URBAN MOBILITY & EQUITY CENTER

Final Report

User Preference Analysis for Mobility-as-a-Service (MaaS) and Its Impact

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16. Abstract

Mobility as a Service (MaaS) integrates diverse transportation modes into a unified platform to offer users personalized, convenient, flexible, and cost-effective trip options. It can address accessibility challenges, particularly for underserved population groups without cars or no driving capability, by providing them various (combinations of) alternative modes such as carpools, shared mobility—such as ridesharing (e.g., Uber and Lyft), bikes and scooters—and public transit. This research consists of two parts; 1) A Comparison of Mobility as a Service (MaaS) Alternatives for Access to Public Transportation Terminals and 2) User Preference for Micro Mobility: An Adaptive Choice-Based Conjoint Analysis Approach.

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ABSTRACT

Mobility as a Service (MaaS) integrates diverse transportation modes into a unified platform to offer users personalized, convenient, flexible, and cost-effective trip options. It can address accessibility challenges, particularly for underserved population groups without cars or no driving capability, by providing them various (combinations of) alternative modes such as carpools, shared mobility—such as ridesharing (e.g., Uber and Lyft), bikes and scooters—and public transit.

This research consists of two parts; 1) A Comparison of Mobility as a Service (MaaS) Alternatives for Access to Public Transportation Terminals and 2) User Preference for Micro Mobility: An Adaptive Choice-Based Conjoint Analysis Approach.

The first part of this research estimates mode shares for several transportation alternatives related to MaaS under various parametric assumptions. A logit model is used to analyze the resulting mode shares if these alternatives compete in providing access to a public transportation terminal, such as a rail transit station. Seven alternatives are considered: (1) Walking, (2) Bicycle, (3) Park & Ride, (4) Auto without parking fee, Conventional Bus with (5) walk access or (6) bicycle access, and (7) Flexible-Route Bus. Three cases in which only some of the seven alternatives compete are also considered. Total cost functions and impedance functions for each alternative are formulated and used to estimate mode shares. Those functions are used to explore the sensitivity of mode shares and impedances to various influencing factors.

The second part of this research conducted an online Adaptive Choice-Based Conjoint (ACBC) survey and estimated people's preferences towards and willingness to pay for various MaaS service bundles. Participants were asked to choose their most favored alternative from several different MaaS trip bundles, which consisted of five attributes (transportation modes, travel time, commuting time, walking distance and weather conditions) and different mode combinations such as driving, transit, bike/scooter, and a combination of transit and bike/scooter.

The study revealed that approximately 56% of the respondents preferred driving, while roughly 44% chose non-driving alternatives like transit, bike/scooter, or a combination of bike/scooter and transit. MaaS products that require no walking or less than a quarter-mile walking distance were preferred by 50% of the participants. Adding a driving option to MaaS products increases users' preferences by 6%. In the context of MaaS attributes, transportation modes were identified as the most crucial with the largest utility range. Moreover, the price attribute attained the highest average importance score, followed by travel time, while weather conditions received the lowest average importance level.

INTRODUCTION

Mobility as a Service (MaaS) integrates diverse transportation modes into a unified platform to offer users personalized, convenient, flexible, and cost-effective trip options. It can address accessibility challenges, particularly for underserved population groups without cars or no driving capability, by providing them various (combinations of) alternative modes such as carpools, shared mobility—such as ridesharing (e.g., Uber and Lyft), bikes and scooters—and public transit.

This research consists of two parts; 1) A Comparison of Mobility as a Service (MaaS) Alternatives for Access to Public Transportation Terminals and 2) User Preference for Micro Mobility: An Adaptive Choice-Based Conjoint Analysis Approach.

The first part of this research will estimate mode shares for several transportation alternatives related to MaaS under various parametric assumptions. A logit model will be used to analyze the resulting mode shares if these alternatives compete in providing access to a public transportation terminal, such as a rail transit station. Seven alternatives will be considered: (1) Walking, (2) Bicycle, (3) Park & Ride, (4) Auto without parking fee, Conventional Bus with (5) walk access or (6) bicycle access, and (7) Flexible-Route Bus. Three cases in which only some of the seven alternatives compete will be also considered. Total cost functions and impedance functions for each alternative will be formulated and used to estimate mode shares. Those functions will be used to explore the sensitivity of mode shares and impedances to various influencing factors.

The second part of this research will conduct an online Adaptive Choice-Based Conjoint (ACBC) survey and estimate people's preferences towards and willingness to pay for various MaaS service bundles. Participants will be asked to choose their most favored alternative from several different MaaS trip bundles, which consist of five attributes (transportation modes, travel time, commuting time, walking distance and weather conditions) and different mode combinations such as driving, transit, bike/scooter, and a combination of transit and bike/scooter.

This research can help to understand the advantages and difficulties of adopting MaaS.

I. A Comparison of Mobility as a Service (MaaS) Alternatives for Access to Public Transportation Terminals

I.1 INTRODUCTION

Many urban residents rely on private cars for commuting to work and other trip purposes. Consequently, those residents must often endure heavy traffic and delays. Moreover, people who drive conventional private cars are concerned about fuel prices, parking spaces, and car maintenance. Governments and their transportation agencies must also consider the resulting energy, environmental, and health issues.

Mobility as a Service (MaaS) is a recent and innovative transportation concept. Although MaaS is still subject to different definitions and interpretations, it generally seeks to integrate various transportation modes and services in order to provide users with a seamless travel experience from the users' perspective *(1).* MaaS is often proposed as a tool for achieving sustainable mobility and increasing the share of public transportation trips in cities.

Mobility as a Service (MaaS) enables the integration of multiple modes of transportation, such as public transit, bicycles, scooters, carpools, and rideshare services while encouraging travelers to reduce their use of private cars. An integrated MaaS platform can realize travel itinerary plans, automatic route planning, and seamless connection of different transportation alternatives. Thus, it may provide users with fast, economical, environment-friendly, and safe ways to reach their destinations.

This study aims to comparatively evaluate MaaS alternatives in urban and suburban environments, using the simplified geographic model illustrated in Figure 1. The effectiveness and mode shares of the seven alternatives are estimated in various circumstances. The following alternatives are considered:

1. Walking
2. Bicycle
3. Park & Ride
4. Auto without parking fee
5. Conventional (Fixed-route) Bus with only walk access
6. Flexible-Route Bus
7. Conventional (Fixed-route) Bus with only bicycle access

I.2 LITERATURE REVIEW

Many studies regarding MaaS have been conducted. In Bianchi, et al. *(2)*, travelers took advantage of the expanding mobility options in cities and used MaaS to integrate multiple mobility options. Among them, the mobility options provided by MaaS were deployed and used in different cities according to different perspectives (such as supply, demand, technology, business, and governance). Various studies have compared innovative ridesharing alternatives for enhancing mobility, such as carshare, bikeshare, transportation network companies, and microtransit *(3-6).*

Chang and Schonfeld *(7-8)*, and Kim and Schonfeld *(9-10)* integrated conventional (fixed-route) and flexible-route bus services by determining the preferable type of service in various regions and time periods, based on demand densities, speeds, unit costs, and other factors. They developed optimization models for determining when available resources should be switched from one service type to another. Guo et al. *(11)* extended such analyses to avoid overly frequent switches in service type due to small demand fluctuations.

To reduce the cost and time spent on rides for carpool passengers, Xiaoshen et al. *(12)* proposed that passengers could be asked to walk to and from nearby pick-up/drop-off points to avoid route redundancies for shared vehicles caused by deviations from door-to-door services. They also showed that short walks by passengers to meet shared vehicles effectively reduced the rejection rate for passengers requesting those trips, as well as the numbers of needed vehicles. Andres *(13)* used a heuristic algorithm to analyze the effects of having passengers walk to a specific origin or destination to avoid detours in shared vehicles. They demonstrated that if passengers walk to designated stops, total costs may be reduced by around one-fifth. They showed that the combination of walking and carpooling provided more convenience for passengers and improved their satisfaction level.

The choice of transportation mode depends on different factors. Yina *(14)* used a multinomial logit model based on random utility theory to analyze residents' preferences for three travel modes (private cars, public transportation, and non-motor vehicles) based on gender, age, the purpose of travel, and income. Among them, males and residents with high incomes were more likely to choose private cars. The analysis confirmed that convenient public transportation at travelers' origin and destination increased the likelihood of selecting public transportation.

In conclusion, using MaaS can provide higher efficiency, better service quality, and lower cost for passenger transportation systems in urban and suburban areas. Additionally, MaaS may revolutionize how everyone lives and works in the future. With MaaS people can avoid the congestion and maintenance requirements of private cars by using various forms of shared mobility. The United Nations *(15)* estimated in 2014 that 66% of people would live in urban areas by mid-century. As urban populations increase, MaaS can play a beneficial role in reducing traffic congestion, reducing pollution, and enhancing mobility.

I.3 METHODOLOGY

A simple geographic module that has been used to analyze transportation alternatives in previous studies such as Chang & Schonfeld *(7-8)*, Kim & Schonfeld *(9-10)* Kim et al. *(16)* and Liu & Schonfeld *(17)* is used here to formulate, compare, and evaluate various mode alternatives consistently. Its spatial configuration is shown in Figures 1a and 1b. It consists of a major terminal, represented as a point, connected by a line haul road to a rectangular residential region in which movements are rectilinear. In this case, the movements are restricted to vertical and horizontal coordinates. This basic module can be combined with others to cover larger urban areas and represent more complex transportation systems (*9*).

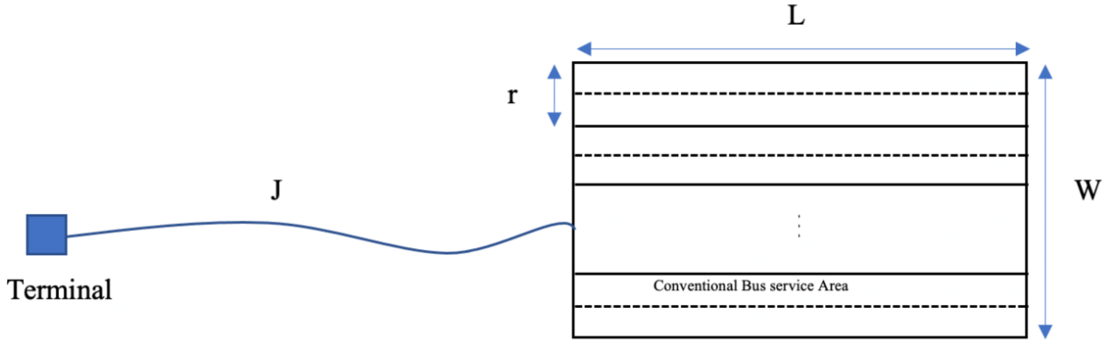


Figure 1a Conventional Bus service.

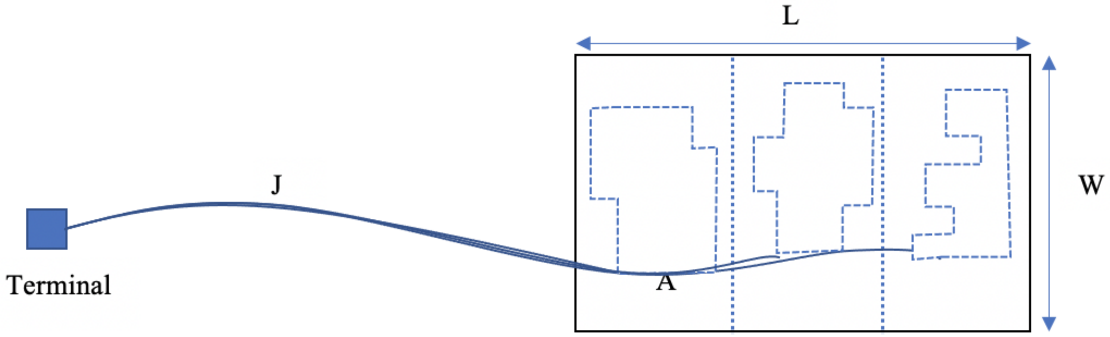


Figure 1b Flexible-Route Bus Service.

The variables used in the analysis, as well as their units and any applicable baseline values, are shown in Table 1.

Table 1. Notation and baseline values

Variable	Definition and units	Baseline values
A	Zone area $= \frac{LW}{N_{zones}}$	-
B	Bus operator cost ($/veh hr)	75.0
c	Out-of-pocket cost ($/h)	-
C_o	Operating cost; for conventional service ($/h)	-
C_{total}	Total cost ($/h)	-

C_u	User cost; for conventional service (\$/h)	-
C_v	In-vehicle cost; for conventional service (\$/h)	-
C_w	Waiting cost; for conventional service (\$/h)	-
C_x	Access cost; for conventional service (\$/h)	-
e	$\ln^{-1}1 = 2.718282$	2.718282
h	Headway (hrs/veh)	-
J	Line-haul distance (miles)	4.0
L	Region length (miles)	4.0
L_{max}	Maximum bus load factor	1.2
M_n	Mode share for alternative n	-
N_{zone}	Number of zones	3
p	Impedance (\$/one way trip)	-
P_n	Probability of choosing alternative n	-
P_p	Parking fee for bicycle and car (\$/one way trip)	1.0 for bicycle and 10.0 for car
q	One-way demand in each direction (passengers/sq. mile*hour)	300
r	Route spacing for bus (miles)	1.0
$r_{bicycle}$	Bicycle rental price (\$/bicycle hr)	5.0
R_b	Bus round trip time (hr)	-
S	Station spacing (miles)	0.2
S_c	Vehicle capacity (seats/vehicle)	50 for Conventional bus and 25 for Flexible-route bus
t	Travel time (hr/trip)	-
t_b	Trip time by bus (hr)	-
t_s	Bus stopping time (hr)	0.01
T	Trips generated or demand density (passengers/sq. mile)	600
u	Utility (\$/one way trip)	-
v	Value of in-vehicle time (\$/passenger hr)	12.0
v_w	Value of waiting time (\$/passenger hr)	24.0
V	Bus speed in local service region (mi/hr)	20.0
$V_{bicycle}$	Bicycle speed (mi/hr)	12.0
V_{car}	Car speed in local service region (mi/hr)	25.0
V_{carf}	Car speed in line-haul (mi/hr)	45.0
V_f	Bus speed in line-haul (mi/hr)	40.0
V_{walk}	Walk speed (mi/hr)	2.5
W	Region width (miles)	3.0
α	Coefficient for trip price	1
β	Coefficient for travel time	12
θ	Coefficient for impedance function	0.2

I.3.1 ASSUMPTIONS

The following assumptions are made for the seven alternatives:

1. There are no operation costs associated with bicycle and walking access at a trip end.
2. The average waiting time on public transportation routes is approximated as half the headway h.
3. The demand is uniformly distributed over time and space in each region.
4. One person can only ride one bicycle.
5. The movements in the service region are rectilinear.
6. The service region is divided into N parallel zones of width r. The local route branches from the main route section and runs along the middle of each zone. The route spacing is $r = \frac{W}{N}$.
7. The rectangular service region with length L and width W is J miles away from the transportation terminal.
8. The headway is optimized according to the demand for trips as well as the capacity of buses on the road.
9. The origins and destinations are "fairly uniformly" distributed over time and over the service region.

I.3.2 MODE CHOICE MODEL

A logit model is used to estimate the probabilities that users would choose any one of the various competing MaaS alternatives. It is formulated as a function of the utilities (i.e., negative impedances) of the competing alternatives.

The following general impedance function is applicable to all alternatives. Out-of-pocket cost (including operating cost and trip price) and travel time are the two most important factors in the impedance function considered here.

$$p = -u = \alpha c_{out-of-pocket\ cost} + \beta t_{travel\ time} \tag{1}$$

Here, the out-of-pocket cost includes prices such as tolls, fares, and parking fees as well as the cost of operating one's own vehicle. A basic logit model is used to estimate the share of each alternative. Its general formula is:

$$P_n = \frac{e^{\theta u_n}}{\sum_m e^{\theta u_n}} \tag{2}$$

The following baseline values will be used in subsequent mode share calculations and then subjected to sensitivity analyses. The coefficient α for the trip price is 1, and the coefficient β for the travel time is the value of time. The utility coefficient (θ) is 0.2. The utility is the impedance multiplied by -1. e is $\ln^{-1}1 = 2.718282$.

There are a total of seven alternatives, each specified by an index n. Competitions among fewer than these seven alternatives are analyzed separately.

$$P_n = \frac{e^{\theta u_n}}{\sum_m e^{\theta u_n}} \qquad n = 1, \dots, 7 \tag{3}$$

n=1: Walking,
n=2: Bicycle,
n=3: Park & Ride,
n=4: Auto without parking fee,
n=5: Conventional Fixed-route Bus with only walk access,
n=6: Flexible-Route Bus
n=7: Conventional Bus with only bicycle access

I.3.3 IMPEDANCE FUNCTION

1. Walking

There are no operator costs, stopping time, and waiting time for walking. Average travel time per trip is the sum of the line-haul distance divided by the walking speed and the region length divided by two times the walking speed plus the region width divided by four times the walking speed. The travel time for walking is formulated in Eq. 4:

$$T_{travel\ time} = \frac{J}{V_{walk}} + \left(\frac{L}{2V_{walk}} + \frac{W}{4V_{walk}}\right) \tag{4}$$

Trip cost is the value of time multiplied by the travel time. Walking requires no cost or price. Its cost function is formulated as:

$$C_{total}\ (for\ one\ way\ trip) = v \times \left(\frac{J}{V_{walk}} + \left(\frac{L}{2V_{walk}} + \frac{W}{4V_{walk}}\right)\right) \tag{5}$$

The impedance function for all alternatives and the mode share function for walking are formulated in Eqs. 6 and 7, respectively.

$$p = -u = \alpha c_{out-of-pocket\ cost} + \beta t_{travel\ time} \tag{6}$$

$$P_1 = \frac{e^{\theta u_1}}{\sum_i e^{\theta u_i}} \qquad \text{(i= } 1, \dots, 7) \tag{7}$$

2. Bicycle

There are no operator costs, stopping time, or waiting time for bicycling. The calculation method for travel time with Bicycle is the same as for the Walking mode choice, but with a different travel speed. The travel time for Bicycle is:

$$T_{travel\ time} = \frac{J}{V_{bicycle}} + \left(\frac{L}{2V_{bicycle}} + \frac{W}{4V_{bicycle}}\right) \tag{8}$$

The parking price and rental price of bicycles are considered here. The out-of-pocket trip cost is the travel time multiplied by the value of time plus the bicycle rental price:

$$C_{total}\ (for\ one\ way\ trip) = (v + r_{bicycle}) \times \left(\frac{J}{V_{bicycle}} + \left(\frac{L}{2V_{bicycle}} + \frac{W}{4V_{bicycle}}\right)\right) \quad (9)$$

The mode share function for Bicycle is formulated in Eq.10.

$$P_2 = \frac{e^{\theta u_2}}{\sum_i e^{\theta u_i}} \qquad \text{(i= 1, ... ,7)} \qquad (10)$$

3. Park & Ride

There are operator costs C_o and the parking price for the car. Two car speeds should be considered here, a faster one for the line-haul distance and a lower speed within the service region.

$$T_{travel\ time} = \frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right) \qquad (11)$$

The trip cost with Park & Ride is the value of time multiplied by travel time plus the operator cost for the car.

$$C_{total}(for\ one\ way\ trip) = v \times \left(\frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right)\right) + (0.5 * \left(J + \frac{L}{2} + \frac{W}{4}\right)) \quad (12)$$

The mode share function for Park & Ride is formulated in Eq.13.

$$P_3 = \frac{e^{\theta u_3}}{\sum_i e^{\theta u_i}} \qquad \text{(i= 1, ... ,7)} \qquad (13)$$

4. Auto without parking fee

There is no parking fee for this alternative. Its travel time is computed similarly to that for Park & Ride.

$$T_{travel\ time} = \frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right) \qquad (14)$$

The trip cost for Auto without a parking fee is formulated as:

$$C_{total}(for\ one\ way\ trip) = v \times \left(\frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right)\right) + \left(0.5 * \left(J + \frac{L}{2} + \frac{W}{4}\right)\right)$$

(15)

The mode share function for Auto without parking fee are formulated as:

$$P_4 = \frac{e^{\theta u_4}}{\sum_i e^{\theta u_i}} \qquad (i = 1, \ldots, 7) \tag{16}$$

5. Conventional bus with only walk access

Waiting time and parking time need to be considered here. Passengers only consider taking the bus to a bus stop near home and then using the walk to access home. The travel time for Conventional bus is formulated as:

$$T_{travel\ time_{walk}} = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s + \left(\frac{S}{4V_{walk}} + \frac{r}{4V_{walk}}\right) \tag{17}$$

The average travel time by bus t_b per passenger trip is:

$$t_b = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s \tag{18}$$

To compute the average round-trip time R_b of Conventional bus, a bus is assumed to travel from the terminal station to the service region at an express speed for a distance *J*, and the central axis of the region along the assigned route of length L. The Conventional bus stops to pick up passengers every *S* miles. The stopping time at each stop is t_s.

$$R_b = 2 \times \left(\frac{J}{V_f} + \frac{L}{V} + \frac{L}{S} \times t_s\right) \tag{19}$$

The hourly in-vehicle cost for the Conventional bus service is formulated as:

$$C_v = TLWvt_b \tag{20}$$

The average waiting time at bus stops is assumed to be half the headway. The hourly user waiting cost for Conventional bus is formulated as:

$$C_w = \frac{h}{2} \times v_w \times LWT \tag{21}$$

The average visit distance of the nearest route is assumed to be a quarter of the route distance r. The access distance to the nearest bus stop along the route is one-fourth of the bus stop spacing *s*. Here is the hourly access cost C_x for Conventional bus with walk access.

$$C_x = \left(\frac{S}{4V_{walk}} + \frac{r}{4V_{walk}}\right) \times LWTv \tag{22}$$

Total cost per one-way trip for Conventional bus is formulated as:

$$C_{total}(for\ one\ way\ trip) = \frac{\frac{R_b \times B}{h} \times \frac{W}{r} + TLWvt_b + \frac{h}{2} \times v_w \times LWT + \left(\frac{S}{4V_{walk}} + \frac{r}{4V_{walk}}\right) \times LWTv}{TWL} \tag{23}$$

The mode share function for Conventional bus is formulated as:

$$P_5 = \frac{e^{\theta u_5}}{\sum_i e^{\theta u_i}} \qquad (i = 1, \dots, 7) \tag{24}$$

6. Flexible-route bus

The number of equal size zones is N_{zones}. Each zone has an area $A = \frac{LW}{N_{zone}}$ in which the number of pick-ups per zone is $n = T \times \frac{LW}{N} \times h$. The travel time per person is the round-trip time per zone divided by 2.

$$T_{travel\ time} = \frac{2 \times \left(\frac{J}{V_f} + \frac{L}{2V}\right) + \frac{k\sqrt{nA}}{V}}{2} \tag{25}$$

The round-trip time per zone R_b is formulated as:

$$R_b = 2 \times \left(\frac{J}{V_f} + \frac{L}{2V}\right) + \frac{k\sqrt{nA}}{V} \tag{26}$$

Total cost per one-way trip for Flexible-route bus is formulated as:

$$C_{total}(for\ one\ way\ trip) = \frac{\frac{R_b}{h} \times B \times \frac{LW}{A} + TLWv\frac{R_b}{2} + \frac{h}{2} \times v_w \times LWT}{TWL} \tag{27}$$

The mode share function for Flexible-route bus is formulated in Eq. 28.

$$P_6 = \frac{e^{\theta u_6}}{\sum_i e^{\theta u_i}} \qquad (i = 1, \dots, 7) \tag{28}$$

7. Conventional bus with bicycle access

Passengers consider using the bicycle between a major terminal and a bus stop near them to home. In this case, waiting time and parking time must be considered.

$$T_{travel\ time_{bicycle}} = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s + \left(\frac{S}{4V_{bicycle}} + \frac{r}{4V_{bicycle}}\right) \tag{29}$$

The average travel time by bus t_b per passenger trip is:

$$t_b = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s \tag{30}$$

The average round-trip time R_b of Conventional bus is:

$$R_b = 2 \times \left(\frac{J}{V_f} + \frac{L}{V} + \frac{L}{S} \times t_s\right) \tag{31}$$

The hourly in-vehicle cost for Conventional bus service is:

$$C_v = TLWvt_b \qquad (32)$$

The hourly user waiting cost for Conventional bus is:

$$C_w = \frac{h}{2} \times v_w \times LWT \qquad (33)$$

The hourly access cost C_x for Conventional bus with bicycle access is:

$$C_x = \left(\frac{S}{4V_{bicycle}} + \frac{r}{4V_{bicycle}}\right) \times LWT \times (v + r_{bicycle}) \qquad (34)$$

Total cost per one-way trip for Conventional bus with bicycle access is formulated as:

$$C_{total}(for\ one\ way\ trip) = \frac{\frac{R_b \times B}{h} \times \frac{W}{r} + TLWvt_b + \frac{h}{2} \times v_w \times LWT + \left(\frac{S}{4V_{bicycle}} + \frac{r}{4V_{bicycle}}\right) \times (v + r_{bicycle}) \times LWT}{TWL} \qquad (35)$$

The mode share function for Conventional bus with bicycle access is formulated as:

$$P_7 = \frac{e^{\theta u_7}}{\sum_i e^{\theta u_i}} \qquad (i= 1, \ldots ,7) \qquad (36)$$

8. Competition of Auto without parking fee (Alternative 4) and Flexible-route bus (Alternative 6)

The travel time for Auto without parking fee is formulated in Eq. 37.

$$T_{travel\ time} = \frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right) \qquad (37)$$

The travel time for Flexible-route bus is formulated as:

$$T_{travel\ time} = \frac{2 \times \left(\frac{J}{V_f} + \frac{L}{2V}\right) + \frac{k\sqrt{nA}}{V}}{2} \qquad (38)$$

The trip cost for Auto without parking fee is:

$$C_{total}(for\ one\ way\ trip) = v \times \left(\frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right)\right) + \left(0.5 * \left(J + \frac{L}{2} + \frac{W}{4}\right)\right)$$

(39)

The mode share is formulated in Eq. 40.

$$M_4 = \frac{e^{\theta u_4}}{e^{\theta u}{}_{4+}e^{\theta u_6}} \tag{40}$$

The mode share for Flexible-route bus is:

$$M_6 = \frac{e^{\theta u_6}}{e^{\theta u}{}_{4+}e^{\theta u_6}} \tag{41}$$

9. Competition of Conventional fixed-route bus with walk access or bicycle access (Alternative 5& Alternative 7)

The travel time for Conventional fixed-route bus with walk access is:

$$T_{travel\ time_{walk}} = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s + \left(\frac{S}{4V_{walk}} + \frac{r}{4V_{walk}}\right) \tag{42}$$

The travel time for Conventional fixed-route bus with bicycle access is:

$$T_{travel\ time_{bicycle}} = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s + \left(\frac{S}{4V_{bicycle}} + \frac{r}{4V_{bicycle}}\right) \tag{43}$$

The trip cost for Conventional fixed-route bus with walk access is:

$$C_{total}(for\ one\ way\ trip) = \frac{\frac{R_b \times B}{h} \times \frac{W}{r} + TLWvt_b + \frac{h}{2} \times v_w \times LWT + \left(\frac{S}{4V_{walk}} + \frac{r}{4V_{walk}}\right) \times LWTv}{TWL}$$

(44)

The trip cost for Conventional fixed-route bus with bicycle access is:

$$C_{total}(for\ one\ way\ trip) = \frac{\frac{R_b \times B}{h} \times \frac{W}{r} + TLWvt_b + \frac{h}{2} \times v_w \times LWT + \left(\frac{S}{4V_{bicycle}} + \frac{r}{4V_{bicycle}}\right) \times (v + r_{bicycle}) \times LWT}{TWL} \tag{45}$$

The mode share for Conventional fixed-route bus with walk access is:

$$M_5 = \frac{e^{\theta u_5}}{e^{\theta u}{}_{5+}e^{\theta u_7}} \tag{46}$$

The mode share for Conventional fixed-route bus with bicycle access is:

$$M_7 = \frac{e^{\theta u_7}}{e^{\theta u}{}_{5+}e^{\theta u_7}} \tag{47}$$

10. Competition of Auto without parking fee (Alternative 4), Flexible-route bus (Alternative 6), and Conventional fixed-route bus with bicycle access (Alternative 7)

The travel time for Auto without parking fee is:

$$T_{travel\ time} = \frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right) \tag{48}$$

The travel time for Flexible-route bus is:

$$T_{travel\ time} = \frac{2\times\left(\frac{J}{V_f}+\frac{L}{2V}\right)+\frac{k\sqrt{nA}}{V}}{2} \tag{49}$$

The travel time for Conventional fixed-route bus with bicycle access is:

$$T_{travel\ time_{bicycle}} = \frac{J}{V_f} + \left(\frac{L}{2V} + \frac{W}{2V}\right) + \frac{L}{2S} \times t_s + \left(\frac{S}{4V_{bicycle}} + \frac{r}{4V_{bicycle}}\right) \tag{50}$$

The trip cost for Auto without parking fee is formulated as:

$$C_{total}(for\ one\ way\ trip) = v \times \left(\frac{J}{V_{carf}} + \left(\frac{L}{2V_{car}} + \frac{W}{4V_{car}}\right)\right) + (0.5 * \left(J + \frac{L}{2} + \frac{W}{4}\right)) \tag{51}$$

The trip cost for Conventional fixed-route bus with bicycle access is:

$$C_{total}(for\ one\ way\ trip) = \frac{\frac{R_b\times B}{h}\times\frac{W}{r}+TLWvt_b+\frac{h}{2}\times v_w\times LWT+\left(\frac{S}{4V_{bicycle}}+\frac{r}{4V_{bicycle}}\right)\times(v+r_{bicycle})\times LWT}{TWL} \tag{52}$$

The mode share for Auto without parking fee is:

$$M_4 = \frac{e^{\theta u_4}}{e^{\theta u_4}+e^{\theta u_6}+e^{\theta u_7}} \tag{53}$$

The mode share for Flexible-route bus is:

$$M_6 = \frac{e^{\theta u_6}}{e^{\theta u_4}+e^{\theta u_6}+e^{\theta u_7}} \tag{54}$$

The mode share for Conventional fixed-route bus with only bicycle access is formulated in Eq. 55.

$$M_7 = \frac{e^{\theta u_7}}{e^{\theta u_4}+e^{\theta u_6}+e^{\theta u_7}} \tag{55}$$

I.4 RESULTS

Table 2 presents the results obtained with baseline values (shown in Table 1) for seven competing alternatives in terms of trip cost, travel time, impedance, and mode share. For the same service region size, it can be seen that Walking has the highest trip cost and travel time, making it the least favored option. The mode share for Flexible-route bus exceeds that for Walking by 28.93%. For the baseline values used here Flexible-route bus has the lowest trip cost and, hence, the highest mode share.

Table 2. Travel time, costs and mode shares for seven MaaS alternatives

Result							
	Walking	Bicycle	Park & Ride	Auto without parking fee	Conventional bus with walk access	Flexible-route bus	Conventional bus with bicycle access
Trip cost ($/one-way trip)	32.4000	9.5625	5.7617	5.7617	7.8886	4.9299	6.8736
Travel time (hours)	2.7000	0.5625	0.1989	0.1989	0.4950	0.3000	0.4000
$p\ (Impedance)$ ($/one-way trip)	32.4000	7.7500	15.7617	5.7617	5.9400	3.6000	5.8000
$P_n\ (mode\ share)$	0.09%	12.65%	2.55%	18.83%	18.17%	29.02%	18.69%

Tables 3, 4 and 5 show more limited combinations of alternatives, in which fewer than seven alternatives compete in the same space. Thus, in Table 3 Auto without parking fee competes with Flexible-route bus. Here, the Flexible-route bus has the lower impedance and, hence the higher mode share. In Table 4, when Conventional bus with bicycle access is added to the two alternatives in Table 3, it captures a share of about 28%, but Flexible-route bus remains the most favored alternative.

Table 3. Travel time, costs, and mode shares for two competing alternatives: Auto without parking fee and Flexible-route bus

	Auto without parking fee	Flexible-route bus
Trip cost ($/one-way trip)	5.7617	4.9299
Travel time (hours)	0.1989	0.3000
$p\ (Impedance)$ ($/one-way trip)	5.7617	3.6000
$M_n\ (mode\ share)$	39.36%	60.64%

Table 4. Travel time, costs, and mode shares for three competing alternatives

	Auto without parking fee	Flexible-route bus	Conventional bus with bicycle access
Trip cost ($/one-way trip)	5.7617	4.9299	6.8736
Travel time (hours)	0.1989	0.3000	0.4000
$p\ (Impedance)$ ($/one-way trip)	5.7617	3.6000	5.8000
$M_n\ (mode\ share)$	28.30%	43.61%	28.09%

In Table 5, the competing alternatives for accessing Conventional bus are Bicycle and Walk. It should be noted that the impedance functions for Walk and Bicycle access do not sufficiently reflect the different physical difficulties and risks of using these two access alternatives.

Table 5. Travel time, costs, and mode shares for two competing access modes to Conventional bus

	Conventional bus with walk access	Conventional bus with bicycle access
Trip cost ($/one-way trip)	7.8886	6.8736
Travel time (hours)	0.4950	0.4000
$p\ (Impedance)$ ($/one-way trip)	5.9400	5.8000
$M_n\ (mode\ share)$	49.30%	50.70%

I.5 SENSITIVITY ANALYSIS

The effects of some influential variables on mode shares are explored through sensitivity analyses around the baseline values and illustrated in the following figures.

Figure 2 shows the effects of increases in the service region length, while the other dimension stays unchanged. Hence the region size and total trips increase proportionally with the region length.

In Figure 2, as the length of the service region increases from 3 to 10 miles, the mode shares for Auto without parking fee, Bicycle, and Park&ride increase linearly (Figure 2). Among them, the mode shares of Bicycle and Conventional fixed-route bus with only walk or bicycle access gradually converge. The mode shares of Flexible-route bus, and Conventional fixed-route bus with only walk/bicycle access decrease linearly. Flexible-route bus has the highest mode share at all region length values considered here. A threshold (i.e., crossover point) between P_n (Conventional fixed-route bus with only bicycle access) and P_n (Auto without parking fee) occurs when the region length L is approximately 3.65 miles. Beyond that threshold, the share of Auto without parking fee exceeds that of Conventional fixed-route bus with bicycle access.

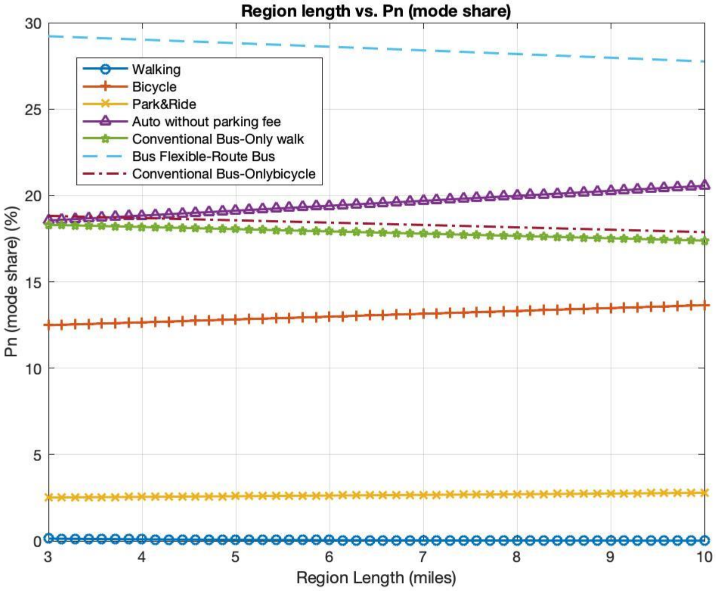


Figure 2 Mode share P_n vs. region length

In Figure 3, as the line-haul distance increases from 2 to 10 miles, the share for Flexible-route bus is the largest and grows with line-haul distance, while the shares of Conventional fixed-route bus with only Walk or Bicycle access increase relatively slowly. A threshold (i.e., crossover point) between P_n (Conventional fixed-route bus with bicycle access) and P_n (Auto without parking fee) occurs when the line-haul distance J is approximately 4.08 miles. Another threshold between P_n (Conventional fixed-route bus with walk access) and P_n (Auto without parking fee) occurs when the line-haul distance J is approximately 4.38 miles. As the line haul distance increases beyond 4.38 miles, the shares of Conventional bus with either Walk or Bicycle access exceed the share of Auto.

In Figure 4, unlike in Figure 2, the region area and thus the total trips stay constant as the region length increase. As the region length increases from 3 to 10 miles, the mode shares of Bicycle and Conventional fixed-route bus with walk or bicycle access gradually converge. A threshold (i.e., crossover point) between P_n (Conventional fixed-route bus with only bicycle access) and P_n (Auto without parking fee) occurs when the region length L is 3.37 miles. The mode share for Flexible-route bus is still the largest and grows with region length.

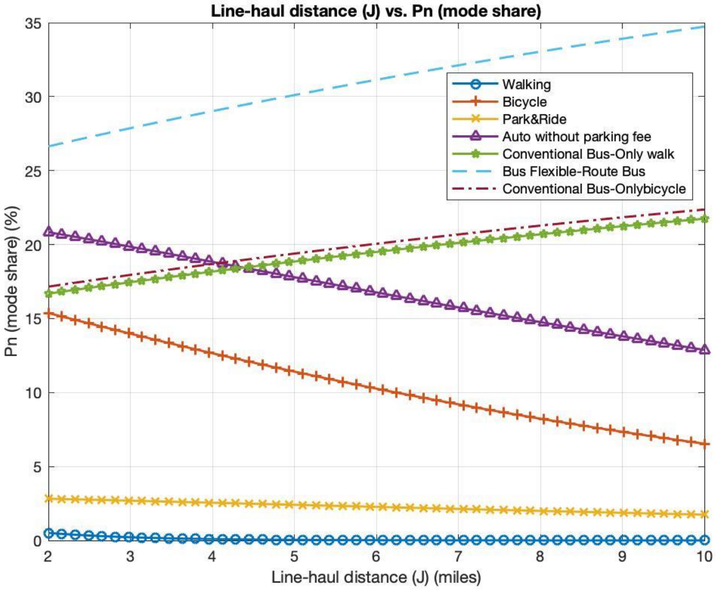


Figure 3 Mode share P_n vs. line-haul distance J

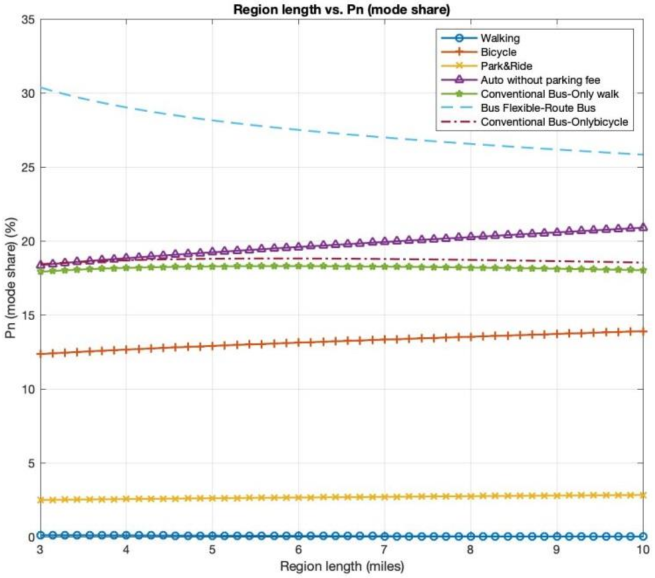


Figure 4 Mode share P_n vs. region length for constant region area

In Figure 5, as the value of time increases from 8 to 16 \$/passenger hr, the share for Flexible-route bus is the largest and grows roughly linearly. The shares for Conventional fixed-route bus with only walk or bicycle access and Bicycle decrease as the value of time increases. Beyond value of time (v) of about 10.5\$/passenger hour, the share of bicycle access to Conventional bus exceeds that of walk access to Conventional bus because a faster mode is favored by a higher value of time. The share of Auto without parking fee starts to exceed that of Conventional fixed-route bus with only walk access when value of time (v) exceeds approximately11.4\$/passenger hr. Beyond a value of time (v) of about 11.8$/passenger hour, the share of Auto without parking fee exceeds that of Conventional fixed-route bus with bicycle access.

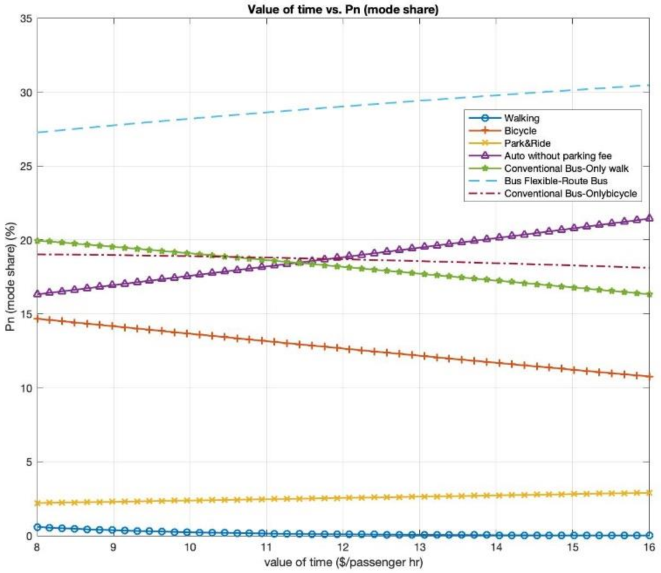


Figure 5 Mode share P_n vs. value of time v

In Figure 6, as the bicycle speed increases from 9 to 16 miles/hr, the shares of Auto without parking fee, Flexible-route bus, Conventional fixed-route bus with walk or bicycle access, and Park&ride gradually decrease. The share of Bicycles grows rapidly as the bicycle speed increases. A threshold between P_n (Conventional fixed-route bus with bicycle access) and P_n (Auto without parking fee) occurs when the bicycle speed $V_{bicycle}$ is 13.75 miles/hr. Beyond that threshold, the share of Conventional fixed-route bus with bicycle access exceeds Auto without parking fee, since the travel time for bicycle access to Conventional fixed-route bus decreases.

Figure 7 shows how the coefficient α, which determines the relative importance of trip price in the utility function, affects the relative mode shares. As α increases, the shares of Flexible-route bus and Conventional fixed-route buses with walking access gradually increase. Among them, the mode share of Park&ride approaches zero as the coefficient α for the trip price increases. Flexible-route bus mode has the highest share throughout the range of α values.

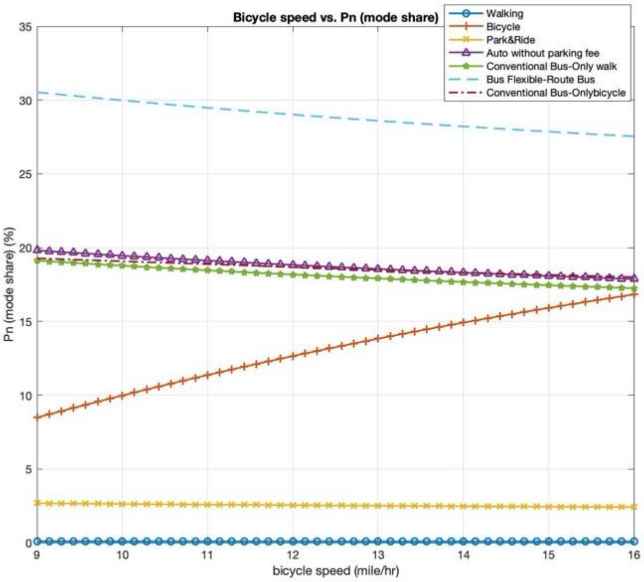


Figure 6 Mode share P_n vs. bicycle speed $V_{bicycle}$

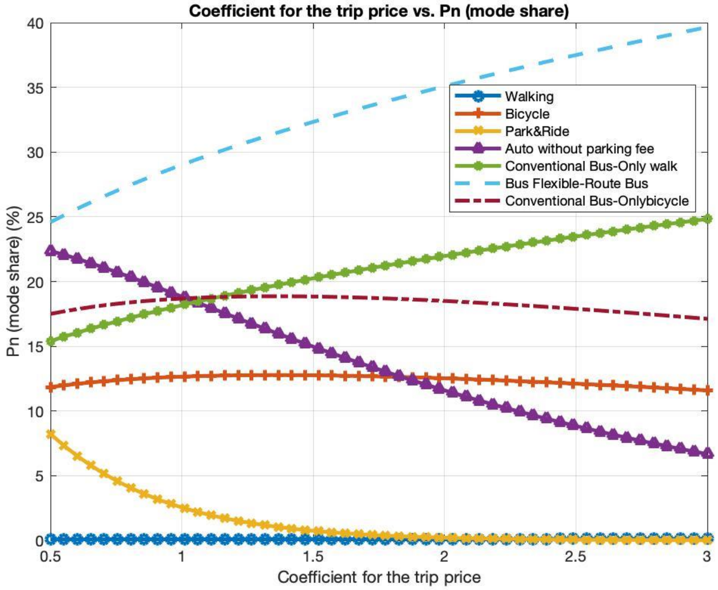


Figure 7 Mode share P_n vs. coefficient α for the trip price

In Figure 8 coefficient $\boldsymbol{\alpha}$, which indicates the value of travel time, varies from 6 to 18. The mode shares of Flexible-route bus, Auto without parking fees, and Park & ride increase gradually as β increases. Flexible-route bus mode still has the highest mode share.

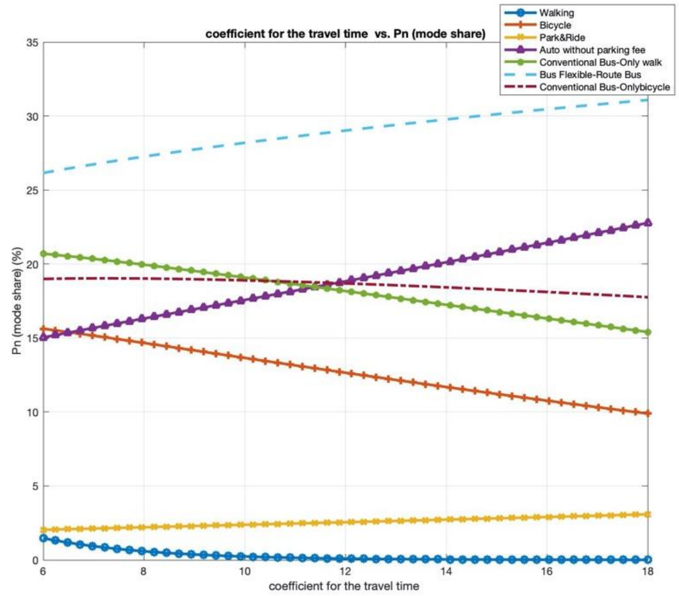


Figure 8 Mode share P_n vs. coefficient β for travel time

In Figure 9, as the coefficient θ, which affects the sensitivity of mode choices to utility differences, increases from 0.1 to 0.6, the share of Flexible-route bus increases fairly linearly, while the shares of Walking and Park & ride approach 0.

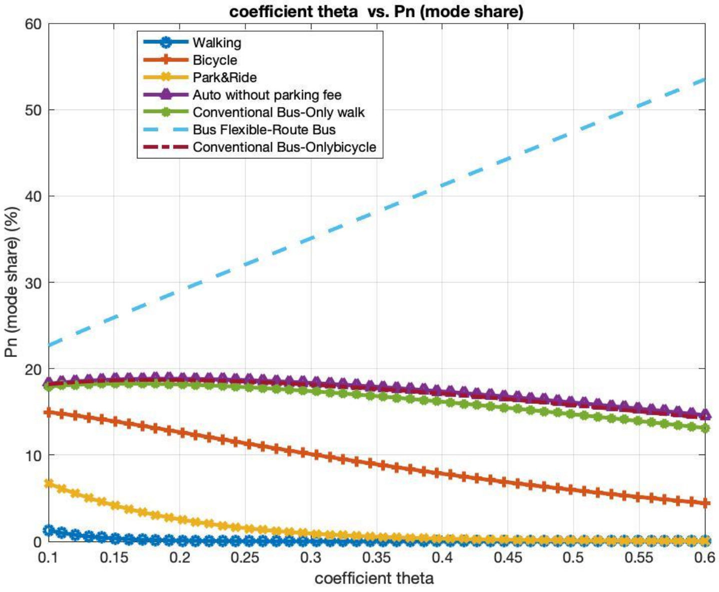


Figure 9 Mode share P_n vs. utility coefficient θ

In Figure 10, the line-haul distance increases from 2 to 10 miles. As the line distance increases, the impedance p of all alternatives increases gradually. Among them, the impedance p of Walking has the fastest growth rate, which also indicates that Walking is the least popular alternative. However, the Flexible-route bus has the highest share, since the impedance p of the Flexible-route bus is the smallest and increases slowly.

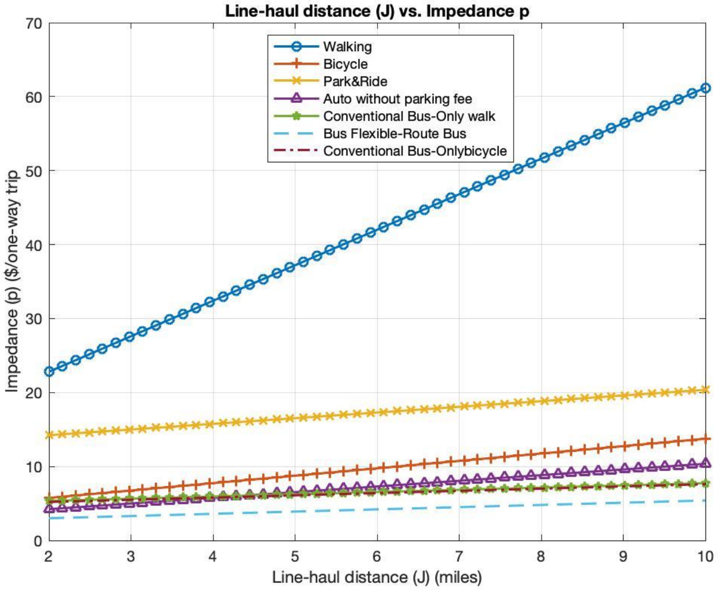


Figure 10 Impedance *p* vs. line-haul distance *J*

In Figure 11, as the value of time increases from 8 to 16 $/passenger hr, the impedance *p* of Walking is the largest and grows linearly. As in Figure 5, a higher value of time favors a faster mode. Thus, when the value of time *v* exceeds 10.5$/passenger hr, the impedance of Conventional bus with walk access exceeds that of Conventional bus with bicycle access.

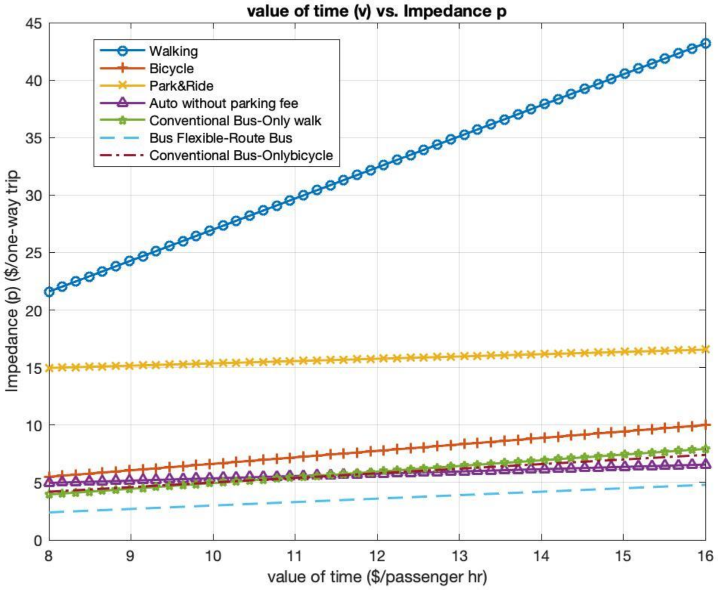


Figure 11 Impedance *p* vs. value of time *v*

I.6 CONCLUSIONS

A model has been formulated to analyze mobility alternatives. Seven alternatives with different access modes were considered, namely Walking, Bicycle, Park & Ride, Auto without parking fee, Conventional bus with only walk access or only bicycle access, and Flexible-Route Bus, as well as three cases in which only some of the seven alternatives compete for users. A basic logit model was used to estimate probabilities that users would choose certain competing alternatives. Hence, the shares of various alternatives reflected the probabilities of those choices. Sensitivity analyses were conducted to evaluate the influence of several variables on impedances and mode shares. The results especially show how line-haul distances and the users' values of time significantly affect mode shares. The results also show that for baseline values as well as considerable variations around them, Flexible-Route Bus had the highest mode share due to its low cost per trip. It was usually followed by Auto without parking fee and Conventional fixed-route bus with either walk or bicycle access. These results suggest that, in the absence of severe traffic congestion affecting autos, additional incentives for use of other modes or additional disincentives for the use of autos (such as tolls and parking fees) would be needed to shift users away from autos.

Although these trends in the shares of various alternatives seem unsurprising, the model presented here enables planners to quantify those trends and estimate the relative effects of various policies by varying the relevant input parameters.

The method and results presented in this paper may contribute to the integration of multiple transportation modes and services in order to provide travelers with fast, economical, and safe ways to reach their destinations without relying on private cars. They may help travelers in choosing the appropriate transportation alternatives based on their own situations and preferences. They may also help governments address the environmental, energy and health problems caused by traffic congestion and excessive use of private cars.

II. User Preference for Micro Mobility: An Adaptive Choice-Based Conjoint Analysis Approach

II.1 INTRODUCTION

Mobility as a Service (MaaS) aims to provide an integrated transportation experience by combining various modes of transportation into a single platform. MaaS offers users convenient, flexible, and cost-effective mobility options using technology such as digital platforms, real-time data collection, route optimization algorithms, integration of services, and payment systems (18). An integrated MaaS platform can be easily accessed via the Internet or smartphones, which allows users to plan, book, and pay for their preferred MaaS service options. MaaS has the potential to transform how people travel by generating optimal mode choice options for trips. By integrating different modes of transportation and optimizing routes, MaaS can reduce traffic congestion, air pollution, and carbon emissions.

Moreover, it provides more equitable mobility options for underserved communities and people without a car by integrating various transportation options into a single platform (19). MaaS has become increasingly viable with the rise of smartphones and advancements in mobile technology. Consolidating transportation modes into a single platform aligns with the growing awareness of shared mobility options and other alternatives to driving alone. MaaS can deliver a cost-effective and personalized mobility service to the public through contract-based or "pay-as-you-go" options (20-21).

One advantage of MaaS is its potential to mitigate traffic congestion. By promoting shared transportation options and optimizing routes, MaaS platforms reduce the number of private vehicles on the road, improving traffic flow and efficiency**.** Additionally, MaaS addresses accessibility and mobility challenges for underserved community residents. MaaS offers a sustainable solution that maximizes existing urban planning and infrastructure development resources. Rather than solely expanding road networks or building new transit systems, MaaS optimizes routes and integrates various transportation modes, reducing the need for costly infrastructure expansions.

To design and implement MaaS services efficiently, it is necessary to understand the potential MaaS users' preferences and willingness to pay (WTP) for various MaaS services. Against the backdrop of these innovations and expected benefits, this study conducted an adaptive choice-based conjoint (ACBC) survey. The collected survey responses were analyzed to estimate people's acceptance of and willingness to pay for MaaS. The study objectives are as follows:

- Investigate users' preferences for various combinations of features and attributes of MaaS services.
- Determine the factors that influence users' acceptance of the MaaS service.
- Assess the WTP of potential MaaS users for various MaaS service packages.
- Provide valuable insights for policymakers and service providers in designing and optimizing MaaS offerings based on user preferences and economic perceptions.

II.2 LITERATURE REVIEW

II.2.1. Mobility as a service (Maas)

MaaS is a groundbreaking concept that has revolutionized passenger mobility and related services. It represents an integrated approach to transportation, providing users with convenient access to various transportation options through a single platform. Before this concept was introduced, mobility on demand (MOD) was used to commodify goods delivery, transportation management, and passenger mobility. However, MaaS mainly aims at passenger mobility and related services (22). MaaS was introduced by Hietanen (23) as a distribution model that uses a single interface to meet passengers' mobility requirements by combining different transportation modes (mainly sustainable ones) via innovative and emerging technologies such as the Internet and mobile apps. Thus, interconnectivity among transportation modes plays a central role in the success of MaaS (20).

The modes in MaaS include bike-share, car, and ridesharing systems, shared last-mile transit services, ride-hailing systems, parking facilities, public transit, and taxis. Emerging ridesharing and ride-hailing services have contributed to declining public transportation ridership in the U.S. (24). Moreover, emerging new active modes such as bikeshare captured a share of trips. For example, almost 4% of all daily trips in the U.S. use bikeshare services (22). A study by Rayle (25) discovered that ride-hailing services are responsible for 30% of the decline in public transit ridership in San Francisco. Gehrke et al. (26) explored ride-hailing services in the Boston area and found that Transportation Network Companies (TNCs) trips increased by about 15%. Carpooling has also decreased public transit ridership, as approximately 75% of San Francisco Bay Area carpool users shifted from public transportation (27).

MaaS is implemented in many European cities. MOBiNET (28) is a successful MaaS in Europe that integrates taxi, car-sharing, parking, and ticket booking in an advanced digital platform. This service offers real-time traffic information and user-friendly payment methods to its users. Rome2rio (29) is another successful platform in Italy that integrates public transit, car rental, bike sharing, walking, and air travel. The company added features such as hotel reservations, trip planning, and advanced payment options to increase attractiveness. Although MaaS competes with traditional mass transit rideshares, it is also considered a new type of public transportation that can reduce private car ownership and usage. In addition, MaaS can improve accessibility and mobility for people who cannot afford or drive private vehicles. Various studies investigate the utility of MaaS for improving transportation mobility. For example, Butler et al. (30) and Santos and Nikolaev (31) have explored MaaS usage by examining traveler behavior through surveys, experiments, interviews, or systematic literature reviews.

A recent U.K. study revealed that people using cars and public transit were likelier to use MaaS than captive public transit users (32). The results also showed that offering a pay-as-you-go option increases the utility of MaaS. Moreover, they showed that users who subscribed to a monthly payment option were more likely to use public transit and active modes. Jittrapirom et al. (33) found that younger daily public transit users and those with flexible working hours are more likely to adopt MaaS than other groups. People with flexible working hours prefer using MaaS over cars because MaaS is convenient, flexible, and offers various transportation options through a single platform, accommodating their changing schedules.

On the other hand, car owners who drive to work daily are less likely to adopt MaaS. Ratilainen (34) explored how payment packages, discounts, and registration conditions may motivate travelers to use MaaS and found that these features can be motivating factors for travelers to adopt MaaS. However, studies about attitudes toward MaaS should be conducted locally because preferences may vary at different locations and depend on various fixed or temporary conditions. Various other researchers, including some co-authors of this paper, have published MaaS-related studies (35-43).

II.2.2. User preferences and willingness to pay

Matyas and Kamargianni (44) found a significant correlation between the popularity of MaaS systems and the inclusion of public transport in addition to other mobility services like taxis or rideshare. Caiati et al. (45) showed that public transportation is the top choice among individuals, whereas options such as taxis or car rentals are not as commonly preferred. Using GPS traces collected from students, Reck and Axhausen (46) identified possible MaaS plans by examining the usage of different mobility services and assessing the substitution of car trips with sharing systems while considering the generalized cost. Moreover, Tsirimpa et al. (47) found that respondents preferred shorter and more flexible trips when using MaaS services.

Ho et al. (48) conducted a survey in Sydney, Australia, using a scaled multinomial logit (MNL) to analyze individuals' preferences for MaaS packages. The study estimated users' WTP for various mobility entitlements within MaaS plans. Mulley et al. (49) conducted a study targeting elderly individuals in Australia to examine their WTP for MaaS packages. They explored mobility plans offering different accessibility options (e.g., social trips, medical trips) without specifying the mode of transportation. The results showed that older adults' WTP was notably lower than the actual services costs, posing a challenge for MaaS providers. Moreover, a survey conducted in Finland showed that people are willing to pay an average of 137€ (approximately $162) per month for MaaS plans that cater to their mobility needs (50). In another study (51), participants were presented with choices between standalone transportation services and mobility bundles. The results indicated that participants would pay more for the bundled MaaS services than the other option.

II.3 METHODS

This section discusses the techniques employed in this study. First, an online adaptive choice-based conjoint (ACBC) survey and analysis were conducted to estimate people's acceptance and WTP for various MaaS options. The ACBC analysis allows researchers to identify the relative importance of product attributes and the most preferred product bundles by measuring part-worth utility scores (52). Part-worth utility is computed using a hierarchical Bayesian (HB) method, which is more appropriate for estimating preferences and the WTP for new products not yet on the market or at their early marketing stage. Survey participants also found ACBC surveys more engaging than conventional conjoint surveys (52). Furthermore, ACBC surveys have lower standard errors, improve prediction of hold-out task choices, and provide better estimates of real-world product decisions (53). The ACBC analysis offers advantages over the CBC (Choice-Based Conjoint) analysis by reducing the number of questions, improving respondent engagement, and providing more accurate utility scores (54).

II.3.1. Survey design and attributes

An online survey (using Sawtooth Software's software) was developed to gather information on people's preferences and willingness to pay (WTP) for MaaS alternatives from May 3, 2023, through July 10, 2023. The survey was divided into three sections. The first section asked questions about vital socioeconomic characteristics (e.g., gender, age, race, city of residence), number of daily trips, and number of mileage trips, while the second and third sections asked questions specific to the product under consideration. The last two sections asked participants to choose their most favored alternative from bundles comprising five attributes (Mode mix, Travel time, commuting time of day, walking distance, and weather conditions) and nineteen levels (Table 6).

Table 6. MaaS Choice Attributes and Levels

Attributes	Levels	Costs ($)
In which modes mix, do you prefer using travel?	• Transit only	$3
	• Transit, bike/scooter	$5
	• Bike/scooter	$5
	• I will drive anyway	$12
With what maximum increase in travel time do you choose MaaS?	• About 30% longer	
	• About 50% longer	
	• About 100% longer	
	• Time doesn`t matter and I will definitely choose MAAS	
	• Time doesn`t matter and I will not definitely choose MAAS.	
In which commuting time of day do you prefer using Maas or driving?	• Peak	10% more
	• Off peak	
	• Evening/After dark	
	• Commuting time doesn't matter.	
How much do you prefer to walk in your travel?	• Less than ¼ miles	
	• Less than ½ miles	
	• Less than 1 mile	
	• No walking	

In which weather conditions do you use MAAS or drive?	• Sunny or cloudy • Rainy or snow • Weather doesn't matter

II.3.2. ACBC Analysis

The ACBC method is a recent variant of conjoint analysis, differing in its analysis and computation stages. It computes utility values based on an interval scale that reflect preferences. Utility values are typically scaled to maintain an average utility of zero within each factor. The utility scores assigned to the attribute levels indicate the participants' assessment of the importance or desirability of having or not having that particular element. In practical terms, the utility function of ACBC can be expressed as Eq.56 (55):

$$U_v = \sum_{a=1}^{A} \sum_{L=1}^{l_a} \gamma_{aL} \times y_{aLv} \tag{56}$$

where U_v, A, l_a and γ_{aL} are the utility of choosing an alternative bundle, attributes, levels of attribute a, and the part-worth utility value of the level L of each attribute a. y_{aLv} is a dummy variable for level L of attribute a for vehicle v as follows:

$$y_{alv} = \begin{cases} 1 & \text{perceived level} \\ 0 & \text{not perceived level} \end{cases}$$

A Hierarchical Bayes (HB) analyzer built into the ACBC survey software estimates choice preferences. The primary objective of HB models in ACBC is to estimate the part-worths associated with each respondent contained in a vector β, the average for all respondents included in the vector α, and the variances of all respondents contained in the matrix M (56). The lower level (LL) refers to models where the utility of the final selected sets is determined by summing the part-worths of its attribute levels. On the other hand, the upper level (UL) indicates that respondents' vectors of part-worths are derived from a multivariate normal distribution. In addition, the followings are provided for the levels and associated probability.

$$LL = u = \sum \beta_i \ , \ UL = \beta N(\alpha, M), \quad p = \frac{\exp{(u)}}{\exp{(u_j)}} \tag{57}$$

The ACBC survey was initiated by introducing the various attributes, corresponding levels (i.e., features), and costs. Participants were asked to choose each attribute's most preferred service feature (Figure 12). This task is called Build Your Own (BYO). Features represent different service options associated with each attribute. This task aims to identify participants' initial (i.e., raw) preference structures before estimating their choice behavior and identifying individuals' most favored MaaS alternative in the next task, a screener. This next task is often "a choice tournament," showing a series of alternatives (Four at each tournament stage).

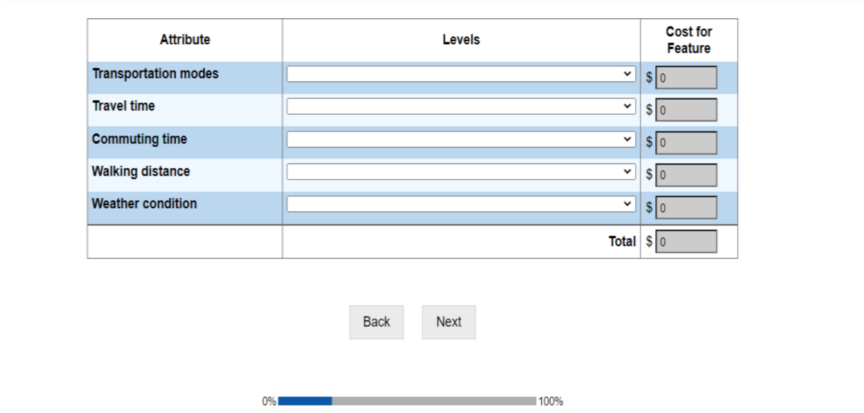
In the screener section, respondents must choose which bundles of options are "Unacceptable" or "the most important option," which helps assess the responses' consistency. (Figure 13). Over a series of screeners, the respondent had to decide which bundles were either "unacceptable" or "must-have." The purpose was to check the consistency of responses. Then, the information collected from this section became input for the next section (i.e., choice tournament).

The related bundles for each respondent were presented, four bundles at a time. Bundles identified as possibilities during the screener section were carried forward to the choice tournament. To reduce the complexity of the choices, constant attribute levels across the bundles were grayed out (Figure 14). The winning concept from each tournament moved on to a subsequent round, and the choice tournament proceeded until the most preferred bundle was determined. The survey ended with additional demographic questions.

In the BYO section, prices depend on the choice level of the participants. However, a ±30 percent change in BYO prices is applied during the ACBC screening choice questions to resemble the variations in the actual WTP of participants. This adjustment is made based on Sawtooth Software recommendations, allowing the utility of non-price attributes to be interpreted independently from those associated with price increments (57). Details of price estimation for selected attributes and levels are based on the ideas and experiences of the research team and Todd Litman`s work (58) about transportation cost estimation. The ACBC method offers several advantages that make it well-suited for the analysis approach in this study:

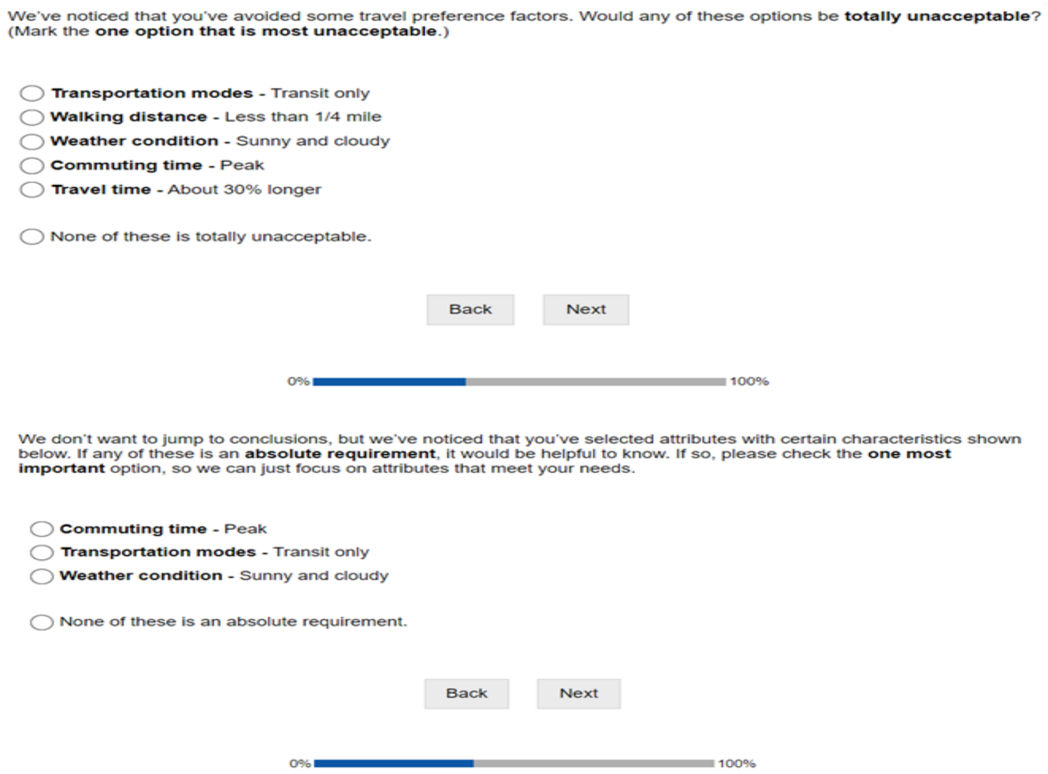
1. Considering the complexity of choices and the presence of multiple attributes with various levels for the desired service, ACBC allows for an optimal selection pattern toward the respondent's most preferred service by utilizing the BYO exercise.
2. The advanced tools for capturing preferences in ACBC enhance its efficiency compared to standard CBC, mainly when dealing with smaller sample sizes.
3. ACBC incorporates cutoff principles based on the respondent's previous answers and includes must-have and must-avoid options, enabling a precise understanding of the exact service preferences of the respondent.

These tools collectively make ACBC an ideal method for conducting a comprehensive analysis in the current study.



Attribute	Levels	Cost for Feature
Transportation modes		$ 0
Travel time		$ 0
Commuting time		$ 0
Walking distance		$ 0
Weather condition		$ 0
	Total	$ 0

Figure 12. Build-your-own (BYO) Task



We've noticed that you've avoided some travel preference factors. Would any of these options be **totally unacceptable**? (Mark the **one option that is most unacceptable**.)

○ **Transportation modes -** Transit only
○ **Walking distance -** Less than 1/4 mile
○ **Weather condition -** Sunny and cloudy
○ **Commuting time -** Peak
○ **Travel time -** About 30% longer

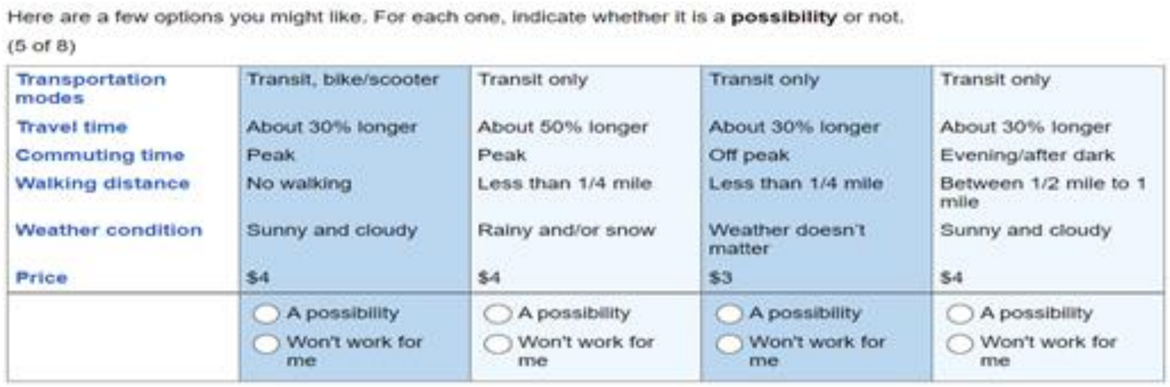
○ None of these is totally unacceptable.

We don't want to jump to conclusions, but we've noticed that you've selected attributes with certain characteristics shown below. If any of these is an **absolute requirement**, it would be helpful to know. If so, please check the **one most important** option, so we can just focus on attributes that meet your needs.

○ **Commuting time -** Peak
○ **Transportation modes -** Transit only
○ **Weather condition -** Sunny and cloudy

○ None of these is an absolute requirement.

Figure 13. Unacceptable" and "the most important option" questions



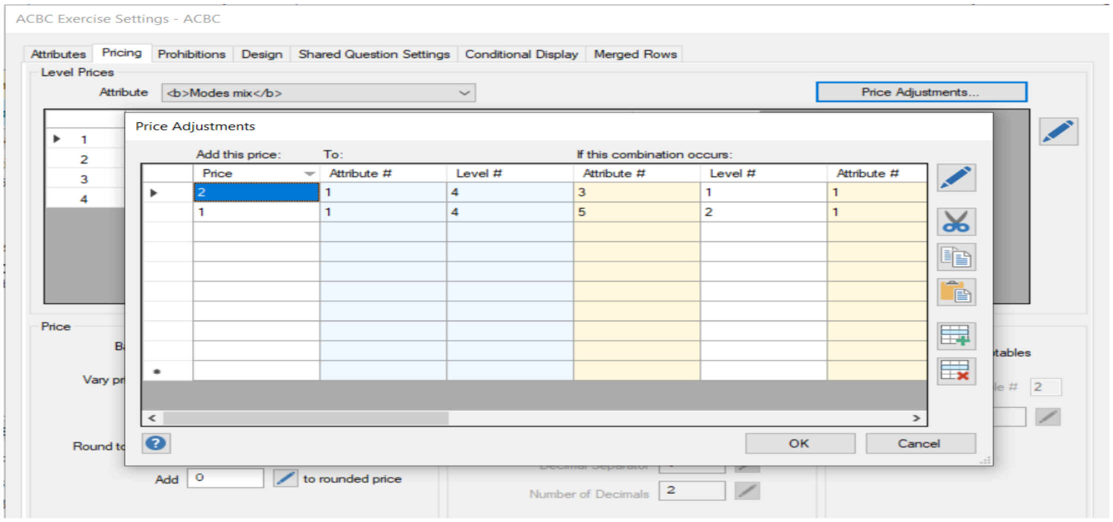
Here are a few options you might like. For each one, indicate whether it is a **possibility** or not.
(5 of 8)

Transportation modes	Transit, bike/scooter	Transit only	Transit only	Transit only
Travel time	About 30% longer	About 50% longer	About 30% longer	About 30% longer
Commuting time	Peak	Peak	Off peak	Evening/after dark
Walking distance	No walking	Less than 1/4 mile	Less than 1/4 mile	Between 1/2 mile to 1 mile
Weather condition	Sunny and cloudy	Rainy and/or snow	Weather doesn't matter	Sunny and cloudy
Price	$4	$4	$3	$4
	○ A possibility ○ Won't work for me	○ A possibility ○ Won't work for me	○ A possibility ○ Won't work for me	○ A possibility ○ Won't work for me

Figure 14. The Screen Section Task

II.3.3. Price adjustment

An ACBC user can assign price increases or decreases to different levels within the research through "Summed Pricing" and by setting Level Prices on the Pricing tab. Nevertheless, there may be situations where more sophisticated price adjustments are needed that go beyond the basic additive prices available through Summed Pricing. For example, $2 will be added to attribute 1 level (I will be driving), combined with attribute 3 level 1 (peak time). Moreover, $1 will be added to attribute 1 level (I will be driving) and attribute 5 level 2 (the weather in rainy or snow conditions), as in Figure 15.



Attribute Modes mix

Price Adjustments

Add this price:	To:		If this combination occurs:		
Price	Attribute #	Level #	Attribute #	Level #	Attribute #
2	1	4	3	1	1
1	1	4	5	2	1

Add 0 to rounded price

Number of Decimals 2

Figure 15. Price Adjustment

II.4 RESULTS AND DISCUSSION

II.4.1. Socioeconomic Characteristics of the Participants

After the completion of data collection, a total of 101 valid responses were included for analysis. Table 7 presents a summary of the selected socioeconomic variables. The collected demographic information is relatively representative of national-level statistics. The gender distribution leaned slightly towards females, with 51.5% female and 47.5% male respondents, showing a slight difference from the national average, according to the United States Census Bureau (2019). The age distribution of the participants also closely resembled the national statistics, except for the age range of 30 to 49. The lowest and highest percentages in terms of race belong to Native Hawaiian or Other Pacific Islander and White, respectively, which resemble the minimum and maximum rates. For education, 65.4 % had higher academic degrees at graduate levels, much higher than the national average of 12 % (United States Census Bureau, 2019).

Table 7. Summary of Participants' Characteristics

Demographic Characteristics		**Study (%)**	**US (%)**
Gender	Male	47.5	49.2
	Female	51.5	50.8
	N/A	1	
Age	Under 20	1	27.0
	20 to 24 years old	7.9	7.0
	25 to 29 years old	6.9	6.8
	30 to 39 years old	28.7	13.0
	40 to 49 years old	24.8	13.1
	50 to 59 years old	17.8	13.6
	60 to 69 years old	10.9	9.5
	70 and older	2	9.0

Race/ethnicity	White (non-Hispanic)	52.5	60.6
	Hispanic	2.0	18.7
	Black or African American	24.8	13.4
	American Indian or Alaska Native	2.0	0.7
	Asian	8.9	5.9
	Native Hawaiian or Other Pacific Islander	0.9	0.2
	Other	8.9	0.5
Education	Associate degree and lower	10.8	61
	Bachelor's degree	23.8	21
	Master's degree	40.6	9
	Doctoral/professional degree	24.8	3
Marital Status	Single	20.8	51.8
	Married	71.3	48.2
	Others/ Prefer not to answer	7.9	-
Annual income	Less than $50,000	42.6	46.5
	$50,000 to $99,999	15.8	29.9
	$100,000 to $149,999	19.8	18.3
	$150,000 to $199,999	8.9	-
	$200,000 or more	12.9	5.3
Number of Persons	I live by myself.	19.8	27.6
	1 additional person	24.8	33.7
	2 additional persons	55.4	38.7
Transportation modes	I will drive anyway	56.4	76
	Transit only	25.7	10
	Transit, bike/scooter	11.9	-
	Bike/scooter	5.94	-

II.4.2. Importance of Attributes

Figure 16 illustrates the relative importance of attributes. Relative importance was determined as the average of all ratios of the individual importance scores to the total individual importance scores. The importance scores provided insight into the extent to which each attribute could influence the overall utility of a product (36). The survey results showed that mode is the most important attribute for choosing a mobility service, followed by price. The commuting time and walking distance scores are relatively equal, and weather conditions are the least important.

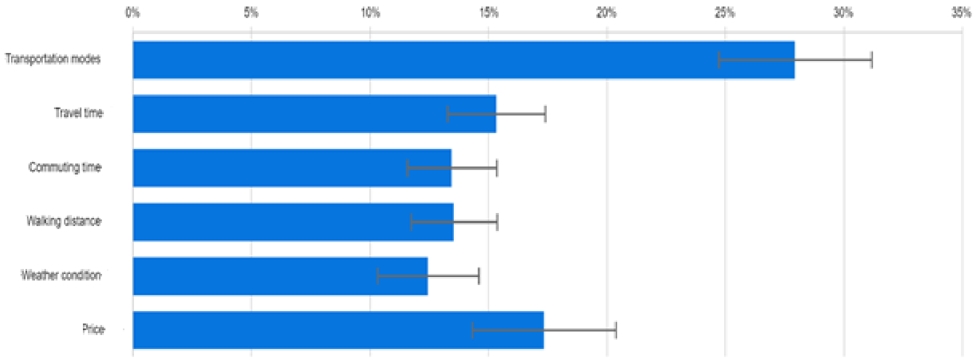


Figure 16. Importance of Attributes

II.4.3. Attributes Utility

The results of utility levels of all attributes are presented in Table 8. The "Drive anyway" level of the transportation mode attribute had the highest utility relative to other levels. More than 56% of participants preferred to drive (Table 8, Selection’s Percent column), even if it meant paying more. The "Transit-bike/scooter" and "Bike/scooter" levels had negative utilities, meaning people were less likely to take cheaper offers in exchange for much longer travel times. The "Transit only" product had about half the utility of driving; this means that participants considered transit to be half as important as driving.

The survey results showed that "Price" was the second most important attribute for choosing a mobility service, closely followed by travel time. The lowest price of $2.10 had the highest utility. Of the four different levels of "Travel times," respondents chose "Fastest mode" as the most preferred level, while "About 50% longer" and "About 100% longer or more" showed negative preferences.

Participants considered "Commuting time" and "Walking" distance equally important. However, commuting "Anytime" was preferred among the four commuting time levels, and commuting during the "Evening/after dark" period had negative utilities. Similarly, the "No walking" level had the highest utility among the five levels of the walking distance attribute. The shorter the walking distance, the higher the preference, but the "More than 1-mile" level had negative utilities. The least important attribute was the weather conditions. Respondents preferred "Sunny and cloudy" weather conditions. "Rainy and/or snowy" weather conditions had negative utilities. However, for more than 45% of the participants, "weather did not matter," possibly because the majority of the respondents preferred driving.

Table 8. The Results of the Conjoint Choice Model

Attribute	Attribute Level	Utility	Lower Level	Upper Level	t-Ratio	Selection`s Percent
Transportation modes	Transit only	17.75	2.94	32.57	1.62	25.74
	Transit, bike/scooter	-28.31	-39.91	-16.72	-6.72	11.88
	Bike/scooter	-41.32	-54.30	-28.33	-9.92	5.94
	I will drive anyway	51.88	35.52	68.24		56.44
Travel time	About 30% longer	7.11	0.36	13.85	2.46	27.72
	About 50% longer	-7.19	-13.82	-0.57	-2.80	11.88
	About 100% longer or more	-29.32	-38.22	-20.42	-6.52	6.93
		29.41	20.87	37.95		53.47

	The fastest mode					
Commuting time	Peak	4.03	-2.57	10.63	1.64	26.73
	Off peak	7.42	0.85	14.00	4.38	26.73
	Evening/after dark	-29.21	-38.63	-19.79	-5.24	0.99
	Anytime	17.76	11.78	23.73		45.54
Walking distance	Less than 1/4 mile	10.60	3.69	17.51	2.67	30.69
	Between 1/4 mile to 1/2 mile	2.40	-4.08	8.88	1.34	20.79
	Between 1/2 mile to 1 mile	-6.04	-12.08	0.00	-2.49	12.87
	More than 1 mile	-21.06	-29.18	-12.95	-4.46	15.84
	No walking	14.11	7.39	20.83		19.80
Weather condition	Sunny and cloudy	23.71	15.24	32.19	7.83	51.49
	Rainy and/or snow	-27.76	-35.31	-20.21	-5.40	1.98
	Weather doesn't matter	4.05	-2.72	10.82		46.53
Total price importance	PRICE: 2.1	10.18	-3.34	23.69	-3.70	
	PRICE: 19.5	-10.18	-23.69	3.34		

II.4.4. Effect of the Interaction Across Attributes

Even though all attributes were statically significant with different levels of preference, a close look at the different levels of combination indicated that different combinations may provide additional utilities. For instance, "Transit only" had higher utility than a combination of "Transit and bike/scooter." A combination of transit and driving may have higher utilities. It is, therefore, essential to have insights into some combination of attributes. The analysis for the effects of interaction was adopted to predict the utilities of a combination of multiple attributes. The interaction effect of the combined attributes is presented in Table 9. The results of interaction effects show that nine interactions are statistically significant, with the highest importance coefficient being "Transportation modes x Walking distance" and the least important coefficient being "Travel time x Walking distance."

The interaction results indicated that the attributes of transportation mode had the most significant effect when interacting with other attributes. The utilities predicted a 61% likelihood that a rider would select transportation modes by considering walking distance.

Table 9. Estimated Effect of the Interaction Terms

Alternative	Log-Likelihood Fit	P-Value for Interaction Effect	Gain in Pct. Cert. over Main Effects
Main Effects	-3,870.91		
Transportation modes x Travel time	-3,858.55	0.00330**	29.42%
Transportation modes x Commuting time	-3,854.61	0.00016***	38.81%
Transportation modes x Walking distance	-3,845.13	0.00000***	61.37%

Transportation modes x Weather condition	-3,856.69	0.00008***	33.85%
Transportation modes x Price	-3,869.65	0.47055	3.01%
Travel time x Commuting time	-3,865.78	0.32986	12.21%
Travel time x Walking distance	-3,860.62	0.05701*	24.48%
Travel time x Weather condition	-3,867.52	0.34065	8.08%
Travel time x Price	-3,861.20	0.00022***	23.11%
Commuting time x Walking distance	-3,858.81	0.01905**	28.81%
Commuting time x Weather condition	-3,865.81	0.11612	12.15%
Commuting time x Price	-3,861.15	0.00021***	23.22%
Walking distance x Weather condition	-3,866.58	0.37151	10.31%
Walking distance x Price	-3,849.13	0.00000***	51.85%
Weather condition x Price	-3,869.74	0.31099	2.78%

II.4.5. MaaS Products Share Preference

The share of preference analysis was used to estimate the proportion of the best and worst alternatives of mobility as a service and the competitiveness of these services in the future market. Four cases (with product names) were considered using the simulator of Sawtooth software. The first product consists of levels with the minimum utility of each attribute, the second product consists of levels with the maximum utility, and the third and fourth products were considered as a combination. The characteristics of these products are listed in Table 10. The results showed that "Product 2" had the highest utility while "Product 1" had a negative utility (Figure 17). Product 2 can capture 56% of MaaS demand compared to the other three products, as presented in Table 11.

Table 10. The Features of the Products, Their Attributes, and Their Levels

	Product 1	Product 2	Product 3	Product 4
Transportation modes	Bike/scooter	I will drive anyway	Transit, bike/scooter	Transit only
Travel time	About 100% longer or more	The fastest mode	The fastest mode	About 50% longer
Commuting time	Evening/after dark	Anytime	Peak	Off peak
Walking distance	More than 1 mile	No walking	No walking	Less than 1/4 mile
Weather condition	Rainy and/or snow	Sunny and cloudy	Weather doesn’t matter	Weather doesn’t matter

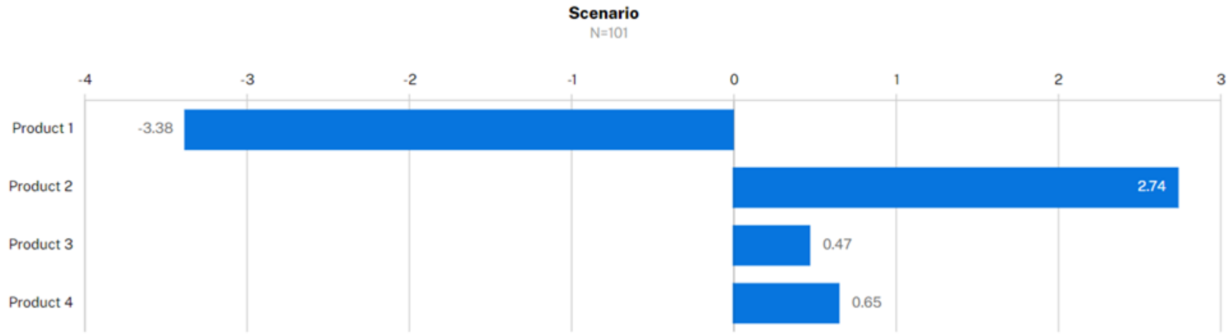


Figure 17. The Utility of Products

Table 11. Products Share Preference

Product	Share of Preference	Total Utility	Standard Error
Product 1	7.51%	-3.38	0.35
Product 2	56.36%	2.74	0.21
Product 3	14.93%	0.47	0.19
Product 4	21.20%	0.65	0.21

II.4.6 Preferences by Demographic Characteristics

Demographic characteristics are related to people’s preferences. A series of one-way analysis of variance tests were conducted on the demographic (independent) variables and the attributes (dependent variables) to assess the relationships between these variables. The results are summarized in Table 12. P-values greater than 0.05 indicates that independent variables have no significant impact on the dependent variables at a 95% significance level.

It can be observed that gender had no significant impact on mode, travel time, commuting time, and weather conditions. The number of female respondents who choose transit or driving or a combination of transit and bike/scooter is not significantly different from that of male respondents. Age, Education, Income, Number of Trips, and Mileage had no significant impact on any attributes. In contrast, the impact of Race, Marital Status, Number of Children, and Hybrid Ownership on Walking distance is evident. The only variable that significantly affected two attributes, namely Transportation modes and Weather conditions, is Household Number.

Table 12. Analysis of Variance

Variables	Gender	Age	Race	Education	Marital Status	Income	Household Number	Nearest Station	Number of Children	Car Ownership	Hybrid Ownership	Number of Trips	Milage
Transportation modes	0.21	0.6	0.68	0.2	0.43	0.93	0.002	0.62	0.525	0.526	0.40	0.52	0.60
Travel time	0.23	0.75	0.66	0.49	0.29	0.89	0.78	0.27	0.348	0.69	0.20	0.14	0.12
Commuting time	0.08	0.31	0.84	0.08	0.006	0.63	0.24	0.02	0.15	0.04	0.11	0.09	0.24
Walking distance	0.003	0.39	0.002	0.17	0.003	0.96	0.40	0.05	0.02	0.2	0.02	0.17	0.32
Weather condition	0.20	0.25	0.57	0.95	0.001	0.10	0.03	0.008	0.32	0.33	0.16	0.68	0.55

II.5 CONCLUSION

This study aimed to analyze user preferences and WTP for Mobility as a Service. Such knowledge is essential for policymakers in the MaaS ecosystem to establish customers' preferences and recognize the market's needs and the necessity for investment. A review of past studies found the need to localize studies about attitudes toward MaaS because preferences may vary at different locations or under various fixed or temporary conditions. Therefore, this study tried to conduct a comprehensible survey using the CBCB method, considering six critical attributes believed to have the most impact on MaaS user travel behavior. The sophisticated preference capture features in ACBC (screening section tasks and must-have and must-avoid options) make this method more efficient than typical choice-based conjoint analysis, particularly when utilizing smaller sample sizes (40). As a result, the study's very modest sample size can be justified.

The results indicated that mode combination is the most critical decision factor in travelers' choice of MaaS product, followed by price, travel time, walking distance, commuting time, and weather conditions. The majority of respondents preferred driving even when transit, bike/scooter, and a combination of transit and bike/scooter options were available. However, more than 21% of the respondents preferred transit with longer travel times. A combination of transit and bike/scooter had a 15% market share, while bike/scooter only captured about 8% of the market. The majority of respondents preferred driving even when transit, bike/scooter, and a combination of transit and bike/scooter options were available. However, more than 21% of the respondents preferred transit with 30% longer travel times. A combination of transit and bike/scooter had a 15% market share, while bike/scooter only captured about 8% of the market. These findings mean that MaaS products based on transit, bike, and scooter have the potential to capture 44% of the market.

Furthermore, this may be better because only 1% of the respondents are 20 years and below, compared to the US national average of 27% (Table 7). MaaS could potentially attract some of the 56% of respondents that choose to drive if driving-based MaaS products are included in future studies. Moreover, MaaS is viable in both peak and off-peak periods, as the ratio of respondents who chose peak or off-peak periods is similar. MaaS products with no walking or less than a quarter mile walking distance were adopted by 50% of respondents.

The studies made the following contributions:

1. It investigated the importance of micro mobility of several variables, such as user preference for different modes, prices, travel time, commuting period, walking distance, and weather conditions.
2. It performed a comprehensive online survey to generate data on commuters’ preferences regarding the MaaS and analyzed the associated attributes of travel behavior and demographic characteristics.
3. It investigated the impact of the mentioned variables on user choice for mobility products. The main limitation of this research was the relatively low number of survey participants. Efforts were made to improve on this during the survey; however, it is recommended that future studies use some incentives to increase the number of participants.

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