A UTILITY-BASED MODEL FOR THE EVALUATION OF “MOBILITY AS A SERVICE” APPLICATIONS

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ABSTRACT

Mobility-as-a-Service (MaaS) can be summarized as a move away from a world dominated by a need to personally own a primary mode of transportation (typically, a car) and towards a world where the travelling public utilize mobility solutions via a service model. At its core, MaaS combines transportation services from public and private providers through a unified gateway that handles individual door-to-door trips, managing all stages of their creation and implementation (planning, payment, real-time monitoring, etc.). By providing tailored solutions to individual users according to their needs and those of the system as a whole, MaaS enables not only more efficient usage of transport infrastructure, but also a better customer experience. The paper reviews a developed utility model to analyze a set of sub-optimal trips to compare the utility of generally accepted trip routes to the utility of a MaaS-suggested trip. The utility of a trip is calculated based on a set of factors that an individual user considers when selecting a trip route. Ultimately, the study shows that a MaaS application can add significant utility on top of a traditional journey planner by optimizing a trip based on user-response preferences for transit factors such as convenience, carbon emissions, and reliability, and integrating local, third party private transportation providers.

1 INTRODUCTION

Transport is at the heart of the development of urban regions, as the advantages in carrying out economic activities in proximity (often called "economies of agglomeration") justify the very existence of cities. However, providing an efficient transport system in a city to enable the smooth mobility of people and goods does not come without a cost. In many cities today the existing transport infrastructure cannot cope with the relentless increase in demand, and the continuous rise of urban population from the demand side, combined with inefficiency in the provision of adequate service from the supply side, has rendered many transport systems obsolete. This affects not only the economic aspects of city life but also the quality of life of the residents. Cities today face a number of problems, including congestion, pollution and accidents, which result from their own contradictory objectives of providing efficient transport to meet the growing demand, while ensuring sustainability and a high standard of living (1). It has also been shown that multi-modal transportation options on multiple providers requiring the rider to pay separately for each leg of a trip deters users. Evidence shows that where multiple agencies can be accessed with one transit account, the use of public transportation has increased. It is clear that providing solutions to these problems is a complex task, requiring planners to think "outside the box" in order to adequately address them.

A concept that has been gaining global traction as a new and viable solution to transport problems is "Mobility as a Service" (MaaS), facilitated by recent technological developments in the field of Information and Communication Technology (ICT). At its core, MaaS combines transportation services from public and private providers (public transit, ride-sharing, bike-sharing, autonomous vehicles, parking, etc.) through a unified gateway that handles individual door-to-door trips, managing all stages of creation and implementation. By providing tailored solutions to individual users according to both their needs and those of the system as a whole, MaaS enables more efficient transport infrastructure utilization, as well as better customer experience. Through this feature, MaaS contrasts with existing “conventional” approaches by offering a much more holistic approach to addressing the transport needs of cities and their residents. Although there are varying interpretations of what MaaS means and how it can be achieved, the objective in every case is the same – to join up multi-modal journeys and optimise the capacity of all modes. This is managed by combining transportation services from public and private mobility providers through a single, unified gateway that creates and manages the trip, all of which is paid for via a single account. Although it is common to find MaaS described in subscription terms (that is to say, emphasising the payment model as the core of the concept), this is in fact somewhat limiting, since how exactly a user pays for their service is largely irrelevant when considering the effectiveness of the MaaS approach. The more critical element that must underpin all MaaS ecosystems is the single account, covering all modes across a city or region. Multi-modal single accounts already exist in the public transit sphere (e.g. Oyster in London and Ventra in Chicago) – what is required is for their applicability to be extended across all modes of travel.

However, every new product concept takes a number of years for the relevant market to form, and MaaS is no exception. Indeed, having been conceived very recently, the MaaS concept continues to take many different forms, and despite a number of studies having highlighted the value of MaaS for authorities and travelers alike at the conceptual level, there is still a prevailing confusion and a lack of consensus among thought leaders, organizations and end-users as to the exact scope, definition and benefit of MaaS. The lack of a large enough sample of real-life applications and practical examples (and correspondingly of a knowledge base of “lessons learnt”) contributes to this confusion and currently acts as a hurdle to the wider implementation of MaaS by authorities and service providers as well as the adoption by consumers.

The aim of this study is to provide a further insight into MaaS by developing and applying a utility-based model for the evaluation of MaaS applications. Focusing on the perspective of the user, the model is intended to calculate the utility of traveling on existing modes of transportation (and fixed combinations thereof) in major cities and compare it with the expected utility benefit drawn when using a MaaS solution instead. In this way, the model facilitates assessment of what extent key user and city needs are addressed by the existing transportation options in a specific city, as well as estimating how well these needs could be provided for by proposed MaaS solutions. The model calibration is performed on the basis of user survey data, while validation is carried out by means of expert knowledge relating to a number of specific example scenarios in the city of San Francisco, California, USA. Indeed, it is often the case that efficient non-obvious route and mode combinations are intuitively known and regularly used by “expert” travelers (e.g. commuters), but are not identified by existing mobility planning services, such as journey planning tools, who instead provide sub-optimal mobility guidance. Since the very nature of MaaS applications means that these options would be identified due to better service integration, such scenarios present an excellent platform for the application and validation of the proposed model.

The present paper is structured as follows: Section 2 presents the background of the study, focusing on the topic of MaaS and reviewing previous related work. Section 3 then goes on to present the methodology for calculating the utility of traveling on different modes of transport and to describe the resulting model for evaluating the impacts of MaaS applications. Section 4 applies the methodology and the model introduced to a number of example scenarios in order to demonstrate the accuracy and applicability of the method. Section 5 concludes the paper and identifies possible areas of future research.

2 BACKGROUND OF MOBILITY AS A SERVICE

Kamargianni et al (2) defined the term "MaaS" as the novel business model through which consumers purchase mobility services, as opposed to the traditional model where they purchase transport means (e.g. vehicles, tolls, tickets, etc.). More specifically, MaaS systems enable consumers to buy and use different services for their travel needs, which may be supplied by one or more operators, but using just one common platform and making a single payment. Such an integrated platform offers a number of functionalities, including: multimodal journey planning (offering itineraries involving combinations of different transit modes); booking the use of specific modes at specific times, hence guaranteeing availability (e.g. train and bus seats, parking spaces, shared bicycles, etc.); paying for the services purchased through an integrated method (i.e. a single payment for all modes used); and providing real-time information about any events or other factors that may affect the trip. MaaS may be offered on a pay-as-you-go basis or as part of mobility packages, hence providing seamless door-to-door mobility and improving the overall travel experience.

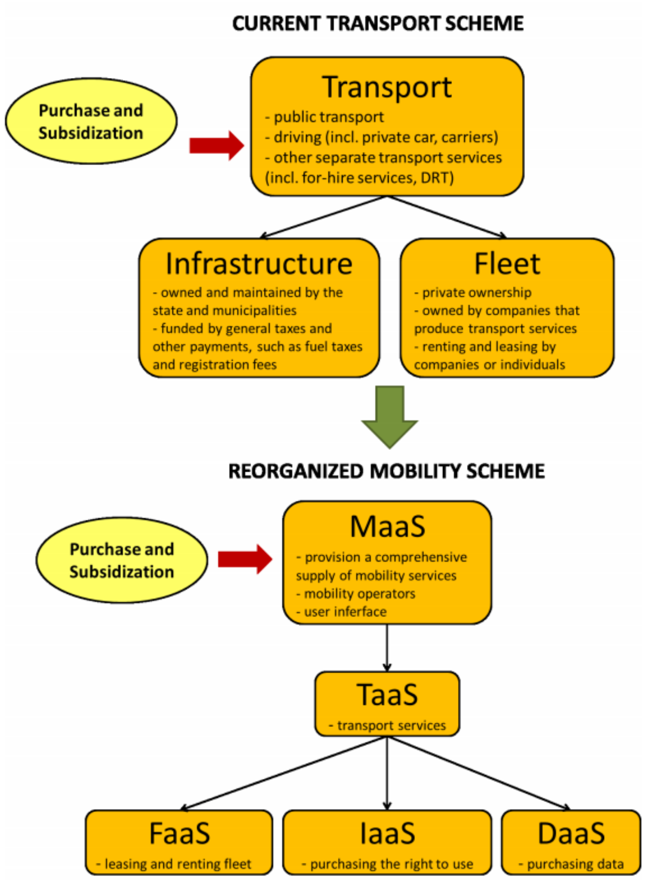


FIGURE 1: MaaS as part of a systemic change in the provision of transport services (3)

The concept of MaaS was first introduced by Heikkilä (3), who, using the example of the city of Helsinki, Finland, identified MaaS as the product of the systemic change that is to occur in the transport sector by the year 2025. Conceptualizing the organization of transport service provision (Figure 1), the current state is that the consumer purchases and uses individual transport service components on offer, which rely on the provision of certain infrastructure components and certain fleet-related components. The systemic change, however, sees MaaS being inserted as an additional top layer to the organizational structure, providing the, currently absent, user interface of the transport services. At the same time, the transport services layer is transformed to a "Transport as a Service"

(TaaS) level, where transport providers produce services, but instead of selling them directly to consumers as divergent and originally separate products, they sell them to mobility operators in the MaaS layer, who bundle them into service packages that are tailored and more easily accessible to consumers. The TaaS layer, though, still requires the use of infrastructure and fleet, and given technological developments which enable the provision of continuously advanced services, a third component is added to the lowest level of the organization – data. The fact that there are already companies that specialize in fields like “big data” shows the importance of this component. And in analogy to MaaS and TaaS, the lowest layer of the organization now sees the “Infrastructure as a Service” (IaaS), “Fleet as a Service” (FaaS) and “Data as a Service” (DaaS) components added.

The concept of MaaS has gained widespread interest and publicity among public sector and industry stakeholders around the world, and has motivated a number of initiatives, the most prominent of which has been the founding of the MaaS Alliance (4) in Europe in 2015. The MaaS Alliance has been formed as a public-private partnership with the mission of creating a common approach to MaaS so as to “unlock the economies of scale needed for successfully implementing MaaS”, focusing initially on Europe but also looking beyond. Topics tackled by the MaaS Alliance include: defining business rules so as to establish a single MaaS market; mapping the end-user perspective (economic sustainability, social inclusion, environmental aspects etc.); providing guidelines with respect to setting the appropriate legal framework, and tackling technical issues (such as open data, standards, multivendor capability etc.).

But apart from the conceptual level, a number of real-life applications of transport service integration have been developed in recent years, and further ones have been planned, demonstrating that MaaS is, indeed, gradually becoming reality. A comprehensive review of such applications is given in (2), but a few notable ones worth mentioning here are the:

- Hannovermobil 2.0 scheme in Hannover, Germany (5-6), which integrates public transit, car sharing, taxi, long-distance rail and car rental, offering exclusive discounted fares and usage fees to customers with long-period travel passes, as well as integrated billing;
- EMMA card scheme in Montpellier, France (7), which offers tailored mobility “contracts” and payment structures to regular travelers in the city with respect to public transit, bike-sharing, and car and bicycle parking;
- Moovel scheme in Germany (8-9), which offers nationwide journey planning, booking and payment functionalities via a single smartphone platform covering public transit, car sharing, car rental, national rail, bike sharing and taxi, all of which are provided by separate operators such as Car2go, Nextbike and Deutsche Bahn (10); and
- UbiGo system in Gothenburg, Sweden (11-13), which fosters the cooperation of several different providers and operators in the city, such as public transit (Västtraffik), car sharing (Sunfleet), car rental (Hertz), taxi (TaxiKurir) and bike-sharing (JCDecaux), to offer an ICT, payment and ticketing integrated service, combining everything in a single application (even the cars can be opened and accessed with the app), as well as tailored monthly packages for individual households.

Further MaaS implementations are at their planning stage, the most prominent of which are the “Helsinki Model” proposed by Heikkilä (3) as a result of her work on the conceptualization of MaaS, and the “MaaS-London” proposal, as introduced by Kamargianni et al (2). With respect to the former, the aim is to develop an open market model based on brand cooperation, foreseeing the provision of pre-purchasable and pre-constructed mobility packages to users, each of which can be tailored towards a specific socio-demographic group (such as families, commuters, businesses etc.), facilitated through integrated ICT, ticketing and payment functionalities. As it concerns the latter, the goal is to integrate a variety of functions, such as registration and package selection, intermodal journey planning, booking, smart ticketing and payment, into a centralized platform, with the most outstanding feature being the provision of mobility packages, which consist of tailored bundles of mobility services customized to individual needs. It is foreseen that in both schemes operators and travelers alike will benefit as a result of more efficient mobility offerings in their respective cities.

Building on the results of the conceptual studies and the few applications so far, the present study develops a methodology and model to evaluate the benefits of MaaS applications from the user perspective and applies it to a set of real-life travel scenarios.

3 UTILITY-BASED EVALUATION METHODOLOGY AND MODEL

One feature of MaaS is that, as an application, it is able to analyze a trip and provide the most optimal method of travel according to the user's needs. This may be the same route and mode combination that a conventional mobility planning tool would offer, but could also be a more optimized trip based on the specific set of a user's needs, which "traditional" existing tools may not be able to identify. Once a specific route and mode combination is accepted, MaaS applications can provide the user with the ability to manage, book, and monitor the trip, and suggest changes in case the user's needs are no longer met for any reason. The purpose of the proposed utility-based model is to act as the analytical engine that quantifies how well a travel option matches a user's needs, and consequently suggests a journey plan that yields the highest utility for the user.

3.1 Definitions and assumptions

A number of terms need to be defined prior to introducing the model. First, the term *utility* is used to express a measure of preference by a traveler over some set of goods and services. Utility is made up of nine *sub-utility factors*, which are the most important conceptual component of this study. In order to understand the value of a trip, the study assesses what the most traditionally important factors are when a user makes a trip decision. To assess which factors should fall in this list, each factor is assessed individually to understand the impact it has on a consumer's decision. The original list has been collated through conducted research and survey validation through a small sample size study conducted in San Francisco to assess travel behaviors across the bay area transportation network. These factors are then given a *Weighted Importance*, which defines the average user's personal preference that he or she associates to that factor for a trip:

TABLE 1: Sub-Utility Factors and Weighted Importance in Measuring Utility

Sub-Utility Factor	**Definition**	**Weighted Importance (14)**
Cost	Cost has a strong negative correlation with trip utility. As the trip cost increases, rational thought dictates that trip utility decreases. Another way to conceptualize this is to assume that consumers would be willing to take the cheapest – or free – trip available to them, all else equal.	0.38
Time	Time has a strong negative correlation with trip utility. As time spent on the trip increases, rational thought dictates that trip utility decreases. This is shown through real estate values as several studies indicate that real estate properties, on average, maintain a higher value when closer to major transportation hubs, which reduces commute time.	0.50
Convenience	Convenience is defined as the flexibility and functionality provided by a mode of transport. For example, public transportation riders benefit from simply paying for a trip rather than owning the responsibilities of a private vehicle. However, the convenience of a private vehicle, such as being able to transport large items or multiple people can be beneficial.	0.67
Carbon Footprint	Carbon footprint impact is still developing into a decision changing factor. While the United States has had	0.23

Sub-Utility Factor	Definition	Weighted Importance (14)
	growing demand for electric vehicles, the country has shown less interest in achieving higher MPG relative to other countries in Europe and Asia as shown in MPG future targets (17). Nonetheless, consumers continue to be interested in understanding the impact of their carbon footprint and how it can be reduced.	
Safety	While all travelers consider safety as a critical choice in their daily travel habits, data suggests that it's not a primary factor in their travel decision (18). This is evidenced by the popularity of private vehicles when compared to public transportation despite public transportation being considerably safer than driving.	0.16
Reliability	Reliability has a strong positive correlation with trip utility. Trip reliability can be defined as the ability for a transport mode to be relied upon on a frequent enough basis that consumers can predict the trip outcome. As reliability increases, consumers are more willing to forego other factors such as cost or comfort. For example, some fixed transit systems are more reliable than others, thus increasing the service demand in that area.	0.45
Quality	Trip quality is defined as the perceived standard or degree of excellence. In public transportation, an unkempt bus or unusually loud subway can reduce the overall trip quality. Alternatively, owning an old vehicle or driving on roads with frequent potholes can also reduce the overall trip quality.	0.36
Comfort	Comfort is defined as the trip's ability to provide additional value or benefit other than simply moving you from origin to destination. For example, public transportation benefits from not having to focus on driving. Newer modes of transit also enable connectivity, food, or more comfortable seating. However, public transportation can become congested as well, which reduces perceived comfort. Private vehicles provide sustained, guaranteed personal comfort, but require focus, attention, and potential traffic congestion.	0.33
Convenient Location	Convenient location is defined as ease of access for transportation. Private vehicles traditionally score very well as most private vehicles are within a short distance of the passenger. However, in more urban environments such as San Francisco, the opposite may take effect in that private vehicles may be parked further away.	0.58

Each of these factors can be assessed at an individual level to understand what the Weighted Importance should be. For example, a consumer living in downtown San Francisco might prefer carbon footprint impact at the lowest cost possible, and therefore rely on public transportation at the expense of other factors such as comfort. However, a consumer living in the suburbs may prefer the quality and comfort of a private vehicle at the expense of cost. In order to assess this, an in-depth conjoint analysis study must be performed to assess the impact of each factor against the other factors. This would enable the model to react to different behaviors at the user level. In this study, these are derived from HNTB's America Thinks National Public Transportation Survey (14) and are provided in Table 1 above.

Utility is also related to the *utility score* (US), which is a quantitative measurement of the market's perceived utility for a mode of transportation. The *raw sub-utility score* is defined as the raw score calculated for each sub-utility factor. Once multiplied against the Weighted Importance, the *sub-utility scores* can be aggregated into a total utility score. Finally, *sub-optimal trip* is a trip that a consumer may take out of habit or because conventional mobility planning tools are recommending it, but is not the trip with the maximum utility based on their individual user needs.

A few key assumptions for the model can be made. First, it is assumed that a traveler in a "perfect" transportation network would experience equal utility across each mode, such that they are presented with a set of equal choices to choose from when making a decision; this may not be the case in reality due to external factors, market friction and lack of information, so some modes may provide better utility than others. Then, the additional benefits of a MaaS application, such as integrated payment, transit subscription plans, journey planning and other services related to an individual's trip are not measured; investments or sunk costs in certain modes are also not considered (e.g. subscription to an annual bike-sharing membership or private vehicle ownership). Finally, if the "traditional" transit option is already the optimal choice, this would also be identified by a MaaS application, and so the minimal utility provided by a MaaS application transit option should be equal to or greater than the optimal "traditional" transit option.

3.2 Model formulation

The model proceeds by calculating a utility score for any route and mode option considered, whether "traditional" or MaaS-related. The utility score can be viewed as a theoretical score based on the modal choices available to a user, combined with the sub-utility factors listed in the previous sub-section. The utility score can be calculated in one of two ways, based on the immediate control that users have over the factors used to make a trip decision. For example, users are not able to define how long a trip will take using a certain travel mode relative to the rest of the region and travel modes, whereas the user can define how comfortable or convenient a trip is: As described in the previous section, for some utilities, a negative linear correlation can be assumed between the utility of a transit option and a factor of that utility. Therefore shorter trips have a higher sub-utility score based on the utility towards the end consumer, while longer trips score lower. By assuming a simplified linear correlation of -1 between the yielded sub-utility and factor, the focus is placed on the impact that the factor would, at minimum, have on the overall trip utility:

$$y = mx + b$$

where y = raw sub-utility score, x = the factor's represented value such as time in minutes or cost of ticket, m = slope of -1 representing the correlation between the trip factor's value *(x)* and its utility *(y)*, and b = y-intercept. The linear equation requires a single set of coordinates, represented by a sub-utility score value and its associated raw sub-utility score. In order to assess the utility of factors that have a strong, negative correlation, the model calculates the average factor value *(x coordinate)* and receives a sub-utility score *(y coordinate)* of 5. The model then compares actual trip factor values against the region's average factor value. For example, the model calculates average commute time to be 4 minutes per mile in San Francisco. A trip that provides an average commute time of less than 4 minutes per mile would then receive a sub-utility score of greater than 5. When determining these factors, the type of transit must be considered for model practicality purposes. For example, for long distance trips, the model takes car rental/private vehicle costs into consideration. Once b is solved for a particular trip's linear equation, the equation is set to solve for the y coordinate (raw utility score) based on the input of the x coordinate (sub-utility score).

The raw sub-utility scores for the remaining factors are, then, user-driven and, in a practical application, should reflect each user's specific requirements. The relevant scores can be set by individual travelers to match their preferences for specific trips (e.g. rating safety as more important that convenience), or they can be determined on the basis of consensus among experts (e.g. through the Delphi method), or can be the result of surveys with large numbers of relevant respondents. For the study, users were surveyed on how they would rate each factor within the traditional trip compared to a MaaS-based trip. For example, users generally preferred the convenience and comfort factors of a ride-share vehicle compared to a subway train ride, thus scoring ride-sharing higher than trip legs that included subway rides. The raw sub-utility scores for each sub-utility factor are then weighted according to the Weighted Importance factors defined in the HNTB study. Specifically, the Weighted Importance value is taken based on the percentage of respondents rating the importance of each factor in their overall trip decision making process in the survey; for example, 38% of respondents in the survey rated cost as important in their overall decisions. Therefore, the model assumes that the Weighted Importance of cost is .38. Effectively, the model assumes that the national survey conducted by HNTB validates the analysis and impact of each factor within its survey. This provides a baseline assumption of each factor's impact on a consumer's decision for a transit trip, and thus, the overall utility score. With an expanded scope, future studies can analyze preferences at a user level before aggregating to a regional level. An ideal application would provide each user the flexibility of adjusting each factor's importance in an intelligent manner.

The sub-utility score for each factor above is calculated by taking the product of the raw sub-utility score for each factor and its Weighted Importance. The sub-utility scores for the nine factors are then aggregated into one total utility score as shown in the total Utility Score equation below:

$$\sum_{i=Sub\ Utility\ Factor}^{9} (\boldsymbol{Weighted\ Importance_i * Raw\ Sub\text{-}Utility\ Score_i})$$

4 MODEL APPLICATION AND VALIDATION

In this study, the utility model demonstrates the added value of a MaaS application when compared to a traditional transit decision-making application. In a commercial setting, the model can immediately be used as an outreach tool that will enable transit agencies to educate consumers on their transit options. The utility model can also be modified to analyze the effects of transport demand in a given region, and even enable dynamic pricing based on supply and demand of all modes of transportation – as opposed to just public transit. Such dynamic pricing is already in use by companies such as Uber and Lyft. By studying consumer data on preferred habits, transit agencies can partner with local transit providers or other service providers to help manage and re-route demand to assist over-stressed portions of a transportation network – by interacting directly with the consumer. Trip behavior factors were researched and validated through a 15-person survey conducted with San Francisco Bay Area residents. The survey displayed similar results to the national survey used to drive the Weighted Factoring, however, may have been skewed by homogenous demographics of the survey participants. Therefore, the model, in its current form, utilizes the national survey to drive the Weighted Importance values.

4.1 Study area description

There were a number of prospective cities that the team validated in order to pick the most appropriate study area. The selected region had to pass a number of requirements such as high transit usage, a diverse population, multiple modes of transportation, and regional cost pressures. While each city showed strong factors as a study area, we limited our selection to San Francisco, selected in large part due to the availability of public transport survey results and feedback.

The San Francisco Bay Area has a highly dense and diverse population with strong tourism levels. The local economy has also enabled San Francisco to develop into a “tech capital” with a very high median salary. However, a large portion of the San Francisco population still falls on the lower end of the socio-economic spectrum and relies heavily on the public transportation network. Finally, demand for the existing public transportation network often exceeds capacity, reaching 160% during peak hours (15).
These factors, among others, cause the San Francisco population to rely heavily on different transportation options, with more than 50% of trips taken using modes other than private vehicles (16). This enables the model and application to take advantage of multiple transportation sources to connect and pull data when developing the optimal trip for the user, thus framing San Francisco as an excellent case study to adopt a MaaS solution.

4.2 Scenario definition

Scenarios are defined as special cases in which we believe that MaaS can provide a more optimal trip than the traditionally defined trip scenario in the form of added utility over the traditional transit method. This is called a “sub-optimal trip”. These trips replicate real-life situations in which the traditional route may not be the most appropriate. Sub-optimal trips were defined via input from San Francisco commuters as well as research done using traditional journey planning methods in areas known for having limited transit data. Table 2 defines each of the tested sub-optimal trips:

TABLE 2: Sub-Optimal Trips

Trip #	City	Trip Type	Origin	End	Transit Type
SOT 1	San Francisco	Tourist Trip	Hyatt Hotel Emeryville	Fox Theater	Public/Private Shared
SOT 2	San Francisco	Standard Trip	Yoshi's Oakland	Embarcadero Station, San Francisco, CA	Public
SOT 3	San Francisco	Multi Leg Trip	Hillstone Restaurant	AT&T Park to University of San Francisco	Public/Private Shared
SOT 4	San Francisco	Standard Trip	AT&T Park	Palace of Fine Arts	Public/Private Shared
SOT 5	San Francisco	Long Distance Trip	Embarcadero Station	Robert Mondavi Winery	Public/Private Shared

As seen in Table 2, sub-optimal trips can occur in daily, weekend, and even tourist commutes. These trips are hypothesized to be sub-optimal because the traditional trip yields a lower utility than a MaaS trip is hypothesized to yield. Generally, lower utility is caused by over-stressed transit systems reducing the quality of the ride, lack of integrated journey planning information from other transit options, or even inaccurate data presented by journey planning applications. In SOT 1, until recent integration of ride sharing into traditional journey planning applications, the described trip would take three times longer than simply driving to the location. Today, the traditional journey planner offers a ride-sharing option for a nominal fee, which enables users a car-free, but faster transit option. However, during research, a free transit option in the form of a shuttle was uncovered that reduces the traditional travel time by 40% when using the public transit option combined with the free option.

This option does not currently display on traditional journey planning applications. In SOT 2, the traditional trip is impacted by subways that provide a more direct route, but are delayed and overcrowded, forcing users to experience a lower quality ride or even skip the subway until a less crowded one appears. Finally, SOT 3-5 depict sub-optimal trips that do not accurately represent reliability and quality factors in a traditional journey planner and do not provide the most optimal route, which would be uncovered by a MaaS application that is better integrated into local transit options such as bike sharing.

4.3 Application results and model validation

After performing testing on sub-optimal trip scenarios, it was found that 83% of the studied scenarios, MaaS trips had a clear utility advantage over the traditional travel route, with 50% of total trips having a significant utility advantage (significant advantage defined as anything greater than a 10% increase in utility). In fact, where MaaS trips yielded an incremental utility advantage, overall utility increased by an average of 12%. For MaaS trips that yielded a significant utility advantage, overall utility increased by an average of 20%. Table 3 shows the Adjusted Utility scores, which take total utility scores and displays it on a normalized scale of 0-100, with the goal of logically quantifying the impact that Mobility as a Service had on optimizing the tested trips.

TABLE 3: Sub-Optimal Trip Utility Model Test Results

Trip #	Origin	End	Adjusted Traditional Score	Adjusted MaaS Score	Adjusted Incremental Utility Increase of MaaS over Traditional Trip	% Increase
SOT 1	Hyatt Hotel Emeryville	Fox Theater	85.05	58.00	-27.04	-32%
SOT 2	Yoshi's Oakland	Embarcadero Station, San Francisco, CA	71.76	75.05	3.29	5%
SOT 3	Hillstone Restaurant	AT&T Park to University of San Francisco	39.67	50.73	11.05	28%
SOT 4	AT&T Park	Palace of Fine Arts	44.55	53.65	9.10	20%
SOT 5	Embarcadero Station	Robert Mondavi Winery	65.10	67.62	2.52	4%

Figures 2, 3, and 4 compare the traditional routes against the MaaS-suggested route for sub-optimal trips with a significant utility advantage (greater than 10% increased efficiency).

FIGURE 2: SOT 3

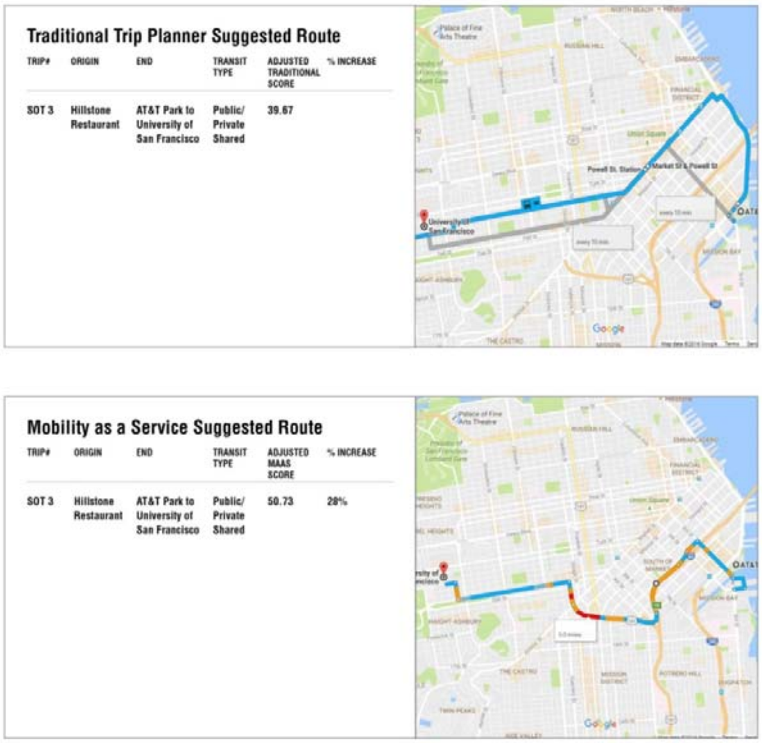
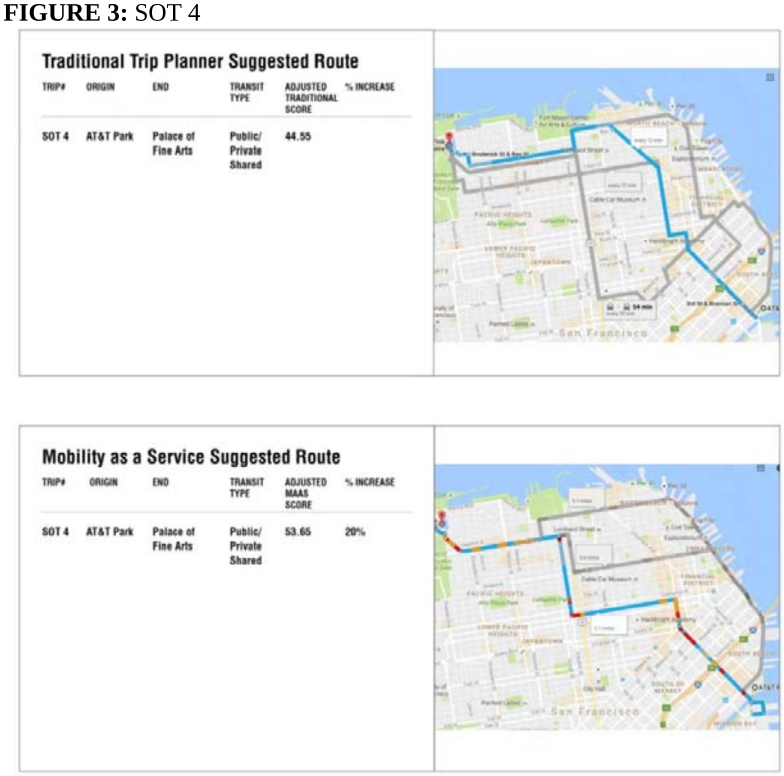


FIGURE 3: SOT 4



Validation

Validation is required in two areas:

1. Validating national survey assumptions regarding the importance of each factor in relation to one another when the consumer makes their transit decision. This is determined by administering a survey to a random group of 15 San Francisco commuters. Their responses are then compared to the national survey results in order to understand the variance between the assumed national Weighted Importance of each factor against the local Weighted Importance. Overall results and variance are shown in Table 4 below:

TABLE 4: Variance in Local vs. National Weighted Importance

Weighted Importance			
Factor	***National Survey***	***San Francisco Survey***	***Absolute Variance***
Cost	38%	45%	7%
Time	50%	55%	5%
Convenience and Comfort	67%	55%	12%
Carbon Footprint	23%	27%	4%
Safety	16%	36%	20%
Reliability	45%	36%	9%
Quality	36%	45%	9%
Convenient Location	58%	55%	3%

As depicted in the graph above, almost all factors are within a 10% variance in assumed factor importance when compared at a national level and at city level, with convenience showing a slightly higher than average variance. The only category that may need to be reviewed in the model is safety, with San Francisco commuters placing more emphasis on safety than at the national level.

2. Validating output decisions by a MaaS application for a consumer to determine whether the suggested trip is more favorable than the traditional, sub-optimal trip. This was determined by interviewing a sample of San Francisco commuters on their transit decision for sub-optimal trips compared to the MaaS-suggested trip. The ideal scenario is for the respondents to always prefer the MaaS-suggested trip. However, in some cases, the traditional, suggested route was preferred. For example, in SOT 1, the majority of respondents preferred the expensive, but faster traditional method of transit in the form of ride-sharing, with 20% of the respondents preferring the MaaS-suggested lower cost, but longer public transit route. In all other instances however, 81% of respondents preferred the MaaS-suggested trip over the traditional route.

5 CONCLUSIONS

While the utility model is accurate, local factors can provide a higher level of accuracy, rather than using national assumptions. This could also help fine tune the model's future flexibility as it can then be calibrated for different cities with different consumer behavior. While cost and time have a very strong negative linear correlation with utility, market friction and consumer behavior does not make the correlation perfect, and therefore, the formula can be slightly refined after further research.

The utility model explained in this paper shows that, by integrating private, shared transportation modes with traditional, public modes of transit and analyzing each user's unique set of decision factors used when considering a trip, a MaaS application can provide significant incremental value to each consumer trip within an urban environment. As the number of transit options or the number of data streams increases, the value generated by the MaaS application would also increase. While a MaaS application may not always provide a more optimal choice over a traditional trip, it would simply offer the traditional trip instead, recognizing that there is no incremental value generated in any other trip combination. However, MaaS would still bring consumer value in other areas of transit, such as viewing, managing, and booking a trip under a single platform.

There are many benefits for transit agencies as well. A well-functioning MaaS application can reduce stress on over-utilized segments of the transit network by shifting demand from affected parts of the network to less crowded modes of transit, as consumers take into account quality and comfort as major decision factors when considering public transit. MaaS can also help local governments achieve goals related to traffic congestion and pollution by providing consumers with stronger incentives in the form of optimized trips to use fewer private vehicles and more public/shared modes of transportation. While this has the obvious benefit of improving the overall transit network, it would also improve and expand local relationships with public transit agencies to further innovate on top of MaaS. Additionally, it would increase consumer investment in the public/private transit network instead of in private vehicles, which would reduce consumers' stress of the first mile/last mile problem, increase direct revenue for transit agencies, and even increase the economic benefit generated from consumer investment in local, private shared transit offerings.

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