Incorporating Discrete Characteristics and Network Relationships of Parking into the SF-CHAMP Travel Model

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Introduction

Parking availability, convenience, and cost are critical factors in determining individual travel patterns, including where travelers choose to go and how they choose to go there. In recent years, parking pricing has become a topic of great interest in congestion and travel demand management due to the ubiquitous nature of the parking process and the fact that it generates additional congestion in the search for parking. Parking constraints such as pricing and availability, which have long been a major determinant in destination and mode choice in San Francisco, are poised to become even more prominent and complex. The city's SF*park* initiative will employ pricing to redistribute the demand for parking between peak and off-peak times and on- and off-street parking in order to ensure off-street parking occupancy stays around 85%, above which congestion from "parking spot cruising" rises significantly (Shoup 2006).

Treatment of parking in the San Francisco County Transportation Authority's (SFCTA) tour based travel model SF-CHAMP (Outwater & Charlton 2006) was not sufficient to study the effects of newly proposed parking policies. SFCTA identified five critical attributes that needed to be addressed in SF-CHAMP's parking treatment: (1) separate treatments of on-and off-street parking; (2) parking price and availability variations across time of day; (3) parking search time related to available spaces (4) parking represented explicitly in the roadway network; (5) drivers trade off parking search time, cost, and egress time. The purpose of this paper is to document the improvements to parking representation made in SF-CHAMP.

Previous Representation of Parking in SF-CHAMP

The existing SF-CHAMP model is detailed in Figure 1. SF-CHAMP assumed all travelers park in their destination traffic analysis zones (TAZ) – an unrealistic assumption in downtown San Francisco where TAZs are as small as one city block. Parking attributes are included as part of the model inputs as follows. Each TAZ has five parking-related inputs:

1) *pctPaying*, percentage that pay for parking, to account for subsidies and free parking.
2) *totalParking*, parking spaces in the TAZ (SFCTA 2002).
3) *parkCostWorkHourly* and *parkCostOtherHourly,* the hourly cost of parking for work and non-work purposes, are estimated from base year costs from a published parking lot listing, combined with adjustments based upon changes in employment density (SFCTA 2002).
4) *areatype* categories are assigned to each TAZ based upon their population and employment densities

The tour mode choice step in the existing SF-CHAMP model includes parking costs in the utility equations for the different auto-based modes. The parking-related utility in the auto-based alternatives of the existing tour mode choice model are as follows (example is Drive Alone mode):

$$
\begin{aligned}
U_{\text{DA}} \quad = \quad & C_{\text{IVT}} W_{\text{walk}} t_{\text{terminal}} + \\
& C_{\text{park,inclow}} D_{\text{inclow}} c_{\text{park,DA}} + \\
& C_{\text{park,incmed}} D_{\text{incmed}} c_{\text{park,DA}} + \\
& C_{\text{park,inchi}} D_{\text{inchi}} c_{\text{park,DA}} + \\
& C_{\text{pkind}} a_{\text{dtaz}} + \\
& \text{...(other components of utility)...}
\end{aligned}
$$

The upper case variables represent coefficients:

- C_{IVT} is the in vehicle time coefficient,
- W_{walk} is the weight of walking over in-vehicle time (set to 2.0), and
- $D_{\text{inc\{low,med,hi\}}}$ is a dummy variable for the income of the given traveler, so it is set to 1 if the traveler is in that income category and 0 otherwise. These dummy variables are necessary because model estimation found that parking cost disutility varied by income group, tending to be higher for lower income individuals.

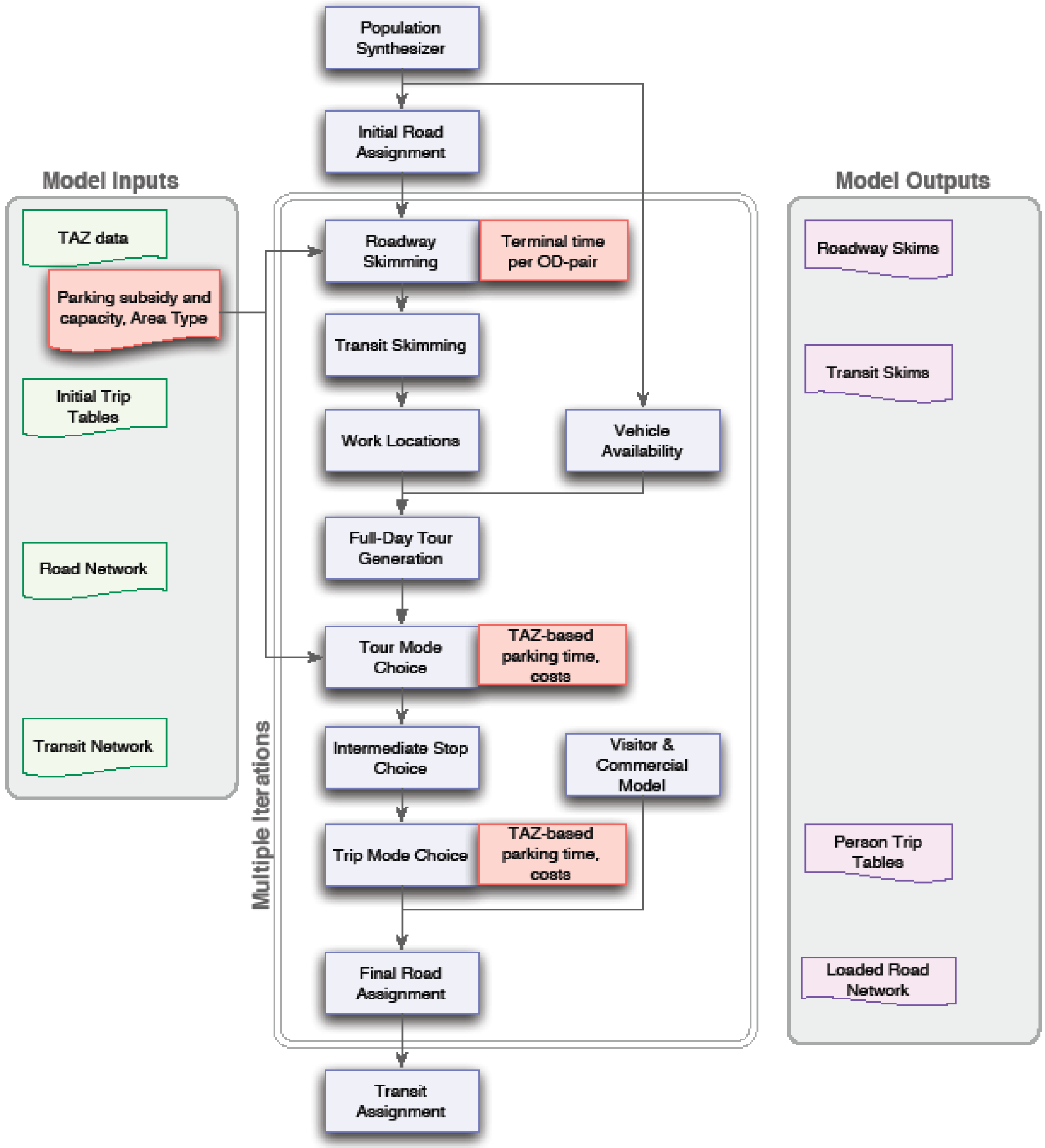
The lower case variables represent values for the particular tour in question:

- t_{terminal} is the terminal time for the trip based on origin-destination *areatype*
- $c_{\text{park,DA}}$ is the cost to park based on duration, *parkCostWorkHourly* and *parkCostOtherHourly*
- a_{dtaz} is the parking availability index, reflecting demand in the destination zone (based on households, employment and visitors) given the supply (based on *totalParking*).

The parking-related component of the utility for trip mode choice is similar to that of tour mode choice with two differences. First, the hourly parking cost of the trip is assumed to be the average of the hourly parking cost at the origin and the destination for all trips, with no parking cost at the tour origin. This is because of the assumption that the trip mode is chosen given that tour destinations are already selected. Thus, a traveler's decision to drive to (and pay for parking at) a destination is made with the understanding that he will need to drive to the trip origin to have his automobile, thus incurring parking charges there too. Thus, parking costs at both the origin and the destination are relevant for the mode choice of a given trip that does not start or end at home.

The second difference in parking-related utility of trip mode choice compared to tour mode choice is that the parking availability component is excluded. This is due to the fact that parking availability was not found to be statistically significant for trip mode choice during model estimation.

Figure 1. Existing SF-CHAMP model with parking components highlighted in red.



Available Data

At the time of this model development, the San Francisco Municipal Transportation Agency was in the process of collecting detailed data on curbside parking inventory and occupancy throughout the city for its extended parking meter study (SFMTA 2009) and also in preparation for SF*park*. Additionally, because San Francisco imposes a 25% tax on all off-street parking spaces in the city, some data on parking inventory, pricing and occupancy for off-street facilities was thought to be available from the city Treasurer's office. Although neither of these data sources has become available at the time of this writing, the parking model has been developed as a framework with these data sets in mind. Initial runs used existing TAZ-level assumptions based on city block face diagrams and a city-owned garage parking inventory.

In addition, SFCTA conducted a stated-preference survey in 2006 to understand parking choice behavior. The survey asked 3,000 respondents to trade off parking cost, access/egress time, and search time as shown in Table 1.

Table 1. SFCTA residential parking survey choice alternatives, varying search time and walk distance.

	Low Price Level	High Price Level
Search Time	Pay **$0.50 to $1.00 more per hour** to **find a parking space in less than 5 minutes** but may require me to **walk 2 to 3 blocks** from my parking space to my destination	Pay **$1.50 to $2.00 more per hour** to **find a parking space immediately** but may require me to **walk 2 to 3 blocks** from my parking space to my destination
Walk Distance	Pay **$0.50 to $1.00 more per hour** to **park within 1 to 2 blocks of my destination** but may require me to **drive around for more than 5 minutes** searching for a parking space	Pay **$1.50 to $2.00 more per hour** to **park right in front of my destination** but may require me to **drive around for more than 5 minutes** searching for a parking space

Parking Choice Model

A multinomial logit (MNL) model was estimated based on the stated preference data described above. Several characteristics turned out to be significant in affecting the respondent's utility evaluations of those variables:

- the frequency that the respondent parked,
- the frequency that the respondent rode transit,
- household vehicles,
- weekdays versus weekends, and
- disability that limited physical movement.

Parking frequency, transit use and vehicle availability characteristics were highly correlated, so only the parking frequency was actually used in the final model, shown in Table 2.

Results indicate that the disutility of paying an extra $1 per hour for parking is equivalent to spending another 3.1 - 3.5 minutes of extra search time or to walking an extra 1.8-2 blocks, depending on the purpose. Interpreting values of time from these results is complicated by the lack of parking duration information in the question. Assuming that travelers park for one hour and park an average frequency of 3.5 times per week, Table 3 translates these coefficients into values of time, the value of search time comes out to be $14.46 - $17.63 per hour, with the highest value of time for worker trips. The value of walk time is around $11.57 - $13.74 per hour; both of these sets of values are reasonable. However, assuming a parking duration of two hours, all of these values of time double, resulting in rather high values of time. It is possible that survey respondents do not really take parking duration into account in their responses, and therefore interpret costs in the question closer to absolutes rather than to hourly costs.

Table 2. Model results. n= 5187, ρ^2= 0.165, adjusted ρ^2= 0.160

Variables	Value	t-test	p-value
Alternative 1	0.00		
Alternative 2	0.0557	0.72	0.48
Cost (“Additional Dollars/hour”)			
No. times park per week	0.438	2.11	0.03
Trip purpose: errand	-5.44	-5.02	0.00
Trip purpose: shopping	-4.84	-3.98	0.00
Trip purpose: work	-5.80	-4.29	0.00
Trip purpose: work-based errand	-5.45	-2.88	0.01
Search Time (“Minutes”)			
Physical disability	0.138	6.18	0.00
No. times park per week	0.176	2.41	0.01
Trip purpose: errand	-1.69	-4.40	0.00
Trip purpose: shopping	-1.56	-3.63	0.00
Trip purpose: work	-1.87	-3.91	0.00
Trip purpose: work-based errand	-1.56	-2.35	0.02
Walking Distance (“Blocks”)			
Physical disability	-0.202	-4.37	0.00
No. times park per week	0.318	2.09	0.03
Trip purpose: errand	-3.01	-3.79	0.00
Trip purpose: shopping	-2.69	-3.03	0.00
Trip purpose: work	-3.23	-3.26	0.00
Trip purpose: work-based errand	-2.75	-1.99	0.05

Table 3. Values of search and walk time for model results

Trip Category	Value of Search Time ($/hour)	Value of Walk Distance ($/block)	Value of Walk Time ($/hour)
Trip purpose: errand	16.49	0.49	13.45
Trip purpose: shopping	17.13	0.48	13.21
Trip purpose: work	17.63	0.50	13.74
Trip purpose: work-based errand	14.46	0.42	11.57

New SF-CHAMP Parking Representation

Given these available inputs, the parking model was designed as shown in Figure 2. The following sections address each change in more detail.

Deciding who pays

At the outset, trips are assumed to have either:

1) Free, reserved parking, or
2) Parking requiring payment.

The parking submodel enhancements mainly refer to second group. Free and reserved parking is defined as commute trips with assigned parking, trips with home destinations, trips for residents with disabled placards, and trips occurring between 6:30pm and 6:00am (this is configurable).

Network Representation

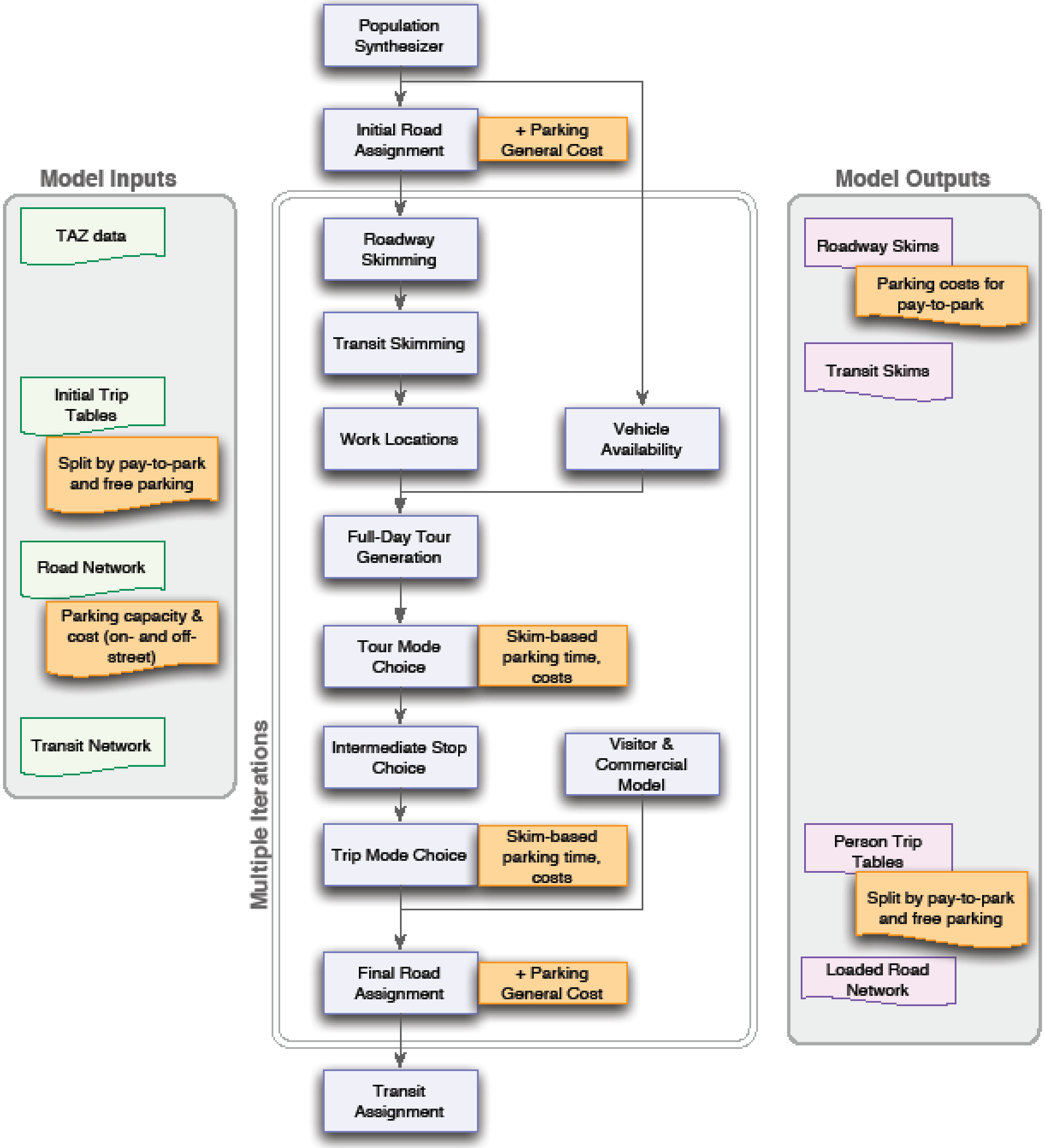
To utilize future parking datasets (to be developed by *sf*Park), the roadway network distinguishes on- and off-street parking. Off-street parking nodes represented in a GIS database are converted into parking links in the model network. Off-street garages represented by a node in the location of the garage, have links connecting the garage to the roadway network representing garage entrances and exits. The link representing the garage includes the parking capacity of the facility. The garage link is connected to walk links that connect to every TAZ within walking distance. Curbside parking is similarly encoded, with each link representing the on-street parking within a specified geographic boundaries (in this draft version, TAZ boundaries are used). The inbound parking link is assigned a cost of parking using an asserted parking duration of two hours based on two facts:

1) The San Francisco Municipal Transportation Agency is transitioning the majority of parking meters in commercial districts to have two hour time limits on weekdays (SFMTA 2009).
2) SFCTA's 2009 Parking Study found average vehicle duration per space to be 1.7 hours, 2.4 hours, 3.6 hours and 1.75 hours for 2 hour limited spaces in neighborhood commercial areas (SFCTA 2009).

Assumed durations are limiting because in reality parking duration varies quite a bit and influences the location that drivers park (SFMTA 2009).

This structure does not force individuals to leave their origin TAZ using the same parking node with which they arrived; rather the roadway assignment will optimize the outgoing trips independently of the incoming trips. This could be attempted in future work by requiring TAZ to parking-link volumes to match their corresponding parking-link to TAZ volumes. The issue is further complicated by trip durations of longer than one time period.

Figure 2. SF-CHAMP, with enhanced parking submodel highlighted.



Highway Assignment
After initially assigning all trips for each origin zone to paths, the link costs are updated to reflect the congestion on each link, and the assignment process reiterates using these new link costs until convergence criteria are met. Thus, a formula for the general cost incurred traveling on each link of the network must be specified based upon how users interpret the tradeoffs of financial costs, travel time costs, and travel distances. Additionally, each link must specify a formula for how travel time on that link degrades with congestion (or the volume/capacity ratio). The enhanced model requires the pay-to-park subset of individuals to "walk" from their TAZ origin to a parking link, exit the garage or curbside parking center onto the roadway network, and find a parking link at the destination as well (Figure 3).

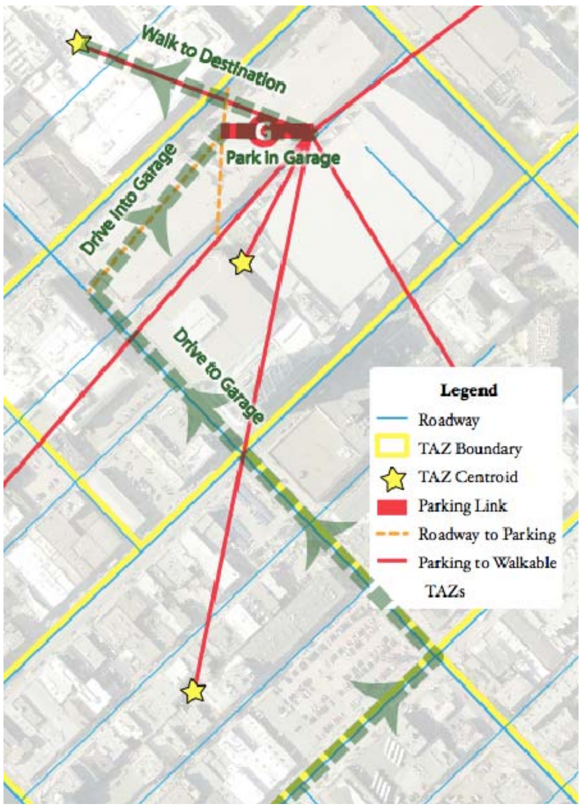


Figure 3a. Garage Parking Representation.

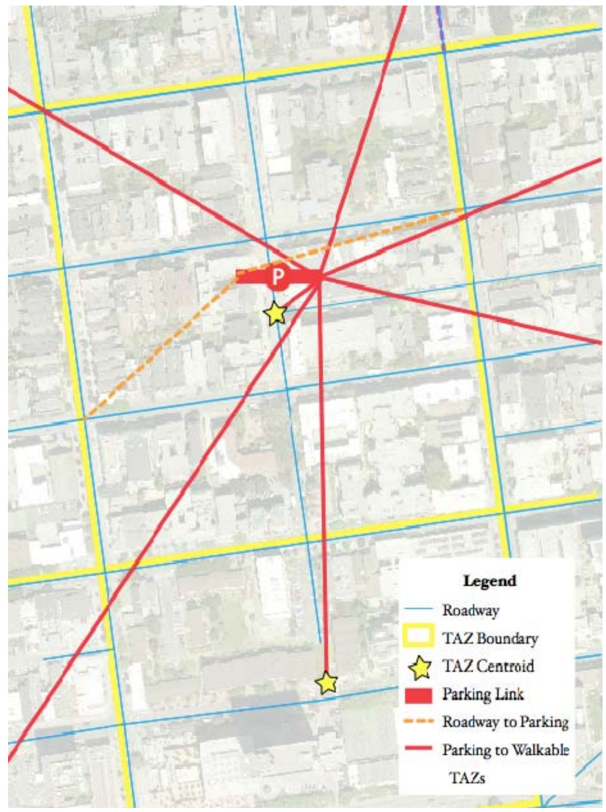


Figure 3b. Curbside Parking Representation

Generalized Cost of Parking Links
In order to incorporate the parking links and their related changes to the roadway network, the general cost for those links must be determined. Because the use of the parking link represents the search for parking as well as the payment made for parking, the general cost function includes valuations of those attributes. These weights are determined from the stated preference model described in the Parking Choice Model section. Likewise, the generalized cost for the walking link must weight the walk distance appropriately as out of vehicle time.

Since roadway assignment is done for different user classes such as drive alone, 2-person shared ride, 3+ person shared ride, the purpose-based coefficients of Table 3 need to be converted to user classes in order to calculate general costs. This is done by weighting the coefficients according to the trip purpose composition of the user class. Incorporating the weekday-only coefficients into the model, and assuming a parking frequency average of 3.5 days per week and disabled likelihood of 8.31%

(U.S. Census Bureau 2000), the general cost functions are thus formulated as follows with the betas as specified in Table 4.

$$GC = \beta_C C + \beta_S S + \beta_D D$$

Table 4. General cost coefficients used in roadway assignment, by user class.

	β_C(Utility/$)	β_S(Utility/min)	β_D (Utility/mile)
DA	-3.908	-1.100	-25.904
SR2	-3.722	-1.031	-24.450
SR3+	-3.643	-1.002	-23.844

Finally, since utility units are purely theoretical, the generalized cost must be scaled relative to the other link costs. Unfortunately, the stated preference survey did not include any questions which would allow the utility to be framed in terms of in-vehicle time. Literature generally finds search time to have a higher (but highly variable) disutility compared to in vehicle time. In this case, since search time disutility is close to 1.0, and the general costs for other roadway links in the existing model are scaled to an in vehicle disutility of 1.0, the general cost coefficients were assumed to be about the same (or 10% larger for drive alone trips) as in-vehicle time disutility.

Parking Search Time

Although the road network described above includes data on parking costs and walk distances for parking-to-TAZ connections, search time is not specified. Some parking search time research exists (see Polak and Axhausen 1990, Thompson and Richardson 1998, Martens and Benenson 1998, and Shoup 2006), but here for simplicity it is asserted using the conventional BPR equation for congested link time and the parameters in Table 5, with the resulting search times shown in Figure 6.

Table 5. Parameters for Search Time of Parking Links.

Parameter	On-Street	Off-Street	Off-Street "Smart" Garage
Uncongested Search Time	1	1	1
alpha	19	14	4
beta	18	4	3

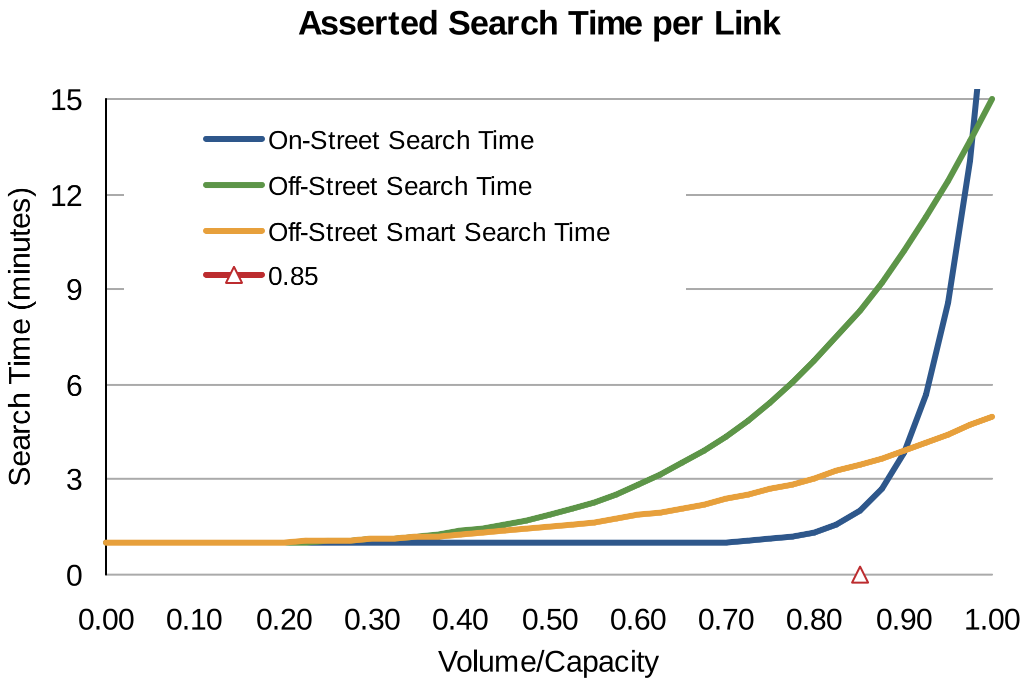


Figure 6. Asserted Search Times per Parking Link. 85% is marked because it is generally thought to be the parking occupancy ratio where available parking is still easy to find.

Conclusions

Fully disaggregating parking behavior and choices within the context of the SF-CHAMP travel demand model has proven to be a substantial undertaking that will continue as more data and model development time are available. The implementation described in this paper essentially achieves the goals outlined in the introduction; however, the development team was forced to make substantial simplifications and assertions to fit within constraints on tolerable computing time and memory as well as development time.

This framework was developed to be mindful of these future improvements and SFCTA will continue to develop the parking sub-model as data and resources are available.

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