Bundle Design for Mobility as a Service

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SHORT SUMMARY

Mobility as a service (MaaS), which offers users access to different transportation modes through an integrating platform by paying a discounted subscription fee, is becoming prevalent worldwide due to its potential in increasing transportation equity and accessibility. The success of the MaaS depends on users shift to subscribing than pay-as-you-go for using different transportation modes, which is highly reliant on bundle assortment, and its subscription fee. This paper investigates the optimal assortment and cost of the MaaS bundle considering the users travel needs, and provides a foundation for designing optimal MaaS bundles. The analysis shows that the number of trips offered in MaaS bundles should be equal to or greater than the travel needs of the users. Moreover, the analysis shows that the market share of the MaaS is at most 50%, and the majority of the users still prefer to pay for their trips as they go.

Keywords: Mobility as a Service, bundle assortment, bundle subscription fee

1. Introduction

The proliferation of smartphones and internet connectivity in the past decade has enabled the concept of mobility as a service (MaaS) in which users can travel using different modes (e.g. taxi, public transportation, and bike-share) offered by different providers through a discounted single payment to an integrating platform. The MaaS operator can provide different subscription plans which provide users a quota for using each transportation mode by paying a monthly subscription fee. Hence, MaaS bundles can be seen as similar to cell phone plans in which users have a quota for call duration, text messages, and data for a fixed monthly fee. MaaS users can seamlessly transfer between different modes to travel between their origins and destinations depending on which transportation mode suits their needs best during their trip. The objective of MaaS is to decrease the need for owning a car and increase the usage of shared modes by ensuring the availability of alternative modes to complete a trip.

The number of users who subscribe to MaaS, and the profit of the integrating platform would highly depend on the subscription fee and MaaS bundle assortment, which is the number of trips using different modes a user can make. By providing the bundles the integrating platform can secure the demand and buy trips from the different mode providers at lower costs. Also, MaaS bundles can be used to promote and introduce less utilized and new modes such as scooter-sharing by providing them in combination with more popular modes such as ride-sourcing or public transport. Even though subscription plans or bundles in which users receive services at a lower cost compared to pay-per-usage are common practices in many industries, their systematic design has not been investigated in the transportation domain to the best of my knowledge. The main difference between the transportation domain and others is that transportation demand is derived from the need to participate in activities rather than for its own sake. For instance, users data usage would change significantly depending on the quota available in their cell phone plans. In contrast, the number of trips users make would not change much due to subscribing to a MaaS bundle, but a MaaS bundle can impact their travel mode. Hence, the goal of this research is to develop a stylized model to find the optimal MaaS bundle assortment and its subscription fee to maximize the integrating platform profit.

Since the first trial of MaaS in Sweden (Sochor, Karlsson, & Strömberg, 2016), researchers and MaaS operators have started investigating users preferences and uptake of MaaS bundles. For instance, Whim, which is the first commercial MaaS, states that they are trying to design their bundles considering users socio-demographics characteristics (Hietanen, 2014). To explore the impact of users socio-demographics characteristics on MaaS uptake, Matyas & Kamargianni, 2019a conduct a stated preference survey where participants chose among three MaaS bundles. Similarly, Ho, Mulley, & Hensher, 2020 perform a stated choice analysis, in which they first ask about each participant's travel behavior and provide two MaaS bundles considering their travel behavior to investigate users MaaS uptake. These researches and others (Stopka, Pessier, & Günther, 2018; Ho, Hensher, Mulley, & Wong, 2018; Robinson, 2018; Strömberg, Karlsson, & Sochor, 2018; Matyas & Kamargianni, 2019b) are heavily dedicated to conducting stated preferences to investigate users attitudes to MaaS. To the best of my knowledge, the optimal pricing and composition of MaaS bundles from the operator perspective have not been investigated. Therefore, the main contribution of this research is to fill in this gap by optimally finding the price and the assortment of the MaaS bundles to maximize the profit of the operator considering the users travel needs.

In this paper, we model the MaaS bundle assortment and its monthly subscription fee, and investigate how these factors impact users uptake of MaaS services. More specifically, we consider that the users experience disutilities from using each transportation mode separately or subscribing to a MaaS bundle. The users disutility for subscribing to a MaaS bundle depends on the number of trips they can make using each transport mode and its monthly fee. We assume that the users are rational and would subscribe to the MaaS bundle if their experienced disutility is less than using different modes separately. The primary contributions of this work are that *(i)* the number of offered trips in the MaaS bundle for all modes should be at least equal to the number of travel needs of the users; *(ii)* the market share of the MaaS is at most 50%, and the majority of users prefer to pay to different transportation providers separately as they use them.

2. Model

We consider that the users incur a disutility U_i from subscribing to a MaaS bundle (presented by b) or using different modes separately (presented by s). The subscript $i \in \{b, s\}$ is mnemonic for the two cases. We first assume that all users are homogeneous in terms of the number of trips they make. An example of such a scenario is the MaaS bundles designed for a specific group of users, e.g. students, who have similar travel needs. We relax this assumption later in this section to take into account the heterogeneity in the number of trips. We define the users disutility for subscribing to a MaaS bundle, denoted by U_b, as follows:

$$U_b = f_b + \sum_m f_m max(0, n_m - n_m^b), \tag{1}$$

where f_b is the monthly subscription fee to the MaaS, f_m is the fare for mode m, and n_m and n_m^b are the number of trips per month each user makes using mode m and the quota for using mode m included in the MaaS bundle, respectively. Hence, the first term is the monthly subscription fee, and the second term is the fare that users need to pay for any additional trips they make after using their quota.

Similarly, the users disutility for paying separately to each mode provider, denoted by U_s, is defined as follows:

$$U_s = \sum_m f_m n_m + \beta, \tag{2}$$

where β is the discomfort cost of separate payment to each mode provider. Hence, the disutility of using different modes separately is defined as the fare paid by users plus a discomfort cost, denoted by β, to pay to each provider.

The MaaS operator maximizes its profit, denoted by π, by optimally choosing the assortment of the bundle n_m^b, and its monthly fee f_b via the following mathematical model:

$$\max_{n_m^b, f_b} \pi_1 = \lambda(f_b - \sum_m f_m n_m), \tag{3a}$$

$$\text{s.t. } U_b \leq U_s, \tag{3b}$$

$$f_b \leq \alpha \sum_m f_m n_m^b, \tag{3c}$$

where λ is the total number of users, and α is the price discount for subscribing to the MaaS compared to separate payments.

The objective function (3a) calculates the MaaS operator profit, which is the difference between the monthly fee and the actual cost of users trips. Constraint (3b) states that users experience a lower disutility from MaaS compared to paying for each mode separately. Finally, Constraint (3c) ensures that the MaaS subscription fee is lower than paying for the same amount of trips separately.

The mathematical model (3) is a non-convex problem. We now analytically derive the optimal solution to (3) and discuss the insights of the model. The first-order necessary conditions yield the optimal bundle subscription fee as:

$$f_b^* = \sum_m f_m n_m + \beta, \tag{4}$$

which results that the total profit of MaaS operator being $\pi_1^* = \lambda\beta$.

• *Insight 1:* The number of trips offered on each mode in the bundle assortment should be at least equal to the number of travel needs of users, and $n_m^{b\,*} = \frac{n_m}{\alpha} + \frac{\beta}{\alpha \sum_m f_m}$ could be used as a rule of thumb for the bundle assortment.

• *Insight 2:* If the discomfort of paying to different providers separately be equal to zero ($\beta = 0$), the MaaS operator profit will be zero, consequently. Currently, in many cities around the world, users can pay the fare of different modes using an app on their cellphones or tapping their banking cards, which leads to negligible discomfort cost for separate payment to different providers, and threatening the economic sustainability of MaaS provision, consequently. This is consistent with the fact that many pilots designed for a specific group of users around the world were not profitable (Zipper, 2020).

We now move on to the scenario where the MaaS operator offers different bundles tailored for different groups of users. Users mode choice and number of trips differ substantially among different socio-demographic groups. For instance, the mode choice of a business person is different from a student, while the latter prefers cheaper modes and is willing to use shared modes such as public transport, or ride-pooling, the former is more interested in faster modes such as taxi or car-sharing. We consider two market segments of “high-value" (presented with “h") and “low-value" users (presented with “l") for analytical tractability, however, extending it to consider more market segments is straightforward. The MaaS operator also targets providing a high-value bundle to the high-value segment and a low-value bundle to the low-value segment. Similar reasoning is provided in Afeche & Pavlin, 2016 and Bahrami, Nourinejad, Mahmoodi Nesheli, & Yin, 2021. The disutilities of high- and low-value users, U_b^h and U_b^l, for subscribing to high- and low-value bundles are

$$U_b^h = f_b^h + \sum_m f_m max(0, n_m^h - n_m^{bh}), \tag{5}$$

$$U_b^l = f_b^l + \sum_m f_m max(0, n_m^l - n_m^{bl}), \tag{6}$$

where f_b^h and f_b^l are subscription fees of high- and low-value bundles, respectively. n_m^{bh} and n_m^{bl} are the numbers of trips on mode m included in high- and low-value bundles, respectively, and n_m^h and n_m^l are respectively the numbers of tips high- and low-value users make using mode m. Similar to the previous scenario, high- and low-value users can choose not to opt-in the bundles, and their experienced disutilities are

$$U_s^h = \sum_m f_m n_m^h + \beta^h \tag{7}$$

$$U_s^l = \sum_m f_m n_m^l + \beta^l, \tag{8}$$

where β^h and β^l are the discomfort cost of paying separately for each trip to its provider for high- and low-value users, respectively, and $\beta^h > \beta^l$.

Consequently, we derive the optimal subscription fees for high-value and low-value bundles, f_b^{h*} and f_b^{l*}, and the assortment of each bundle, n_m^{bh*} and n_m^{bl*}, respectively, from the following mathematical model:

$$\max_{n_m^{bh}, n_m^{bl}, f_b^h, f_b^l} \pi_2 = \lambda^h (f_b^h - \sum_m f_m n_m^h) + \lambda^l (f_b^l - \sum_m f_m n_m^l), \tag{9a}$$

$$\text{s.t. } U_b^h \leq U_s^h, \tag{9b}$$

$$U_b^l \leq U_s^l, \tag{9c}$$

$$U_b^h \leq f_b^l + \sum_m f_m max(0, n_m^h - n_m^{bl}), \tag{9d}$$

$$U_b^l \leq f_b^h + \sum_m f_m max(0, n_m^l - n_m^{bh}), \tag{9e}$$

$$f_b^h \leq \alpha^h \sum_m f_m n_m^{bh}, \tag{9f}$$

$$f_b^l \leq \alpha^l \sum_m f_m n_m^{bl}, \tag{9g}$$

where λ^h and λ^l are the numbers of high- and low-value users.

The objective function (9a) maximizes the profit of the MaaS operator which is the difference between subscription fees of high- and low-value bundles with their actual cost based on the usage. Constraints (9b) and (9c) are similar to Constraint (3b) and ensure that high- and low-value users disutility from bundle subscription is lower than separate payment to each provider, respectively. Constraint (9d) ensures that the high-value bundle is targeted for high-value users, and high-value users experience lower disutility from subscribing to the high-value bundle rather than the low-value one. Constraint (9e) similarly ensures that low-value users experience lower disutility from the low-value bundle in comparison to the high-value one. Finally, Constraints (9f) and (9g) state that the MaaS subscription fees of high- and low-value bundles are less than paying separately to each provider for the same amount of trips offered in bundles. The first-order necessary conditions yield the optimal bundle subscription fees and the MaaS operator profit as:

$$f_b^{h*} = \sum_m f_m n_m^h + \beta^h, \tag{10}$$

$$f_b^{l*} = \sum_m f_m n_m^l + \beta^l, \tag{11}$$

$$\pi_2^* = \lambda^h \beta^h + \lambda^l \beta^l. \tag{12}$$

• *Insight 3:* The number of offered trips in high- and low-value MaaS bundles should be at least equal to the number of travel needs of high- and low-value users, respectively.

We now move on to the case that the users are heterogeneous in terms of the number of trips they make on different transportation modes. The disutility of each user j for subscribing to the MaaS bundle or using each mode separately are similarly defined as

$$U_b^j = f_b + \sum_m f_m max(0, n_m^j - n_m^b), \tag{13}$$

$$U_s^j = \sum_m f_m n_m^j + \beta. \tag{14}$$

From the total population, denoted by $\hat{\lambda}$, only those who experience a lower disutility from MaaS subscription would join the service, and the number of MaaS users can be written as:

$$\lambda = \hat{\lambda} \cdot \text{Probability}\{U_b^j \leq U_s^j\} = \hat{\lambda} \cdot \text{Probability}\{U_b^j - U_s^j \leq 0\}. \tag{15}$$

Therefore, the MaaS operator maximizes its profit by choosing the subscription fee and bundle assortment using the following mathematical model

$$\max_{n_m^b, f_b} \pi_3 = \lambda \left(f_b - \sum_m \sum_{j|U_b^j \leq U_s^j} f_m \cdot min(n_m^j, n_m^b) \right), \tag{16a}$$

$$\text{s.t. } \lambda = \hat{\lambda} \cdot \text{Probability}\{U_b^j - U_s^j \leq 0\}, \tag{16b}$$

$$f_b \leq \alpha \sum_m f_m n_m^b, \tag{16c}$$

For analytical tractability, we assume that the disutilities of MaaS subscription and using each mode separately follow uniform distributions with domain $[0,1]$. We later relax this assumption in the numerical experiments section where we use probability density functions for the number of trips that users made. For uniform disutility distribution functions, the subtraction $U_b^j - U_s^j$ is a triangular distribution with parameters $a = -1, b = 1, c = 0$. Therefore, we have

$$\pi_3^* = \frac{\hat{\lambda}\beta}{2}. \tag{17}$$

Moreover, for normal disutility distribution functions of $U_b^j \sim \mathcal{N}(0,1)$ and $U_s^j \sim \mathcal{N}(0,1)$, the subtraction $U_b^j - U_s^j$ is a normal distribution $\mathcal{N}(0,2)$, and $\lambda \leq \frac{\hat{\lambda}}{2}$.

• *Insight 4:* The market share of MaaS is at most 50%, and at most half of the users subscribe to MaaS bundles if the disutilities of subscribing to MaaS and pay to each mode separately follow

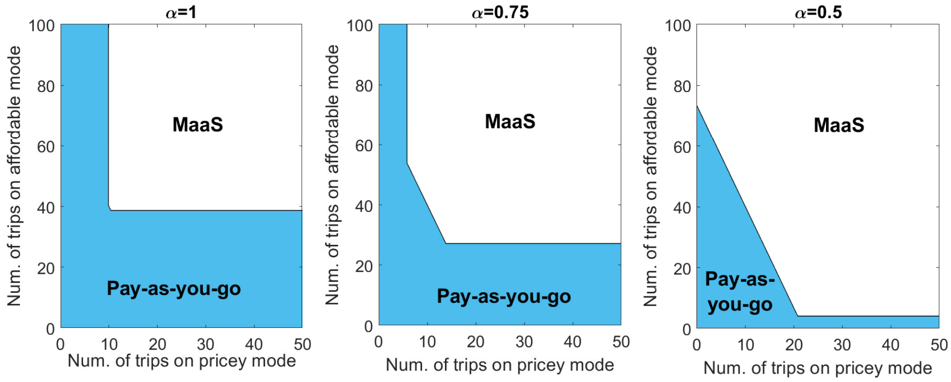

Figure 1: Dominant service for different travel needs and discount levels.

uniform distributions with domain $[0,1]$ or normal distributions. This result is also consistent with the findings of Ho et al., 2018, Ho et al., 2020, and Vij, Ryan, Sampson, & Harris, 2020 in which almost half of the survey respondents state their willingness for subscribing to MaaS bundles.

3. Numerical experiments

This section provides numerical experiments to confirm the analytical insights. We first assume that the MaaS operator provides only one bundle which is designed based on the average travel needs of users. Users on average use an affordable mode such as public transportation 40 times per month and it costs 3€ per trip. They also use a pricey mode such as ride-sourcing 10 times per month and it costs 10€ per trip. The discomfort cost of separate payment is 5€. The MaaS operator considers three levels of price discount of $\alpha = 1$, $\alpha = 0.75$, and $\alpha = 0.5$. Using model (3), the MaaS monthly subscription fee is 225€, and the assortment of the optimal bundle (number of trips allowed on affordable and pricey modes) for the three levels of price discount is (40,10), (54,14), and (81,21), respectively. Figure 1 depicts the dominant space for different travel needs on the two transportation modes. It can be seen that users, whose travel needs are greater than the average, experience a lower disutility from subscribing to MaaS and would become MaaS users. This figure also shows that when the MaaS operator offers a higher discount ($\alpha = 0.5$), users with lower travel needs on the two transportation modes would also become MaaS subscribers. Moreover, this figure depicts that when the MaaS operator provides a high discount and offers 81 and 21 trips using affordable and pricey modes, respectively, users who mostly use pricey mode (more than 21 trips per month), while not traveling much on affordable mode (4 trips per month) would become MaaS subscribers to benefit from this discount. This might lead to a modal shift to affordable mode as observed in MaaS trials (Strömberg, Rexfelt, Karlsson, & Sochor, 2016; Sochor, Strömberg, & Karlsson, 2014) where MaaS subscribers used other transportation modes that were included in their bundle.

Then, we move on to the scenario in which the MaaS operator provides two bundles. The average travel needs of high- and low-value users on affordable mode and pricey mode per month are (20,40) and (60,10), respectively. We assume that the discomfort cost of separate payment for high- and low-value users are 10€ and 5€. The MaaS operator considers no discount for high-value users ($\alpha^h = 1$), and two discount levels $\alpha^l = 1$ and $\alpha^l = 0.7$ for low-value users. Using model (9), the subscription fees for high- and low-value MaaS bundles are 470€ and 285€, respectively. The high-value bundle consists of 60 trips on the affordable mode and 40 trips on the pricey mode. The low-value bundle provides 21.5 trips on pricey mode for both price discount levels, and 60 trips on affordable mode for $\alpha^l = 1$ and 64 trips for $\alpha^l = 0.7$. Figure 2 depicts the dominant space for different travel needs on the two transportation modes. It shows that users with a high number of trips on both modes would switch from the high-value bundle to the low-value bundle to benefit from the provided discount.

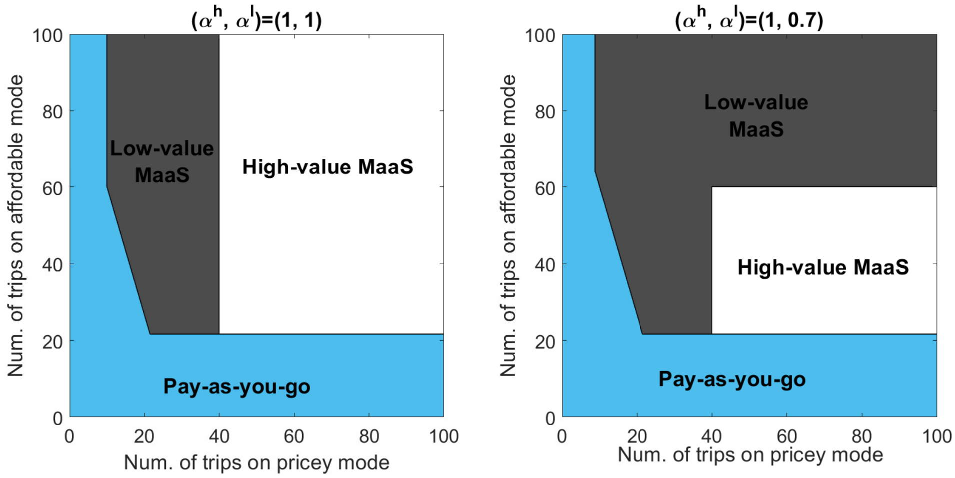

Figure 2: Dominant service for different travel needs and discount levels.

Finally, we consider the case that each user has different travel needs on the affordable and pricey mode, and the MaaS operator designs the bundle considering the travel needs of all users using model (16). The following process intends to validate the analytical insights in more realistic settings with fewer assumptions. Therefore, we have kept the process as simple as possible. The approach is a heuristic model that finds near-optimal bundle design using a genetic algorithm and in a simulation. We assume there are 1000 users, and the number of trips each user makes per month is uniformly distributed between 20 and 100 trips. These trips are done either using the affordable mode or the pricey mode. We generate another uniformly distributed number between 0 and 1 to find the number of trips made using each mode. We simulate this process 100 times and report the results of them. We consider the affordable mode such as public transportation or bike-sharing costs 3€ per trip, and the pricey mode such as car-sharing or taxi costs 10€ per trip. The discomfort cost of separate payment is 5€. The MaaS operator considers three levels of price discount of $\alpha = 1$, $\alpha = 0.75$, and $\alpha = 0.5$. Figure 3 shows the number of users who experience a lower disutility from MaaS and subscribe to the offered bundle for the 100 simulations. It shows that in all cases the number of MaaS users is less than 300, which is consistent with *insight 5* that states the market share of MaaS is less than 50%. Also, the results show that for all price discounts the average number of MaaS subscribers is around 12.5% of the users, which is consistent with the result of Caiati, Rasouli, & Timmermans, 2020 stating the MaaS market share to be around 17% conducting a stated preference survey.

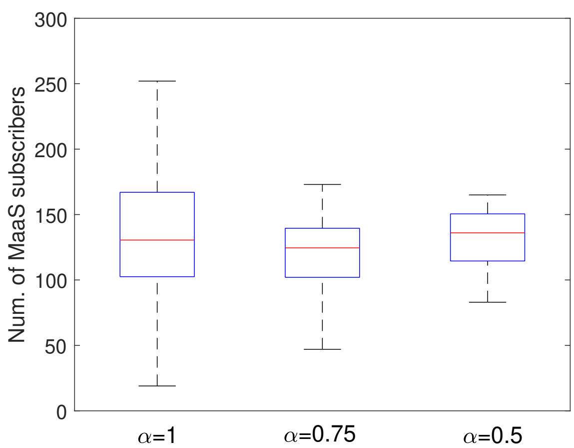

Figure 3: The number of MaaS subscribers.

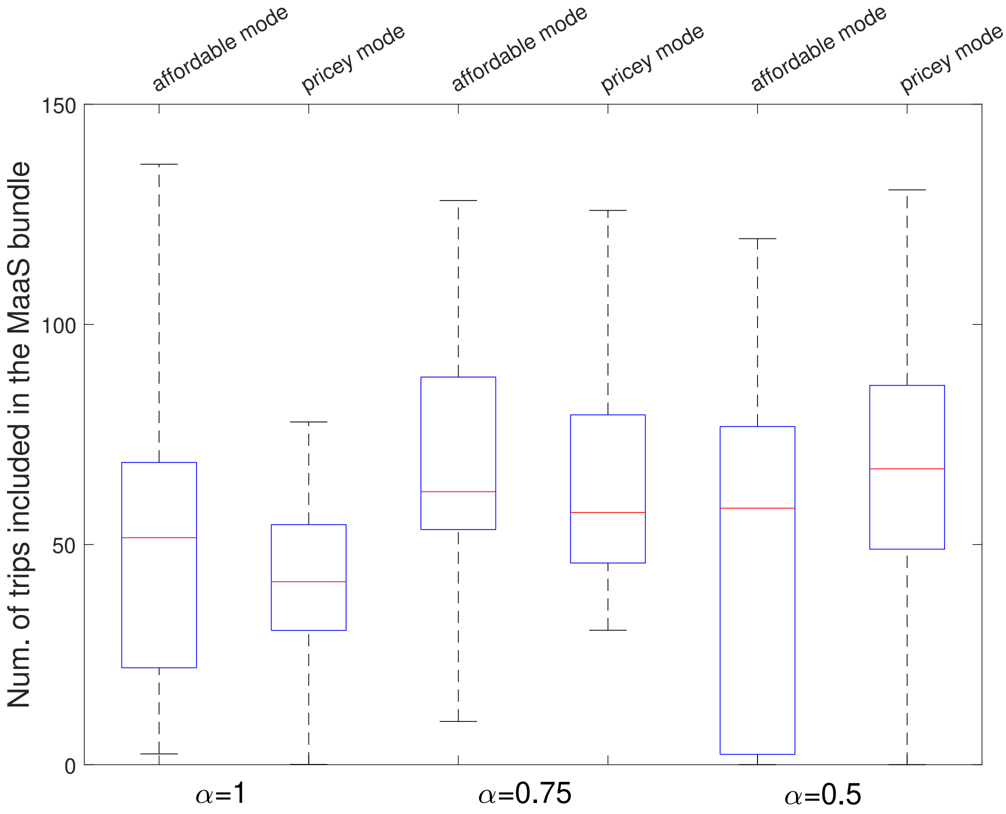

Figure 4: MaaS bundle assortment.

Moreover, Figure 4 shows the number of trips on affordable and pricey modes offered in the MaaS bundle. We can see that when the discount level changes from 1 to 0.5, the MaaS operator offers more trips on the pricey mode in the bundle. This happens because the pricey mode is more expensive and the discount increases the value of the bundle in comparison to the pay-as-you-go option.

4. Conclusions

Mobility as a service is becoming prevalent around the globe, and it can lead to environmental sustainability and transportation equity. However, the existing trials show that the market share of MaaS is not considerable and operating it is not economically sustainable, which necessitates the investigation of optimal bundle assortment and pricing. The primary contribution of this work is providing a foundation for investigating and optimizing MaaS bundles. We develop a stylized model which considers the disutility of paying for different transportation modes separately or subscribing to a MaaS bundle to find the optimal assortment of the MaaS bundle and its monthly subscription fee. We analytically show that the optimal MaaS bundle should offer at least trips equal to the needs of users on each transportation mode. We also show that the profit of the MaaS operator is limited if it cannot buy the trips from service providers with discounts as the discomfort of paying to different providers is decreasing due to the proliferation of new payment methods such as using credit cards or apps. We also show that the MaaS market share is at most 50%, and the majority of users still prefer to pay for their travel needs as they go.

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