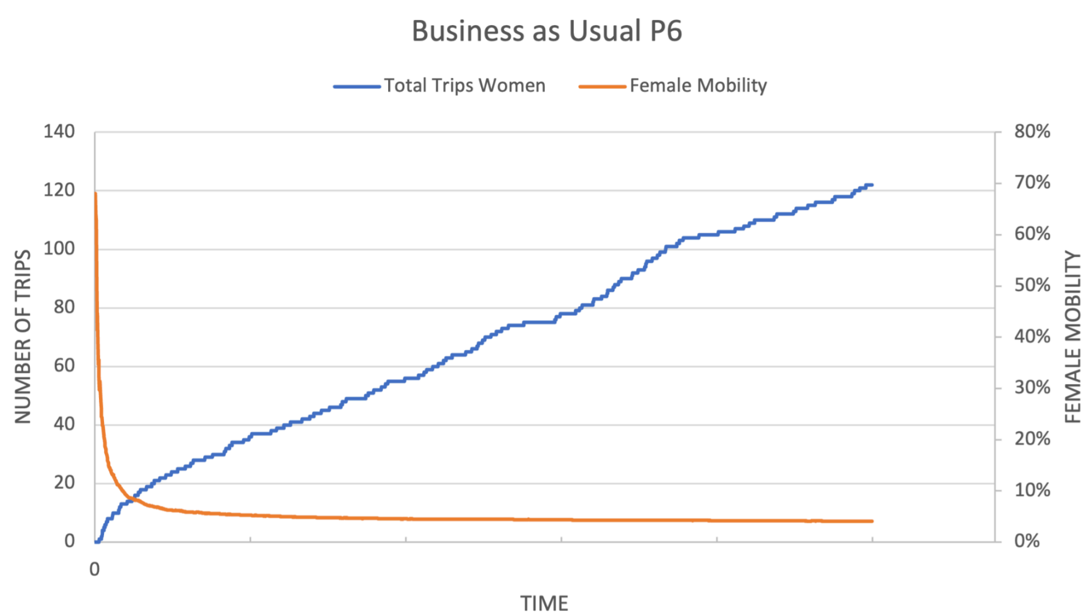


Fig. 29 Business-as-Usual Case with P6

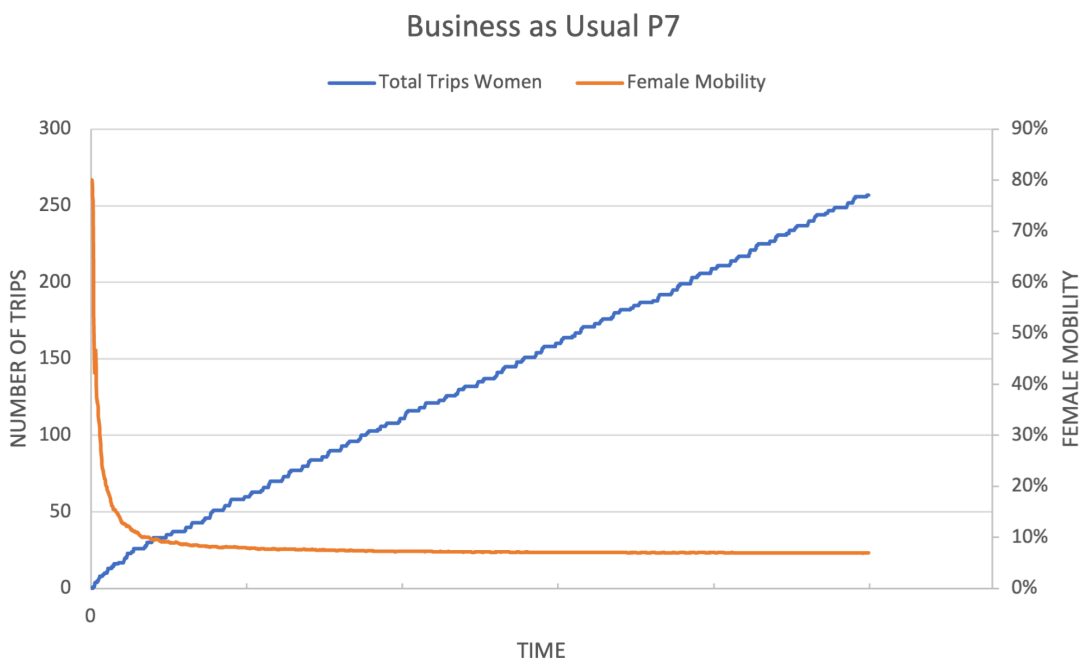


Fig. 30 Business-as-Usual Case with P7

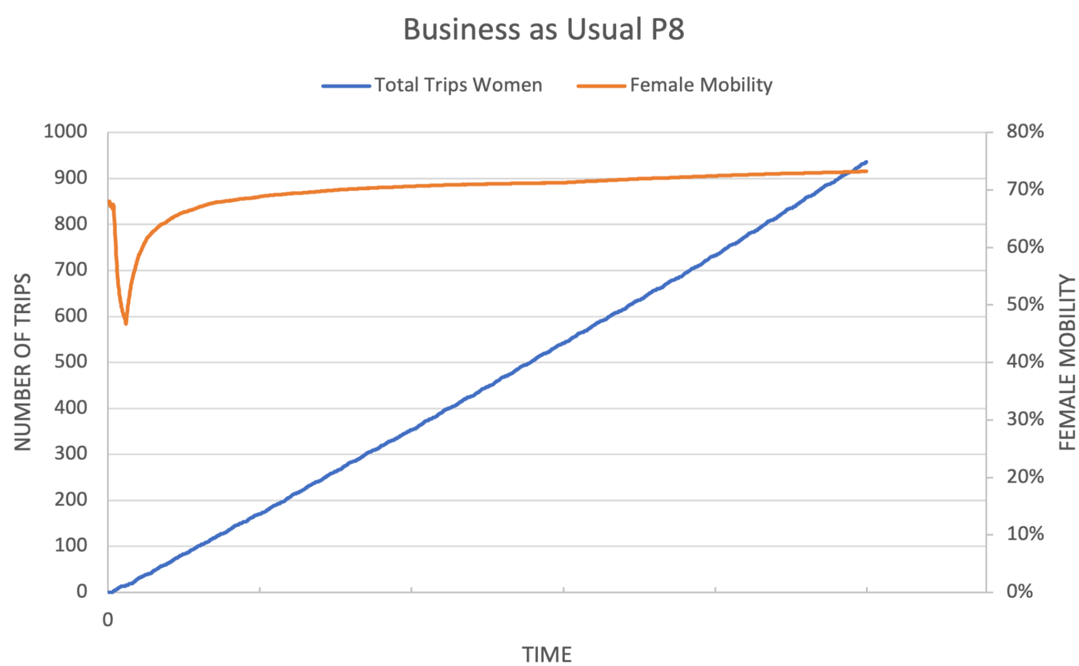


Fig. 31 Business-as-Usual Case with P8

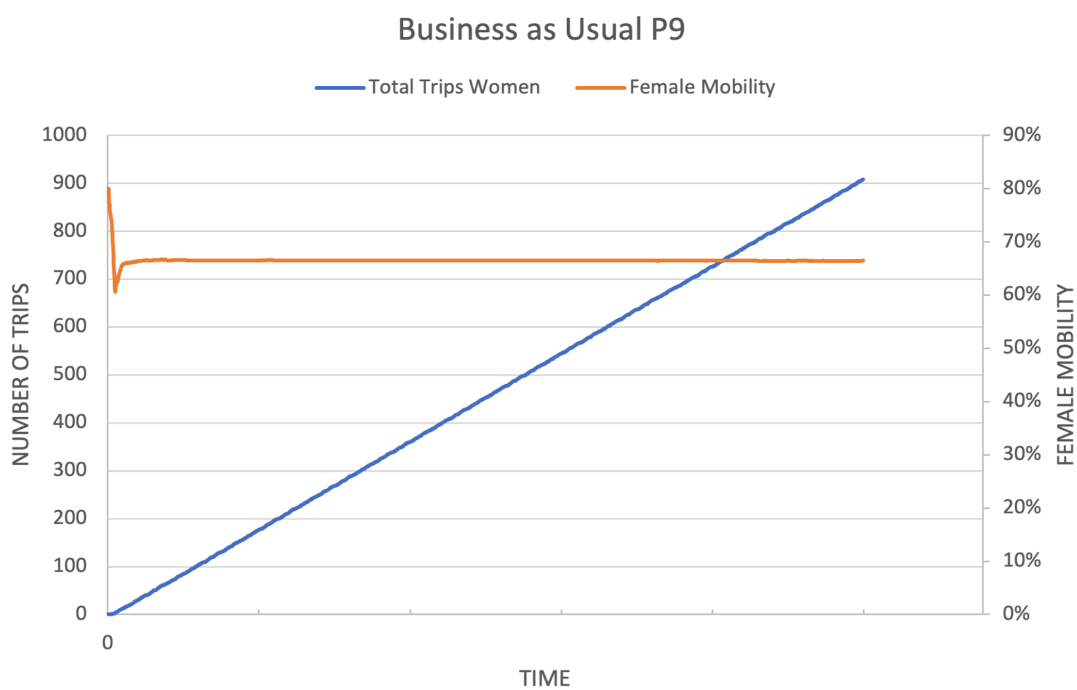


Fig. 32 Business-as-Usual Case with P9

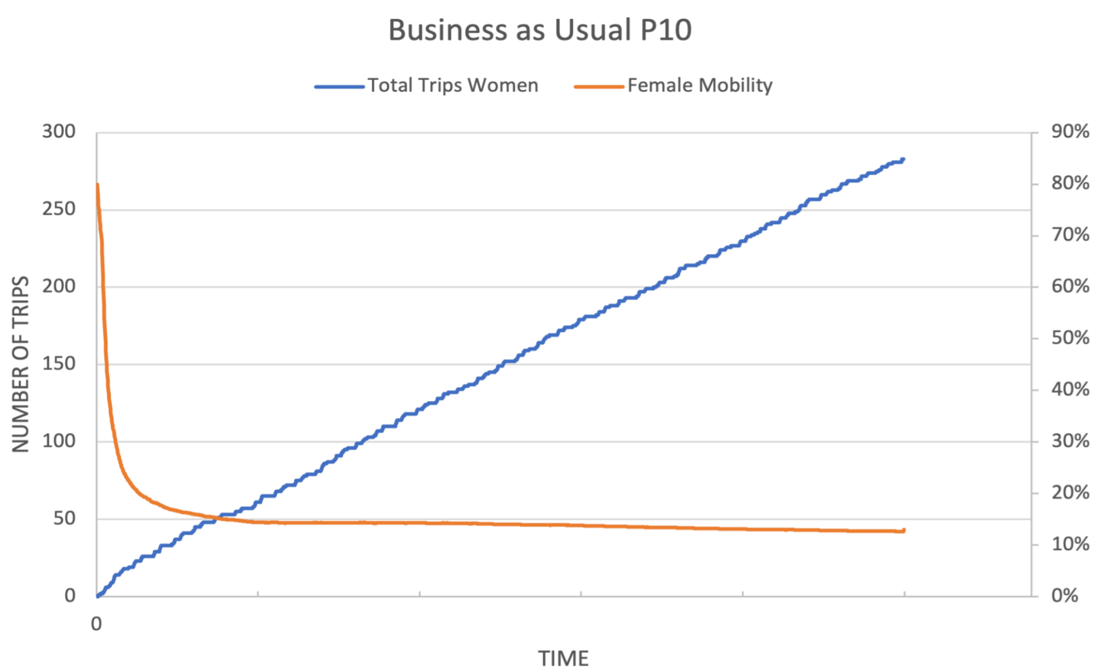


Fig. 33 Business-as-Usual Case with P10

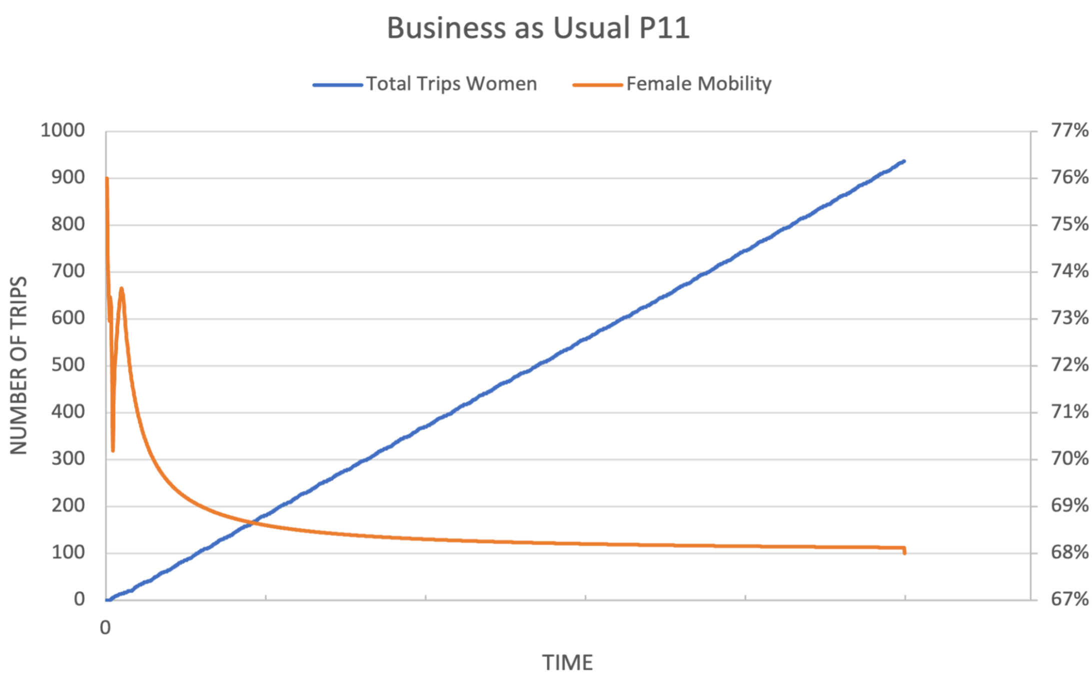


Fig. 34 Business-as-Usual Case with P11

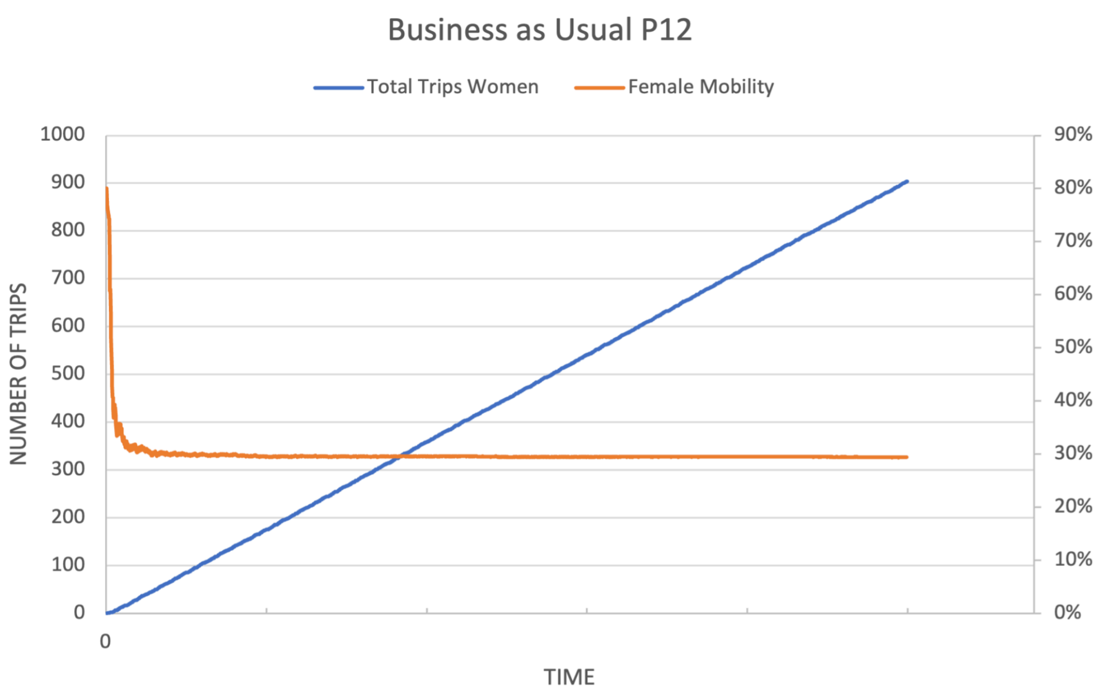


Fig. 35 Business-as-Usual Case with P12

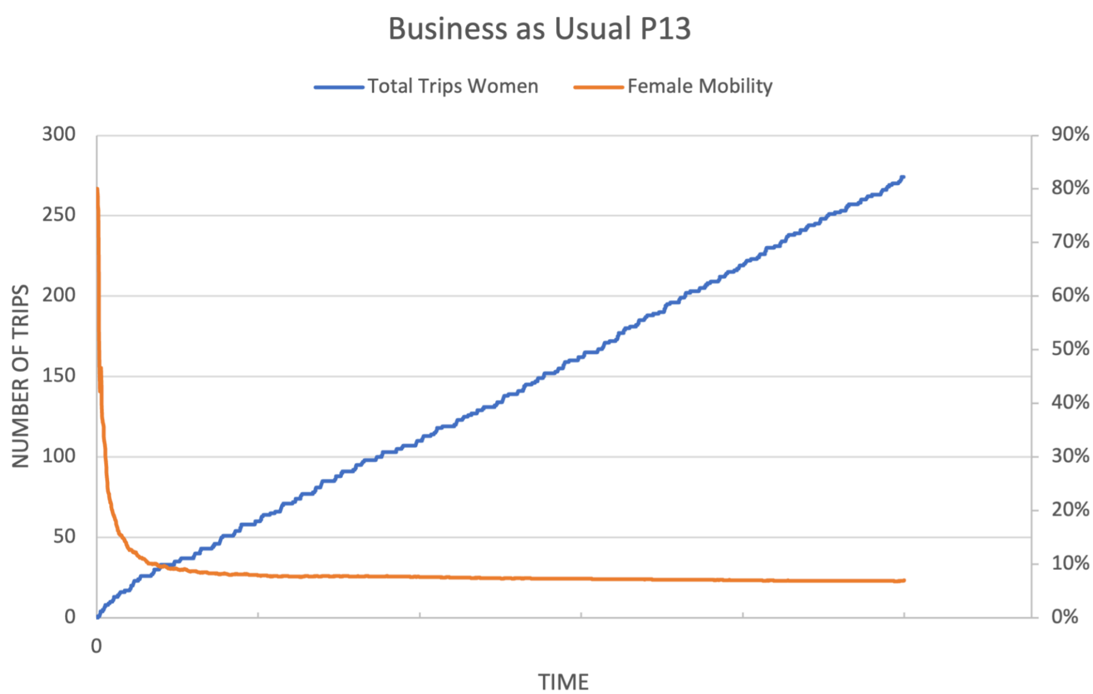


Fig. 36 Business-as-Usual Case with P13

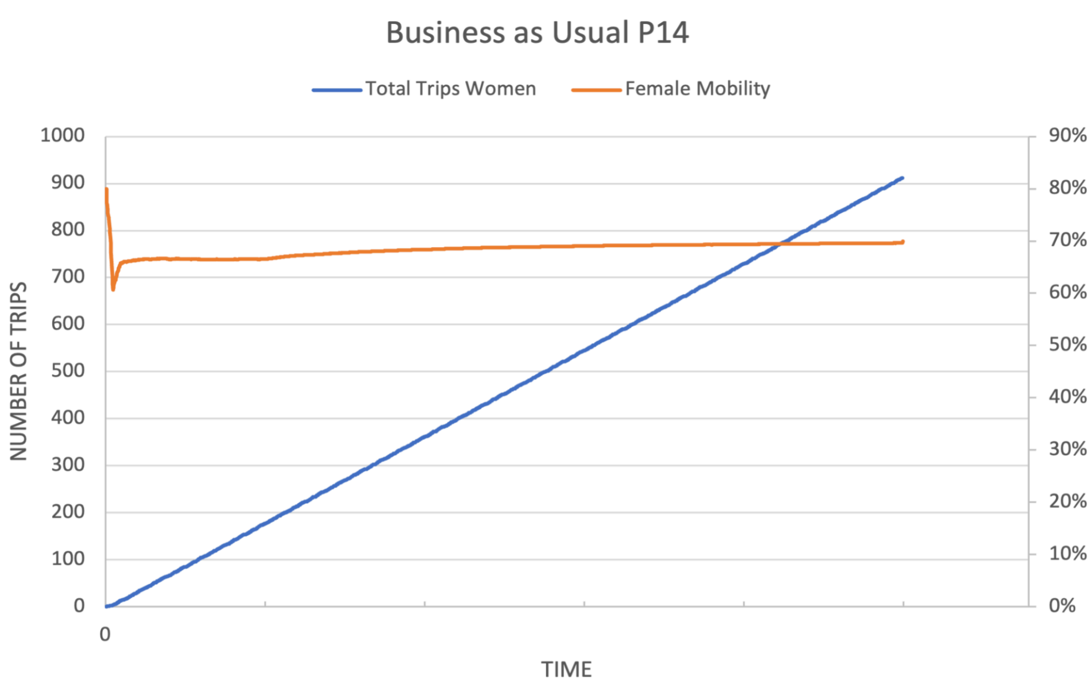


Fig. 37 Business-as-Usual Case with P14

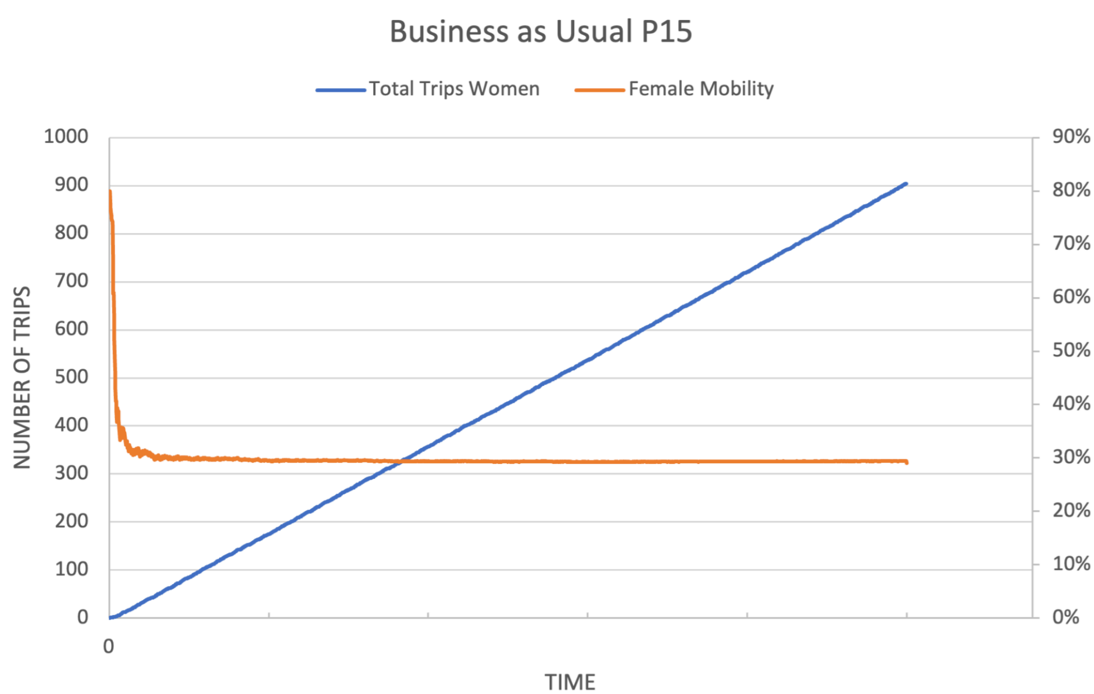


Fig. 38 Business-as-Usual Case with P15

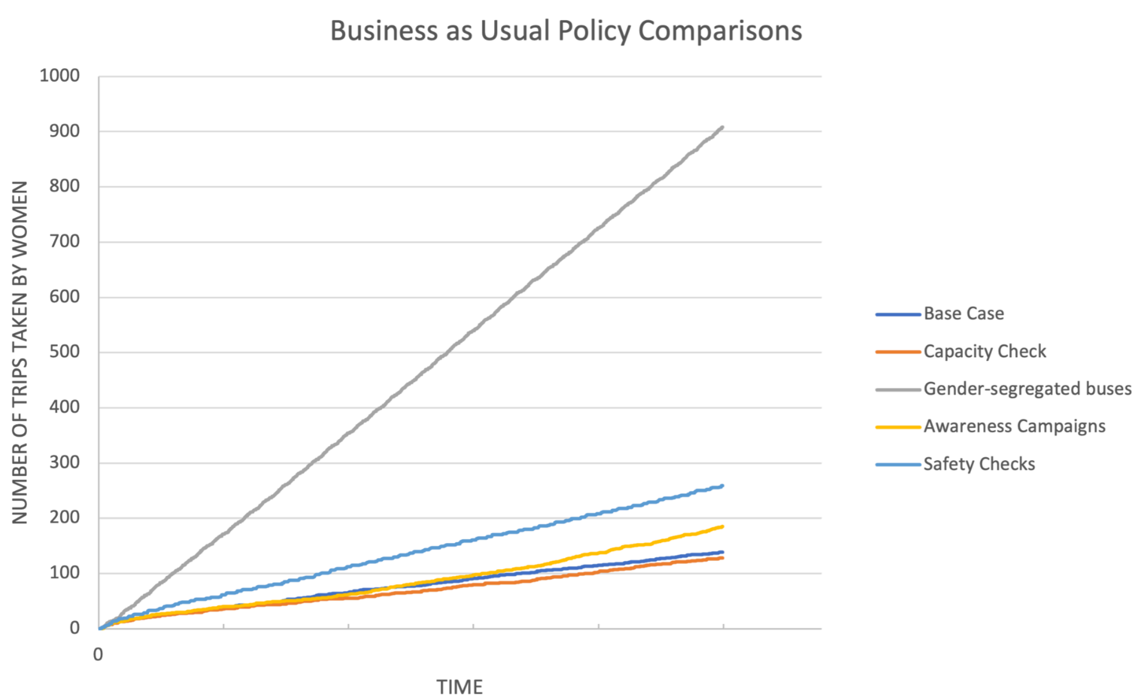


Fig. 39 Number of Trips Taken: Policy Comparison for Business-as-Usual Case

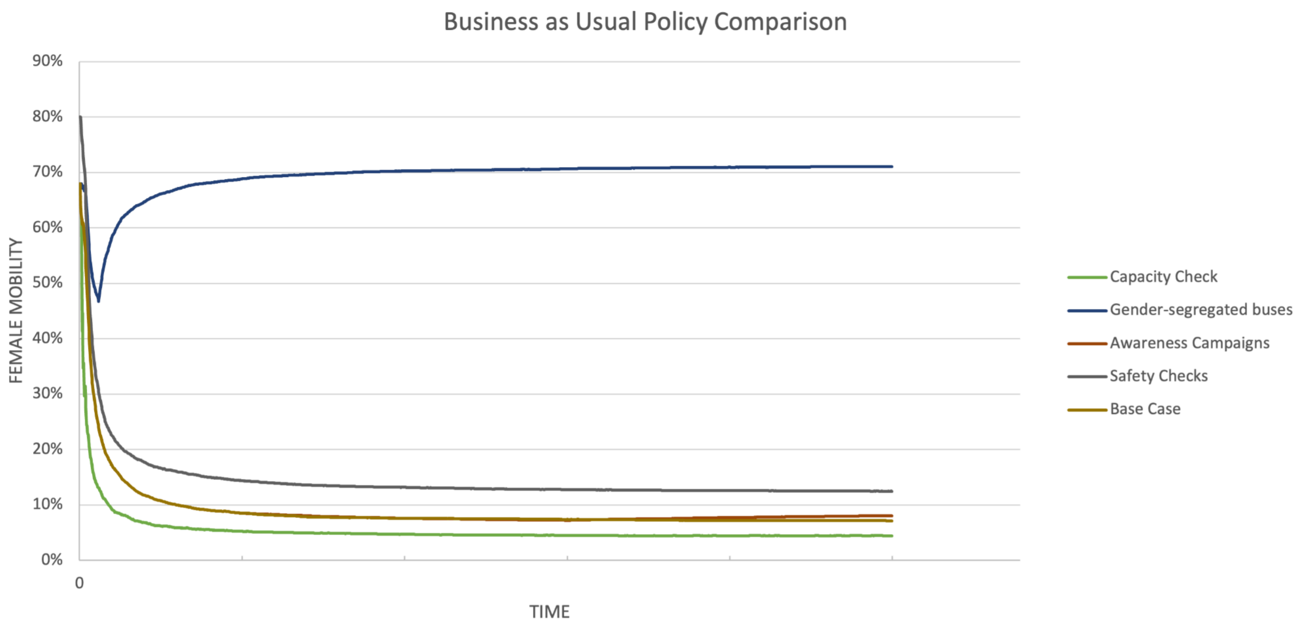


Fig. 40 Female Mobility: Policy Comparison for Business-as-Usual Case

5.3.2: HIGH AWARENESS, LOW CRIME SCENARIO RESULTS

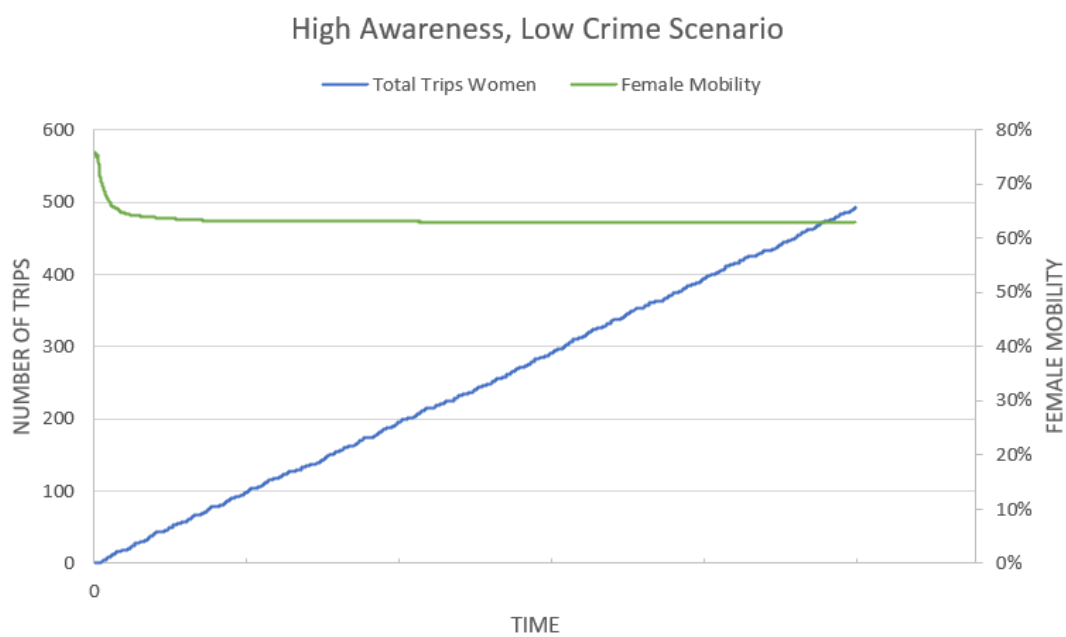


Fig. 41 High Awareness, Low Crime Case with No Policies

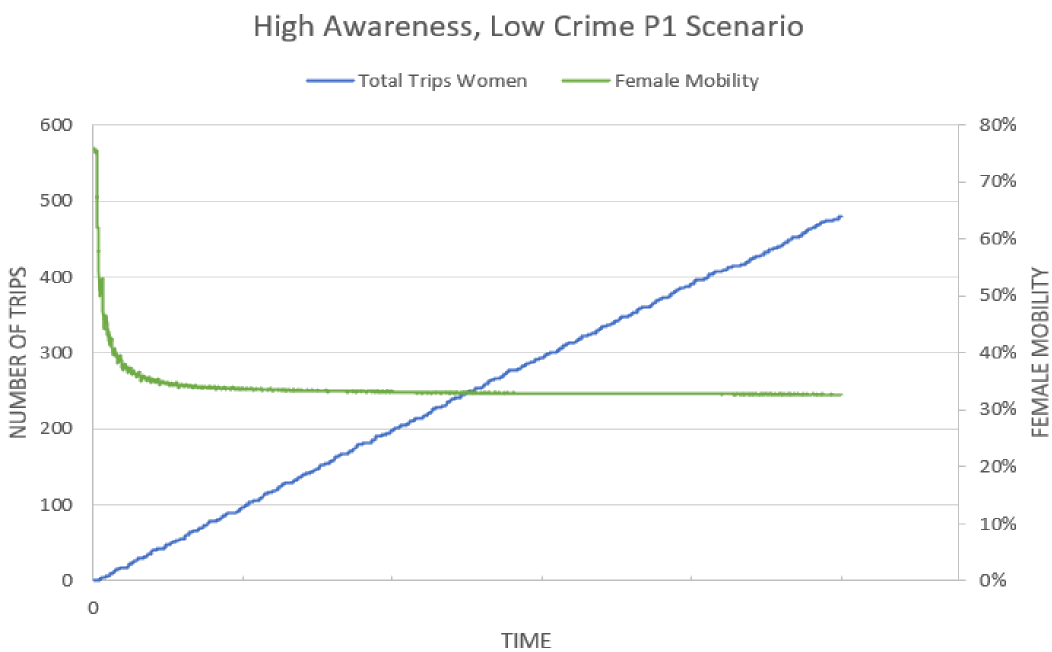


Fig. 42 High Awareness, Low Crime Case with P1

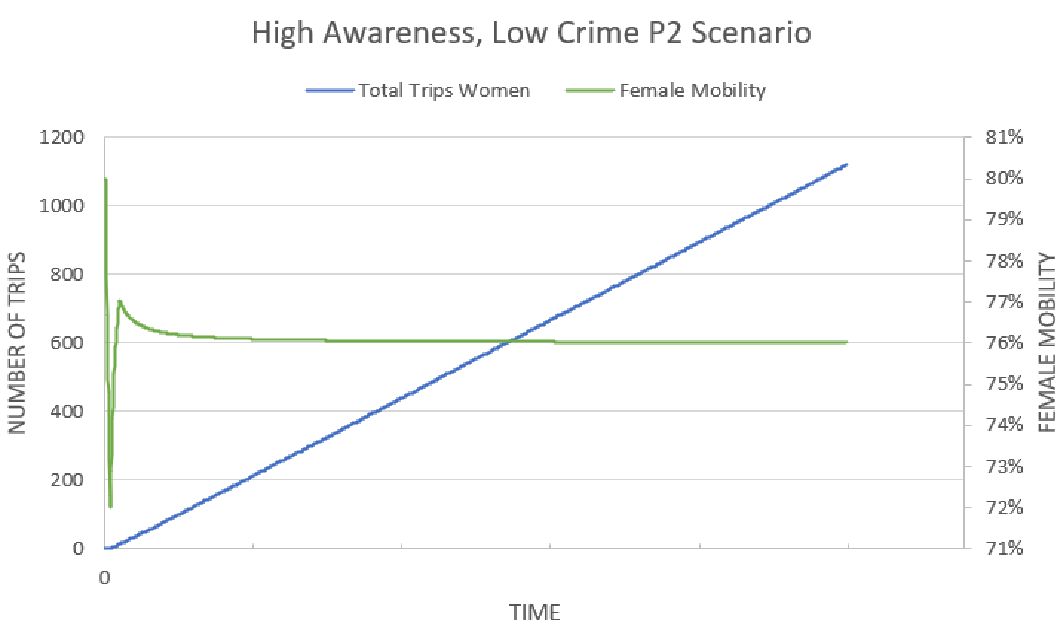


Fig. 43 High Awareness, Low Crime Case with P2

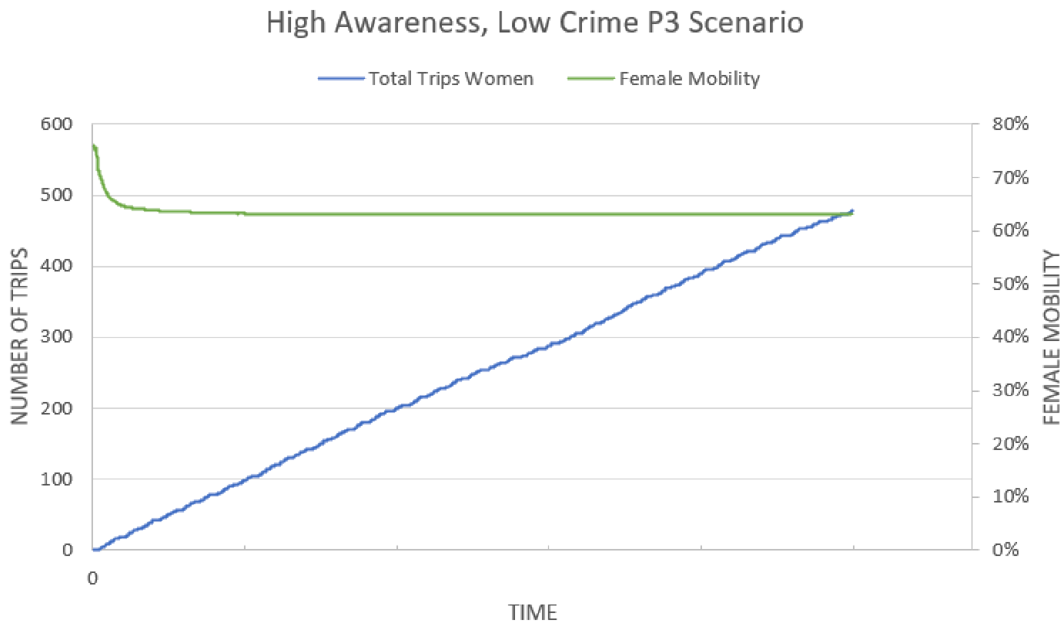


Fig. 44 High Awareness, Low Crime Case with P3

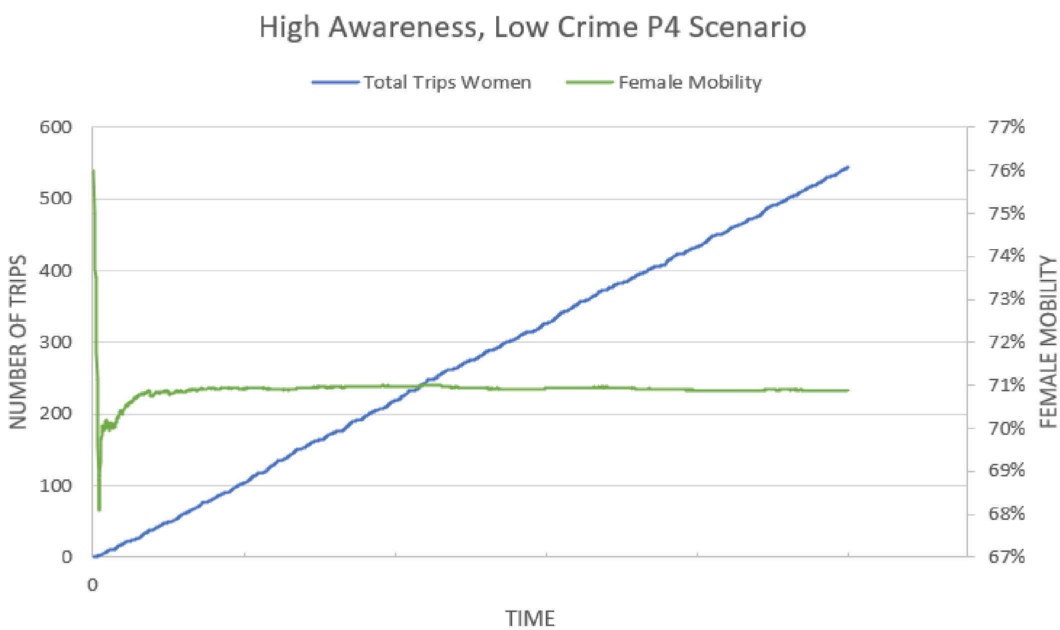


Fig. 45 High Awareness, Low Crime Case with P4

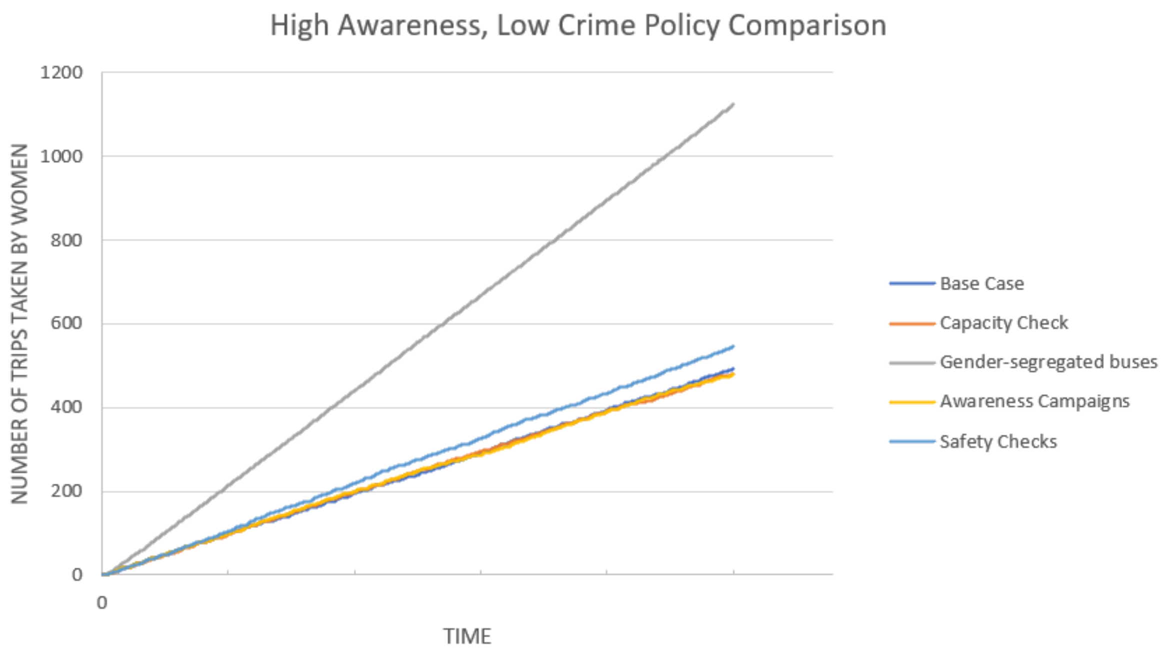


Fig. 46 Number of Trips Taken: Policy Comparison for High Awareness, Low Crime Case

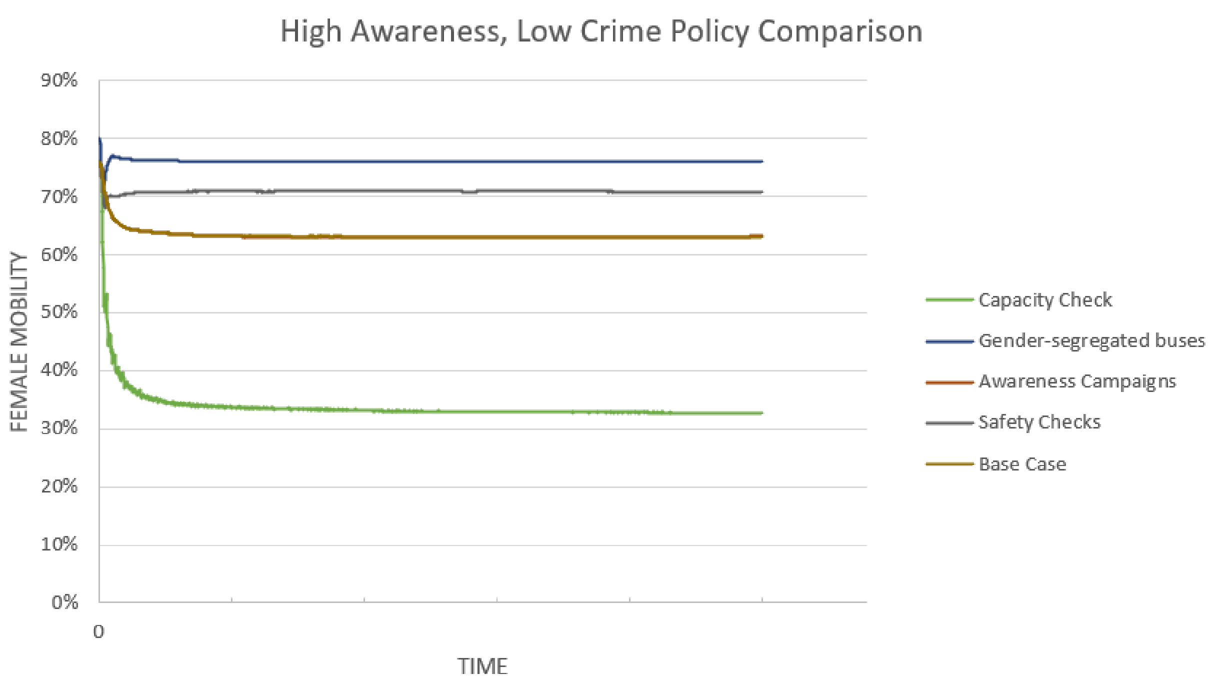


Fig. 47 Female Mobility: Policy Comparison for High Awareness, Low Crime Case

5.3.3: INCREASED GENDER PARITY, LOW SOCIAL STIGMA SCENARIO RESULTS

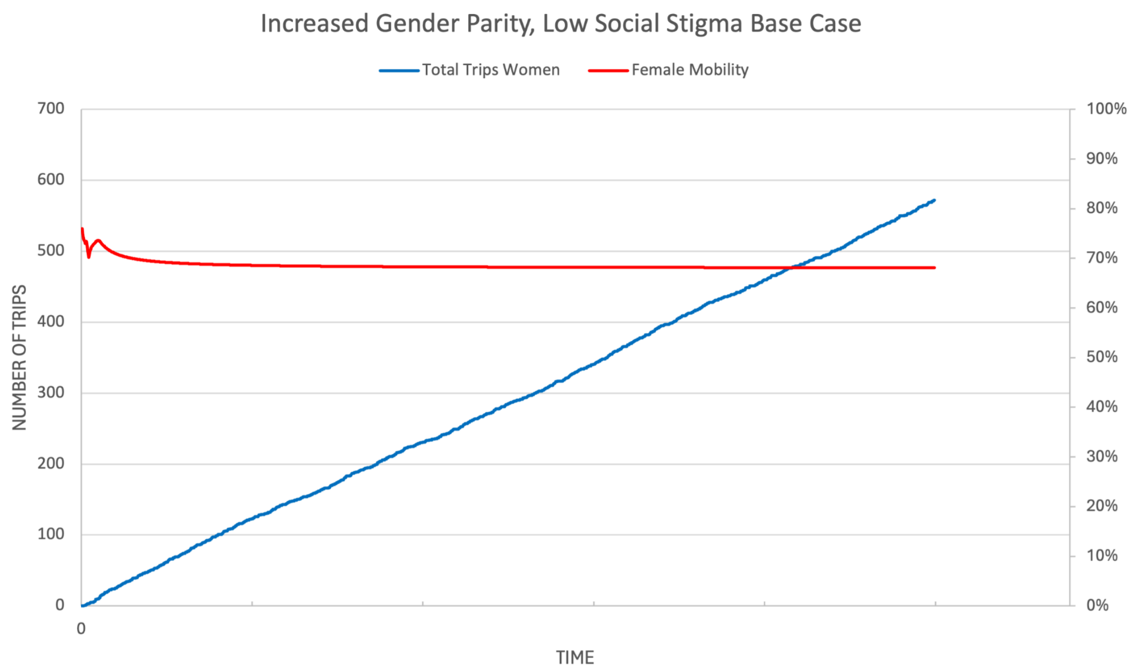


Fig. 48 High Gender Parity, Low Social Stigma Case with No Policies

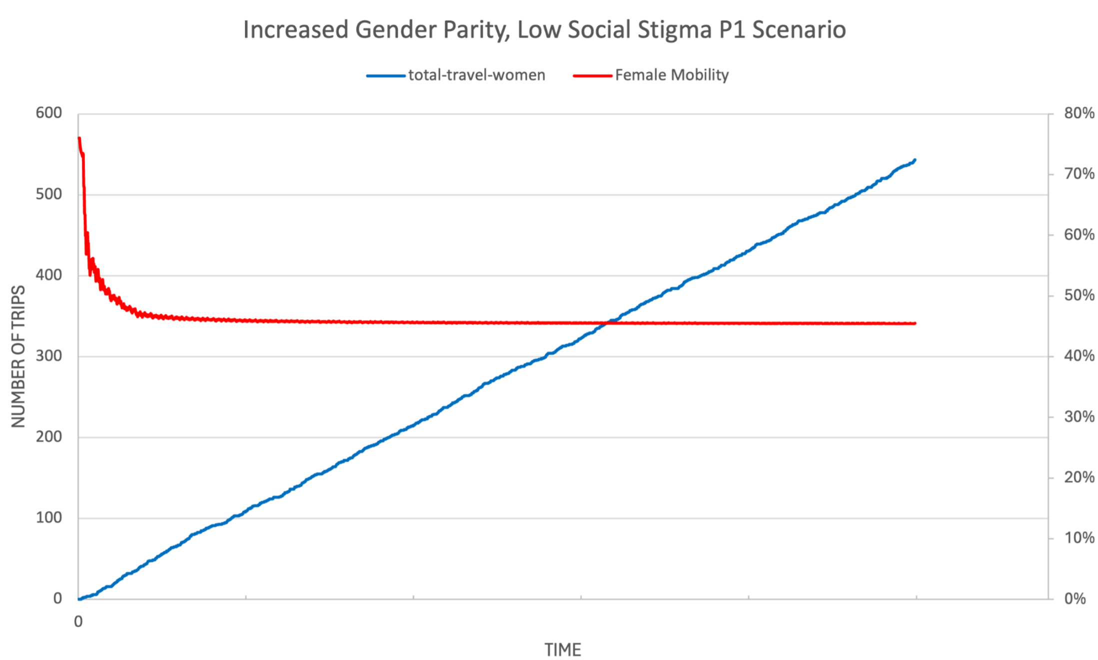


Fig. 49 High Gender Parity, Low Social Stigma with P1

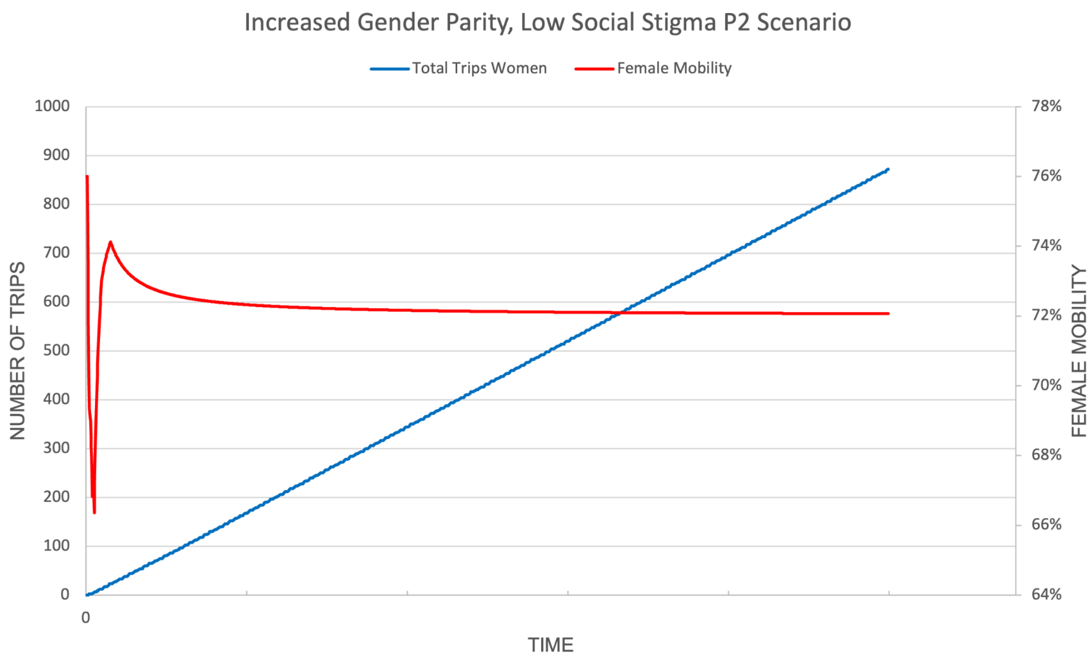


Fig. 50 High Gender Parity, Low Social Stigma with P2

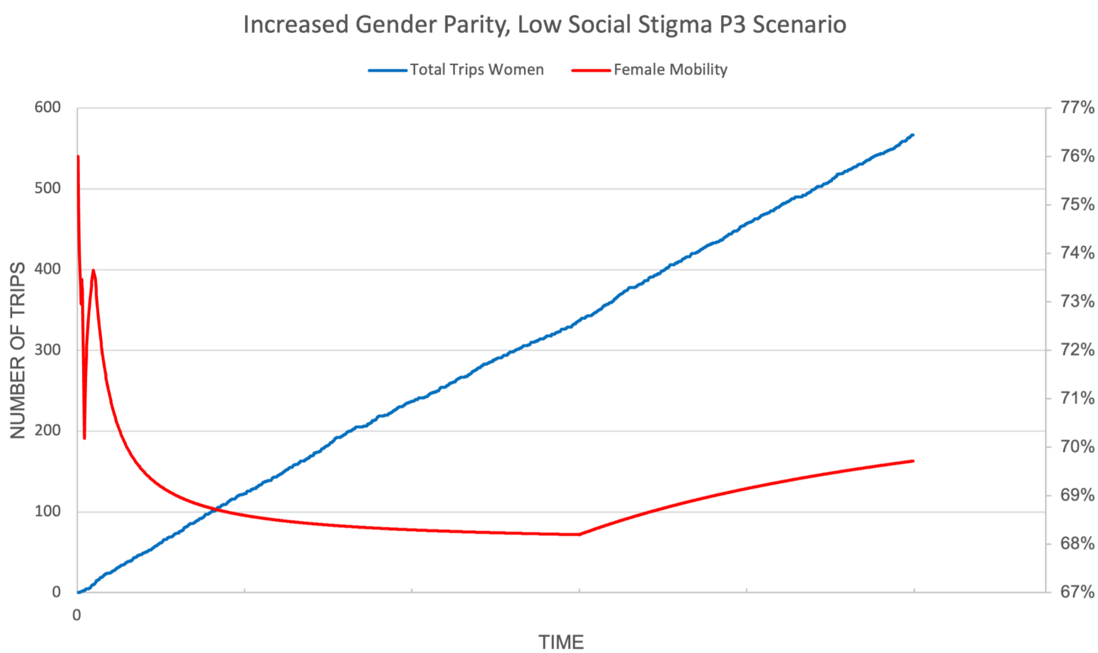


Fig. 51 High Gender Parity, Low Social Stigma with P3

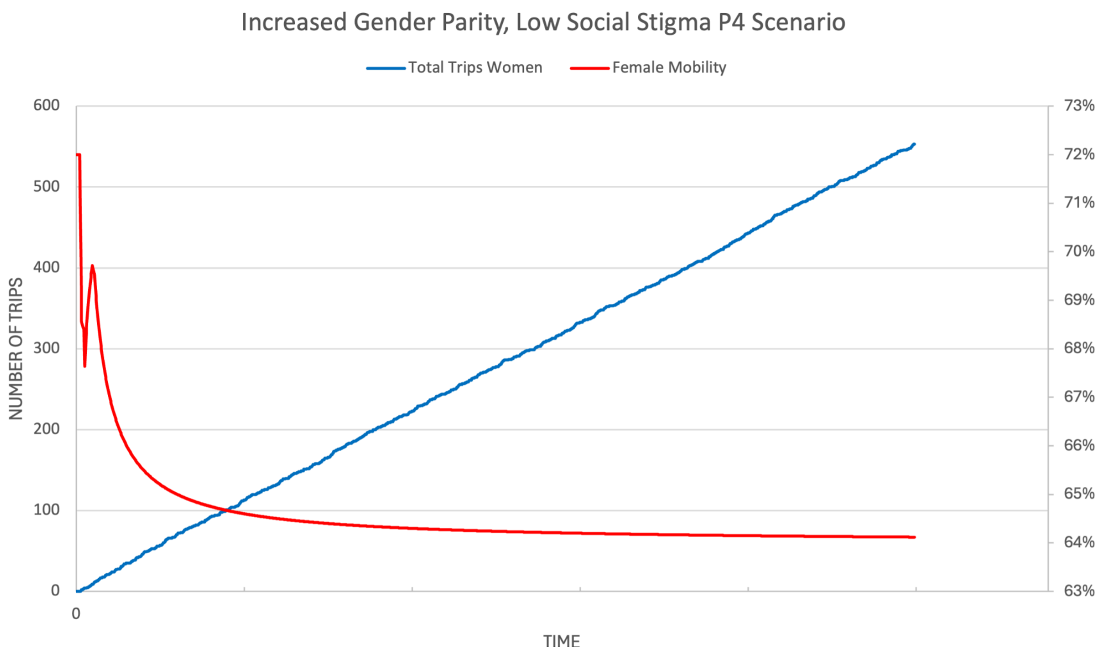


Fig. 52 High Gender Parity, Low Social Stigma with P4

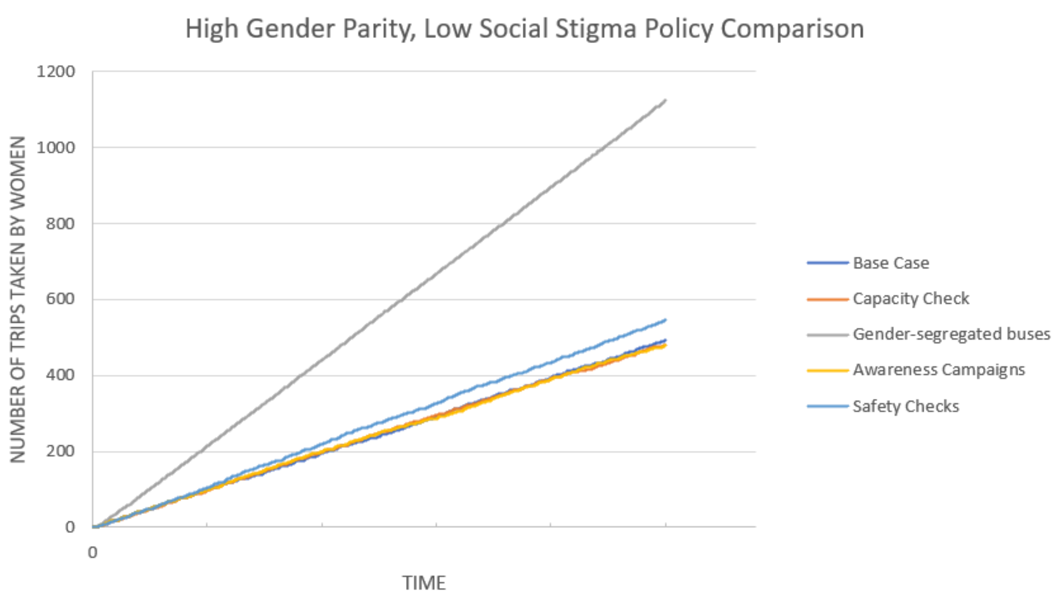


Fig. 53 Number of Trips Taken: Policy Comparison for High Gender Parity, Low Social Stigma Case

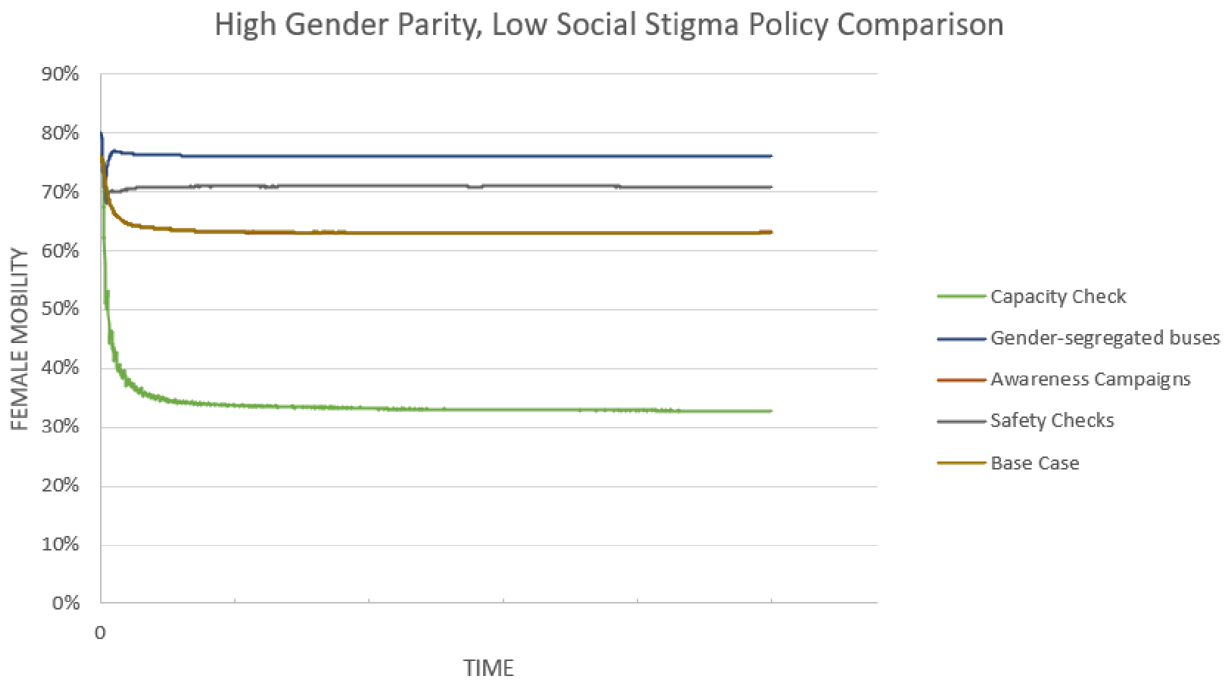


Fig. 54 Female Mobility: Policy Comparison for High Gender Parity, Low Social Stigma Case

5.4: RESULT ANALYSIS AND OUTLOOK

5.4.1: BUSINESS AS USUAL SCENARIO RESULT ANALYSIS

The results for the Business-as-Usual base case and policy scenarios are plotted and shown in figures 23-40. The plots show that P2 (gender-segregated buses) is the most successful policy for increasing female mobility and the total number of trips taken by women.

Table 9 BUSINESS-AS-USUAL: STEADY STATE FEMALE MOBILITY

Policy/Scenario	Steady-State Female Mobility
Base Case	7%
P1	4%
P2	71%
P3	8%

P4	12%

Female mobility is around 8% for the base case. When P1 (capacity-check) is implemented, female mobility decreases to around 5% even though women's comfort levels improve (see figure 24). Similar patterns are observed for P5 (capacity-check and gender-segregated buses), P6 (capacity-check and awareness-campaigns), P11 (capacity-check, gender-segregated buses, and awareness-campaigns), P12 (capacity-check, gender-segregated buses, and safety-check), and P15 (all four policies). However, when capacity-check is implemented in combination with other policies, especially P2 (gender-segregated buses), the overall negative impact of capacity-check on female mobility is minimised (see figure 28).

The results for P2 show a significant increase in female mobility, with the steady-state value of female mobility increasing to around 71%. The graph initially shows a dip in mobility, followed by a rise (see figure 25). The fluctuation may have been caused by initial unfamiliarity and lack of trust in gender-segregated buses among women. As awareness and confidence levels improve over time, more and more women become open to the idea of using gender-segregated buses, leading to improved mobility rates. Similar trends are noted for policy combinations incorporating gender-segregated buses such as P8 (gender-segregated buses and awareness-campaigns) and P9 (gender-segregated buses and safety-check). However, in the case of policies P5, P11, P12, and P15, all of which incorporate capacity-check, an initial adjustment period consisting of oscillatory motion in female mobility is observed. When capacity limits are enforced, they disrupt usual travel patterns, causing confusion and inconvenience for passengers, leading to fluctuations in mobility as users adapt to the new changes. However, over time, passengers become accustomed to these changes, and the fluctuations diminish over time, leading to stabilisation of mobility patterns.

P3 (awareness-campaigns) alone does not significantly improve female mobility, showing only an increase of 1% from the base case (see figure 26). Similarly, when P3 is paired with other policies excluding P2, it again fails to significantly enhance female mobility. This is because awareness campaigns usually require a longer amount of time to influence behaviour and perceptions. However, when P3 is combined with P2 in P8, there is a noticeable increase in female mobility, from 71% to 73% – the maximum female mobility observed across all policy combinations (see figure 31). These results show that combining P3 with other supportive policies, such as gender-segregated buses, is more effective in enhancing female mobility.

P4 (safety-check) minimally improves female mobility, both when implemented alone and in combination with other policies. Compared to the base case, when P4 is run alone, there is a 5% increase in female mobility (see figure 27), and when combined with P3 in P10 (awareness-campaigns, safety-check), the increase is 6% (see figure 33). However, when P4 is combined with P2 in P9 (see figure 32), female mobility reduces from 71% to 66%. This decrease can be attributed to the fact that gender-segregated buses already significantly enhance safety and additional security checks might be seen as unnecessary or inconvenient.

The results indicate that P8 is the most successful policy, achieving a steady-state female mobility rate of 71% while combining all four policies results in a significantly lower female mobility rate of 29%. This outcome highlights that more is not always better. Excessive policy implementation can result in diminished effectiveness due to overlapping measures that complicate usage or minimise the positive effects of individual policies.

5.4.2: HIGH AWARENESS, LOW CRIME SCENARIO RESULT ANALYSIS

The results for the High Awareness, Low Crime base case and policy scenarios are plotted and shown in figures 41-47. The plots show that P2 (gender-segregated buses) is the most successful policy for increasing female mobility and the total number of trips taken by women.

Table 10 HIGH AWARENESS, LOW CRIME: STEADY STATE FEMALE MOBILITY

Policy/Scenario	Steady-State Female Mobility
Base Case	63%
P1	33%
P2	76%
P3	63%

P4	71%

Female mobility is 63% for the base case in the high awareness, low crime scenario. This is significantly higher than the steady-state value for the business-as-usual case, indicating just how impactful world parameters can be in influencing female mobility and respective policy implementation. All policy implementations yield a steady-state value of female mobility greater than 30% in this scenario.

When P1 (capacity checks) is implemented, female mobility steadily declines to 33% - a staggering loss of 30% from the base case (see figures 42 and 47). Similar to the business-as-usual scenario, P2 (gender-segregated buses) is the most effective policy, followed by P4 (safety checks) yielding steady-state values of 76% and 71% for female mobility respectively. Referring to figure 43, it can be seen that female mobility sharply dips to approximately 72% before rising back up to 77% and slowly decaying to a steady-state value of 76% when P2 is implemented. Implementation of P3 (awareness campaigns) does not result in any deviation in female mobility from the base case scenario for the high awareness, low crime scenario, as can be seen in figures 44 and 47. Figure 45 shows that when P4 is implemented on the high awareness, low crime scenario, the female mobility dips to about 68% before rising back to 71%. This transient oscillatory behaviour has been explained in section 5.4.1.

It is interesting to note these results given the parameters that were set for this scenario. The weight for safety in the psychological model was decreased from 0.8 to 0.3 and the harasser percentage was decreased from 70% to 30% to show low crime in this scenario. The weight for awareness was increased to 0.9 to show high awareness. Given these changes, it was predicted that P3 would be more effective as awareness was given higher importance, however similar to the business-as-usual scenario, the female mobility with P3 implemented was similar to that as the base case. Even more interestingly, implementation of P4 yielded a significant increase in female mobility of about 8%, which was not expected as both the safety weight in the psychological model and harasser percentage was decreased. The results obtained from this scenario show that regardless of world parameters, policies targeting safety of women on public transport tend to yield better results as compared to other policies.

Capacity checks continue to hinder female mobility even though they result in higher values of comfort for women using the BRT. This effect is particularly prominent in this case, where the base case female mobility was already quite high. This shows that comfort - while an important part of the decision-making framework - does not take precedence when making modal choices. Attempts in improving female comfort through capacity checks actually limits the number of women that can use the BRT - and this number is quite significant given that the capacity was increased from 4 to 10 in the high awareness, low crime scenario - modelled after the Tokyo bus system.

5.4.3: INCREASED GENDER PARITY, LOW SOCIAL STIGMA SCENARIO RESULT ANALYSIS

The results for the base case and policy scenarios are plotted and shown in figures 48-54. The plots show that P2 (gender-segregated buses) is the most successful policy for increasing female mobility and the total number of trips taken by women. However, when compared to the base case, the increase (4%) is minimal. Surprisingly, policies P1, P3, and P4 decrease female mobility. These results demonstrate the importance of implementing policies only when necessary. As shown in table 11, poorly conceived or excessive policy measures can have the opposite of the intended effect.

Table 11 INCREASED GENDER PARITY: STEADY STATE FEMALE MOBILITY

Policy/Scenario	Steady-State Female Mobility
Base Case	68%
P1	45%
P2	72%
P3	-
P4	64%

Oscillatory motion in female mobility is seen across all five graphs, but is particularly significant for P2 and P3 due to the nature of these interventions.

For policy P3, oscillations in female mobility can be seen during the first two days (see figure 51). This occurs because it takes a lot of effort and time to change entrenched behaviours and attitudes. People often revert to familiar patterns unless they are continuously motivated or reminded of the new behaviours. The rise in female mobility after day 3 shows that awareness campaigns can create change once they have overcome initial resistance.

For policy P2, an initial dip in female mobility is observed (see figure 50). The simulation parameters for this scenario are based on the NYC Bus System, where gender segregation in public transport might be opposed due to cultural norms that emphasise inclusivity. Female mobility continues to rise and drop until steady-state is reached. These fluctuations in female mobility may result from periods where passengers perceive an increased sense of safety due to the segregation, contrasted with periods of backlash from others who view such policies as regressive.

5.4.4: OVERALL ANALYSIS

It is important to note that the simulation results of the scenarios inspired by the Tokyo and New York bus systems may not accurately reflect real-life outcomes. This is because the psychological model used to simulate decision-making is based on the assumptions and parameters of the Calicut model, which does not capture the characteristics of New York or Tokyo. The goal is to explore how female mobility in Lahore would change if the city were to adopt societal and cultural norms similar to those in Tokyo or New York.

From the results obtained, it can be seen that female mobility increased significantly in the high awareness, low crime and increased gender parity, low social stigma scenarios with no policy implementation as compared to the business-as-usual scenario. This indicates the importance of targeting societal issues in Pakistan - specifically those of decreasing crime rates, improving gender parity, and reducing social stigma surrounding the use of public transport. Initiatives to target these issues do not necessarily have to be in the public transport realm. Crime rates could be decreased by improving street lighting and surveillance in the city, police patrolling, etc. Gender parity can be improved through the implementation of equitable policies that promote inclusive education and awareness, as well as ensuring equal opportunities and representation for all genders in all sectors of the society. Social stigma can be decreased through public awareness campaigns, and the enactment of supportive legislation that both protects and promotes the rights of women.

It is interesting to note that across all three scenarios, P1 (capacity checks) actually hindered female mobility. This goes to show that implementing capacity checks in order to improve the feeling of comfort in women actually hinders them from using the BRT system to their needs - showcasing that comfort does not play as vital a role in modal decision making. On the other hand, safety measures - be it through the introduction of gender-segregated initiatives or safety checks - leads to improved female mobility across all three scenarios, underscoring the importance of safety in female decision-making to use the BRT regardless of world parameters.

The business-as-usual scenario further sheds light on the negative consequences of excessive policy implementation, showing that a policy combination of gender-segregated buses with safety checks leads to the highest female mobility rate of 71%, whereas a combination of all four policies implemented together results in a female mobility rate of only 29%. These results indicate the importance of the systematic analysis of policy implementation in order to achieve the optimal result.

Referring to figure 55, a breakdown is given of the number of trips across all three scenarios for the base case and all four policy implementations separately. It can be seen that P2 yields the highest number of trips taken for all three scenarios, however it is important to note that real-world implementation of gender-segregated buses will not result in such a stark difference as compared to other policies. This is due to the implementation of gender-segregated buses in the simulation. As per the code, enactment of gender-segregated buses leads to only women being able to use the BRT system. This means that the entire fleet of buses in the BRT system are converted to women-only. This cannot be replicated in the real world, and normally the introduction of gender-segregated buses means that a certain percentage of the entire fleet of buses are converted to women-only. However, these results show the true demand of women's mobility needs that are currently not being met by the BRT system. This result actually refutes the common misconception that gender-segregated services are bound to fail due to the lack of demand by women.

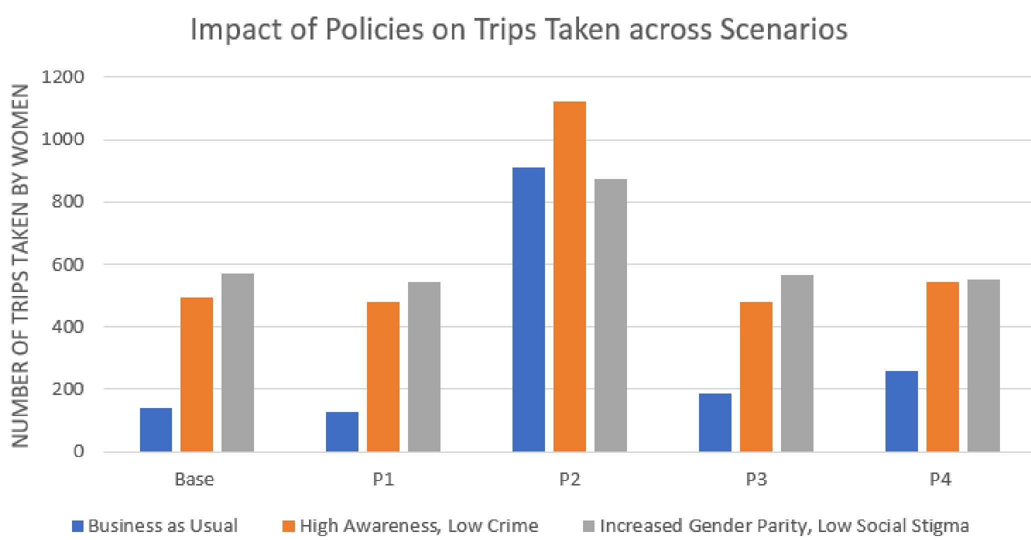


Fig. 55 Impact of Policies on Number of Trips Taken Across all Scenarios

The impact of world parameters on number of trips taken by women can also be seen through figure 55 - i.e. in the increased gender parity, low social stigma scenario, the number of trips taken is higher than the other two scenarios in the base case, P1 and P3 implementation, whereas it is lowest in P2 implementation and about equal to the high awareness, low crime scenario for P4. This shows that while P2 may be the most effective policy as compared to the other three policies for the increased gender parity, low social stigma scenario, the level of impact of P2 on the increased gender parity, low social stigma scenario is actually lower than on the other two scenarios. Therefore, analysis across all three scenarios provides further insights into policy behaviour.

Chapter 6

COST ANALYSIS

N/A

Chapter 7

CONCLUSION AND FUTURE RECOMMENDATIONS

7.1: CONCLUSION

To conclude, we have successfully developed an agent-based model in NetLogo to simulate the Lahore Bus Rapid Transit (BRT) system. Our model incorporated a psychological framework based on the Theory of Planned Behavior, an extensive literature review, and survey data available to us. We simulated three scenarios within the model: business-as-usual, high awareness, low crime, and high gender parity, low social stigma. Each scenario was effectively simulated using BehaviorSpace and the results were graphed and analysed, allowing for an in-depth examination of the potential impacts of various policies on the BRT system. This comprehensive approach enabled us to better understand the dynamics of female mobility within the Lahore BRT context and forms the basis of our policy library which contains tested and analysed recommendations for policymakers and stakeholders to enhance the efficacy and inclusivity of the BRT system, ensuring it serves as a reliable and safe mode of transportation for all users, particularly women.

The three main limiting factors in this research project were time, computational power, and available data. Due to constraints in available data, it was not possible to create a Structural Equation Model (SEM) for the decision-making framework, due to which we had to base our psychological model weights on a pre-existing transport model for Calicut. Given the time constraints of this project, it was also not possible to collect relevant Lahore BRT specific survey data with a focus on the impact of gendered variables on female mobility. Therefore, we had to make certain assumptions in our model - that have been extensively discussed in earlier chapters - which lowered the overall accuracy of the results. Furthermore, due to time and computational constraints, an in-depth sensitivity analysis could not be performed in regards to variables that were set by the user. Sensitivity analysis of parameters can provide further insight into how variables impact overall female mobility. Full policy implementation can also be conducted for the high awareness, low crime and increased gender parity, low social stigma scenarios for better comparison with the business-as-usual scenario. Computational limits led to the results being gathered over a time period of 5 days with exaggerated impacts for harassment and overcrowding in the simulation. With adequate computational power, the impacts can be made more realistic, and the simulation can be run over a longer time frame to give an accurate representation of the time-frame in which female mobility changes and arrives at a steady-state.

Nevertheless, it is important to note that there are numerous avenues of research that can be explored in regards to the systematic analysis of gender-informed transport policy in Pakistan. This project helps bridge the gap by laying the foundations for future systematic analysis in this field. With the correct data, our model can be updated to yield accurate results. This is novel research specifically in the context of Pakistan. It addresses the United Nations' SDG 5 and 11, which are "gender equality" and "sustainable cities and communities" and adds to the scarce global literature available on analysing the gendered impacts of decision-making variables in modal choice.

7.2: FUTURE RECOMMENDATIONS

We suggest the following recommendations for further enhancing the effectiveness of our agent-based model to address low female mobility in Pakistan.

- Future work should focus on gathering data through surveys which address female mobility directly by capturing perceptions of safety, experiences of harassment, and the effects of overcrowding. By incorporating this data into our model, we can enhance the precision and validity of our simulations, especially the dynamic impacts of various factors, and policy recommendations to address the needs and concerns of female users. Furthermore, access to Lahore specific BRT data can allow for a more effective way of populating the simulation - categorically generating users based on their data, instead of randomly assigning values based on percent divisions.

- Awareness campaigns could be modelled much more effectively by employing the concept of social networks. Campaigns should be designed to leverage existing social and communication networks to reach a broader audience and have a more sustained impact.
- The incorporation of enhanced computational capacity in the form of a GPU (graphics processing unit) can be used to show gradual changes and long-term dynamics of transportation systems. Detailed and extended simulations could be run and their long-term effects recorded and analysed. Our current model was constrained by computational limitations, requiring us to set a few parameters to their maximum value to obtain meaningful results within five days.
- Feedback from BRT users, especially women, could be gathered regularly not only to validate and update the model accordingly. This can help in quickly identifying areas where the model may not align with real-world experiences and adjust the simulations and policies accordingly.

The field of gender-informed transport policy is vast, with much work that is yet to be done. Further progress in this field will result not only in improved female mobility, but also beneficial short- and long-term socio-economic impacts for the community as a whole.

APPENDIX

Final Code:

```
extensions [gis]

globals [women-stopped men-stopped passenger-bus0 total-travel-women total-travel-men
total-travel bus-stop no-days women-intention women-stopped-brt women-intention-brt
women-use-brt percent-women-brt score-list]

breed [stations station ]
stations-own [ name ]

breed [buses bus]
buses-own [location reverse? label-of-bus]

breed [ people person ]
people-own [harasser? gender age income employment-status urgency feeling-of-safety
confidence comfort awareness car-ownership? at-work? home-loc work-loc home-tehsil
has-arrived? destination final-station BRT-use-score nearest-station]

patches-own [tehsil kind]


to setup
```

```
  ca
  random-seed 2024;
  import-gis-data ;;layout of map and metroline
  create-brt ;;creating the bus station links
  add-POIs ;;adding points of interest
  create-buses 1 [setxy 34 100 set shape "bus" set size 2 set color red set location station 0 set
reverse? false set label-of-bus "bus0"]
  ;;num-people defined by user
  let lahore-city-ppl round ( 0.3286 * num-people );;32.86 % of total population
  let lahore-city-female round (0.4781 * lahore-city-ppl) ;;47.81% women
  let model-town-ppl round ( 0.2431 * num-people );;24.31 % of total population
  let model-town-female round (0.4741 * model-town-ppl) ;;47.41% women
  let shalimar-ppl round ( 0.2052 * num-people );;20.52 % of total population
  let shalimar-female round (0.4821 * shalimar-ppl) ;;48.21% women
  let raiwind-ppl round (0.0763 * num-people );;7.63 % of total population
  let raiwind-female round (0.4714 * raiwind-ppl) ;;47.14% women
  let lahore-cantt-ppl  num-people - ( lahore-city-ppl + model-town-ppl + shalimar-ppl +
raiwind-ppl );;14.68% of total population
  let lahore-cantt-female round (0.4749 * lahore-cantt-ppl) ;;47.49% women
  ;;defining tehsils using patches. coordinates to be updated later!
  ask patches [
    if pxcor >= 0 and pxcor <= 50 and pycor >= 0 and pycor < 50 [set tehsil "Model Town"]
    if pxcor >= 0 and pxcor <= 50 and pycor >= 50 and pycor <= 75 [set tehsil "Shalimar"]
    if pxcor >= 0 and pxcor <= 50 and pycor >= 75 and pycor <= 100 [set tehsil "Raiwind"]
    if pxcor > 50 and pxcor <= 100 and pycor >= 0 and pycor < 50 [set tehsil "Lahore
Cantonment"]
    if pxcor > 50 and pxcor <= 100 and pycor >= 50 and pycor <= 100 [set tehsil "Lahore City"]
  ]
  ;;setting up population
```

```
  ;;set-people-location [num-ppl-tehsil name-of-tehsil num-women-tehsil]
  set-people-location lahore-city-ppl "Lahore City" lahore-city-female
  set-people-location model-town-ppl "Model Town" model-town-female
  set-people-location shalimar-ppl "Shalimar" shalimar-female
  set-people-location raiwind-ppl "Raiwind" raiwind-female
  set-people-location lahore-cantt-ppl "Lahore Cantonment" lahore-cantt-female
  set-internal-vars
  setup-final-station ;;because it needs entire set of people
  calculate-brt-score
  set score-list []
  ask people [
    set score-list lput BRT-use-score score-list
  ]
  show score-list
  show word "Minimum BRT-use score is: " min score-list
  show word "Maximum BRT-use score is: " max score-list
  show word (precision(((count people with [gender = "female" and BRT-use-score < mean
score-list])/ count people with [gender = "female"]) * 100)1 ) "% of women are below mean
BRT-score"
  set women-stopped 0
  set passenger-bus0 0
  set total-travel-men 0
  set total-travel-women 0
  set total-travel 0
  set women-intention 0
  set bus-stop 1
  set no-days 0
  reset-ticks
end
```

```
to go
  ask people [move-to-nearest-station]
  move-bus;
  check-bus-capacity;
  calculate-brt-score;; this recalculates the BRT-use-score at every iteration! not just setup
  if bus-stop = 53 [tick] ;;works
  if (ticks mod 8 = 0 and bus-stop mod 53 = 0) [
    set no-days no-days + 1
    if awareness-campaigns? = true [
      ask n-of (0.1 * num-people) people [ ;;every day, 10% of people are asked to increase
awareness by 1
        set awareness awareness + 1;
        if awareness > 2 [
          set awareness 2;; max val
        ]
      ]
    ]
  ]
  if no-days = 5 [stop] ;;run the simulation for five days
end

;;this function decreases comfort if overcrowding happens on the bus!
to check-bus-capacity
  let my-bus one-of buses;; to select the bus
  let passengers [out-link-neighbors] of my-bus ;; all the people on the bus (agents not count)
  if passenger-bus0 > bus-capacity [
    ask passengers with [gender = "female"][
      set comfort comfort - over-crowding-impact;
```

```
      if comfort < -2 [
        set comfort -2;
      ]
    ]
  ]
end

to move-to-nearest-station
  set score-list [] ;;empties it at every run
  ask people [
    set score-list lput BRT-use-score score-list
  ]
  if has-arrived? = false [
    (ifelse pink-bus? = true [ ;;only women allowed to board the bus
      let women-score-list [] ;;defining the BRT-use-score of women only
      ask people with [gender = "female"][
        set women-score-list lput BRT-use-score women-score-list
      ]
      (ifelse capacity-check? = true [ ;;implementing overcrowding check with pink-bus!
        ask people with [gender = "female"] [
          ifelse (BRT-use-score > mean (women-score-list)) and (passenger-bus0 < bus-capacity) [
            set nearest-station nearest-station-to patch-here
            face nearest-station
            move-to nearest-station
            if gender = "female" [set women-intention women-intention + 1] ;;women who intended
to travel and did travel
          ][
            ;;counting how many people were stopped from using the brt!
```

```
          if gender = "female" [set women-stopped women-stopped + 1 set women-intention
women-intention + 1] ;;who who intended to travel and move to station
        ]
       ]
      ] capacity-check? = false [ ;;not implementing over-crowding check with pink-bus
       ask people with [gender = "female"] [
        ifelse BRT-use-score > mean (women-score-list) [
          set nearest-station nearest-station-to patch-here
          face nearest-station
          move-to nearest-station
          if gender = "female" [set women-intention women-intention + 1] ;;women who intended
to travel and move to station
        ][
          ;;counting how many people were stopped from using the brt!
          if gender = "female" [set women-stopped women-stopped + 1 set women-intention
women-intention + 1] ;;who who intended to travel but couldn't
        ]
       ]
     ])
    ] pink-bus? = false [
      (ifelse capacity-check? = true [ ;;implementing overcrowding check!
       ask people [
        ifelse (BRT-use-score > mean (score-list)) and (passenger-bus0 < bus-capacity) [
          set nearest-station nearest-station-to patch-here
          face nearest-station
          move-to nearest-station
          if gender = "female" [set women-intention women-intention + 1] ;;women who intended
to travel and did travel
        ][
```

```
        ;;counting how many people were stopped from using the brt!
        if gender = "female" [set women-stopped women-stopped + 1 set women-intention
women-intention + 1] ;;who who intended to travel and move to station
       ]
      ]
    ] capacity-check? = false [ ;;not implementing over-crowding check
     ask people [
       ifelse BRT-use-score > mean (score-list) [
        set nearest-station nearest-station-to patch-here
        face nearest-station
        move-to nearest-station
        if gender = "female" [set women-intention women-intention + 1] ;;women who intended
to travel and move to station
       ][
        ;;counting how many people were stopped from using the brt!
        if gender = "female" [set women-stopped women-stopped + 1 set women-intention
women-intention + 1] ;;who who intended to travel but couldn't
       ]
      ]
    ])
   ])
   ask buses [
    let nearby-people people in-radius 1 with [not any? links with [breed = buses]]
    let harassers nearby-people with [harasser? = true] ;;no. of people with harasser attribute
    create-links-to nearby-people in-radius 1 [tie set color blue]

    ;;IMPACT OF HARASSMENT ON BUSES!
    if any? nearby-people with [gender = "female"][
     if count(harassers) > 0 [ ;;if a harraser is present in nearby-people
```

```
        ifelse pink-bus? = true [
          let new-harasser-impact harasser-impact
          let choice random 2;; this is to basically half the impact of harassment at stations (choice = 0 or 1)
          if choice = 0 [set new-harasser-impact 0] ;;else it stays the same
          ask one-of nearby-people with [gender = "female"] [
            set feeling-of-safety (feeling-of-safety - new-harasser-impact) ;;reduces feeling of safety by 1 unit (2 ->1, 0 -> -1)
            if feeling-of-safety < -2 [set feeling-of-safety -2]
            set comfort (comfort - new-harasser-impact) ;;reduces feeling of safety by 1 unit (2 ->1, 0 -> -1)
            if comfort < -2 [set comfort -2]
            set confidence (confidence - new-harasser-impact) ;;reduces feeling of safety by 1 unit (2 ->1, 0 -> -1)
            if confidence < -2 [set confidence -2]
          ]
        ]
        [ ;;if pink-bus? = false
          ask one-of nearby-people with [gender = "female"] [
            set feeling-of-safety (feeling-of-safety - harasser-impact) ;;reduces feeling of safety by 1 unit (2 ->1, 0 -> -1)
            if feeling-of-safety < -2 [set feeling-of-safety -2]
            set comfort (comfort - harasser-impact) ;;reduces feeling of safety by 1 unit (2 ->1, 0 -> -1)
            if comfort < -2 [set comfort -2]
            set confidence (confidence - harasser-impact) ;;reduces feeling of safety by 1 unit (2 ->1, 0 -> -1)
            if confidence < -2 [set confidence -2]
          ]
```

```
        ]
       ]
      ]
     ]
    ]

end

to move-bus
  ask buses [
    ifelse reverse? = false [
    ;;bus moving in forward direction
      let new-location one-of [out-link-neighbors] of location
      ifelse new-location != nobody [
        face new-location
        move-to new-location
        set bus-stop bus-stop + 1
        set location new-location
        untie-people
        set passenger-bus0 count my-out-links
      ][
        set reverse? true
      ]
    ][
    ;; bus moving in reverse direction
      let new-location one-of [in-link-neighbors] of location
      ifelse new-location != nobody [
        face new-location
        move-to new-location
```

```
    set bus-stop bus-stop + 1
    set location new-location
    untie-people
    set passenger-bus0 count my-out-links
   ][
    set reverse? false
    set bus-stop 1
   ]
  ]
 ]
end

to untie-people
 ask people [
  let my-bus one-of link-neighbors with [ any? my-links with [ end1 = myself or end2 = myself]
and breed = buses ] ;;this is the bus they are linked to
  if my-bus != nobody and final-station = [location] of my-bus [ ;;if bus reaches the final station
of the person
   ask my-bus [ask links with [end1 = myself or end2 = myself] [die]] ;;ask bus to remove the
link with person who has reached station
   set has-arrived? true ;;person has arrived to final station!
   if gender = "female" [set total-travel-women total-travel-women + 1] ;;trips completed by
women
   if gender = "male" [set total-travel-men total-travel-men + 1];; trips completed by men
   set total-travel total-travel + 1; ;;total trips being counted regardless of gender!
   move-to-final-destination
   ]
  ]
end
```

```
to move-to-final-destination
  face destination
  move-to destination ;;if destination is work, moves to work. if destination is home, moves to
home.
    ;;do either or, not both!
  ifelse at-work? = false [
    set at-work? true ;;this means they are at work or at school!
    set destination home-loc
    wait 1.5 ;;to show them spend time at home
    set has-arrived? false ;;goes back into move-to-nearest station loop
  ][ ;;else
    set at-work? false ;; this means they are at home
    set destination work-loc
    wait 1.5;; to show them spend time at work
    set has-arrived? false ;;goes back into move-to-nearest station loop
  ]
end

to calculate-brt-score
  let SN social-stigma;; social-stigma is a global var
  ask people[
    let APV 0;
    if car-ownership? = true [ ;;this is only applicable to those that have a car and prefer it to PT
else no effect
      set APV 1;
    ]
    if gender = "male" [
      set SN (SN * gender-gap-index) ;;effect of SN is less on men as compared to women!
```

```
    ]
    if pink-bus? = true [
      set SN (SN * gender-gap-index) ;;effect of SN is same as for men in the case of pink-bus for
women!
    ]
    let APT ((comfort * 0.153) + (income * weight_d))
    let PBC ((confidence * 1.00) + (feeling-of-safety * weight_a) + (awareness * weight_e))
    let intention ((APT * 0.28) + (APV * -0.49) + (PBC * 0.26) + (SN * -1 * (weight_c)))
;;intention is based on APT, APV, PBC, and SN
    set BRT-use-score precision ((intention * 0.63) + (urgency * weight_b)) 1;
 ]
end

to set-internal-vars
  let num-of-men count people with [gender = "male"] ;;number of men in the model
  let num-of-women count people with [gender = "female"] ;;number of women in the model
  ;;FOR HOUSEHOLD INCOME (BASED ON PHD THESIS DATA)
  let num-lower round (0.262 * num-people) ;;26.2% - 26
  let num-lowermid round (0.193 * num-people) ;;19.3% - 19
  let num-mid round (0.288 * num-people) ;;28.8% - 29
  let num-uppermid round (0.208 * num-people) ;;20.8% - 21
  let num-upper (num-people - num-lower - num-lowermid - num-mid - num-uppermid) ;;4.9% -
5
  ask n-of num-lower people with [income = nobody] [
    set income 0;
  ]
  ask n-of num-lowermid people with [income = nobody] [
    set income precision ((random-float 0.1) + 0.1) 1; 0.1,0.2
  ]
```

```
  ask n-of num-mid people with [income = nobody] [
    set income precision ((random-float 0.2) + 0.3) 1; 0.3,0.4,0.5
  ]
  ask n-of num-uppermid people with [income = nobody] [
    set income precision ((random-float 0.3) + 0.6) 1; 0.6,0.7,0.8,0.9
  ]
  ask people with [income = nobody] [
    set income 1.0;
  ]
  ;;FOR OCCUPATION MAN (PHD THESIS DATA)
  let num-students-men round (0.22 * num-of-men) ;;number of men who are students
  let num-employed-men round (0.73 * num-of-men) ;;number of men who are employed
  let num-unemployed-men num-of-men - (num-students-men + num-employed-men) ;;number
of men who are employed
  ;;we want to ensure that all children are given status of students first, remaining children to be
given unemployed. Then all remaining are employed
  ask n-of num-students-men people with [gender = "male" and age = "child" and
employment-status = nobody] [
    set employment-status "student"
  ]
  ask n-of num-unemployed-men people with [gender = "male" and age = "child" and
employment-status = nobody] [
    set employment-status "unemployed"
  ]
  ask people with [gender = "male" and employment-status = nobody][
    set employment-status "employed"
  ]
  ;;FOR OCCUPATION WOMAN (URRAN DATA)
  let num-students-women round (0.76 * num-of-women) ;;number of men who are students
```

```
  let num-employed-women round (0.15 * num-of-women) ;;number of men who are employed
  let num-unemployed-women num-of-women - (num-students-women +
num-employed-women) ;;number of men who are employed
  ;;we want to ensure that all children are given status of students first, remaining children to be
given unemployed. Then all remaining are employed
  ask n-of num-employed-women people with [gender = "female" and (age = "adult" or age =
"senior") and employment-status = nobody][
    set employment-status "employed"
  ]
  ask n-of num-students-women people with [gender = "female" and (age = "child" or age =
"adult") and employment-status = nobody] [
    set employment-status "student"
  ]
  ask people with [gender = "female" and employment-status = nobody] [
    set employment-status "unemployed"
  ]
  ;;FOR SAFETY (URRAN DATA) - How do we extrapolate this to men? For now we are using
this data for entire population
  let num-very-unsafe round (0.04 * num-people) ;;number of people who feel very unsafe
  let num-unsafe round (0.11 * num-people) ;;number of people who feel unsafe
  let num-neutral round (0.23 * num-people) ;;number of people who feel neither safe nor unsafe
  let num-safe round (0.39 * num-people) ;;number of people who feel safe
  let num-very-safe num-people - (num-very-unsafe + num-unsafe + num-neutral + num-safe)
  ask n-of num-very-unsafe people with [feeling-of-safety = nobody][
    set feeling-of-safety -2;
  ]
  ask n-of num-unsafe people with [feeling-of-safety = nobody][
    set feeling-of-safety -1;
  ]
```

```
  ask n-of num-neutral people with [feeling-of-safety = nobody][
    set feeling-of-safety 0;
  ]
  ask n-of num-safe people with [feeling-of-safety = nobody][
    set feeling-of-safety 1;
  ]
  ask people with [feeling-of-safety = nobody][
    set feeling-of-safety 2;
  ]
  ;;FOR CAR OWNERSHIP MEN (PHD THESIS DATA)
  let men-own-car round (0.41 * num-of-men) ;;number of men who own cars
  ask n-of men-own-car people with [gender = "male"][
    set car-ownership? true
  ]
  ;;FOR CAR OWNERSHIP WOMEN (URRAN DATA)
  let women-own-car round (0.08 * num-of-women) ;;number of women who own cars
  ask n-of women-own-car people with [gender = "female"][
    set car-ownership? true
  ]
  ;;FOR COMFORT (Urran data + Gaussian randomized)
  let num-very-confident round (0.022 * num-people) ;; number of people who feel very
comfortable in the BRT (7% total, 5% from Gaussian dist, 2% separately)
  ask n-of num-very-confident people with [comfort = nobody][
    set comfort 2;
  ]
  ask people with [comfort = nobody] [
    let comfort-val (random-normal 0 1) ;;generate random numbers from a Gaussian distribution
with mean 0 and S.D. 1
```

```
    set comfort map-to-range comfort-val; ;;calling a function to map the distribution to -1, 0, 1, or
2
  ]
  ;;FOR CONFIDENCE (Gaussian randomized)
  ask people with [confidence = nobody] [
    let confidence-val (random-normal 0 1)
    set confidence map-to-range confidence-val; -2, -1, 0, 1, or 2
  ]
  ;;FOR AWARENESS (Urran data)
  let num-fully-aware round (0.2421 * num-people);;
  let num-slightly-aware round (0.5833 * num-people);;
  let num-not-aware (num-people - num-fully-aware - num-slightly-aware);;
  ask n-of num-fully-aware people with [awareness = nobody][
    set awareness 2;
  ]
  ask n-of num-slightly-aware people with [awareness = nobody][
    set awareness 0;
  ]
  ask people with [awareness = nobody][
    set awareness -2;
  ]
  ;;HOW MANY PEOPLE ARE HARASSERS
  let no-harassers round (harasser-percentage * num-people)
  ask n-of no-harassers people with [harasser? = false][
    set harasser? true
  ]
  gender-impact;; call function which changes gendered variable values for men
  if pink-bus? = true [ ;;incrementing feeling-of-safety and confidence of women at the start.
    ask people with [gender = "female"][
```

```
      set feeling-of-safety feeling-of-safety + 1;
      set confidence confidence + 1;
      if feeling-of-safety > 2 [
        set feeling-of-safety 2; max val
      ]
      if confidence > 2 [
        set confidence 2; max val
      ]
    ]
  ]
  if safety-check? = true [
    ask people with [gender = "female"][
      set feeling-of-safety (feeling-of-safety + ((random 2) + 1)) ;;can be increment of 1 or 2
      if feeling-of-safety > 2 [
        set feeling-of-safety 2;;
      ]
    ]
  ]
end

to gender-impact
  ;;gendered variables are social norm (done directly in calculate-brt-score), comfort,
feeling-of-safety, confidence
  ;;gender-impact-disaprity variable determines how male values are scalesd as compared to
women. 0.575:1 (resources for women: resources for men)
  ask people with [gender = "male"][
    ;;comfort and feeling-of-safety go between -2 uptil 2
    ifelse comfort > 0 [
      set comfort round (comfort / gender-gap-index)
```

```
    if comfort > 2 [
      set comfort 2 ;;max value
    ]
  ][ ;;comfort < 0
    let positive-comf (comfort * -1) ;;making comfort positive for calculation purposes
    let impact ((positive-comf / gender-gap-index) - positive-comf) ;;increased value - originial
value gives positive final value
    set comfort round (comfort + impact) ;;value will be less negative
    if comfort > 2 [
      set comfort 2 ;;max value
    ]
  ]
  ifelse feeling-of-safety > 0 [
    set feeling-of-safety round (feeling-of-safety / gender-gap-index)
    if feeling-of-safety > 2 [
      set feeling-of-safety 2 ;;max value
    ]
  ][
    let positive-saf (feeling-of-safety * -1) ;;making comfort positive for calculation purposes
    let impact ((positive-saf / gender-gap-index) - positive-saf) ;;increased value - originial value
gives positive final value
    set feeling-of-safety round (feeling-of-safety + impact) ;;value will be less negative
    if feeling-of-safety > 2 [
      set feeling-of-safety 2 ;;max value
    ]
  ]
  ifelse confidence > 0 [
    set confidence round (confidence / gender-gap-index)
    if confidence > 2 [
```

```
      set confidence 2 ;;max value
    ]
  ][
    let positive-conf (confidence * -1) ;;making comfort positive for calculation purposes
    let impact ((positive-conf / gender-gap-index) - positive-conf) ;;increased value - originial
value gives positive final value
    set confidence round (confidence + impact) ;;value will be less negative
    if confidence > 2 [
      set confidence 2 ;;max value
    ]
  ]
 ]
end

to-report map-to-range [gaussian-dist-value]
 ifelse gaussian-dist-value < -1.5 [report -2]
 [ifelse gaussian-dist-value < -0.5 [report -1]
  [ifelse gaussian-dist-value < 0.5 [report 0]
   [ifelse gaussian-dist-value < 1.5 [report 1]
    [report 2]
   ]
  ]
 ]
end

;;this function creates people as per census data and assigns them a home location and age
to set-people-location [num-tehsil name-tehsil num-women]
 let i 0 ;; counter
 let num-men num-tehsil - num-women ;;variable defining number of men
```

```
 repeat num-tehsil [
   set i i + 1 ;; one person has been created.
   create-people 1 [
     set shape "person"
     let target-tehsil one-of patches with [tehsil = name-tehsil]
     setxy [pxcor] of target-tehsil [pycor] of target-tehsil
     set home-loc target-tehsil ;;home-loc is set as a random patch in tehsil and xy coordinates
initialized to home location
     set pcolor blue - 3 ;;a really deep blue
     set destination home-loc
     set has-arrived? true
     ;;to be set in set-internal-vars fxn
     set employment-status nobody
     set feeling-of-safety nobody
     set income nobody
     set car-ownership? false
     set confidence nobody
     set comfort nobody
     set awareness nobody
     set harasser? false

     set urgency nobody
     set final-station nobody
     set BRT-use-score nobody
     set nearest-station nobody
     set at-work? false

     ifelse i <= num-women [
       set color magenta
```

```
set gender "female"
;;AGE DIVISION FOR WOMEN BASED ON TEHSIL
if name-tehsil = "Model Town"[
  if i <= round(0.39892 * num-women) [set age "child"]
  if i > round(0.39892 * num-women) and i <= round(0.9637 * num-women) [set age
"adult"]
  if i > round(0.9637 * num-women) [set age "senior"]
]
if name-tehsil = "Shalimar"[
  if i <= round(0.409300917 * num-women) [set age "child"]
  if i > round(0.409300917 * num-women) and i <= round(0.968262367 * num-women) [set
age "adult"]
  if i > round(0.968262367 * num-women) [set age "senior"]
]
if name-tehsil = "Raiwind"[
  if i <= round(0.441765763 * num-women) [set age "child"]
  if i > round(0.441765763 * num-women) and i <= round(0.968287458 * num-women) [set
age "adult"]
  if i > round(0.968287458 * num-women) [set age "senior"]
]
if name-tehsil = "Lahore Cantonment"[
  if i <= round(0.401860878 * num-women) [set age "child"]
  if i > round(0.401860878 * num-women) and i <= round(0.962137559 * num-women) [set
age "adult"]
  if i > round(0.962137559 * num-women) [set age "senior"]
]
if name-tehsil = "Lahore City"[
  if i <= round(0.399177972 * num-women)[set age "child"]
```

```
        if i > round(0.399177972 * num-women) and i <= round(0.965726716 * num-women) [set
age "adult"]
        if i > round(0.965726716 * num-women)[set age "senior"]
      ]
    ][
      set color blue
      set gender "male"
      ;;AGE DIVISION FOR MEN BASED ON TEHSIL
      if name-tehsil = "Model Town"[
        if i <= (num-women + round(0.385643053 * num-men))[set age "child"]
        if i > (num-women + round(0.385643053 * num-men)) and i <= (num-women +
round(0.961589147 * num-men)) [set age "adult"]
        if i > (num-women + round(0.961589147 * num-men))[set age "senior"]
      ]
      if name-tehsil = "Shalimar"[
        if i <= (num-women + round(0.406391933 * num-men))[set age "child"]
        if i > (num-women + round(0.406391933 * num-men)) and i <= (num-women +
round(0.964471204 * num-men)) [set age "adult"]
        if i > (num-women + round(0.964471204 * num-men))[set age "senior"]
      ]
      if name-tehsil = "Raiwind"[
        if i <= (num-women + round(0.419189881 * num-men))[set age "child"]
        if i > (num-women + round(0.419189881 * num-men)) and i <= (num-women +
round(0.966423061 * num-men)) [set age "adult"]
        if i > (num-women + round(0.966423061 * num-men))[set age "senior"]
      ]
      if name-tehsil = "Lahore Cantonment"[
        if i <= (num-women + round(0.386850115 * num-men))[set age "child"]
```

```
      if i > (num-women + round(0.386850115 * num-men)) and i <= (num-women +
round(0.959547701 * num-men)) [set age "adult"]
      if i > (num-women + round(0.959547701 * num-men))[set age "senior"]
     ]
     if name-tehsil = "Lahore City"[
      if i <= (num-women + round(0.391991588 * num-men))[set age "child"]
      if i > (num-women + round(0.391991588 * num-men)) and i <= (num-women +
round(0.962560883 * num-men)) [set age "adult"]
      if i > (num-women + round(0.962560883 * num-men))[set age "senior"]
     ]
    ]
   ]
  ]
end

;;sets up the initial final station based on urgency of trip (THIS ALSO NEEDS TO BE LOOKED
INTO)
to setup-final-station
  let high-urgency-trips round (0.857 * num-people) ;;commuting to work/school and health
(urgency 2)
  let low-urgency-trips round (0.071 * num-people) ;;leisure and shopping trips (urgency -2)
  let other-trips (num-people - (high-urgency-trips + low-urgency-trips))
  ;;high urgency trips
  ask n-of high-urgency-trips people with [has-arrived? = true and urgency = nobody][
    ifelse age = "child" [
      let target-patch one-of patches with [kind = "education" or kind = "health"]
      set work-loc target-patch
    ][
      let target-patch one-of patches with [kind = "work" or kind = "health"]
```

```
      set work-loc target-patch
    ]
    set destination work-loc
    set final-station nearest-station-to destination
    set has-arrived? false
    set urgency 2
  ]
  ;;low urgency trips
  ask n-of low-urgency-trips people with [has-arrived? = true and urgency = nobody][
    let target-patch one-of patches with [kind = "leisure" or kind = "shopping"]
    set work-loc target-patch
    set destination work-loc
    set final-station nearest-station-to destination
    set has-arrived? false
    set urgency -2
  ]
  ;;other trips
  ask people with [has-arrived? = true and urgency = nobody][
    let value_rand random 1 ;; a number that is 0 or 1
    ifelse value_rand = 1 [
      let target-patch one-of patches with [kind = "education" or kind = "work" or kind = "health"]
      set work-loc target-patch
      set destination work-loc
      set final-station nearest-station-to destination
      set has-arrived? false
      set urgency 2
    ][
      let target-patch one-of patches with [kind = "leisure" or kind = "shopping"]
      set work-loc target-patch
```

```
      set destination work-loc
      set final-station nearest-station-to destination
      set has-arrived? false
      set urgency -2
    ]
  ]
end

;;reports the nearest BRT station to a given patch.
to-report nearest-station-to [a-patch]
  ;;creates a list of all the turtles stations
  let stations-list stations
  ;;minimizing distance from station turtle to the destination patch
  let nearest-station-1 min-one-of stations-list [distance a-patch]
  report nearest-station-1
end

to add-POIs
  ;;education
  let education-xcor [62 63 42 65 56 34 39 29 55 39 37 56 30 43 54 51 56 54 40 63 64 61]
  let education-ycor [59 73 30 60 15 66 89 64 75 69 80 43 75 61 95 42 61 92 80 52 53 78]
  ;;food, supermarket
  let leisure-xcor [43 41 34 59 42 41 42 39 70 62 67 58 67 60 65 50 67 33 56 31 32 51 34 46 32
58 71 43 53 72 33 63 30 37 72 70]
  let leisure-ycor [88 63 77 76 95 36 28 17 26 53 11 15 62 73 59 29 18 01 93 82 79 85 73 61 62
58 40 29 32 11 14 00 00 99 82 97]
  ;;hospital and pharmacy
  let health-xcor [56 45 71 34 55 38 58 47 38 69 62 32 29 70 30 67 67 43 30 39 59 56]
  let health-ycor [92 79 65 66 64 39 38 26 16 10 20 5 94 93 76 7 16 18 57 27 58 92]
```

```
  ;; bank, police, shop
  let work-xcor [69 63 34 30 38 41 66 70 57 37 59 43 46 47 55 35 60 42 58 34 63 58 43 41 53 47
31 57 63 30 31 45 71 61 69 71 65 43 39 67 40 44 30 31 41 40]
  let work-ycor [05 17 18 12 26 32 33 42 52 45 57 77 83 87 90 04 20 24 35 37 35 52 55 76 83 84
98 98 93 75 66 61 84 51 40 44 34 28 17 03 02 16 72 66 66 63]
  (foreach education-xcor education-ycor [ [edux eduy] -> ask patch edux eduy [set kind
"education" set pcolor red]])
  (foreach leisure-xcor leisure-ycor [ [lex ley] -> ask patch lex ley [set kind "leisure" set pcolor
blue]])
  (foreach health-xcor health-ycor [ [hex hey] -> ask patch hex hey [set kind "health" set pcolor
green]])
  (foreach work-xcor work-ycor [ [wox woy] -> ask patch wox woy [set kind "work" set pcolor
pink]])
end

to create-brt
  create-stations 27;
  (foreach
   [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26]
   [34 38 38 41 41 41 40 41 43 45 47 48 50 51 53 54 56 57 60 62 62 63 64 65 65 66 66]
   [100 93 91 88 84 81 78 75 71 69 65 61 55 52 49 45 41 37 30 27 24 20 15 10 7 3 0]
   ["SHAHDARA" "NIAZI" "TIMBER MARKET" "AZADI CHOWK" "BHATTI"
"KATCHEHRY" "CIVIL SECRETARIAT" "MAO COLLEGE" "JANAZGAH" "QARTABA
CHOWK" "SHAMA"
    "ICHRA" "CANAL" "QADDAFI STADIUM" "KALMA" "MODEL TOWN"
"NASEERABAD" "ITTEFAQ HOSPITAL" "QAINCHI" "GHAZI CHOWK" "CHUNGI AMAR
SIDHU" "KAMAHAN"
    "ATTARI SAROBA" "NISHTAR COLONY" "YOUHANABAD" "DULLU KHURD"
"GAJJUMATA"]
```

```
   [ [station-number x y station-name] -> ask station station-number [hide-turtle setxy x y set
name station-name] ] )
  (foreach
    [0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25]
    [[station-number] -> ask station station-number [create-link-to station (station-number + 1)
[hide-link] ]])
end

to import-gis-data
  gis:load-coordinate-system (word "data/Metro_line.prj")
  let metroline-dataset gis:load-dataset "data/Metro_line.shp"
  let metrostation-dataset gis:load-dataset "data/Metro_station.shp"
  gis:set-world-envelope (gis:envelope-union-of (gis:envelope-of metrostation-dataset)
(gis:envelope-of metroline-dataset))
  gis:import-wms-drawing "https://ows.terrestris.de/osm/service?" "EPSG:4326" "OSM-WMS"
50
  ;;defining the colors for metroline and station datasets
  gis:set-drawing-color black
  gis:draw metroline-dataset 3
  gis:set-drawing-color green
  gis:fill metrostation-dataset 4
  gis:set-drawing-color black
  gis:draw metrostation-dataset 3
end
```

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