# Autonomous vehicles and residential location choice: a scoping review and analytical framework

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## 1. Introduction

Historically, the advent of transportation technologies has significantly contributed to shaping urban forms and structures of cities (Aston et al., 2021). These effects have brought several challenges (e.g., congestion and urban sprawl) as well as opportunities (e.g., housing affordability and employment accessibility). These trade-offs often occur due to the dynamics of urban agents who seek to maximize their access to opportunities and mitigate the drawbacks due to changes in transportation. In light of that, a common response from urban agents to new transportation modes is through residential relocation. Changes in residential locations, in turn, affect travel behaviour, and, consequently, the transportation system. Thereby, residential location choice dynamics are inherently associated with the transportation system and vice versa (Acheampong, 2018). Hence, the development of effective urban planning and transportation policies rely on the comprehension of the mechanisms that drive residential location choice (RLC).

Several modelling techniques have been developed to predict residential location choice. One of first models used to forecast RLC is the Lowry model, which applies a gravity model to predict the patterns of residential and retail land allocations using the industrial land use and employment distribution data (Lowry, 1964). Other types of RLC models have been developed based on the random utility theory (McFadden, 1978). In this theory, agents rationally choose the housing location with maximum utility among a set of mutually exclusive discrete options. Some of the attributes of the utility function may include commute cost, commute time, housing price, neighborhood attractiveness, and housing amenities (e.g., number of bedrooms, land size and housing type). Other RLC studies have applied bid-auction models, which assume that agents tend to maximize their willingness-to-pay (WTP) for a house (Hawkins et al., 2019). Recent advancements in RLC modelling are simulation-based methods, such as agent-based, activity-based and cellular automata models, which are capable of considering travel behavior and large multimodal transportation networks (Pan and Sharifi-Asl, 2023).

A prominent transportation technology that may impact residential relocation patterns in the long-term is autonomous vehicle (AV), also commonly known as driverless car. AVs are expected to impact residential location choice by inducing, for example, changes in accessibility, road capacity, parking demand and travel behaviour (Heinrichs, 2016). AVs may positively affect accessibility by reducing travel costs, parking costs, and the disutility of travel time compared to conventional human-driven cars (Meyer et al., 2017, Zhou et al., 2021). However, reductions in the value of travel time and monetary travel costs may eventually lead to urban sprawl (Cordera et al., 2021, Meyer et al., 2017). The impacts of AVs on residential location choice may also vary with the type of AV. The results of modelling studies have shown that the average housing distance to city centre may vary from -4% to 14% for shared autonomous vehicles (SAV), and from 12% to 14% for private autonomous vehicles (PAV) (Pimenta et al., 2023). In other words, both AV types may induce urban sprawl in similar magnitudes, however, SAVs have also shown potential to attract residents towards city centres.

Research has also shown that parking may be an important mechanism to drive residential relocation in the AV era (Kumakoshi et al., 2021). For example, housing supply in dense areas may increase by replacing obsolete parking slots, what may reduce housing costs and also attract new residents. In addition, the possibility of empty-cruising may allow higher flexibility for parking outside high-density areas, what may eventually reduce parking costs, and attract new residents to city centres. In other words, the assumption of parking as a fixed cost may no longer be valid with AVs. Thus, it is important to consider changes in parking costs, empty-cruising costs and accessibility in the development of RLC models with AVs. In light of that, this study contributes to the field by (1) undertaking the first review of the literature on residential location choice modelling approaches with AVs; (2) proposing the first analytical framework to guide the assessment and development of state-of-the-art residential location choice models with AVs.

# 2. Methodology

The methodology of this study is organized in four steps: (1) identification of a broad search criteria to obtain the population/universe of relevant studies; (2) limiting the universe of studies to targeted/eligible literature using rigorous and clear criteria; (3) developing an analytical framework to assess residential location choice modelling approaches with autonomous vehicles; (4) assessing the eligible studies using the analytical framework indicators.

## 2.1. Search strategy

The following search terms are used to identify studies with modelling of AV impacts on residential relocation.

*"autonomous vehicles" OR "driverless vehicles" OR "automated vehicles" OR "self-driving vehicles" OR "autonomous cars" OR "driverless cars" OR "automated cars" OR "self-driving cars" AND "residential relocation" OR "household relocation" OR "housing relocation" OR "residential location choice" OR "household location choice" OR "housing location choice"*

The aim here is to conduct a scoping review including studies that simulated AV impacts on residential relocation. Solely peer-reviewed journal and conference articles published in the English language between January 2002 and April 2023 were considered. To the best of our knowledge, this timeframe encompasses all articles published on AV impacts on the built environment (Pimenta et al., 2023). Two major databases are used for this review: Scopus and Web of Science. Snowballing of the references is also used to identify additional studies that are not found on the databases.

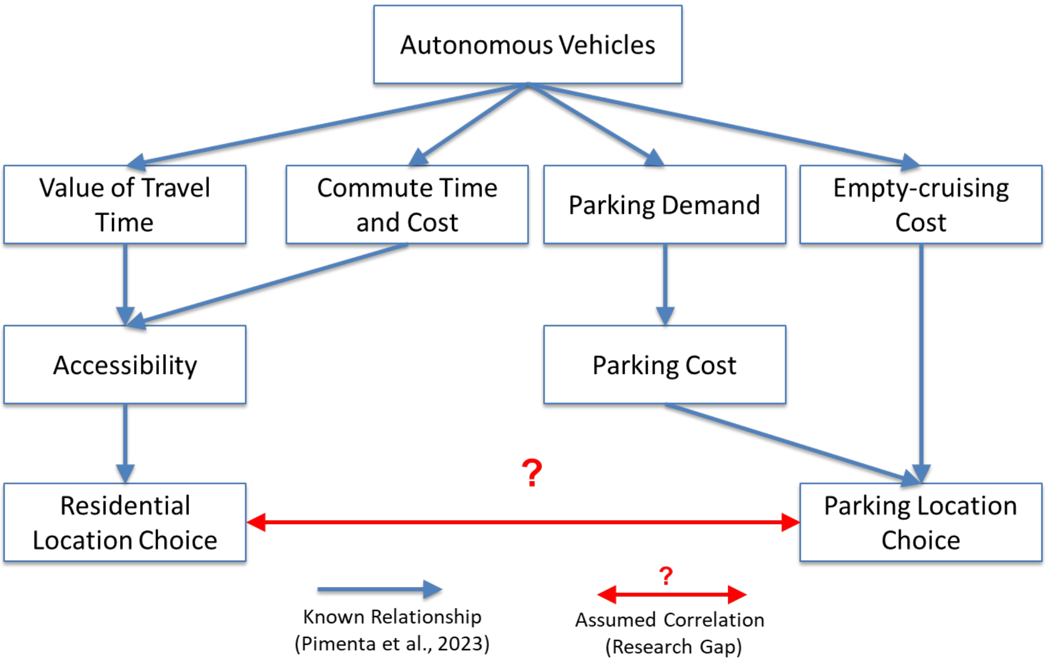
## 2.2. Search outcomes

The searches in both databases resulted in 23 potentially eligible studies. These were imported to Endnote, and 10 duplicates were removed, resulting in 13 unique records. The titles and abstracts of these studies were screened to check their relevance to the aims of this review based on the eligibility criteria. Four studies did not meet the eligibility criteria and were removed from the review after the screening of titles and abstracts (Bin-Nun and Binamira, 2020, Moeckel, 2017, Nielsen and Haustein, 2018, Riggs and Steiner, 2017). Nine studies from the database search were considered eligible for full-text reading. Furthermore, two additional studies were included based on the snowballing of the references listed (Gelauff et al., 2019, Meng et al., 2019). Then, a total of 11 studies formed the overall sample for this review, including 10 journal articles and one conference paper.

## 2.3. Analytical framework

An analytical framework (figure 1) is proposed to assess residential location choice models with AVs. The framework is organized based on the results of previous studies that investigated the mechanisms by which AVs may impact residential location choice. A recent review of 86 studies regarding AV long-term impacts on the built environment have shown that changes in accessibility primarily caused by variations of value of travel time, commute time and commute costs may significantly affect residential relocation (Pimenta et al., 2023). Furthermore, AV may affect residential location choice by changing parking demand and costs, and introducing empty-cruising costs. It is still unknown, however, if parking location choice may also be induced by residential relocation or if both choices are interdependent. In light of that, the analytical framework will be used to assess these hypotheses based on the modelling approaches adopted by the studies included in this review.

**Figure 1: Analytical framework for modelling of residential location choice with AVs**




# 3. Results

Table 1 lists the results of the literature review based on the analytical framework indicators. From the 11 reviewed studies, 10 use discrete choice models based on utility-maximization theory to estimate residential location choice. Moore et al. (2020), instead, use a generalised heterogeneous data model to assess the impacts of stochastic latent constructs, such as technology savviness and interest in the productive use of travel time on residential location choice. In addition, five studies modelled the housing supply separately from the housing demand. Basu and Ferreira (2020), Meng et al. (2019) and Moore et al. (2020) adopted hedonic price models to simulate a disaggregate bid-auction housing market using the SimMobility platform, whereas Gelauff et al. (2019) and Hiramatsu (2022) used spatial computable general equilibrium model to estimate housing supply.

Most studies considered accessibility as a mechanism for residential relocation. Four studies used agent-based activity-based accessibility measures (i.e., logsums), which allow disaggregate estimates of commute time, commute costs and values of time (Basu and Ferreira, 2020, Gelauff et al., 2019, Meng et al., 2019, Moore et al., 2020). On the other hand, Hasnat et al. (2023) and Llorca et al. (2022) used aggregated measures of accessibility.

The impacts of parking demand and costs on residential location choice were neglected by eight studies. Gelauff et al. (2019) considered the impacts of both parking demand and parking costs within their land price models. They added land prices at home and job location to the utility functions to account for parking costs and scarcity. They assumed that locations with scarcity of parking lots lead to higher land prices as well as higher parking costs. Likewise, Hiramatsu (2022) includes parking demand as a component of his housing supply model. He considers the replacement of parking lots by residential lots due to the adoption of SAVs. On the other hand, Llorca et al. (2022) included parking availability as a component of the utility functions. If the household demand for parking exceeds the dwelling parking supply, a parking penalty is applied to the utility function. However, none of the reviewed studies considered the effects of empty-cruising costs on residential location choice. Hasnat et al. (2023) added 10% increase in their travel demand model due to empty-trips, however, the empty-cruising costs were not separately considered.

**Table 1: Literature review results for the analytical framework indicators**

| Study | Residential Location Choice Model Approach | AV Type | Accessibility | Commute Cost/Time | Value of Time | Parking Demand | Parking Cost | Empty-Cruising | LUTI Model |
|---|---|---|---|---|---|---|---|---|---|
| (Basu and Ferreira, 2020) | Hedonic Price Model (supply) + Random Utility Model (demand). | Community-based SAV | Activity-based (logsums) | Both are considered in the utility function | Not specified | Not considered | Not considered | Not considered | Agent-based (SimMobility) |
| (Carrese et al., 2019) | Multinomial Logit for adoption of AVs and binary logit for residential relocation | PAV + SAV | Not considered | Not considered | Not specified | Not considered | Not considered | Not considered | None |
| (Gelauff et al., 2019) | Equilibrium Land Price Model (seller) + Nested logit for home location, job location and mode choice (demand). | PAV + SAV | Activity-based (logsums) | Both are considered in the utility function | -5% for high automation and -20% for full automation | Included in the land price model | Included in the land price model | Not considered | Spatial General Equilibrium (LUCA) |
| (Hasnat et al., 2023) | Mixed Multinomial Logit | PAV + CAV | Employment accessibility estimated using number of jobs and travel times | Both are estimated for each household | Not considered | Not considered | Not considered | 10% empty-cruising as additional travel demand | Aggregated Trip Based Travel Demand Model + Cluster Analysis |
| (Hiramatsu, 2022) | Cobb-Douglas Utility Functions for consumer and producer models | PAV + SAV | Not considered | Considers generalised costs as monetary + non-monetary costs | It changes based on a rate of in-vehicle leisure time | Obsolete parking area replaced by residential area | Included as parking lot fee at home location | Not considered | Spatial Computable General Equilibrium |

**Table 1: Continued.**

| Study | Residential Location Choice Model Approach | AV Type | Accessibility | Commute Cost/Time | Value of Time | Parking Demand | Parking Cost | Empty-Cruising | LUTI Model |
|---|---|---|---|---|---|---|---|---|---|
| (Krueger et al., 2019) | Mixed Multinomial Logit | PAV | Not considered | Both are collected in the SP survey | Estimated for different modes, and housing cost (owner vs renter) | Not considered | Not considered | Not considered | None |
| (Llorca et al., 2022) | Random Utility Choice Model | PAV | Gravity-based | Both are considered in the utility function | -40% | Parking availability is included in the utility function | Not considered | Not considered | Agent-based (SILO/MITO/MATSim) |
| (Meng et al., 2019) | Hedonic Price Model (supply) + Multinomial Logit Model (demand). | PAV + SAV | Activity-based (logsums) | Both are considered in the utility function | Not specified | Not considered | Not considered | Not considered | Agent-based (SimMobility) |
| (Moore et al., 2020) | Generalized Heterogeneous Data Model | PAV | Not considered | Not considered | It varies with the willingness-to-relocate from -68% to -30% | Not considered | Not considered | Not considered | None |
| (Zhang and Guhathakurta, 2021) | Multinomial Logit Model + MonteCarlo Simulation | SAV | Not considered | Both are estimated for each household | Not specified | Not considered | Not considered | Not considered | Agent-Based |
| (Zhou et al., 2021) | Hedonic Price Model (supply) + MNL (demand). | SAV | Activity-based (logsums) | Included in the utility function | Not specified | Not considered | Not considered | Not considered | Agent-based (SimMobility) |

# 4. Discussion and conclusion

The review findings show that the assumption of parking as a fixed cost is dominant in residential location choice modelling with AVs. The few studies that accounted for parking cost and demand variations still neglected empty-cruising costs. These assumptions may compromise the validity of modelling approaches with PAVs since empty-cruising costs may have double effect on the generalised travel costs. In other words, the vehicle may travel empty from drop-off to search for a parking spot, and back from the parking spot to pick-up. If the vehicle owner needs the vehicle to return to their home garage or their neighbourhood, there may be, therefore, interdependencies between empty-cruising costs and housing location choice that may not be disregarded.

In addition, some modelling approaches do not consider AV impacts on accessibility or fails to include disaggregate measures, such as activity-based accessibility (i.e., logsums). These disaggregate measures are critical for AVs because their impacts on the value of time may significantly vary for different socio-demographics and activity types. Furthermore, the studies that considered disaggregated accessibility measures used household travel survey data to calibrate their models. Three of the reviewed studies used stated-preference (SP) survey data to calibrate their RLC models (Carrese et al., 2019, Krueger et al., 2019, Moore et al., 2020). Choice experiments, such as SP surveys, may be more reliable tools than general travel survey data to calibrate value of time equations, disaggregate accessibility functions, and discrete choice models with AVs as existing general travel survey data do not include AVs as a mode choice. However, hypothetical biases are common in SP surveys, and their effects on transport studies may significantly compromise the validity of the results (Haghani et al., 2021, Hensher, 2010). Furthermore, the absence of empirical revealed preference data is an important challenge to assess the magnitude of hypothetical biases in choice experiments with AVs.

To sum up, the analytical framework has highlighted important limitations of existing residential location choice models with AVs. Future research should use this framework for more holistic residential location choice models with AVs including the combined effects of AV empty-cruising costs, parking costs and disaggregate accessibility measures on residential location choice. Some unanswered research questions include: How will the possibility of sending the vehicle back home after commute affect housing location choice? How will household size and composition affect the decision of sending an AV back home after commute? What are the trade-offs between WTP for empty-cruising costs and parking fees? How will empty-cruising and self-parking capabilities affect the need for residential parking attributes (e.g., home garage, residential building car-parks, and residential on-street parking bays), and, consequently, residential location choice? What are the hypothetical biases for stated housing location choice experiments with AVs?

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