Simulating Transport Mode Choices in Developing Countries

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Abstract. Agent-based simulations have been used in modeling transportation systems to gain deeper understanding of travel behavior and transport mode choices. This study focuses on analyzing the factors that influence transportation mode decisions specifically in developing countries. As motorcycles are the preferred mode of transport in these economies, we have developed an agent-based model that includes two-wheeler vehicles as a transport alternative for commuters. Our model represents individuals who must make decisions regarding their choice of transport mode for their daily commute to work or school. These decisions are influenced by a combination of factors, including personal satisfaction, uncertainty about trying a new transport solution, and social comparisons of these two aspects within their social network. The model was ran using data from a Colombian city. The results show that our model represents the behavior of the system, which means in the absence of any policy intervention, the number of motorcycles and private cars will continue to increase in the coming years. This growth exacerbates negative impacts such as traffic congestion and road accidents, presenting significant challenges to the transportation system. Several key factors emerge as influential in the decision-making process. The time of travel and personal security considerations play a significant role, leading individuals to favor private transport alternatives over public transit. These findings underscore the need for targeted interventions that address these factors and promote sustainable and efficient modes of transportation.

Keywords: Agent-based simulation · Motorcycles · Social influence.

1 Introduction

Agent-based simulation is a powerful modeling technique that takes a bottom-up approach, representing individual agents as interdependent decision-makers. These agents autonomously interact with each other and their environment,

adapting their behaviors and decisions accordingly. The collective actions and interactions of these individual agents within an agent-based system give rise to crowd behavior [1]. This modeling approach has gained widespread adoption globally, as it proves effective in capturing the complexities of systems such as transportation and studying individual travel behavior [2]. While a significant amount of research has been conducted in developed economies, it is important to note that motorcycles are often overlooked in favor of cars, bicycles, and public transportation [3, 4]. However, in developing countries, motorcycles serve as the preferred mode of transportation for middle- and lower-class individuals due to their affordability, autonomy, and speed [5, 6]. The increasing number of motorcycles on the roads in these countries contributes to issues such as traffic congestion, accidents, and pollution, necessitating the implementation of effective public policies [7]. It is crucial to note that policies derived solely from studies conducted in developed territories may not effectively address the dynamics of the system (the environment), since socioeconomic and cultural conditions significantly influences decision-making patterns. Therefore, further research is needed to understand how individuals make decisions regarding their choice of transportation mode and the social factors that impact those decisions. This paper presents results obtained with an agent-based simulation developed by Salazar et al. [7]. Although the model is not presented in this paper in detail, it represents the interactions of urban travelers as they make decisions regarding their primary mode of transport. The model includes motorcycles and incorporates parameters that capture realistic human behavior patterns within the specific socioeconomic context. A Colombian city is selected as a case study to analyze commuter behavior in developing countries. The objective of this research is to provide a testbed to identify the factors that influence transport mode choice, considering motorcycles as a full-fledged mode of transport. Ultimately, the study aims to inform the development of policies that can mitigate the negative impacts of the increasing motorcycle circulation on mobility.

2 Related Works

Agent-based simulations have emerged as a valuable tool for investigating a wide range of transportation issues. These applications consider driver-vehicle elements to simulate and assess decision-making behaviors under various traffic conditions, such as congestion, lane changes, and traffic light coordination [1]. In the realm of transport mode choice research, there are a few studies applying agent-based modeling; for instance, Faboya [9], introduces the Modal Shift (MOSH) framework, which analyzes the adaptive travel behavior of individuals commuting to and from a university. This framework considers multiple user groups, including public transit users, car drivers, bicyclists, and pedestrians. The findings highlight the significant impact of comfort on transport mode selection and emphasize the role of social interactions in influencing mode adoption. Another study by Kangur et al. [10] presents an agent-based model that explores consumer behavior and the large-scale interactions between consumers and the

system in the context of electric vehicle adoption. The analysis encompasses gasoline, hybrid, and electric cars. Importantly, both of these studies incorporate the CONSUMAT approach [12], a consumer behavior model that considers agents' social and personal needs, as well as their levels of satisfaction and tolerance for uncertainty. By assessing satisfaction and uncertainty levels, individuals in these studies can employ various decision strategies, such as repetition, imitation, inquiry, and deliberation. This approach acknowledges the rational and calculative nature of human decision-making and emphasizes the engagement of individuals with similar travelers to gather information and reduce decision uncertainties. Nevertheless, the approach does not propose a specific way to calculate the satisfaction or the uncertainty and it is a generic consumer model that needs to be adapted to the transportation context.

Our model similarly to the MOSH approach, integrates the CONSUMAT to capture the interactions of interdependent agents who employ diverse decision-making strategies to select their transportation mode. In addition, we are considering motorcycles as an alternative to commute in a whole city and including additional influencing factors i the mode shift. In order to incorporate social influence into the decision-making process, we establish a social network that connects individuals with similar attributes, enabling them to gather information and make decisions in uncertain situations. As Carley [11] suggests, the cultural context plays a significant role in shaping the social structure and the likelihood of interactions among individuals. Our study extends previous works by proposing an approach that combines personal and collective experiences, weighted by the level of importance individuals assign to social engagement. This level of importance is parameterized based on the cultural dimensions studied by Hofstede et al. [14], specifically individualism and uncertainty avoidance. Additionally, our research includes motorcycles as a transportation alternative and examins travel behavior within the context of a developing country.

3 Simulation Model

In this section, we provide a high-level view of our agent-based model. The model simulate the transportation choices made by commuters during the peak hour as they travel from their homes to work. The available transport modes include motorcycles, cars, and public transit. Agents have attributes such as gender, age, and socioeconomic status. Individuals are distributed in the environment (the city) and located in one neighborhood that align with their socioeconomic condition and need to travel to the assigned workplace. The model is implemented with NetLogo 6.3.0 [15], in which time steps are counted in ticks. One tick corresponds to one minute of a peak hour in the real world.

3.1 Decision-making Module

The conceptual model that guides agents in their mode choice decisions is explained in Fig. 1. Transport users select a mode of transportation for their journey from home to work. Subsequently, they assess their satisfaction with the

journey based on a list of influencing factors. Simultaneously, agents check the uncertainty about the satisfaction that will obtain with their current transport mode. This uncertainty is a combination of their personal user experience and the experiences of their contacts within the social network, reflecting how individuals can be influenced by the experiences of their immediate peers. As agents accumulate more experience, their level of uncertainty decreases. Agents utilize both satisfaction and uncertainty to evaluate a mental model, which determines the strategy for the decision-making process and, consequently, the mode of transportation for the subsequent period. To implement the mental model, we employ the CONSUMAT approach [12] and the MOSH framework [9].

Fig. 1. Conceptual model of transport mode choice.

Similar to previous studies [9, 13], our agents take into account various factors or needs to calculate their satisfaction. These factors encompass the cost of acquisition, operating cost, road safety, personal security during travel, travel comfort, commuting time, and pollution generated. Each of these factors holds a varying degree of importance for individuals. Consequently, the overall satisfaction is determined by a weighted sum of satisfaction with each specific need. The values associated with these needs are influenced by the state of the system, which is a result of individual and aggregate decisions made by the agents at each tick. Weights are established according to the socioeconomic and cultural context. For this purpose, we applied a survey in our case study city (See Supplementary Materials section).

3.2 Social Influence

The decision-making process of individuals is often influenced by their social connections or social network ties [9]. When faced with uncertain situations, people often seek information from others within their social network who have similar experiences. Previous research suggests that large social networks exhibit a power-law distribution, and this characteristic can be extended to the dynamics of transportation [10]. In our model, we establish connections between individuals who share similar conditions, forming a scale-free network within socioeconomic groups. Additionally, across these groups, some individuals are connected using the concept of a small world network [17]. Figure 2 illustrates the social network structure, using parameters specific to Cali, a selected Colombian city serving as a case study.

3.3 Validation

Data from Cali city was used to parameterized the model. Cali is located in the southern part of Colombia and has a population of 1.8 million people. The population of Cali is concentrated mainly in the middle class (41%) and low-income class (35%). Due to the impact of the pandemic on public transit usage, historical data of transport mode users prior to 2019 were utilized. The vali-

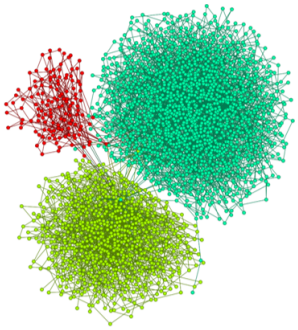

Fig. 2. Social network connecting agents.

dation of the model was conducted using the "validation in parts" technique, as suggested by Carley [18]. This approach involves separately validating inputs, processes, and outputs. Inputs were validated to ensure they followed the distributional properties observed in the real system. Census data and official records were employed to parameterize the initial distribution of accident rates, fleet distribution, and agent properties such as age, gender, and socioeconomic status. The internal processes within the model were designed to resemble real-world processes, with qualitative alignment between model elements and their real-world counterparts. A conceptual model was initially defined based on the literature on transport modeling and human behavior theories. The code procedures were then incrementally validated in each module, including setup and go procedures. Validation techniques such as dimensional consistency, extreme value analysis, and structure validation, were employed. Furthermore, experts in agent-based simulation and transportation studies were consulted to validate the model's assumptions conceptually. For outputs, the model's mean predictions were compared to the general patterns of behavior observed in the real system or historical examples. Pattern modeling validation, was performed by configuring a tailored scenario that represented the conditions of the system in 2017. The proportion of people using private vehicles and public transportation was analyzed. As demonstrated in Figure 3, the simulation results from 100 runs indicated that the emerging macro-level outputs were comparable to real-world patterns observed in subsequent years.

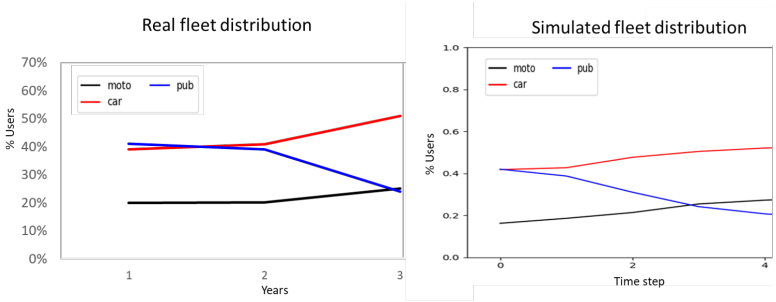

Fig. 3. Social network connecting agents.

4 Virtual Experiment

We conducted a virtual experiment using data from Cali city to analyze the shift in transport modes over time and the factors influencing this change. The model employs a scale of 1:1000 and simulates a synthetic population of 1,121 individuals, each characterized by their socio-economic attributes and an initial transport mode. These attributes follow distributions derived from our case study. Each agent is assigned thresholds for satisfaction and uncertainty, which are normally distributed, and they are connected to other individuals within the virtual society. The independent variables introduced into the model are listed in Table 1. The transport modes are parameterized based on technical specifications such as average efficiency, average CO2 emissions, average possible speed, and average costs. Historical data is utilized to calculate accident rates. The analysis period spans 10 years, equivalent to 600 ticks in NetLogo, where each tick represents one typical peak hour. Agents evaluate information annually to make decisions regarding mode changes. The simulation is run 100 times, and the average results are calculated.

Table 1. Model parameters.

Parameters
Socio-demographics
Initial fleet distribution
Satisfaction and Uncertainty thresholds
Mode costs
Accident and incident rates
Mode speeds
Mode emissions

Figure 4 illustrates the proportion of users by mode over the 10 analyzed periods. In the absence of any changes or policies introduced in the system, an increase in private vehicle usage and a continued decrease in public transit are

expected. Two-wheeler registrations are projected to increase by 95%, resulting in an additional 215,000 motorcycles in the city. Car registrations would increase by 50%, adding approximately 228,000 more cars. As a consequence, the share of public transit would decline from 41% to 14%. This validates that the model represents the expected behavior from the real system and that later implementation of policies in the agent-based simulation can provide reliable results.

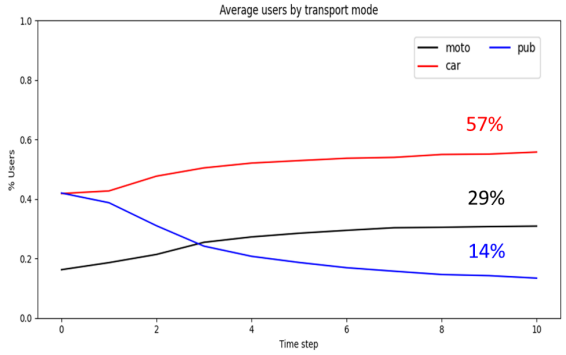

Fig. 4. Average users by transport mode.

5 Discussion and Future Work

As a result of the evaluation of the mental model, individuals employ different strategies to make decisions. In our model, agents are categorized into four groups based on the CONSUMAT approach. When agents' uncertainty fall below the threshold, the decision-making process is conducted individually, and depending on whether the satisfaction level is high or low, they may repeat the selection from the previous period. High levels of uncertainty prompt agents to engage with individuals in their social network. For agents with high satisfaction, the social comparison results in an imitation process where they adopt the most popular mode among their contacts. High uncertainty and low satisfaction values mean agents inquire in their network and compare their own satisfaction to the expected satisfaction if using the others' transport modes. If any of those expected satisfactions surpasses their current satisfaction level, the agent will opt for that alternative. Figure 5 demonstrates how individuals are classified into groups of decision-makers based on the strategies they employ to select a transport mode over time. As people begin transitioning from public transit to private alternatives, uncertainty increases (as shown in Figure 6b), leading to a greater number of people seeking information from their peers. In contrast, motorcyclists tend to be more satisfied than users of other modes (see Figure 6a), resulting in their tendency to repeat their mode selection.

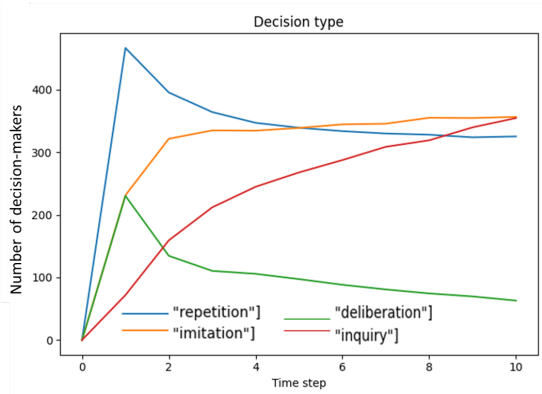

Fig. 5. Average satisfaction by transport mode.

The satisfaction calculated in every decision period depends on the values that each agent obtains for the transport mode attributes; some of them have a greater influence, for instance, the travel time and the personal security. As seen in Figure 7, those variables disfavor the public transit. In contrast, accidents has a big impact on motorcyclist safety, but this factor is less important for individuals.

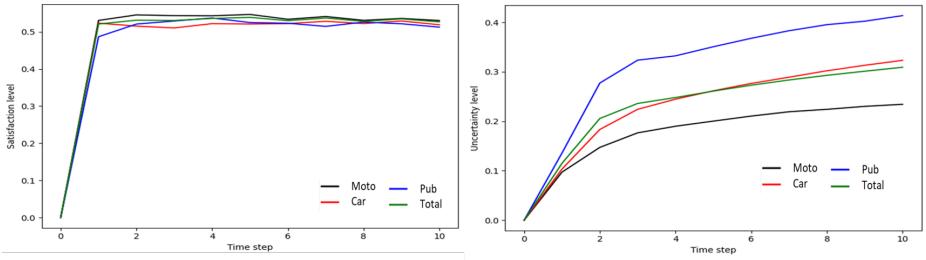

Fig. 6. a) Average satisfaction by transport. b) Average uncertainty by transport mode.

For future work, we intend to analyze the dynamics of mode shift within demographic groups. This facilitates the identification of factors for intervention through segmented policies. Based on this analysis, we will select some policies to implement in the model and study their impact on the system. Currently, the model does not include the road capacity, this limitation will be addressed in later work. This model can be parameterized with information for different cities, taking into account their economic, social, and cultural conditions. We hope this research can be a reference point for policymakers and contribute to the design of better transport systems in developing countries.

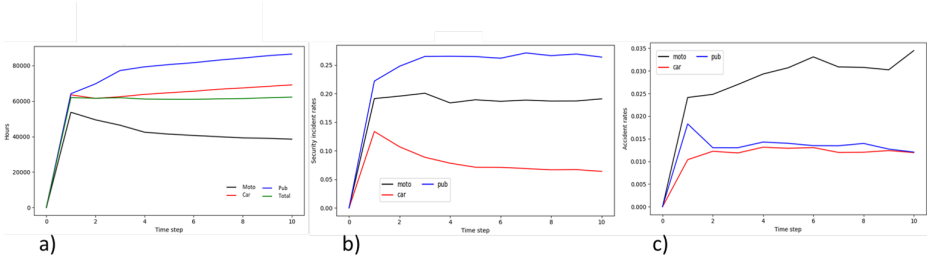

Fig. 7. a) Average travel time. b) Average insecurity rate. c) Average accident rate.

6 Conclusions

In this paper, we present results from an agent-based model that simulates the decision-making process of urban commuters and analyze the factors that influence their choice of transportation mode. Our study examines how commuters assess their satisfaction and uncertainty by comparing themselves to their social network, ultimately leading them to select one of three alternatives: cars, motorcycles, or public transit. The findings from our case study reveal that motorcycle users report higher levels of satisfaction and their numbers are projected to continue increasing at the highest rate among the alternatives examined. The primary reason behind this preference is the swift commuting experience offered by motorcycles, which is highly valued by users. Furthermore, the migration of public transit users to private transportation is driven by two key factors: the prolonged travel time and the heightened perception of personal insecurity. Despite the significant impact of road accidents, this factor is generally undervalued, particularly among motorcyclists, who exhibit the highest accident rate. By shedding light on these dynamics, our study serves as a starting point for the development of targeted public policies aimed at addressing mobility issues. Policymakers can leverage these insights to formulate strategies that cater to specific commuter groups based on their individual behaviors and preferences.

Acknowledgement We thank CASOS at Carnegie Mellon University and the CBIE at Arizona State University for providing support during Kathleen Salazar's visit as a PhD student at Universidad Nacional de Colombia. Alike to the Fulbright Scholarship Program for making her visit possible.

Supplementary materials Additional information can be found at:
https://github.com/Kathleenss/SBP-Brims23-SupplementaryMaterials

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