UTTRI
Research Report

Development of a Prototype Agent-based Microsimulation Model of the Asunción Metropolitan Area

Volume I: Final Report

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April 2017

SATA: Simulador de Actividad de Transporte de Asunción

DEVELOPMENT OF THE SATA PROTOTYPE VOLUME I: FINAL REPORT

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April, 2017

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EXECUTIVE SUMMARY

The purpose of this study is to develop a prototype agent-based microsimulation (ABM) model system of travel within the Asunción metropolitan region. Asunción is facing many important transportation-related urban planning issues, including the redevelopment of its Historic Centre and the proposed implementation of major new high-order transit lines to address growing congestion problems in the region. A travel demand forecasting model system for the region would be extremely useful, both to quantitatively and objectively explore the benefits and costs of a range of transportation policy options and to provide a common data and analysis framework within which the various stakeholders could come together to discuss and explore these options.

At the same time, the CAF, the Development Bank of Latin America, is interested in demonstrating the advantages of agent-based microsimulation (ABM) methods for modelling travel behaviour for policy analysis in Latin American cities. ABM models represent the current state-of-the art in travel demand modelling. They provide many advantages relative to the conventional modelling methods that have been standard practice worldwide for the past several decades. In particular, they are better suited to exploiting new sources of travel information that are becoming available through modern information technology, and they are more appropriately sensitive to current and emerging policy issues. As Latin American cities strive to build sustainable urban mobility systems capable of meeting their social and economic goals in the 21st Century, advanced analysis methods such as ABM travel models are essential tools to successfully and cost-effectively achieving these goals.

The outcome of this project has been the development of *SATA: Simulador de Actividad de Transporte de Asunción* (Transportation Activity Simulator for Asunción). SATA is an ABM model system for generating estimates of all trips by all purposes and modes for a typical 24-hour weekday within the Asunción metropolitan region. As one means of demonstrating SATA's potential, the Bus Rapid Transit (BRT) and Light Rail Transit (LRT) proposals currently under consideration within the Asunción region are examined within this project using SATA.

Due to significant limitations in the travel-related data available for the Asunción region, the current version of SATA is a prototype that is adequate for demonstrating the capabilities and potential of the ABM approach, but which is not yet sufficiently validated to be used as an operational planning tool. It is recommended that a "Phase 2" project be launched that would: (a) gather the data needed to properly calibrate and validate the SATA model system; and (b) use these new data for fully upgrade the SATA prototype to be fully useful by Asunción planners as an operational policy analysis and decision-support tool.

ACKNOWLEDGEMENTS

This study was funded by CAF and could not have been possible without the enthusiastic support of the work by CAF and, in particular, Nicolas Estupiñan and Andres Alcala. Similarly, the extensive support that we received from our many colleagues in Asunción was critical to our being able to complete the project. These include Juan Carlos Cristaldo, from ASULAB; Megumi Yamanaka, from the Ministry of Public Works and Communications; Luis Pereira and Juan José Rolón and from the Municipality of Asunción and many other actors that enabled the development of this project. Your professional interest in and support of the project, as well as your warm and welcoming friendship were hugely appreciated. The provision of data and EMME networks by German Freiberg of LOGIT is also very gratefully acknowledged.

A special acknowledgment is due to the National Government of Ecuador and its National Secretariat of Higher Education of Science, Technology, and Innovation (*SENESCYT)*, for betting on human capital as a key driver of development, and for providing scholarship opportunities to Ecuadorian citizens to study abroad. This allowed Mr. Francisco Calderón to pursue his graduate education at the University of Toronto, and thus the opportunity of getting involved in projects such as this study. For this opportunity, Mr. Calderón will always be grateful.

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STUDY PURPOSE & MOTIVATION

The purpose of this study is to develop a prototype agent-based microsimulation (ABM) model system of travel within the Asunción metropolitan region. As is discussed in more detail in Chapter 2 of this report, Asunción is facing many important transportation-related urban planning issues, including the redevelopment of its Historic Centre and the proposed implementation of major new high-order transit lines to address growing congestion problems in the region. A travel demand forecasting model system for the region would be extremely useful, both to quantitatively and objectively explore the benefits and costs of a range of transportation policy options and to provide a common data and analysis framework within which the various stakeholders could come together to discuss and explore these options.

At the same time, the CAF, the Development Bank of Latin America, is interested in demonstrating the advantages of agent-based microsimulation (ABM) methods for modelling travel behaviour for policy analysis in Latin American cities. As discussed in Chapter 3 below, ABM models represent the current state-of-the art in travel demand modelling. They provide many advantages relative to the conventional modelling methods that have been standard practice worldwide for the past several decades. In particular, they are better suited to exploiting new sources of travel information that are becoming available through modern information technology, and they are more appropriately sensitive to current and emerging policy issues. As Latin American cities strive to build sustainable urban mobility systems capable of meeting their social and economic goals in the 21st Century, advanced analysis methods such as ABM travel models are essential tools to successfully and cost-effectively achieving these goals.

The University of Toronto Transportation Research Institute (UTTRI) is a recognized world leader in transportation systems analysis, modelling and policy analysis. It has recently launched a major research initiative called *iCity: urban informatics for sustainable metropolitan growth*. iCity is a collaborative "virtual lab" for urban design that develops and applies advanced data, analysis and visualization capabilities to find innovative ways to improve urban transportation system performance and design efficient, sustainable cities for the well-being of individuals and society. iCity applies *urban informatics* – the combination of high-performance computing (HPC), massive "big data" sets, and advanced analysis, simulation and visualization software -- to the analysis of urban transportation problems. The iCity virtual lab utilizes powerful, comprehensive computer models to simulate the evolution of urban spatial socio-economic systems (transportation, the regional economy, etc.) in response to a wide variety of scenarios and policies. Combined with equally powerful and advanced visualization capabilities, this virtual lab provides the analytical environment needed to develop and test:

- Hypotheses about urban system processes and system interactions to develop deep understandings of cities as systems of systems.
- Practical solutions to specific problems that begin with the "here" of the current metropolis and recognize that getting to a more resilient and sustainable "there" requires finding feasible pathways into the future.
- A rich suite of performance measures, detailed benefit/cost distributions, etc. for comprehensively understanding the impacts of alternative policies.

- New tools, methods and software for real-time transportation system management and control.
- Compelling, readily transmittable "stories" demonstrating the feasibility and efficacy of the solutions developed: why they are better than the status quo and how they can feasibly come to be.

As one component of CAF's strategy for promoting its urban sustainable mobility objectives, it has partnered with UTTRI to create the *iCity-South* research program to apply the iCity urban informatics vision and capabilities in Latin American cities. The first specific project within the iCity-South program is the development of a prototype ABM travel demand model system for the Asunción metropolitan region in order to address the two purposes stated above: to provide a powerful transportation policy analysis tool to Asunción planners and decision-makers, and to provide a practical demonstration of the ABM modelling approach within a Latin American context.[1]

The outcome of this project has been the development of *SATA: Simulador de Actividad de Transporte de Asunción* (Transportation Activity Simulator for Asunción). SATA is an ABM model system for generating estimates of all trips by all purposes and modes for a typical 24-hour weekday within the Asunción metropolitan region. It is based on the *GTAModel V4.0* model system developed by UTTRI for the Greater Toronto-Hamilton Area (GTHA) and which has been in operational use by the City of Toronto since early 2016. As one means of demonstrating SATA's potential, the Bus Rapid Transit (BRT) and Light Rail Transit (LRT) proposals currently under consideration within the Asunción region are examined within this project using SATA.

Due to significant limitations in the travel-related data available for the Asunción region, the current version of SATA is a prototype that is adequate for demonstrating the capabilities and potential of the ABM approach, but which is not yet sufficiently validated to be used as an operational planning tool. It is recommended that a "Phase 2" project be launched that would: (a) gather the data needed to properly calibrate and validate the SATA model system; and (b) use these new data for fully upgrade the SATA prototype to be fully useful by Asunción planners as an operational policy analysis and decision-support tool.

This report is the first in of two reports documenting the SATA prototype development project. It is the overall final project report, providing an overview of the work undertaken within the project and the major findings and conclusions of this work. It is supplemented by Volume II, which consists of a set of technical appendices which provide much more detail concerning the data used in the study (and their limitations), the computerized representations of the road and transit networks developed for use in the model system, the SATA model system itself, and the example case study applications of SATA that were undertaken within this project.

In addition to this introduction, this report consists of 5 chapters. Chapter 2 contains a brief discussion of the planning issues and modelling needs in Asunción that motivate the need for developing a modelling tool such as SATA. Chapter 3 provides a relatively non-technical

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[1] A second, parallel CAF-sponsored iCity-South project has also been launched. It is exploring new travel data collection methods in Montevideo.

overview of agent-based microsimulation models and the Toronto model system upon which SATA is based. Chapter 4 presents the prototype SATA model system and discusses key issues in its development. Chapter 5 summarizes the findings of the example case study applications to which SATA have been applied to date in order to demonstrate its capabilities. These consist of the current base case and two alternative scenarios: implementation of the BRT line, and implementation of the LRT line. Finally, Chapter 6 summarizes the projects findings, conclusions and recommendations for a Phase 2 study designed to fully operationalize the SATA model system.

CHAPTER 2
PLANNING ISSUES & MODELLING NEEDS IN ASUNCIÓN

2.1 INTRODUCTION

This chapter provides a brief overview of planning issues in the Asunción metropolitan region in order to establish an institutional and socio-economic context for travel demand modelling needs in the region. It first positions Asunción within the Paraguayan political and policy context and then focusses on the planning issues and needs of the city's historical centre, which represent an important motivation for this project.

2.2 ASUNCIÓN IN CONTEXT

The Republic of Paraguay is composed by eighteen departments; each one of these is subdivided into districts. Asunción is the capital district as well as a department. As of 2014 the country had an overall population of 6.657 million while Asunción had 527thousand inhabitants (DGEEC, 2014).

The City of Asunción has been experiencing severe traffic congestion problems, mainly because of its urban expansion and its attractiveness as an active economic centre within Paraguay. There are very well defined travel patterns typical of a centrally-oriented conurbation, where high travel demand and congestion is observed for inbound trips into the city centre in the morning, and likewise for outbound trips in the afternoon/evening. Specifically, the main issue is that the city has only five major arterials connecting it to its surrounding region to accommodate this demand, coupled with many unpaved and poor quality alternative routes. In addition, the public transit system currently consists of buses of varying quality operating in congested shared rights of way. Consequently, providing efficient and timely solutions to this problem is one of the main concerns and objectives of the city's political and policy agenda.

Before considering modelling needs in Asunción, it is important to get a sense of the political and policy context of Paraguay and Asunción, in order to properly understand the structures, institutions, regulations, and mechanisms that shape decision-making and infrastructure investments.

2.2.1 Political Context

Paraguay is a unitary presidential constitutional republic, in which powers are separated into three independent branches: executive, legislative and judicial. Executive power is exercised by the President. The legislative power is composed by two chambers, the upper house formed by senators, and the lower house formed by deputies. Judicial power is exercised at tribunals and Courts of Civil Law. All the representatives for these powers are elected through democratic elections by popular vote. Furthermore, it is noteworthy that while the political system is a central one, there are two tiers of government consisting on the nation-state and the local governments and municipalities.

The central government delegates specific sectors of public administration to ministries. Of primary relevance to this study is the Ministry of Public Works and Communications (MOPC), and more specifically, the Vice-Ministry of Transport. MOPC handles nation-wide transport policy-making and project formulation, among other issues (Ministry of Public Works and Communications, 2016). Another key actor is the National Secretariat of Culture, which launched the initiative of revitalizing and regenerating the Historic Centre of Asunción (discussed further below) with the objective of preserving the cultural and built heritage that this area of the city represents.

With respect to the second tier of government, local authorities and municipalities are autonomous in terms of local ordinances, politics, and administration. Furthermore, municipalities have the power to levy and allocate their resources and revenues at their own discretion (Municipality of Asunción, 2010). In the context of this study, the most important municipality is the Municipality of Asunción, which deals with urban planning in all its dimensions, including, but not limited to, land use and sustainable development. The municipality also regulates, operates and supervises public transport. It is also noteworthy that minimum requirements for citizens to drive as well as minimum standards of public transit are regulated by the National Direction of Transport (DINATRAN) and the Transport Secretary for the Metropolitan Region (SETAMA), whenever applicable.

2.2.2 Policy Context

With respect to policies, municipalities are responsible for developing their Sustainable Development Plans and their Land-use Plans in coordination with the MOPC and the National Planning Secretariat. Important plans for Asunción include the Metropolitan Strategic Plan for Asunción (PEMA) financed by a technical cooperation with the Inter-American Development Bank (BID), the Action Plan for the Metropolitan Area of Asunción under the Emerging Sustainable Cities Initiative carried forward by BID as well, and the Plan for the Historic Centre of Asunción (PlanCHA), the last of which is discussed further below. Common to these policy initiatives is that they all identify transportation as one of the least sustainable dimensions of the region. Specifically, the 20-year-old bus fleet is extremely old compared to sustainable standards of 6 years (Inter-American Development Bank, 2015). Another pressing matter that is widely identified is the increasing proportions of motorcycle and automobile mode shares coupled with a decrease in public transit mode share. Further, this trend in mode share shifts is also attributed to the severe congestion that is currently happening due to poor public transit service and the overutilization of the main arterials for access to and egress from the city centre. In summary, these studies all recognize the urgent need for improvement in mobility and transport, whether at the local, regional, or national level. In general these various initiatives are aligned, but it is often observed that better coordination among plans and agencies would be beneficial to ensure their maximum effectiveness.

2.2.3 Other Considerations

Cultural and historic heritage plays a very important role in transportation matters in Asunción, sometimes its role might even be pivotal. Such is the case for the proposed BRT *Corredor Eusebio Ayala – Mcal Estigarribia* project (LOGIT, 2011), where consideration of different alignment alternatives has been subject to extensive discussion fueled by the potential impacts these might have on heritage buildings and landscape.

Another important issue to highlight relates to the fact that the Historic Centre of Asunción has been experiencing a consistent trend of population outmigration towards suburban areas; consequently, land-use patterns in the Historic Centre have shifted heavily towards business and office-oriented activities only. This is a pressing issue in the policy and political agenda of the city, in that cultural and historic heritage as an asset of the people should be intimately tied to mixed use. Therefore encouragement of residential uses within the Historic Centre is essential to ensure a vibrant urban setting.

2.3 The Development Plan for the Historic Centre of Asunción (PlanCHA)

In response to the current outmigration trend mentioned above, the National Government of Paraguay through the Secretariat of Culture proposed the creation of a master plan for the revitalization of the Historic Centre of Asunción. Subsequently, an international contest of proposals for a master plan was carried forward. The project that was chosen was developed by a consortium by the name of *Ecosistema Urbano*. Their proposal consists of ten strategies for urban regeneration and is referred to as the Plan for the Historic Centre of Asunción (PlanCHA).

In summary, PlanCHA recognizes that an integral reformulation of current normative frameworks, physical renewal, and heritage conservation is needed, and thus it proposes a master process rather than a master plan. In order to articulate this process, ASULAB was created as an entity that would lead and manage the PlanCHA. PlanCHA also coordinates interactions among different public and private institutions, and the public. The Plan notes that there is no lack of projects or funding, but rather a lack of evaluation, implementation, and management. Furthermore, PlanCHA recognizes that proposing a whole array of new projects is not feasible. Thus it focuses on gathering existing initiatives to coordinate and align them into an integrated master process, and it relies on ASULAB to coordinate and manage these tasks as an institution that accounts for both public and private sectors.

CAF provides non-reimbursable technical support for the implementation of PlanCHA as a process to achieve urban renovation in the Historic Centre of Asunción (National Secretariat of Culture, 2015). Among all the dimensions that urban regeneration implies, mobility and transportation stand as key factors, since the impacts of major infrastructure investments heavily influence travel demand and activity patterns, as well as the evolution of urban form. As part of this technical support, CAF is supporting UTTRI's development of the SATA model system to provide advanced policy analysis and decision support for transportation planning and implementation work within Asunción.

CHAPTER 3
AGENT-BASED MICROSIMULATION MODELLING OF TRAVEL DEMAND

3.1 INTRODUCTION

This chapter provides an overview discussion of urban travel demand modelling, to motivate the adoption of an agent-based microsimulation (ABM) modelling approach for developing a travel demand model system for the Asunción metropolitan region. Section 3.2 briefly describes and critiques the conventional travel demand modelling approaches. This critique motivates the need for a much more disaggregate, behaviourally-sensitive approach to model travel demand: the agent-based microsimulation approach, in which the travel behaviour of individual *agents* (persons and households) are simulated in detail. Section 3.3 then describes in some detail the GTAModel Version 4.0 ABM travel demand modelling system that has been developed for the Greater Toronto-Hamilton Area (GTHA). GTAModel V4.0 is fully operational and is used by the City of Toronto in its day-to-day planning applications. It constitutes the starting point for the development of SATA, which largely involved transferring GTAModel V4.0 from Toronto into the Asunción context.

3.2 TRANSITIONING FROM CONVENTIONAL METHODS TO ABM

One of the main challenges of transportation planning is to forecast travel demand in the most accurate way possible, especially for long-term planning purposes. The first and foremost linkage that must be acknowledged is the interaction between the urban system and the transportation system. Specifically, the transportation system consists of physical road networks, public transit lines and schedules, etc.; while the urban system includes socio-economic, geographic, and demographic attributes of the population and employment that ultimately generate the need to travel and thus observed activity patterns. Travel demand forecasting is inherently a non-trivial task given the complexity of factors and processes that shape travel behaviour and activity patterns.

World-wide, the current and most commonly applied method for travel demand forecasting is the so-called four-step model, as illustrated in Figure 3.1. Given projections of the future year population and employment in each traffic zone within the urban region daily trip-making within the region is estimated using the following four steps:

- *Trip generation*, in which the number trips originating in and destined to each traffic zone are estimated for each trip purpose (work, school, etc.) and each time period (morning peak period, etc.).
- *Trip distribution*, in which these "trip ends" (trip origins and destinations) are then linked together to create origin-destination trip flows for all possible origin-destination (OD) pairs for each trip purpose and time period.
- *Mode choice*, in which OD flows are split into trips by each travel mode available to the trip-makers (auto, transit, etc.). These mode shares are determined given the relative levels of service provided by the competing travel models, as defined by their in-vehicle

travel times, travel costs, out-of-vehicle travel times, etc., as well as the socio-economic characteristics of the trip-makers, such as income, age, etc.

- *Trip assignment*, in which auto OD trips by time period are "assigned" to paths through the road network and transit OD trips are similarly assigned to paths through the transit network. Path choices depend upon the travel times and costs provided by competing routes to the trip-makers. But these travel times depend upon the levels of congestion generated by the users of the paths (i.e., the more trip-makers using a given road or transit line, the slower the service on the road or transit line is). And so, an equilibrium is solved for in which the number of users on a given path depends on the path travel time, but this path travel time depends on the number of path users. Normally, both road and transit assignments are performed using specialized commercial software packages such as EMME, TransCAD, VISUM, etc.

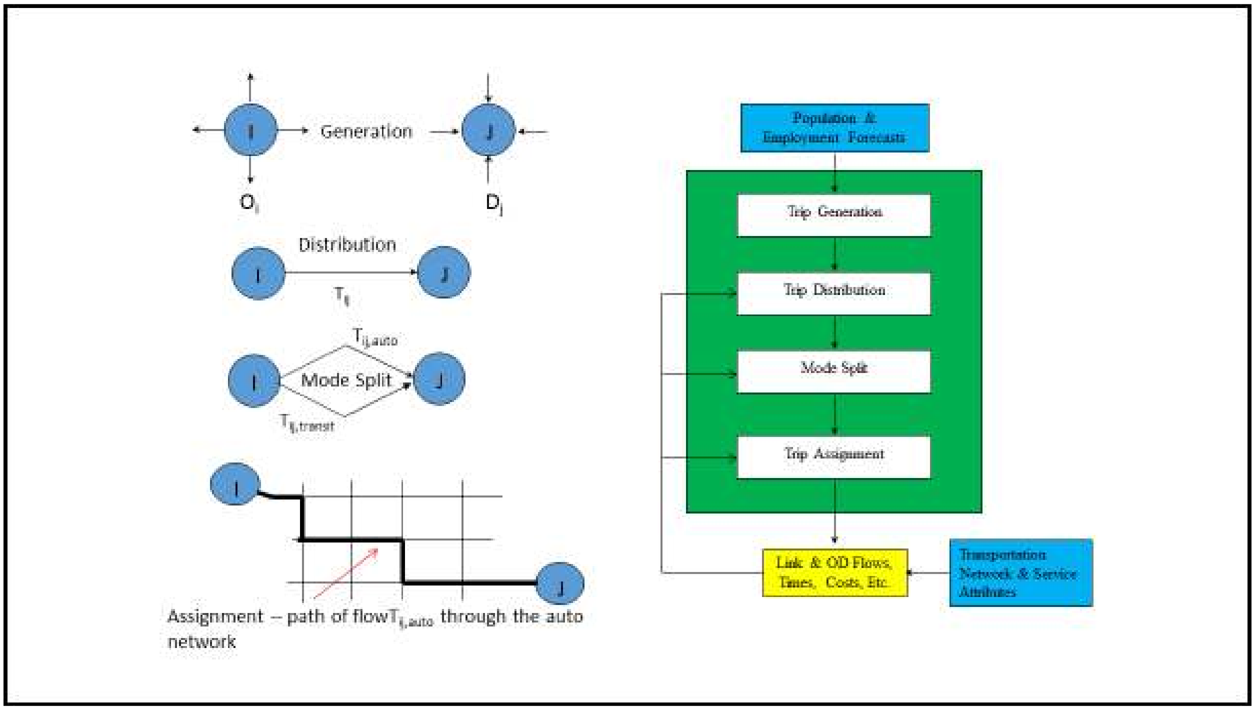

Figure 3.1: The Four-Step Travel Demand Modelling Process
Meyer & Miller (2001)

Despite its widespread use, the shortcomings of the four-step method are widely recognized within the literature (Mladenovic & Trifunovic, 2014). Current "best practice" travel demand models in North America and some European countries adopt an *activity-based* paradigm in which travel is modelled as the outcome of the need to participate in out-of-home activities. Key advantages of activity-based models relative to the conventional four-step approach include:

- Activity-based models are developed at the *disaggregate* level of individual trip-makers. This eliminates the *aggregation bias* that exists in four-step models, which try to model the travel behaviour of the aggregate population of a traffic zone without taking into account differences in socio-economic attributes (income, age, etc.) that affect people's tastes and preferences. As illustrated in Figure 3.2, the average behaviour of a low-income person and a high-income person is not the same as the behaviour of someone with average income! In order to predict travel behaviour correctly, we need to model each person's choices given their own characteristics and the specific contexts within which they are making their decisions.

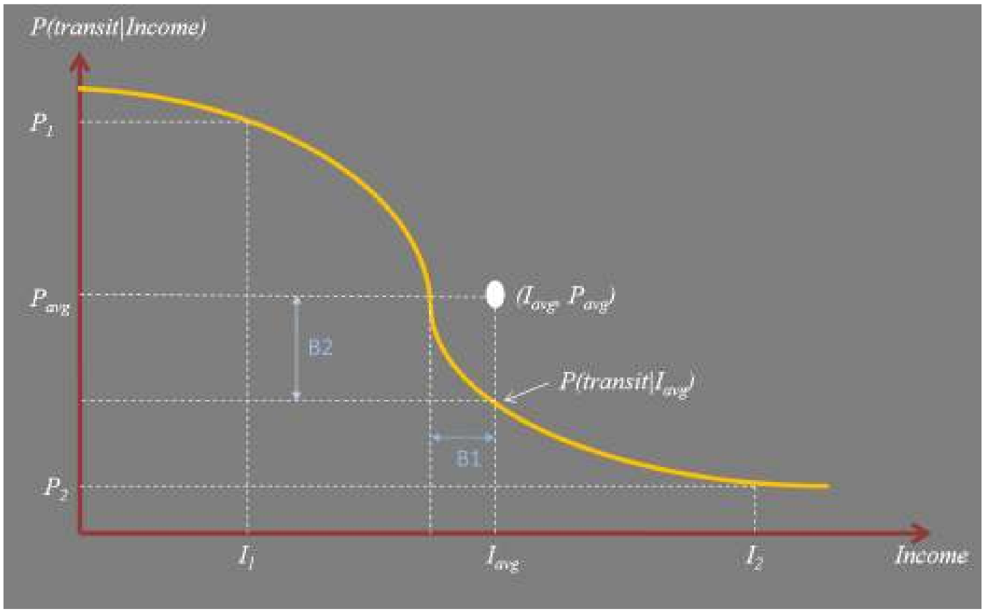

Figure 3.2: Example of Socio-Economic Aggregation Error

The probability of taking transit depends on income. The average probability of a low-income (I_1) person and a high-income (I_2) person taking transit, P_{avg} is not the same as the probability of a person with average income (I_{avg}) taking transit, P(transit|I_{avg}). Developing and/or applying a model using aggregate (zone average) data will introduce biases into the model and its forecasts.

- Activity-based models can model this behaviour with the context of the household within which each person resides (rather than treating them as isolated individual trip-makers), so that household-level constraints and interactions can be accounted for in travel decision-making. These include:
  - Competition among household members for household auto use (cf. Figure 3.3).
  - Joint travel among household members (participation in joint activities by two or more household members; "chauffeuring" children to/from school and other activities; within-household "ridesharing" – cf. Figure 3.4).
- Activity-based models represent travel at the level of the *tour* or *trip-chain*, as illustrated in Figure 3.5, rather than isolated, individual trips. This allows the model to capture the interconnections between trips (e.g., I drive to work rather than take transit since I also have to go shopping on my way home after work; I choose a shopping location that is convenient to stop at on my way from work; etc.). It also allows trip-making over an entire 24-hour day to be modelled consistently and efficiently (e.g., if a car is driven to work in the morning it must be used to return home in the evening).

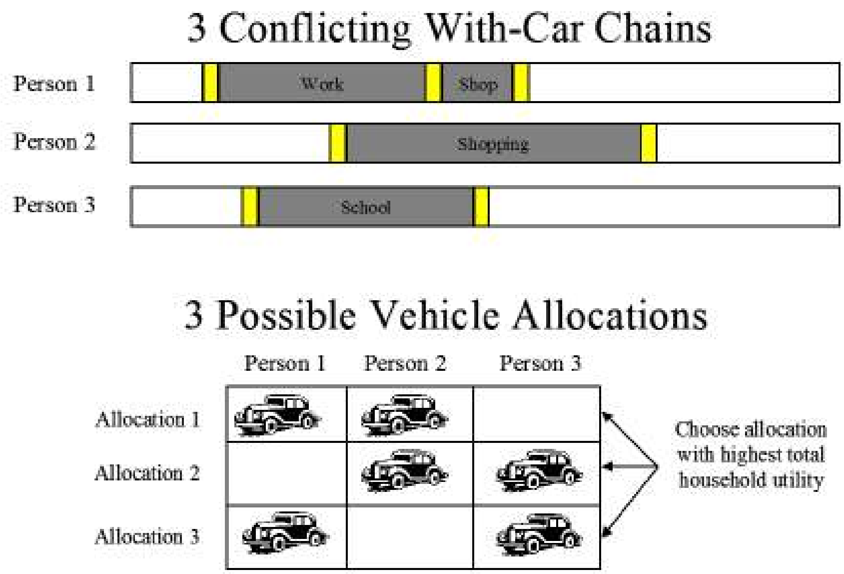

Figure 3.3: Within-Household Competition for Use of a Household Car

Three drivers in a household may all wish to use a car to execute their planned trips for the. Their activity schedules overlap, so only two persons can use a car. The two who "need it the most" will get a car and the third person will have to use another travel mode (e.g., transit), or else re-arrange his/her planned activities to a point in time in which a car is available

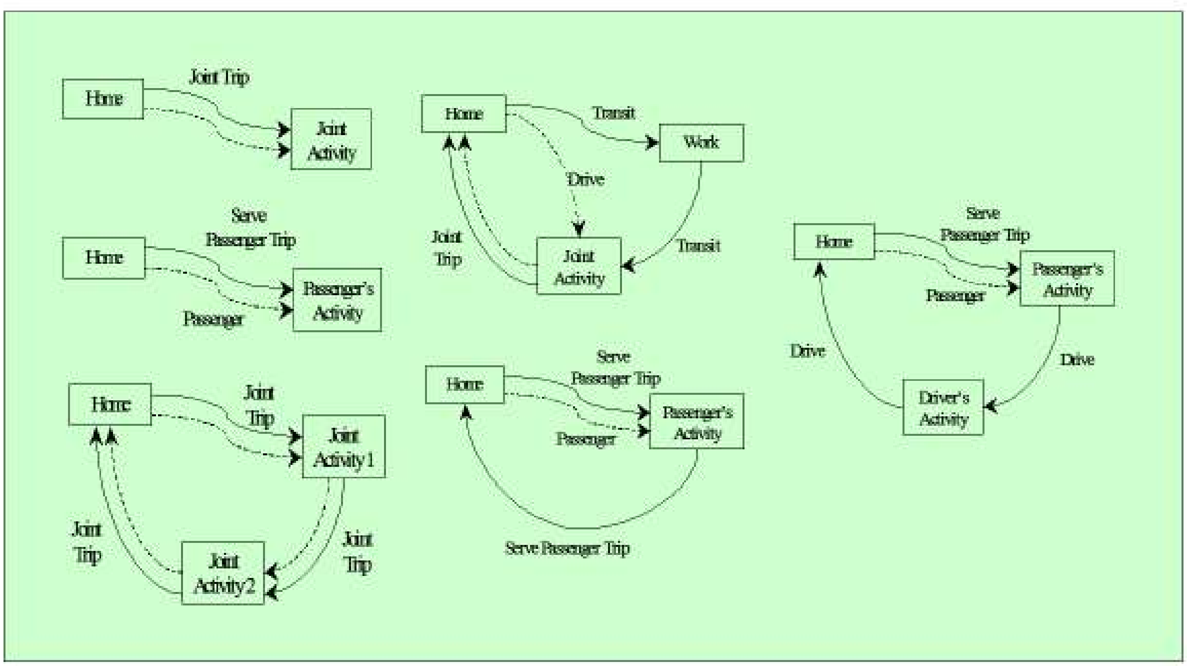

Figure 3.4: Examples of Within-Household Ridesharing

Complex combinations of ridesharing among household members can be modelled within TASHA.

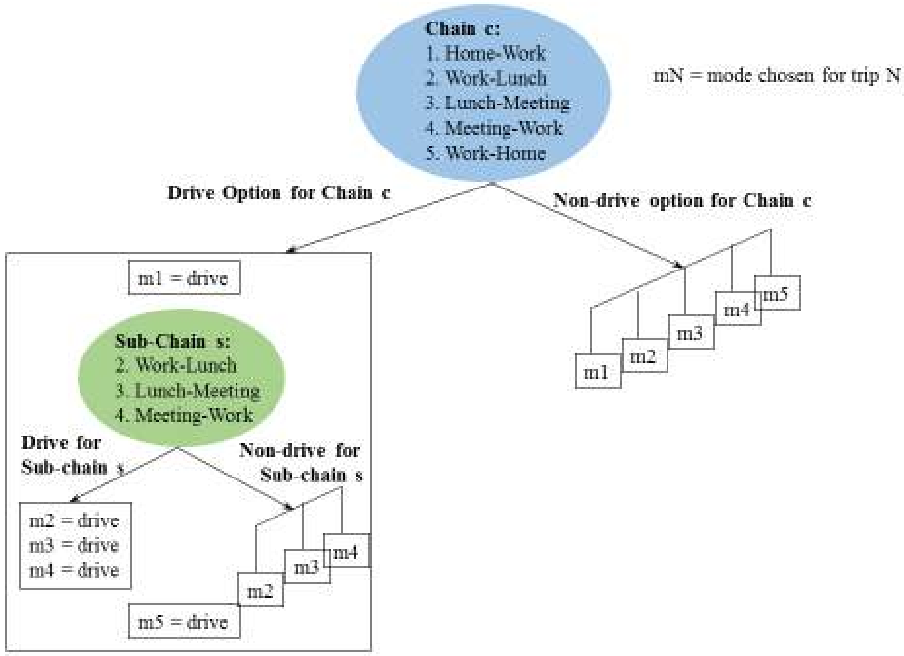

Figure 3.5: Trips & Trip-Chains

Example of a complex daily trip chain or tour, which consists of a 5-trip tour involving going to work, a work-based sub-tour involving going to lunch and afternoon business meeting and then returning to work before returning home again in the evening. If a car is used to go to work, it must be used to return home again in the evening. The car need not be used on the work-based sub-tour, but if it is, it must be used for all three trips within the sub-tour. Bicycles must also be used on a tour basis (if the bicycle leaves home it must eventually return home). Non-auto/bike modes can be chosen on a trip-by-trip basis so as to maximize the overall utility of the tour.

Disaggregate activity-based models must be implemented within an *agent-based microsimulation* (ABM) computer model. Each person and household being modelled is an *agent* that is responsible for making its activity and travel choices for the typical weekday in a given forecast year being modelled. The model is a *simulation* engine that evaluates the probabilities of each agent choosing from among the set of activity/trip purposes, destinations, mode of travel, etc. and selecting a specific activity/travel pattern for the day based on these probabilities. It is a labelled a *micro*simulation since it operates at the disaggregate (micro) level of each agent in the system

A critical input to any ABM is the list of agents for which the ABM is to simulate their behaviour. This list of agents usually needs to be *synthesized* from more aggregate population data, such as forecasts of the total population living in each traffic zone. A *population synthesis* procedure is used to disaggregate the total population into a list of individual persons, each with specific attributes (age, occupation, etc.) that are needed by the travel model to predict the agent's travel behaviour. This synthesis process is done in a way that results in the joint distribution of the attributes of the zone's population (e.g., income by age) to be as statistically representative of the expected zonal distributions as possible.

3.3 THE TORONTO ABM: GTAMODEL V4.0

3.3.1 Overview

SATA, the ABM travel demand model system developed in this project for the Asunción metropolitan region is directly based on GTAModel V4.0, which is the ABM travel demand forecasting model system that has been developed by UTTRI for operational use by the City of Toronto. GTAModel V4.0 models all travel for a typical 24-hour weekday in the Greater Toronto-Hamilton Area (GTHA). The GTHA is Canada's largest urban region, while the City of Toronto at the core of the region is North America's fourth largest city.

GTAModel V4.0 is documented in a series of reports listed in the References section at the end of this report. Figure 3.6 provides a high-level overview of GTAModel V4/0's major components, which include:

- Synthesis of the set of individuals and their households residing in each traffic zone in the urban region, given the forecasted total population for the zone. Each individual is assigned an age, employment status, occupation category (if employed), student status, and driver's licence status, based on assumed distributions of these attributes within the population. Household attributes include the persons assigned to the household and the number of cars in each household.
- Synthesis of the set of jobs by occupation type and status (full-time or part-time) in each traffic zone, given the forecasted total employment in the zone.
- Each worker is assigned a specific workplace zone given the workers occupation and employment status class and the accessibility of the worker to employment given the worker's residential location (e.g., a worker is more likely to be employment in large employment zones close to his/her home than smaller employment zones and/or employment zones that are further away from the worker's home).
- Each student is assigned a specific school zone.
- Each person in each household determines his/her activity/travel pattern (number of trips, their purposes and locations, the start time of each trip, and the mode of travel for each trip) using the TASHA (Travel/Activity Scheduler for Household Agents) model that has been developed at the University of Toronto over the past fifteen years. TASHA is discussed further in Section 3.3.2. The output from TASHA is the set of every trip predicted to be made within the GTHA for a typical 24-hour weekday. Each trip is described by its:
    - Origin traffic zone.
    - Destination traffic zone.
    - Purpose (activity type) at its destination.
    - Trip start time.
    - Travel mode (auto driver, auto passenger, public transit, walk, bicycle, etc.).
- These trips are aggregated by time period for the time period definitions used for the GTHA) and mode (car and public transit) into origin-destination (O-D) trip matrices that are assigned to the road and transit networks[2] for each time period using the commercial network modelling software package, Emme V4.2, to determine the following outputs:
    - O-D travel times and costs.

2 Trips by walking and bicycle are not assigned to explicit paths through the transportation system.

- o Road link travel times and costs, volumes and congestion levels.
- o Transit line travel times and costs, link and line volumes and congestion levels.
- o Road pollution and greenhouse gas (GHG) emissions.

Emme is discussed further in Section 3.3.3

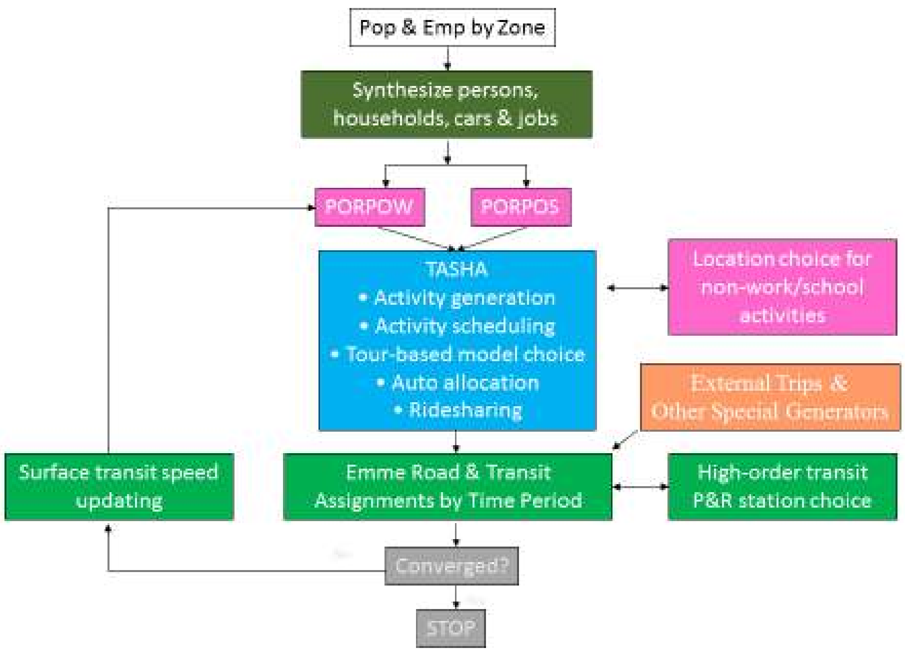

Figure 3.6: GTAModel V4.0 Overview

3.3.2 TASHA

TASHA is an ABM model that generates and schedules all out-of-home activities for all persons within a given household. It assumes that all attributes of the persons and their household have been previously defined. TASHA is documented in a number of academic papers and project reports, listed in the References section at the end of this report. As illustrated in Figure 3.7, TASHA performs the following tasks:

- For each person it generates a set of feasible out-of-home *activity episodes* in which the person wishes to engage during the simulated day. Each activity episode has the following attributes:
  - o Type (purpose). Episode types include: work, work-related meetings, school, shopping and "other purposes".[3]
  - o Episode start time.
  - o Episode duration.
  - o Episode location (destination). For work and school episodes these locations are known. For shopping and other purpose episodes, a destination choice model is used to selection the specific location for each episode.
- In addition to individual person activity episodes, joint activity episodes in which two or more household members are also generated. For each joint activity episodes the same

[3] The model structure permits any set of activity types being modelled. The GTAModel set of activity types reflects the information available in the TTS survey data used to construct the model.

attributes as for individual activity episodes are generated; in addition, the household members engaging in the activity episode are also determined. Joint episodes can occur for both shopping and "other" activity purposes.

- Once all individual and joint activity episodes are known for a person they are *scheduled* so as to construct a feasible *activity pattern* or *schedule* for each person, consisting of the sequence of out-of-home activities in which the person will engage. If there are sufficiently large "gaps" between two episodes, the person can return home from the prior episode before going the posterior episode. As each episode is added to the person's schedule, trips are generated to travel to each episode from the previous episode location (which may be "home") and from the episode to the next episode location (which, again, might be "home"). Note that through this scheduling process, trip-chains (tours) naturally emerge as episodes are added to the schedule.
- Once a person's schedule for the day has been determined, a *tour-based mode choice model* is used to determine the travel mode for each trip within each tour within the daily schedule. This model respects both trip-level constraints (a person cannot use the auto-drive mode if he/she does not have a driver's licence or if a car is not available to use at the time that the trip is made) and tour-level constraints (if a person leaves home driving a car, then the person must eventually return home with the car), as illustrated in Figure 3.5.

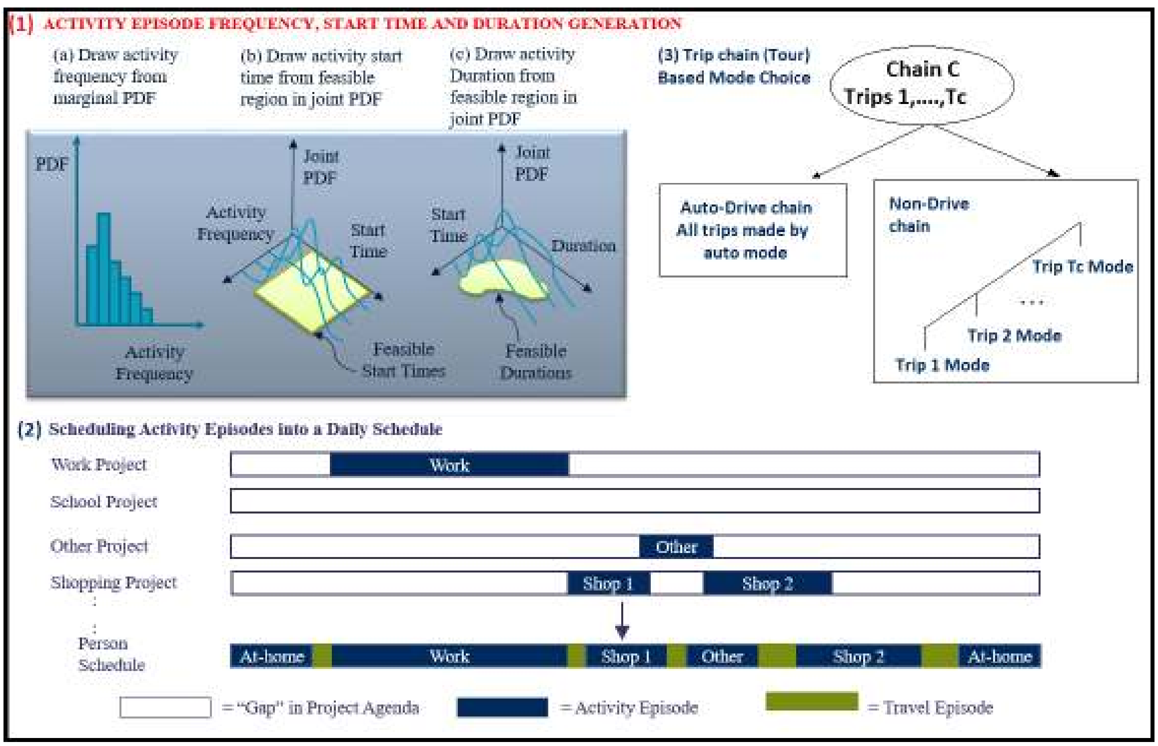

Figure 3.7: TASHA Overview

- Once all persons within a household have determined their mode choice preferences, specifically their desire to use a household vehicle for a given tour within their schedule, these "requests" to use a household vehicle are checked to ensure their feasibility. As illustrated in Figure 3.3, if more drivers want to use a vehicle at a given time than there are vehicles available within the household to use at that time (e.g., two drivers want to use the single household vehicle at the same time), then the household allocated the vehicle(s) to the driver(s) so as to maximize total household travel utility. That is, the person(s) who need the vehicle(s) "the most" will get to use the vehicle(s), while the person(s) for whom reasonable alternatives (e.g., transit) exist, will not.

- Once the household vehicle have been allocated to drivers, the household checks to see if drivers can provide rides to non-driving household members (e.g., drop a spouse off at work while on the way to one's own workplace), as illustrated in Figure 3.4. If such ridesharing is feasible given the travel time constraints of the household members and generates a net gain in household utility, it will be chosen.

3.3.3 The Emme Network Model

Once the origin-destination (O-D) trip matrices for auto and transit trips are known for each time period within the day, the commercial software package Emme is used to do the road and transit assignments for each time period. Emme is one of several such commercial transportation network modelling packages.[4] It has been used in the GTHA as the region's standard network modelling package for almost 30 years. A few key points to note about the GTAModel V4.0 network assignment component of the model system include the following:

- Road assignment in Emme uses an aggregate,[5] static, deterministic user equilibrium (DUE) procedure. This is standard practice in the field. The DUE procedure accounts for congestion effects by increasing the travel time on each link as a function of the traffic volume using the link. It is an equilibrium model in that it balances the flow on each link with the resulting travel time. This aggregate DUE procedure does, however, impose limitations on modelling queuing and other dynamics of traffic flows, as well he ability to "track" individual trip-makers through the road system. More dynamic microsimulation assignment software exists (such as MATSim[6]), but these are generally not yet operationally feasible to implement within a large urban region, especially within the time and budget limitations of the current Asunción project.
- The transit assignment procedure used is also an aggregate, static procedure. The GTAModel V4.0 transit assignment procedure, however, has several important features for accurately modelling transit path choice in a large, complex urban transit system. The procedure used is a:
    - *Probabilistic* assignment that accounts for the fact that two trip-makers facing the same path choice may choose different paths.
    - *Fare-based* procedure, which accounts for differences among alternative paths in terms of both travel time and fares in determining path choices.
    - *Congestion-based* in that the number of passengers onboard the transit vehicles in each segment of each transit line affects the "disutility" of travelling on that line, reflecting the impact of crowding on passenger comfort, as well as the delays imposed on transit vehicle operations due to boardings and alightings. This is an

[4] https://www.inrosoftware.com/en/products/emme/

[5] I.e., as opposed to the rest of the GTAModel V4.0 model system, the traffic assignments are not microsimulations of individual trip-maker path choices but rather the assignment of aggregate flows to paths. The same is true for the Emme transit assignment procedure used.

[6] http://www.matsim.org/

exact analogue to the modelling of congestion effects on roadway delay in the road assignment model.

- In order to use Emme (or any similar network modelling package) the road and transit networks must be *coded* into computer-readable representations as connected graphs of roadway and transit links and nodes, transit lines (defined as the set of links/nodes used by a given line) and associated link, node and line attributes (number of lanes, lane capacities, link speeds, etc.). An extensive set of tools for undertaking this coding process are provided within Emme. Nevertheless this coding task as a labour-intensive and error-prone process which requires considerable effort to undertake. Further, each time a new network scenario is to be tested (e.g., introduction of a BRT line into the base network), the network needs to be edited. Thus, expertise in coding and editing Emme networks is required in order to use GTAModel V4.0 or SATA.

3.3.4 eXtensible Travel Modelling Framework (XTMF)

GTAModel V4.0 is implemented within a modelling software system known as the eXtensible Travel Modelling Framework (XTMF). XTMF has been developed by the Travel Modelling Group (TMG) within UTTRI specifically to support the efficient, rapid development of travel demand modelling systems. It is coded in the C# object-oriented programming language within .net. The design philosophy of XTMF is to create many individual *modules*, where each module performs a well defined task (or small set of tasks). Models and model systems can then be constructed by simply assembling the appropriate set of modules, much in the way that a toy house can be constructed by assembling a set of Lego blocks. This approach permits the very rapid development of a new model system based on the template of a pre-existing model system (such as has been done in the case of SATA being very quickly developed based on GTAModel V4.0), as well as providing great flexibility for model system extensions and improvements over time (as it is hoped will be the case with SATA in the proposed Phase 2 of this project).

CHAPTER 4
SATA: SIMULADOR DE ACTIVIDAD DE TRANSPORTE DE ASUNCIÓN

4.1 INTRODUCTION

The objective of this project is to transfer Toronto's GTAModel V4.0 to the Asunción metropolitan region for use in transportation planning applications within the region. The transferred version of the model system has been named *SATA: Simulador de Actividad de Transporte de Asunción*.

The intent was to change the basic model structure as little as possible during the transfer. The model system, however, did need to be recalibrated so that it could reproduce base year travel behaviour in Asunción as best as possible. In order to do this, a wide variety of data characterizing the Asunción region's population, employment, land use, transportation networks and services, and travel behaviour needed to be assembled. This proved to be a challenging task, taking much longer than originally expected. It was also found that significant gaps in the available data exist, which limited the extent to which SATA could be fully calibrated to Asunción base travel conditions.

A second major task required to calibrate SATA was to construct base year road and transit networks within the Emme network modelling software used by GTAModel/SATA to model road and transit network performance and trip assignments. A base Emme network was obtained for the region, but upgrading this original network for use in SATA was also a major task which, again, took much longer than originally expected. Data limitations concerning the road system and transit services also limited the extent of calibration of the network model that was possible to do.

A third major task was to develop a population synthesizer to turn traffic zone population totals into the disaggregate list of individual persons and households and their attributes (age, occupation, etc.) required by the TASHA activity/traveller scheduler within the overall travel demand system. Data limitations also posed challenges for this task.

Section 4.2 defines the Asunción study region modelled by SATA. Section 4.3 discusses the determination of the base year for SATA calibration, given the data available. Section 4.4 then discussed the data used in the base year model system calibration. Section 4.5 discusses the Emme base network development. Section 4.6 provides an overview of the population synthesis procedure used in SATA. Section 4.7 then discusses the model calibration, including where possible, statistical estimation of Asunción-specific model parameters. In all cases, additional technical detail concerning the data, networks, model system, etc. is available in technical appendices that are contained in Volume II of this project's report series,

4.2 STUDY AREA DEFINITION & TRAFFIC ZONE SYSTEM

The study area includes the City of Asunción and the Central Department. It consists of 19 planning districts. The final zone system divides this area into 278 Traffic Analysis Zones (TAZs). The TAZs are smaller in the areas with high population or job density. Figure 4.1 shows the map of the study area and the final zone system.

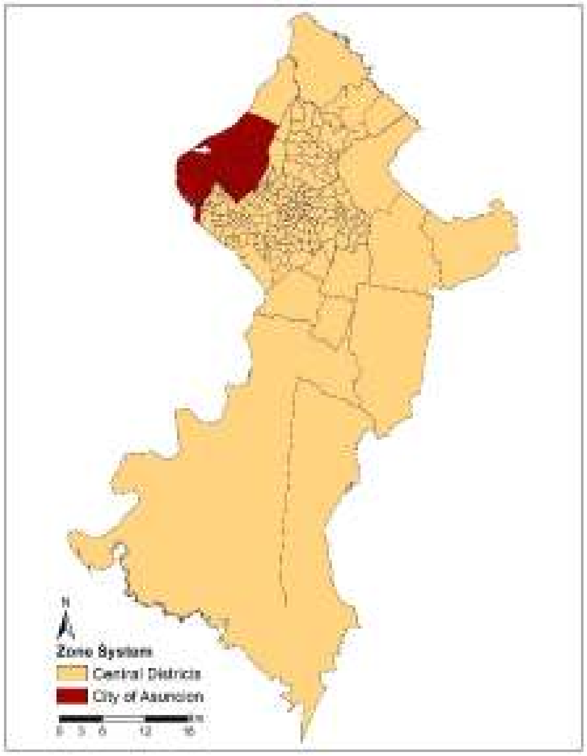

Figure 4.1: Study Area & Zone System

4.3 DATA

Considerable amounts of detailed data are required to build an agent-based microsimulation model such as SATA. Specifically, the most important inputs required for to construct such a model are:

- Digital information on the zoning system that will be implemented in the model, such as an ARCGIS shapefile.
- A travel survey that provides detailed information about population residential location, employment location, population demographics, population labour force participation and occupation, household structure, household vehicle ownership and detailed travel information concerning all trips made by all persons within each household surveyed. The travel data needed for each trip include:
    - Start time.
    - Origin zone.
    - Destination zone.
    - Purpose.

  - Mode(s) used.
- A representation of the road network coded in Emme, in a sufficient level of detail; categorizing road links by: volume-delay function, directionality, free flow speed, capacity, number of lanes, and spatial location.
- A representation of the transit network coded in Emme, in a sufficient level of detail; including transit lines, schedules, headways, stops, and operating speeds.
- Traffic counts and public transit data that allow for calibration and validation of the model.

Every effort was made to assemble all relevant data that are available for the Asunción region. In the end, the data available for constructing SATA are listed below. Much of these data were provided by the ASULAB team; other data sources are noted where relevant. For further detail, see Appendix A.

- 24-hour Origin-Destination (O-D) matrices from the PlanCETA (Japan International Cooperation Agency, 1998) transportation study in PDF format. These were classified by mode (auto, bus), and by purpose (work, study, business, other).
- The 1998 zoning system from the PlanCETA study, in PDF format.
- Traffic counts from the 1998 PlanCETA study. Transit counts were only bus counts, not passenger counts.
- The 2011 study zoning system from the Metrobus BRT study (LOGIT, 2011), in shapefile format.
- Visual occupancy surveys (FOV) from the Metrobus 2011 study, within the area of influence of the BRT corridor.
- Boardings and alightings from the Metrobus 2011 BRT study, covering the metropolitan area to a good extent.
- An estimated O-D matrix for public transit only, from the Metrobus 2011 study, in Microsoft Excel format and calculated based upon the visual occupancy surveys and the boardings and alightings. The Metrobus final report itself acknowledges that this O-D matrix is only representative within the proposed BRT service corridor.
- A LRT study named *Tren de Cercanía* (FEPASA, 2014) This study was based on a very small-sample Stated Preference (SP) surveys conducted only with the LRT corridor., Binary mode choice models were constructed which predicted LRT usage versus individual other modes. The final report was provided in PDF format, while the SP survey data were provided in Excel format. Unfortunately the data that supported the estimation of the logit model mode choice parameters were not provided.
- Population by zone, its socio-economic and demographic attributes, and household structure data were obtained from the General Direction of Statistics, Surveys, and Censuses of Paraguay (DGEEC). This microdata was provided to the UTTRI team after formally asking for it, in SPSS file format and came from the Permanent Household Survey (EPH) databases handled by DGEEC. These data covered the period from 2010 to 2015, where the only standardized years that could be used for synthesis were from 2012 to 2015.
- Employment by zone and by occupation types was obtained from the DGEEC website, it was available to the general public as part of the 2011 National Economic Census (General Direction of Statistics, Surveys, and Censuses, 2011). This information was provided in PDF format. Note that the latter did not include information regarding the

agriculture sector. This information was obtained by the 2008 Agricultural Nacional Census (Ministry of Agriculture and Livestock, 2008).

- An Emme network package containing a raw representation of Asunción road networks (i.e. just the link shapes and lengths, without any further classification), and a rather detailed representation of public transit networks containing lines, schedules, headways, and observed speeds. This network package was fundamental for the development of the model, especially in terms of network coding time. It is noteworthy to mention and acknowledge the Brazilian firm LOGIT, which kindly provided this data source to the UTTRI team.

It is evident from this list that the available data sources are very sparse and fragmented. Challenges in working with these data in the construction of SATA included:

- Converting all data sources into digital format in order to be of use. Unfortunately, the most complete data source (both spatially and in terms of the level of detail) is actually PlanCETA 1998, which happens to be the least digitalized source since it was produced more than eighteen years ago.
- While the Metrobus 2011 study was indeed in digital format, it was only public transit-oriented and representative only along the area of influence of the project.
- DGEEC and National Agriculture Census datasets where only available at a highly aggregate level: districts for the case of Central Region, and the City of Asunción (the densest area of the study) was not subdivided at all into smaller units.
- The sample size of the EPH surveys was small, therefore, the samples from year 2012 to 2015 were combined into a single, more statistically representative sample.
- Coding the road network provided by LOGIT was extremely difficult and time-consuming. The whole array of links belonging to the Asunción and Central districts needed to be classified by: volume delay functions, number of lanes, directionality, speed, capacity, and spatial location. Furthermore, the physical network was shifted and misplaced at some sectors, so a reshaping process was carried forward in the most relevant locations.

Finally, by far the greatest shortcoming with respect to data availability was the lack of detailed trip records from a recent travel survey. Despite all the efforts made throughout most of the timeframe of this study, records from the travel survey that was undertaken during the PlanCETA 1998 study could not be found (which, again, is the only complete study to date). It is essential to acknowledge that a travel survey is a comprehensive source of information since it provides data about household structure, demographic and socio-economic attributes of the population, variability of travel demand throughput the day, etc.; but most importantly, it is the base for developing models of activity episode generation, activity location choice and tour-based mode choice – the core elements of TASHA, and, hence, of SATA.

This lack of detailed trip-making information for a recent base year for Asunción made it impossible to develop a fully operational model that is fully representative of travel behaviour within the region. The best that could be done within the timeframe and resources of this project was to directly transfer the Toronto GTAModel V4.0 model system and calibrate its parameters as best as possible to reproduce as best as possible the limited observed base data for the region that were available. The result is a working "prototype" model system for the region which demonstrates the capability and feasibility of the ABM approach, but which is not sufficiently validated to be confidently used for operational planning analysis. Development of such a fully validated, operational model system will most importantly require, among other inputs, the collection of new travel data for the region in a proposed Phase 2 of the project.

The next section describes the calibration of the Toronto model to base year Asunción observed travel behaviour to create the prototype SATA model system.

4.4 BASE YEAR FOR MODEL CALIBRATION

The lack of complete, consistent data for any one historical year made establishing a base year for SATA model development very difficult. The model was calibrated against 1998 data for the city of Asunción since it provided origin to destination information for a variety of different trip purposes and road counts to validate against. There was insufficient data to generate a synthetic population for this year however, so a synthetic population was created using zonal population totals from the 2002 census using the weighted household structures extracted from the 2012 to 2015 EPH surveys.

4.5 BASE ROAD & TRANSIT NETWORKS

The base road and transit network was originally provided by LOGIT. The network, while being fundamentally accurate in terms of road and transit locations, required massive changes to make it an actual representation of the transportation network in Asunción. Volume delay functions, number of lanes, directionality, speed, capacity, and spatial location all needed to be coded into the network in order for the model to be accurate when determining demand and capacity. Most of these tasks were done manually by looking at satellite imagery through Google Maps, leading to it being a time consuming and intensive process. Speed and capacity information was obtained from looking through the 1998 study after determining the state of the road (Japan International Cooperation Agency, 1998). The auto network was then calibrated by assigning demand from the 1998 study and checking to see whether traffic on links in the EMME network corresponded to the traffic on roads observed in reality. This was complicated by the fact that the demand was for a 24-hour period and had to be factored, which did not allow for the directionality in the traffic flow. Furthermore, as the EMME network is a more up to date network with more capacity in the system than in 1998, flows in the system may be different. Nevertheless, the results of the calibration show that the difference between observed and modelled was within tolerable limits. These results are found in Appendix B of the Technical Appendices.

The transit network was largely more ready to use in the Emme model, as compared to the road network, but it also needed to be calibrated. This was done in a similar manner as the auto network above, with the modelled volumes being compared to the observed volumes. However, the demand matrix that was provided from the 2011 BRT Study was not a comprehensive matrix (it only focused on the BRT corridor) and this led to the results when assigning this demand being much lower than the observed volumes. In the absence of better data, the transit network was deemed accurate enough for developing the SATA prototype model. A number of other general network modifications also took place to improve the condition of the network as well the usability of the model. This led to the creation of the base road and transit network used in the SATA model. Further detail about this network is found in Appendix B.

4.6 POPULATION SYNTHESIS

A synthetic population for the SATA model was generated using data from DGEEC (Paraguay Stat) for years 2005-2025. The initial population data was provided at district level (20 districts). Several steps were taken to divide the district level population into the totals represented at the 2011 zone system level.

The population totals at the zonal level was calculated based on each zone's respective area. The following procedure details generating population data for the 2011 zone system:

- For districts with exactly corresponding zones (9 districts- outskirt of the study area) and outside of the 1998 zoning system, the population information was used directly.
- For one remaining district outside of the 1998 zoning system, the population information was transferred based on the area of each zone (58 zones).
- For districts in the 1998 zoning system (10 districts including Asunción), the population information for 2002 is available in Table 4.3 of the LRT study. The population share of each zone in 2002 is multiplied by the district population in 2011 to generate the population for 1998 zoning system. Then based on geographic area, the 1998 zoning system population (88 zones) was transferred to 2011 zoning system (243 zones).

Individual persons and households were drawn from seeds taken from the 2012 census database. Only those households and individuals located in the appropriate departments were chosen as seed candidates for synthesis. The population totals were used as controls for generating a synthetic population. Seed data was taken from the 2012 census and were made to match the controls calculated in the previous steps. Total vehicle ownership was estimated by the household's ownership of either a motorcycle or vehicle; e.g. A household could own a total of 2 vehicles; inferred from the ownership of either a motorcycle, vehicle, both or neither.

Several challenges were met in transforming categorical census data (particularly occupation type) in the seed population to the totals defined in the DGEEC statistics. These categories were also restricted to those imposed by GTA Model 4.0. Due to these constraints, several adjustments and overlaps occurred in order to map the census and DGEEC datasets. In addition, there was little information quantifying vehicle ownership at the household level. Specifically, vehicle ownership defined in the census was a categorical "yes" vs "no" for either motorcycle or vehicle. To satisfy TASHA's reliance on vehicle ownership, totals for each household were artificially calculated from the census data, thus possible total values were either 0, 1 or 2.

4.7 MODEL CALIBRATION

For the production of SATA several sub-models needed recalibration from GTAModel V4.0: Place of Residence to Place of Work (PoRPoW), Activity Generation, and finally mode choice. All of these models were estimated with data trying to approximate the conditions surrounding the year 1998 so that the model results could be compared against PlanCETA 1998 data.

To estimate a model for linking person agents to their places of work we needed observed data. Since this was unavailable we approximated it by taking the 1998 PlanCETA work trips and broke them down by the three estimated occupation groups, Service, Commerce, and Industry. Using these approximations to observed truth, TMG's particle swarm optimizer optimized model parameter estimates for each occupation category based on road distance, transit time, and auto in-vehicle travel time. There was a fourth occupation category, Farmers, that was not estimated as it was shown to work mostly intra-zonally and given limited data was just assigned as an identity matrix.

With place of residence estimated we were then able to move onto balancing the amount of activities that TASHA would produce. Initially GTAModelV4.0's calibrated activity generation rates were used. The model was then run for a single iteration against the 2002 synthetic population and activity rates were compared against their equivalent activities from PlanCETA 1998. The GTAModel V4.0 distributions were then hand modified to fit Asunción's.

With activities being generated the next step was to get the mode choice model to reproduce the split between the auto and bus modes from PlanCETA. Initially the applicable mode parameters were taken from GTAModel V4.0 and run against the model in a single iteration. Model splits were then aggregated and compared to PlanCETA 1998's mode splits by activity type and balanced. Once these numbers closely matched, the model was then compared against road counts, also taken from 1998. Calibration was then iterated against the two datasets finding a final balance between the two.

CHAPTER 5
EXAMPLE CASE STUDIES

5.1 INTRODUCTION

In order to test the prototype SATA model and to demonstrate its capabilities three network scenarios were investigated:

- The base case.
- The proposed BRT *Corredor Eusebio Ayala – Mcal Estigarribia* project.
- The proposed LRT Tren de Cercanía project.

Sections 5.2 and 5.3 very briefly describe these three scenarios. Greater detail concerning the scenarios is presented in Appendix C. Section 5.4 provides a few representative results for the base case. Greater detail concerning both the base case and BRT and LRT model run outputs is provided in Appendix D. In all cases, the data presented are meant to illustrate some of the outputs that can be generated by SATA. They should not be interpreted as definitive forecasts for BRT or LRT ridership or other impacts. As discussed in this report, the SATA model system is currently very much a first prototype, developed as a proof of concept, rather than a fully calibrated operational forecasting tool. Improved data and additional time spent on model calibration and testing (both of which were not available within the limited time and budget of the current study) will be required before SATA outputs can be used for operational policy analysis.

5.2 THE BASE CASE

The base case (oftentimes translates as the “do nothing” approach) consists of running the calibrated model according to the current conditions of the study area. This scenario establishes an initial reference that works as a comparison point with respect to the proposed infrastructure investment projects.

The base case is the result of the overall model building process described in Chapter 4. Specific indicators such as transit ridership, automobile trips, and Place of Residence – Place of Work (PoRPoW) can be found in Appendix D. Likewise, for further information regarding data for zoning systems, population, employment, and other data, refer to Appendix A.

Finally, note that in terms of transportation modes, the base case is formed by the road network and the transit network. A very detailed description of the network coding process can be found in Appendix B. For reference, Figure 5.1 depicts a map of most of the currently available transit lines (in blue, yellow, red, and purple colors), and the remaining links represent the roads in the network. A fully detailed description of the transit lines that are part of the base case is provided in Appendix C.

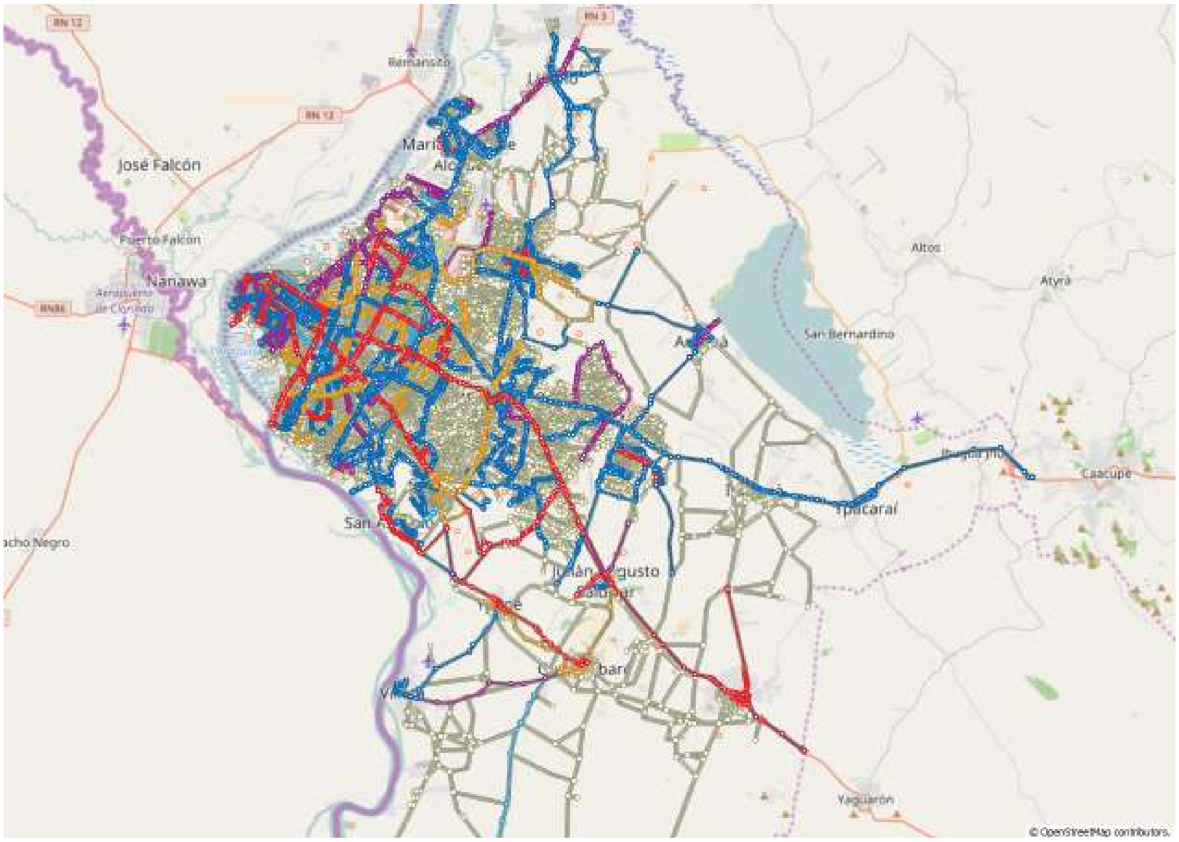

Figure 5.1: Base Case: Current Transit Lines and Roads in the Network

5.3 INFRASTRUCTURE INVESTMENT SCENARIOS

5.3.1 BRT Scenario (The Metrobus Project)

In 2010, the Brazilian company LOGIT conducted studies to address the transportation challenges facing the Greater Asunción Area. These studies followed one of the main recommendations of PlanCETA: the implementation of a mass transit system. In this case, a Bus Rapid Transit (BRT) was the proposed alternative.

The study identifies *Mariscal Estigarribia - Eusebio Ayala* as the main and the most congested transportation corridor of Asunción, and its main premise states that this corridor is the optimal and logical alignment for the BRT system. Furthermore, while the Asunción – San Lorenzo route has long been identified as critical, the study proposes going further to Capiatá, considering that it is a region that has been experiencing strong development, and hence, growing travel demand.

As previously mentioned in the Data section of this report, LOGIT provided valuable data to set up the SATA model in terms of the codification of the physical network in EMME. Moreover, the network package files provided by LOGIT included information about public transit lines and its main attributes such as: headway, design speeds, and observed speeds (by transit line segment).

In order to adjust to demand in an optimal way, four lines were proposed for the BRT project: an all-stop line (T01), an express line (T11), and two semi-express lines (T12 and T13). The alignment of these four lines is shown in Figure 5.2:

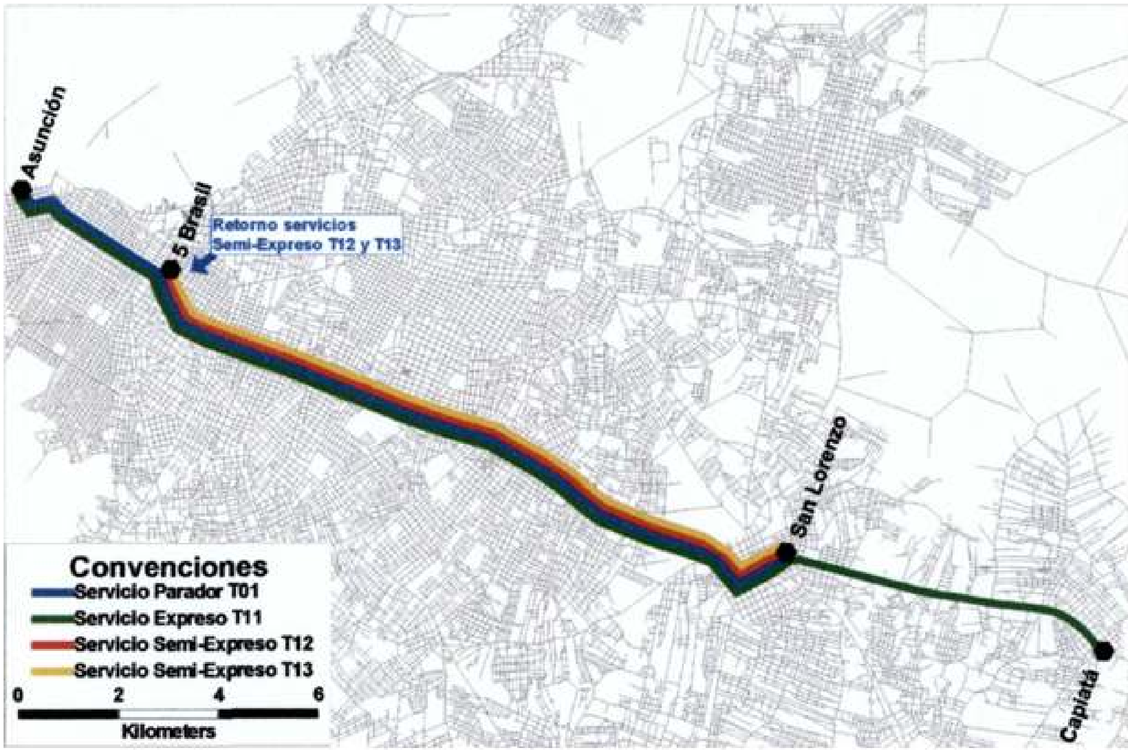

Figure 5.2: Proposed BRT Lines *Source: LOGIT (2011)*

Appendix C describes the proposed BRT lines, along with the modifications to the current bus transit network that are proposed in the LOGIT study.

5.3.2 LRT

In 2014, a consortium formed by the Paraguayan Railroad Company (FEPASA), the Korean Transportation Institute (KOTI), and the Korea Rail Network Authority (KRNA) developed a feasibility study for the implementation of a LRT system as a solution to address the transportation needs of the Greater Asunción Area. The main rationale for the proposed alternative relates to the limited space that the existing road infrastructure provides and the need of a transportation alternative that does not impose additional demand on roads.

As illustrated in Figure 5.3 below, the proposed LRT system considers two lines; the first one going from Central (at the fringe of the Asunción Historic Center) to Luque, and the second one going from Central to Ypacarai).

Refer to Appendix C to find a complete description of the two proposed lines.

Figure 5.3: Proposed LRT Lines

5.4 Sample Results

The outcomes of implementing the LRT and BRT projects can be assessed by analyzing SATA´s outputs. Note that the amount of data generated by SATA is very large, and a model of such dimensions handles highly complex non-linear, stochastic processes; this poses a challenge in presenting and visualizing model results given the massively multidimensional nature of mobility patterns. Having said this, there are standard numerical summaries and graphical representations that can help with visualizing and understanding the complexity of an activity-based-agent based model. A detailed collection of these graphs and summaries is presented in Appendix D, with a few selected examples being presented below in Table 5.1, and Figures 5.4 and 5.5. The analyses of these and other model results can be found in Appendix D.

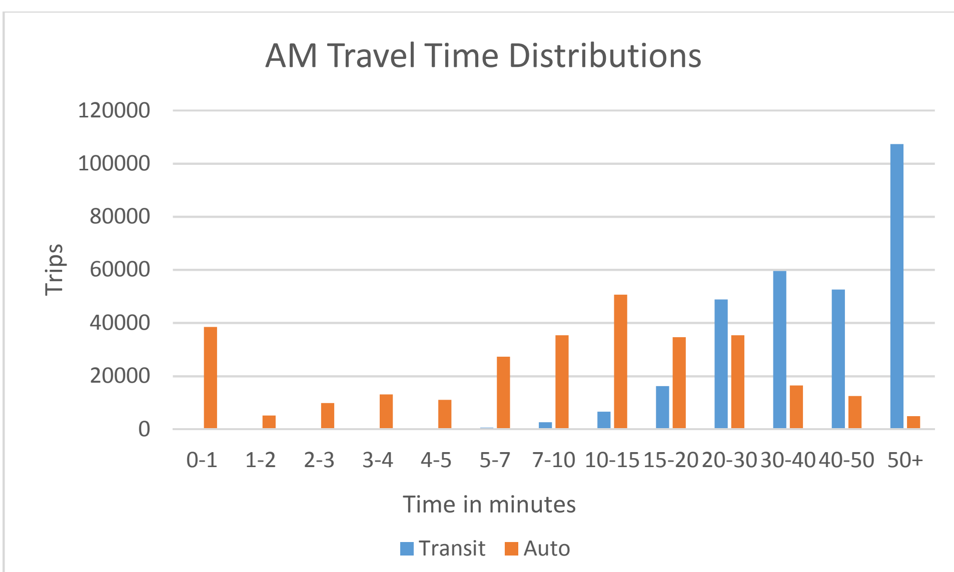

Figure 5.4: AM Travel Time Distributions for Auto and Transit for the Base Case

Scenario	AM Transit Ridership	AM Auto Trips	24-H Transit Ridership	24-H Auto Trips
Base Case	294474	294653	1320924	1036160
BRT	295251	294675	1322466	1036691
LRT	296996	294166	1328348	1034262

Table 5.1: AM Transit Ridership and Auto Trips Generated for Each Scenario

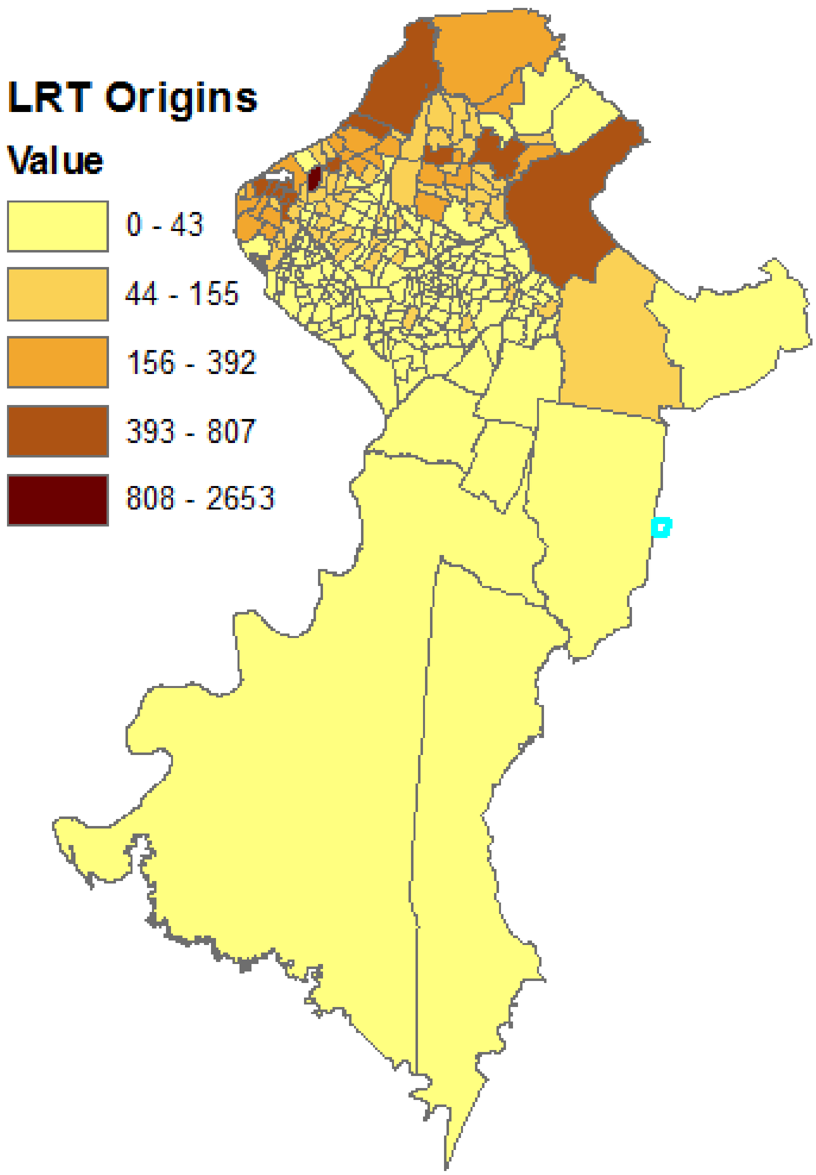

Figure 5.5: AM LRT Origin Catchment Area

CHAPTER 6
SUMMARY, CONCLUSIONS & NEXT STEPS

Asunción is facing many important transportation-related urban planning issues, including the redevelopment of its Historic Centre and the proposed implementation of major new high-order transit lines to address growing congestion problems in the region. A travel demand forecasting model system for the region would be extremely useful, both to quantitatively and objectively explore the benefits and costs of a range of transportation policy options and to provide a common data and analysis framework within which the various stakeholders could come together to discuss and explore these options.

At the same time, the CAF, the Development Bank of Latin America, is interested in demonstrating the advantages of agent-based microsimulation (ABM) methods for modelling travel behaviour for policy analysis in Latin American cities. ABM models represent the current state-of-the art in travel demand modelling. They provide many advantages relative to the conventional modelling methods that have been standard practice worldwide for the past several decades. In particular, they are better suited to exploiting new sources of travel information that are becoming available through modern information technology, and they are more appropriately sensitive to current and emerging policy issues. As Latin American cities strive to build sustainable urban mobility systems capable of meeting their social and economic goals in the 21st Century, advanced analysis methods such as ABM travel models are essential tools to successfully and cost-effectively achieving these goals.

As one component of CAF's strategy for promoting its urban sustainable mobility objectives, it has partnered with the University of Toronto Transportation Research Institute (UTTRI) to create the *iCity-South* research program to apply the iCity urban informatics vision and capabilities in Latin American cities. The first specific project within the iCity-South program is the development of a prototype ABM travel demand model system for the Asunción metropolitan region in order to address the two purposes stated above: to provide a powerful transportation policy analysis tool to Asunción planners and decision-makers, and to provide a practical demonstration of the ABM modelling approach within a Latin American context.[7]

The outcome of this project has been the development of *SATA: Simulador de Actividad de Transporte de Asunción* (Transportation Activity Simulator for Asunción). SATA is an ABM model system for generating estimates of all trips by all purposes and modes for a typical 24-hour weekday within the Asunción metropolitan region. It is based on the *GTAModel V4.0* model system developed by UTTRI for the Greater Toronto-Hamilton Area (GTHA) and which has been in operational use by the City of Toronto since early 2016. As one means of demonstrating SATA's potential, the Bus Rapid Transit (BRT) and Light Rail Transit (LRT) proposals currently under consideration within the Asunción region are examined within this project using SATA.

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[7] A second, parallel CAF-sponsored iCity-South project has also been launched. It is exploring new travel data collection methods in Montevideo.

Due to significant limitations in the travel-related data available for the Asunción region, the current version of SATA is a prototype that is adequate for demonstrating the capabilities and potential of the ABM approach, but which is not yet sufficiently validated to be used as an operational planning tool. It is recommended that a "Phase 2" project be launched that would: (a) gather the data needed to properly calibrate and validate the SATA model system; and (b) use these new data for fully upgrade the SATA prototype to be fully useful by Asunción planners as an operational policy analysis and decision-support tool. Appendix E, in Volume II of this project's report series presents a discussion of issues, needs and options associated with this proposed Phase 2 study, along with a preliminary budget and schedule for discussion purposes.

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