Pros and Cons of Transit Access Points

ASSOCIATION OF BAY AREA GOVERNMENTS
METROPOLITAN TRANSPORTATION COMMISSION

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Background

Urban planners use travel forecasting models to predict the impact of transportation infrastructure and/or services on travel-related outcomes. Travel forecasting models base these predictions on abstract representations of space, time, transit services, roadway networks, sidewalks, bicycle paths, and rail lines. These abstractions are necessary to make travel models computationally practical.

Travel models segment space into geographic units referred to as “travel analysis zones”, or TAZs. Fewer TAZs creates more spatial aggregation error (i.e., the travel model’s representation of a place’s location is increasingly farther away, on average, from the actual location) in exchange for faster simulation time. Travel model designs therefore explicitly trade-off spatial precision with model run time.

One of the challenges of spatial aggregation is the representation of public transit. Consider, for example, an area contained in a single TAZ, as shown in Figure 1 below, which is made up of four neighborhoods. Consistent with common travel modeling terminology, we refer to these neighborhoods as “micro-analysis zones” or MAZs. Each MAZ is labeled with a letter: A, B, C, or D. The single TAZ is labeled with a number: 111.

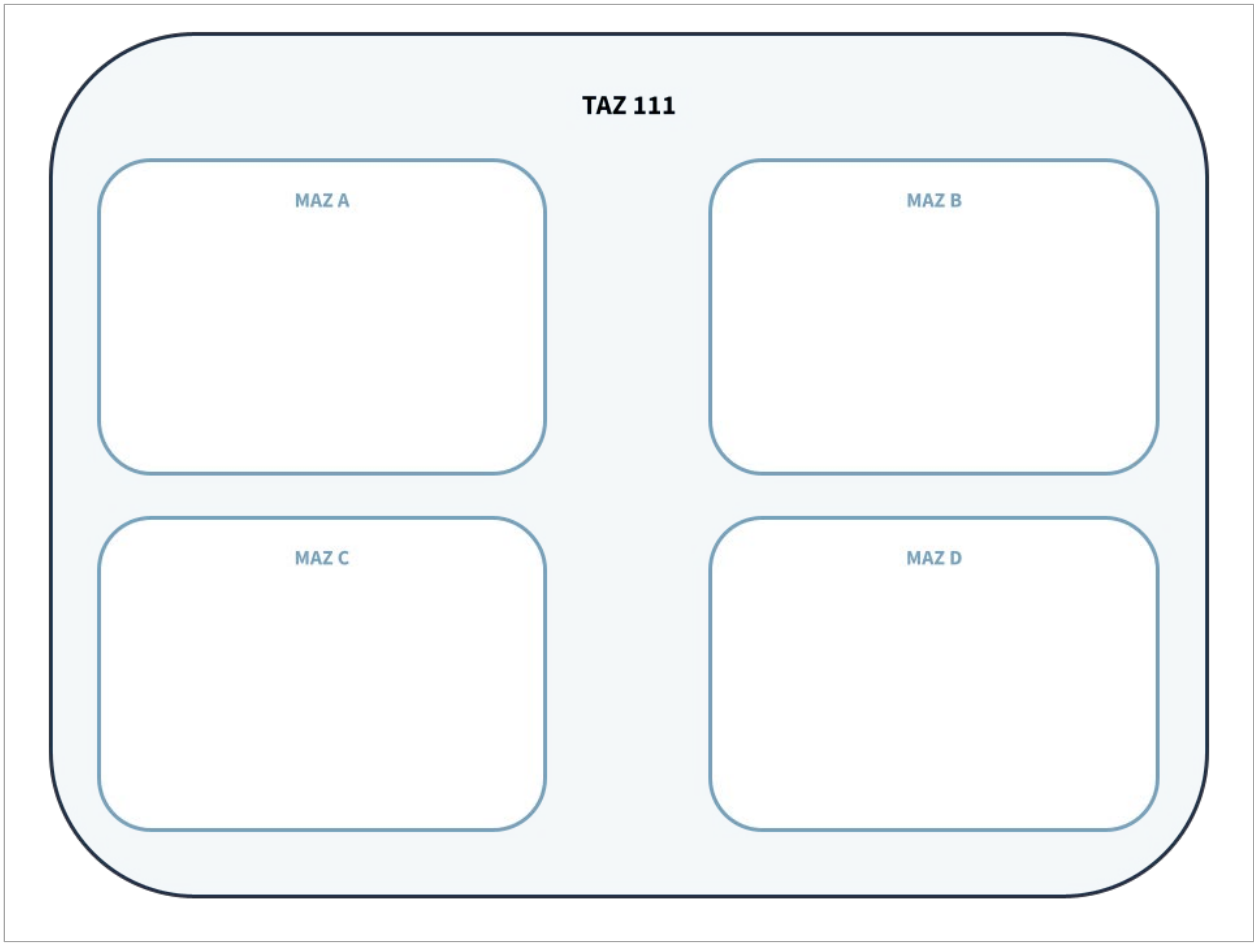


Figure 1: Example Representation of Space

To the above figure, we add a transit route running along a street at the bottom of the boundary of our example TAZ. This transit route has a stop (Stop i) in the lower right-hand corner of the TAZ, as shown in Figure 2 below.

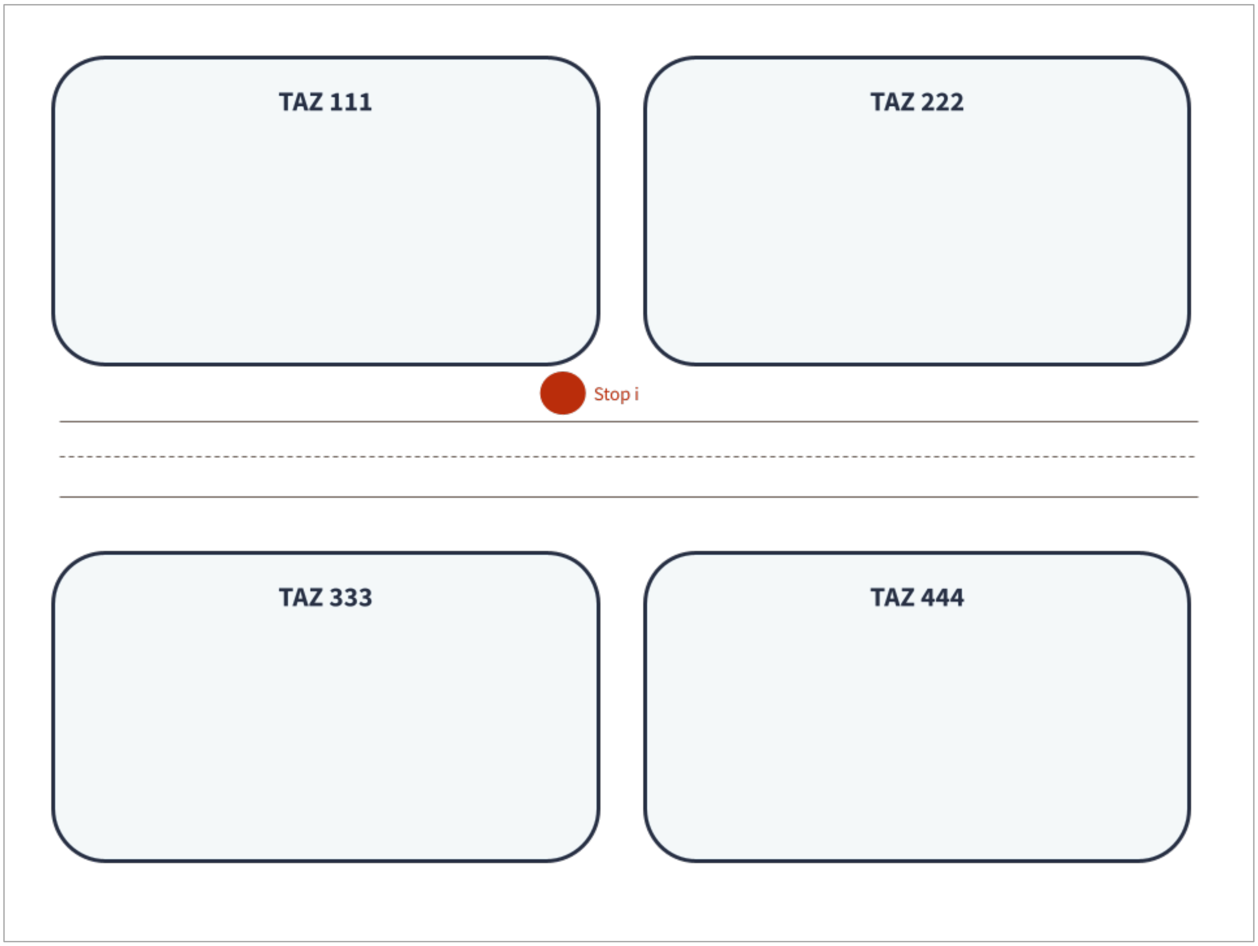


Figure 2: Example TAZ Boundaries with an Example Transit Stop

Travel models use "walk access connectors" to connect TAZs to transit stops. This allows travelers moving between TAZs to board and alight transit services. TAZ "centroids" are typically located in the activity center of a TAZ and represent the spatial location of all movements to or from the TAZ. If we assume that our MAZs are equally and uniformly populated (or, more precisely, generate and attract travel uniformly), the TAZ 111 centroid would be located in the center of the zone and be connected to Stop i, as shown in Figure 3 below.

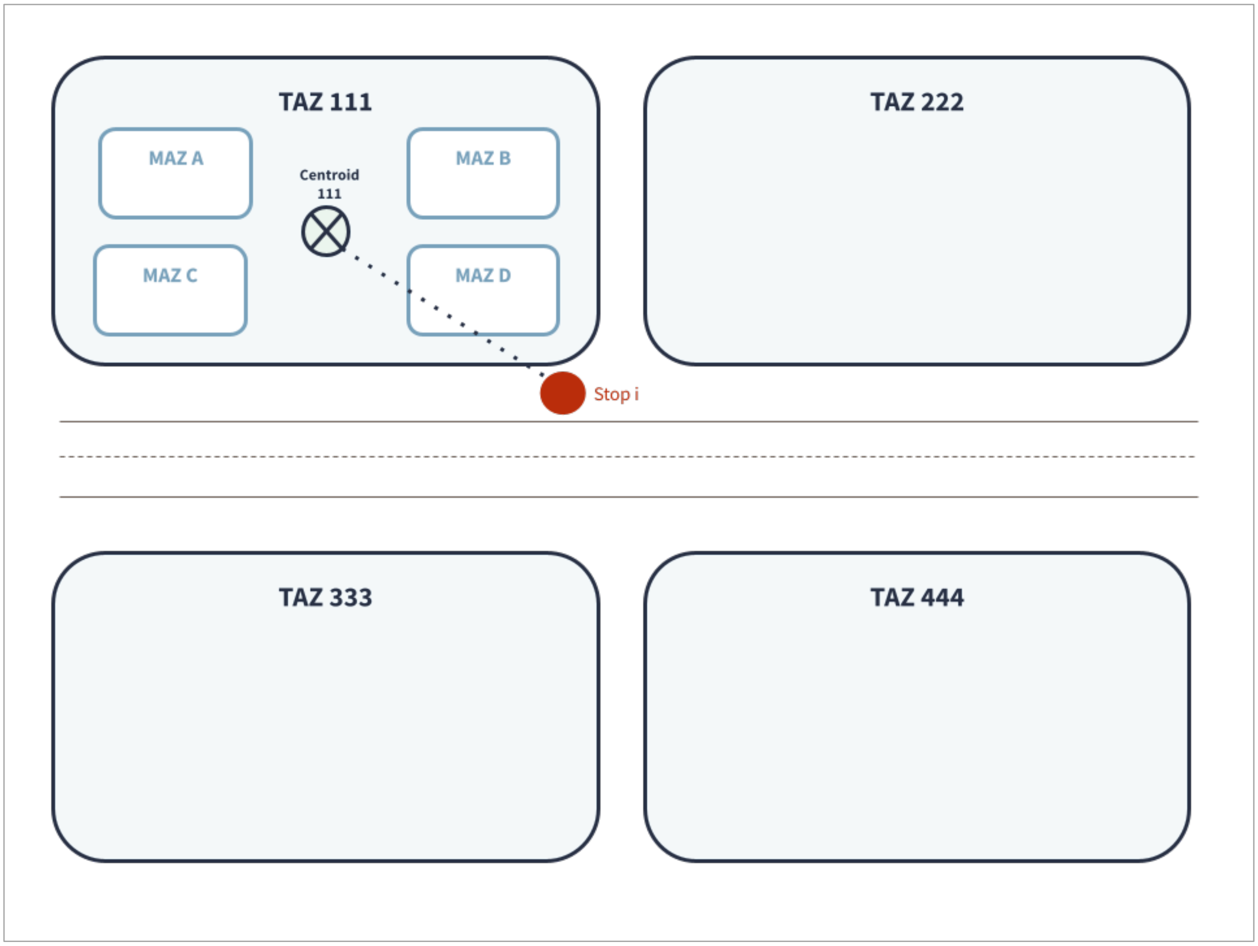


Figure 3: Example Centroid Connector

This representation causes spatial aggregation errors. Specifically, it assumes that everyone living in TAZ 111 has the same access to Stop i, and that this access requires traversing the link connecting the TAZ's centroid to the transit stop. This is imprecise: those living in MAZ A must walk farther to access Stop i than those living in MAZ D. This is the spatial aggregation error caused by using TAZs.

One solution to this problem is to use MAZs to represent transit movements rather than TAZs. Doing so ameliorates the spatial aggregation error, but introduces computational challenges that are unattractive to practical travel models. Another common solution is to segment TAZs into non-spatial walk access categories, such as "cannot walk", "short walk", and "long walk", with activities in each TAZ segmented into one of these categories based on fixed or dynamically-calculated shares. This improves outcomes for heterogeneous TAZs, but falls short of connecting travelers in MAZs to available transit service.

As discussed in detail in the next section, the most sophisticated solution to this problem that has been deployed in practice are so-called transit access points (TAPs).

Transit Access Points

The late Bill McFarlane introduced micro-analysis zones (MAZs) and transit access points (TAPs) to the travel modeling community while working as the modeling manager for the San Diego Association of Governments (SANDAG). TAPs introduce an abstract layer that connects transit stops to MAZs. In its original formulation, each TAP represented a single transit stop. Because there were fewer transit stops than TAZs in the SANDAG model at the time, using TAPs provided the opportunity to reduce the computations needed to represent transit services. In current applications in which there are many more transit stops than TAZs, the number of TAPs is typically restricted to be approximately the same as the number of TAZs — the idea being that, in using this rule of thumb, TAPs create a computational and storage burden comparable to TAZs. Because TAZs are assumed to be computationally acceptable, the number of TAZs is used as a guide for determining the number of TAPs (though, from a computation and memory storage perspective, the fewer the TAPs the better). The diagram below shows a TAP-based network, building from the example introduced above.

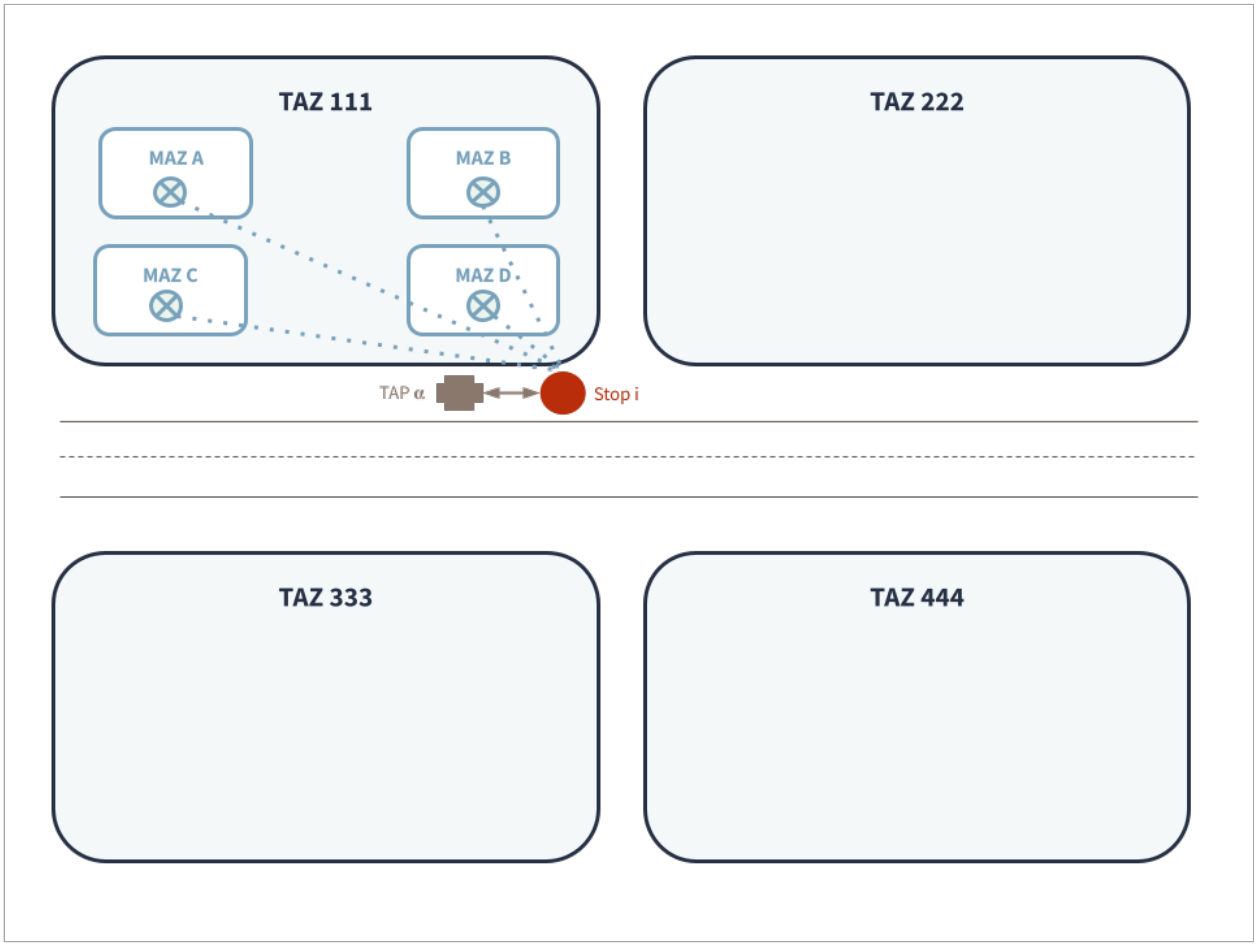


Figure 4: Example MAZs and TAPs

As illustrated in Figure 4, MAZ centroids are first connected to transit stops (either directly or via a pedestrian network); transit stops are then connected to TAPs, typically with zero impedance links (please see below for a discussion on drive access) . This allows the travel model to use MAZ geographies to build walk access connectors in a computationally feasible manner. Because transit stops are not evenly distributed across the region (as TAZs and MAZs roughly are), one TAP can be used to represent multiple transit stops (e.g., in urban neighborhoods with several bus and rail stops in close proximity, a single TAP can be connected to multiple stops). The possibility therefore exists that a number of TAPs similar to the number of TAZs can be used to accurately represent MAZ-scale walk access and egress movements.

Mechanically, this formulation needs software to assemble the best MAZ-to-MAZ transit path from the following pieces of information:

1. MAZ to transit stop movement or connection;
2. Transit stop to boarding TAP connection;
3. TAP to TAP transit movement;
4. Alighting TAP to transit stop connection; and,
5. Transit stop to MAZ movement or connection.

Because MAZs can have viable paths to multiple TAPs (via multiple transit stops), TAP-based models typically use commercial software, such as Emme or Cube, to create TAP-to-TAP transit skims, and then use custom software to find the best MAZ-to-MAZ path using the access and egress connections in combination with the TAP-to-TAP transit estimates. The software used to implement these procedures probabilistically selects the single best MAZ-to-MAZ path from a set of feasible alternatives. A diagram of this procedure is shown in Figure 5 below. The result is MAZ-to-MAZ transit paths with associated level-of-service estimates that have the potential to correct for the spatial aggregation bias of TAZs in a computationally efficient manner.

This is the primary advantage of the transit access point approach to building transit paths: it is the only method used in practice that builds consistent MAZ-to-MAZ transit paths in a computationally efficient manner.

A secondary advantage of the TAP approach is that it adds useful heterogeneity to transit path building, which is often necessary to overcome limitations with commercial travel demand software. For example, it was common for many years for commercial travel demand software to return the single best path for a given TAZ-to-TAZ movement. With a TAP-based approach, the custom software could build several MAZ-to-MAZ movements based on various TAP-to-TAP combinations. Advances in the transit assignment algorithms used in commercial software, including in Emme, ameliorate this advantage, as the commercial software assigns travel to multiple paths in a TAZ-scale assignment.

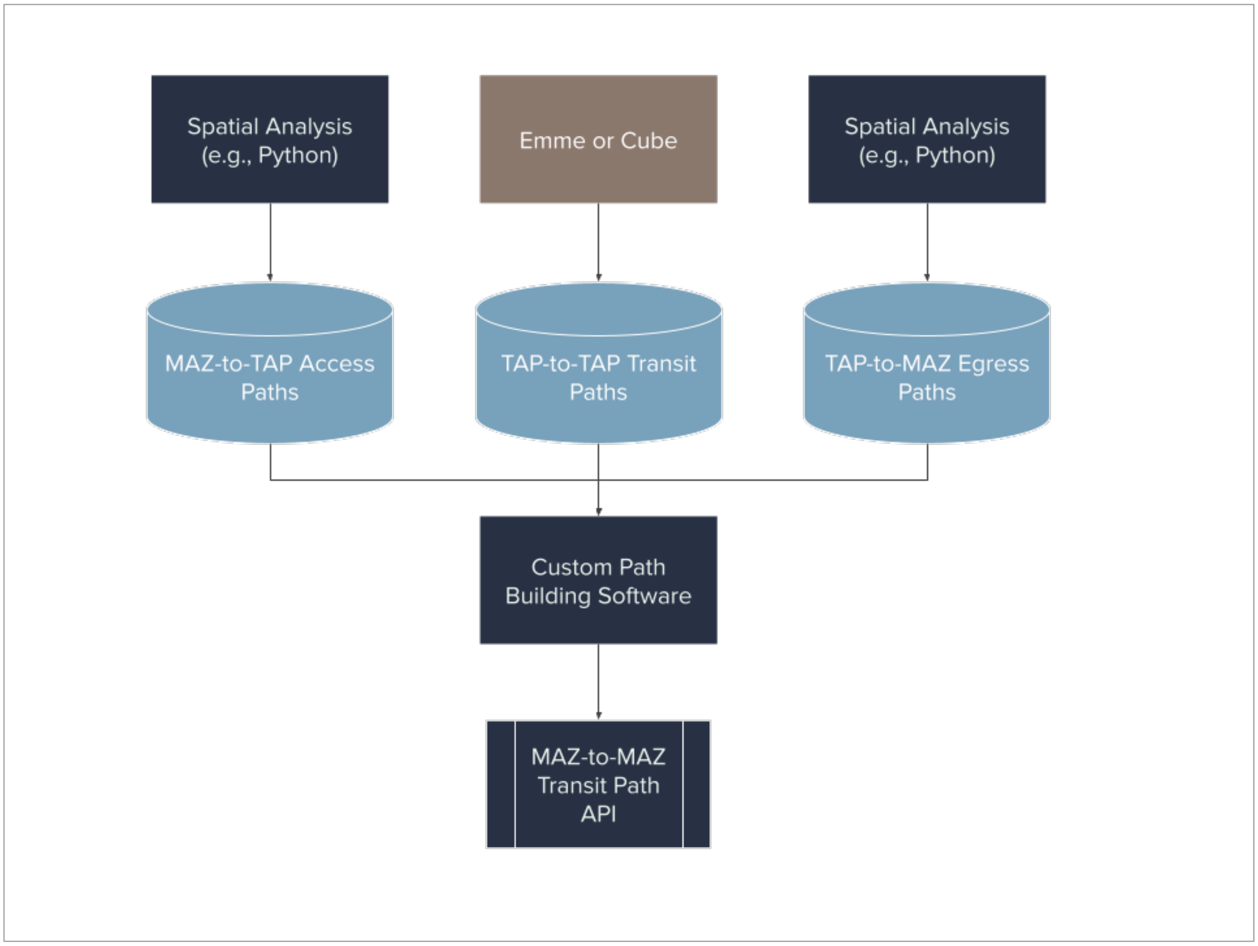


Figure 5: Typical TAP-based Path Building Software Architecture

Walk Access, Drive Access, and Faithful Station Coding

The motivation for TAPs is to improve the representation of walk access/egress, utilizing MAZ geographies. However, TAPs and TAP-to-TAP skims make the mechanics of creating drive access to transit paths easier. Specifically, creating drive access station choice models outside of commercial software packages benefits from having readily available skims from each drive access station alternative to all potential trip origin/destination locations. TAZ-to-TAP skims contain this information, provided there is a TAP coded at each drive access station.

These procedures, however, can be readily mimicked in a non-TAP-based approach using “dummy” or “psuedo” TAZs or using the TAZ nearest to each drive access station as a proxy for the station’s true location.

On the whole, the usability advantages of building drive access paths with TAP and non-TAP-based approaches are minor relative to the usability disadvantages of using TAPs for walk access paths. The focus in this document is, therefore, on walk access paths.

Both TAP and non-TAP approaches allow users to faithfully and accurately represent transit station coding. Both allow for detailed walk networks to represent station access and transfers.

The Drawbacks of Transit Access Points

The possibility of creating MAZ-to-MAZ transit paths was attractive to practitioners, and the SANDAG approach pioneered by Bill McFarlane gained followers in the late 2000s. Activity-based models used in Miami and Chicago, for example, followed the approach. With experience, the downsides of TAPs began to reveal themselves. They are described here in the following three categories: usability, spatial bias, and congested transit assignment.

Usability

In a travel model that uses TAZ-based transit paths, creating, maintaining, and debugging transit paths is straightforward. The popular commercial software products, including Emme, TransCAD, Cube and Visum, all have tools that make managing these systems straightforward. The commercial vendors do not directly support TAP-based transit paths. Custom software, written by consultants, is used to find the best MAZ-to-MAZ path. This software is harder to use and maintain than the commercial alternatives. The first usability problem is therefore simply executing the software to create MAZ-to-MAZ paths.

The second is the effort needed to determine optimal path parameters. Users seeking to determine the optimal parameters for path building must iterate between the MAZ-to-TAP procedures in the custom software and the TAP-to-TAP procedures in the commercial software to determine the set of parameters that best replicate observed MAZ-to-MAZ paths. Manipulating these two procedures is difficult and requires expertise.

When transit paths are illogical or are suspected to be illogical, travel modelers seeking to investigate the details of the path building procedures must navigate both the commercial and custom software to determine the source of the error. Due to the size of MAZ-to-MAZ skims, the outcomes of the MAZ-to-MAZ transit path building process are not written to disk in the same manner as TAZ-to-TAZ skims. Debugging paths, therefore, requires a specialized skill set, which is expensive and difficult to obtain. This is the third usability problem.

In addition to the requirement of using custom software, the TAP-based system introduces additional complexity when representing transit services. If a new transit line is added, each of its stops needs to be explicitly connected to an existing or newly created TAP. Adding a TAP creates additional runtime overhead, but existing TAPs can fail to accurately reflect transit access/egress movements (see next subsection on spatial bias). TAP-based systems therefore require additional transit network coding and management overhead (the fourth usability problem), in the form of either human labor or software.

Spatial Bias

Going back to the working example introduced above, let us now consider the addition of a second transit stop, Stop ii, located on a perpendicular road to Stop i, as shown in Figure 6 below. The figure shows connections between each of the MAZs and each of the transit stops. Each transit stop is connected to a single TAP, which we label TAP α. Because TAPs are abstract, the connections between stops and TAPs have zero impedance. Walk times are therefore based on the connections between the MAZs and the actual transit stops.

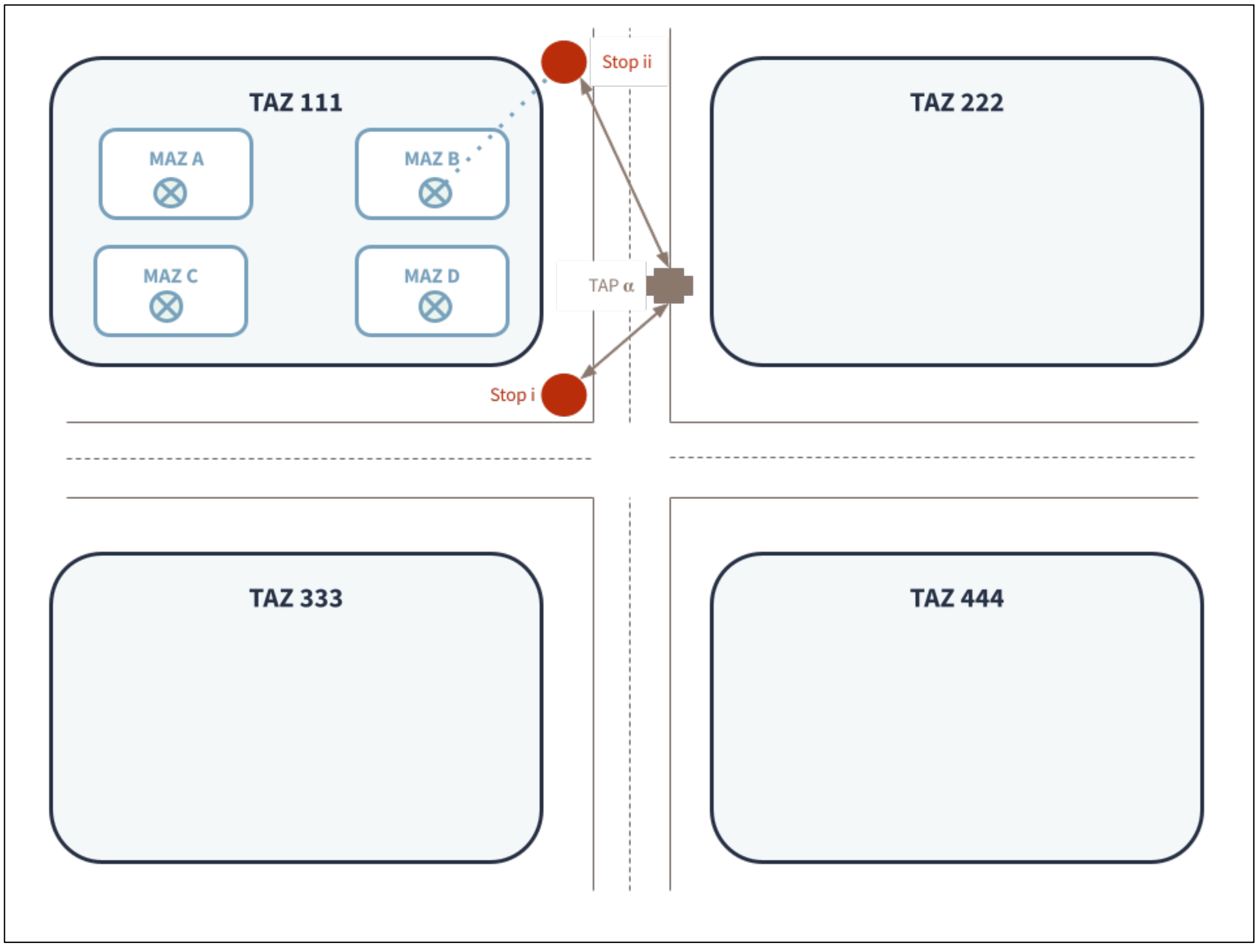


Figure 6: Example of Multiple Stops connected to a Single TAP

As noted previously, in order to improve the computational efficiency of a TAP-based system relative to just using many more TAZs (or MAZs directly), multiple transit stops are often connected to a single TAP. TAPs, therefore, need to be thoughtfully connected to transit stops. No matter how this is done, spatial distortions are inevitable. In the above example, transit service that uses Stop i or Stop ii is represented by TAP α. Travelers moving from MAZ B to TAP α can access service at either Stop i or Stop ii (because the stop-to-TAP connectors have zero impedance, TAP α can be thought of as physically located simultaneously at Stop i and Stop ii). Travelers from MAZ B can walk to Stop ii and then access transit service at Stop i (because the transit service at Stop i and Stop ii is represented by the same TAP-to-TAP skims). Walk access times will therefore be distorted in many cases. This problem may be exaggerated in suburban areas in which transit stops (depending on the approach to allocating TAPs), and therefore TAPs, are often sparse, as shown in Figure 7 below. In this case, the free stop-to-TAP connections allow access to transit stops that are physically far away from MAZ centroids.

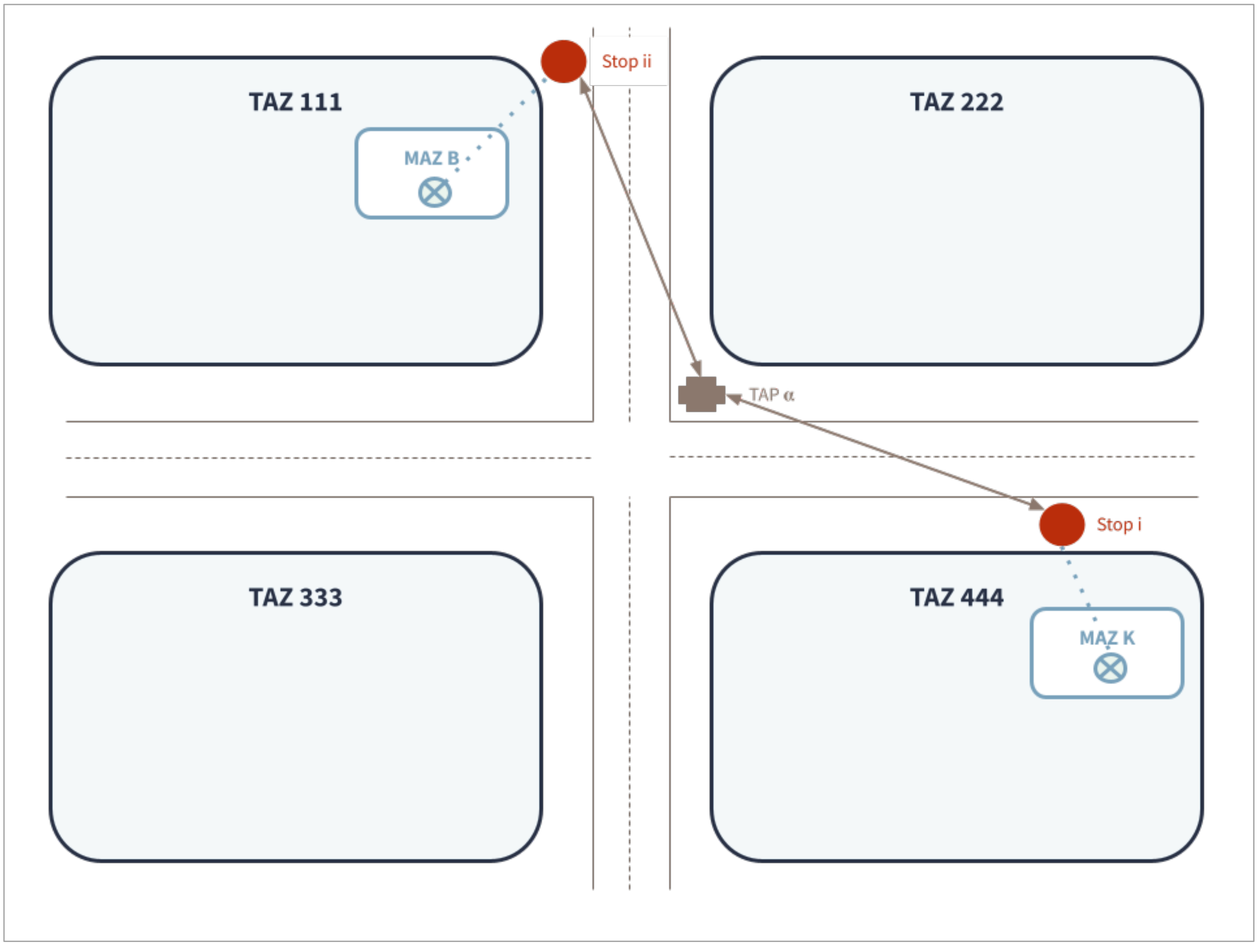


Figure 7: Sparse Transit Stops and TAPs Distort Transit Access

The goal of TAPs is to remove the spatial aggregation bias of TAZs, but doing so may introduce a different type of spatial bias.

We understand from conversations with colleagues that models have also used an alternative approach of first locating TAPs and then connecting MAZs directly to TAPs, as shown in the Figure 8 (we have not seen this ourselves and the subsequent analysis in this document uses a model that connects MAZs to stops, not TAPs). This approach is also problematic, though in a different way. If this was done using the above sparse transit network example, walk distances would also be incorrect. In this case, travelers in MAZ B and MAZ K can still access Stop i or Stop ii at TAP α, but now must walk longer to access the stop closest to them.

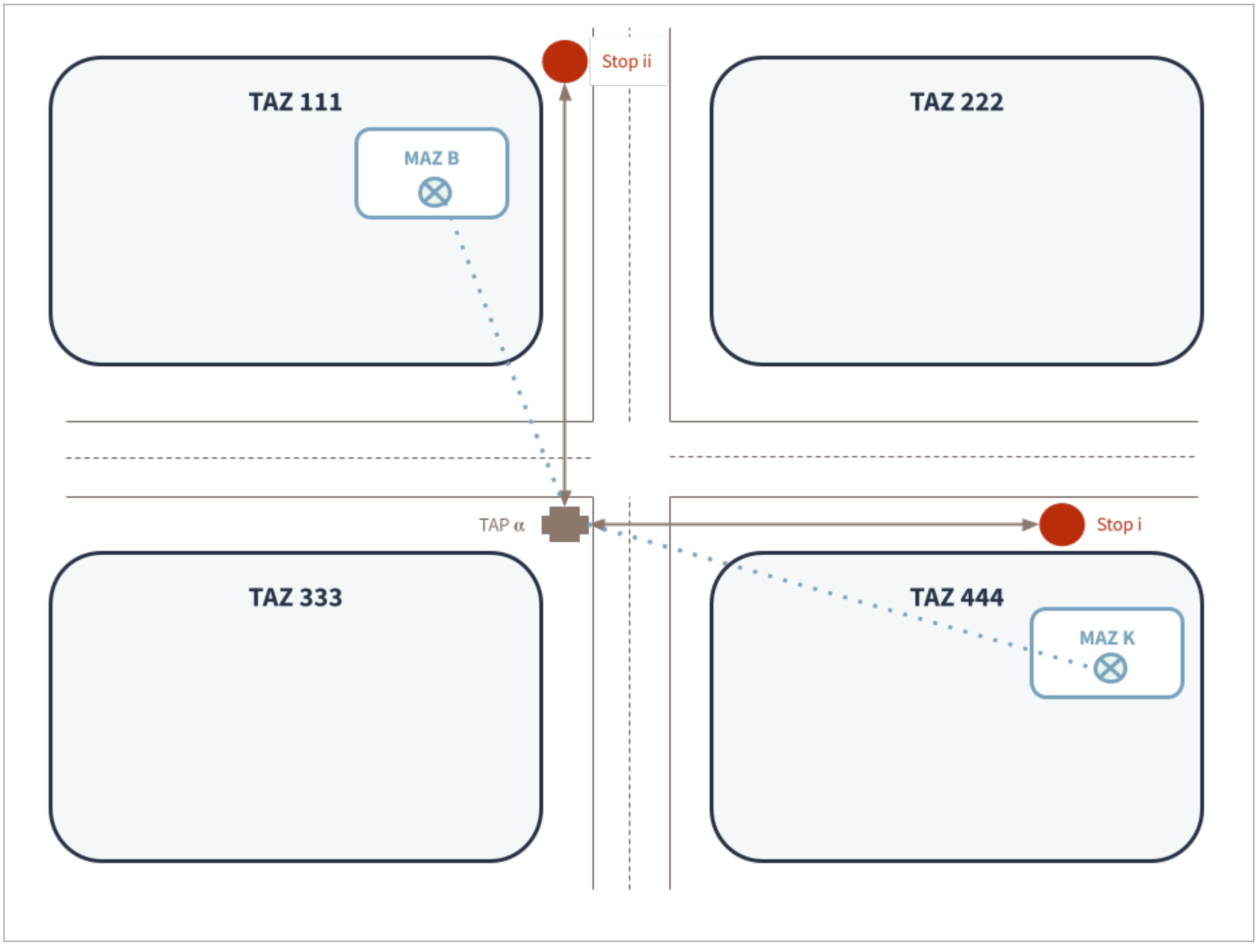


Figure 8: Sparse Transit Stops with MAZs Connected Directly to TAPs

Congested Transit Assignment

Commercial travel modeling software, such as Emme, offers congested transit assignment algorithms in which travelers select alternate transit paths when preferred routes and/or stops are crowded. Experience to date with congested transit assignments in the United States is limited. We are only aware of the Metropolitan Transportation Commission (MTC) attempting to implement a congested transit assignment within a TAP-based approach. As such, the following concerns about using TAPs in a congested assignment are speculative and not yet based on empirical findings.

The concern with using TAPs in a congested assignment is that, in a TAP-based system, the commercial package only sees the TAP-to-TAP movement and can therefore only reallocate transit demand to paths that use the same TAP pairs. This is likely suboptimal, as the best solution for a traveler facing crowded conditions may be to access a different TAP. In order for the TAP-based procedure to move the traveler to a different TAP, it must exit the commercial software and make the change in the custom software's transit path building algorithm, as this portion of the system has awareness of the MAZ-to-TAP leg of the path (see Figure 5: Typical TAP-based Path Building Software Architecture). This increases the burden on the custom software, which must now iteratively find the best MAZ-to-MAZ movement based on TAP-to-TAP outcomes that are provided incomplete information. The iterative nature of this approach may be more computationally demanding than a non-TAP approach.

The advantages of a non-TAP approach in this context depend on the structure of the path building and mode choice approach of the modeling system. It is common in travel demand models to simulate the transit technology choice in the mode choice step, outside of the transit assignment, sometimes called the “labeled approach”. For example, a mode choice model may have separate alternatives for transit technology categories, e.g., “walk to local bus” and “walk to light rail”. To be faithful to the mode choice outcomes, the transit assignment step then allocates the, for example, “walk to local bus” demand to paths that exclude light rail. A variation on this approach is the so-called “unlabeled approach”, in which N transit mode choice paths are created in the path building with specific sets of path weights. The mode choice model is then shown these “unlabeled” paths. Both the labeled and unlabeled approaches give the analyst more flexibility on shifting demand between transit modes during calibration. To gain significant runtime savings in a congested assignment, however, all the transit demand must be allocated to a single path for assignment. Meaning, for example, collapsing the “walk to local bus” and “walk to light rail” demand into a single “walk to transit” category in both mode choice and assignment. Or, in the unlabeled approach, collapsing the “walk to transit path A” and “walk to transit path B” demand into a single “walk to transit” category. By collapsing the demand, the transit assignment algorithm would be aware of all the demand on the system and be able to make adjustments accordingly, removing the need to iterate between the transit assignment and mode choice step. However, this simpler mode choice structure would give the analyst less flexibility in modifying mode choice constants to shift demand between sub-modes. Flexibility would still be present, as path weights and mode choice constants triggered by the presence of non-zero travel times on specific technologies, could still be used to match observed travel patterns, but this flexibility would be reduced relative to the labeled or unlabeled approaches.

An Alternative to TAPs

The problems with TAPs discussed in the previous subsection motivated the travel modeling community to find alternatives that are both computationally comparable to using TAZs and utilize information from MAZ geographies.

A thorough analysis would consider a range of alternatives to TAPs, comparing the alternatives within a consistent framework. Logical alternatives include the following:

- Use TAZs directly, which should improve the computational performance of the model in exchange for increased spatial aggregation error.
- Use MAZs directly (i.e., an MAZ-scale assignment), which would improve the spatial aggregation error in exchange for poor computational performance and large disk storage requirements.
- Create a third zone system used only for transit assignment, which would seek a middle ground between computational burden and spatial aggregation error. In this approach, MAZs would be aggregated into a third zone system that is mindful of areas where there is more/less transit activity.
- Leverage MAZ-scale information to improve the representation of transit without adding a transit-specific zone system.

In the present analysis, we examine only the last alternative by comparing TAPs to another method used in practical travel models that use MAZs. This solution, variations of which have been deployed in travel models in Ohio, Arizona, and Los Angeles, starts with TAZ-based transit paths and skims. The TAZ-based estimates of walk access and egress movements are then replaced with MAZ-scale information, while the other skim values (in-vehicle time, transfer time, wait time, etc.) are retained. To illustrate how this works, we use the same example introduced above and shown in the figure below.

- We start with TAZ-based paths that would result, for example, in a walk access estimate for TAZ 111 to Stop i of 7 minutes and a walk access estimate to Stop ii of 8 minutes (see Figure 9 below).
- Next, we connect each MAZ to each transit stop (Stop i and ii in Figure 9 below).
- We then compute a walk access time for each MAZ, using information from the transit stop locations, MAZ-scale demand, and TAZ-scale assignment (please see the Access/Egress Estimation Algorithm subsection below for details).

Such an exercise would yield something like the following MAZ-specific walk access times:

- MAZ A: 15 minutes
- MAZ B: 4 minutes
- MAZ C: 12 minutes
- MAZ D: 5 minutes

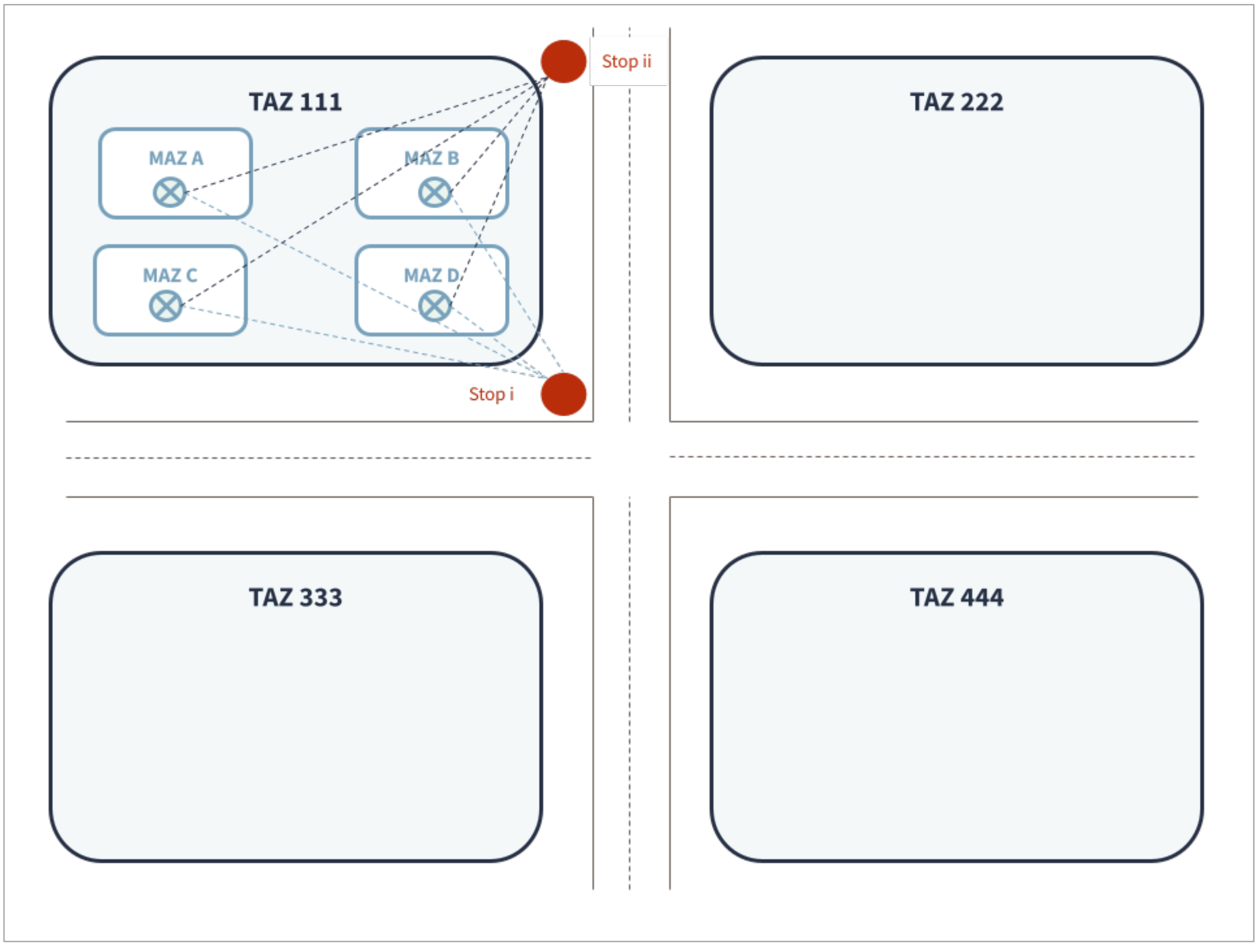
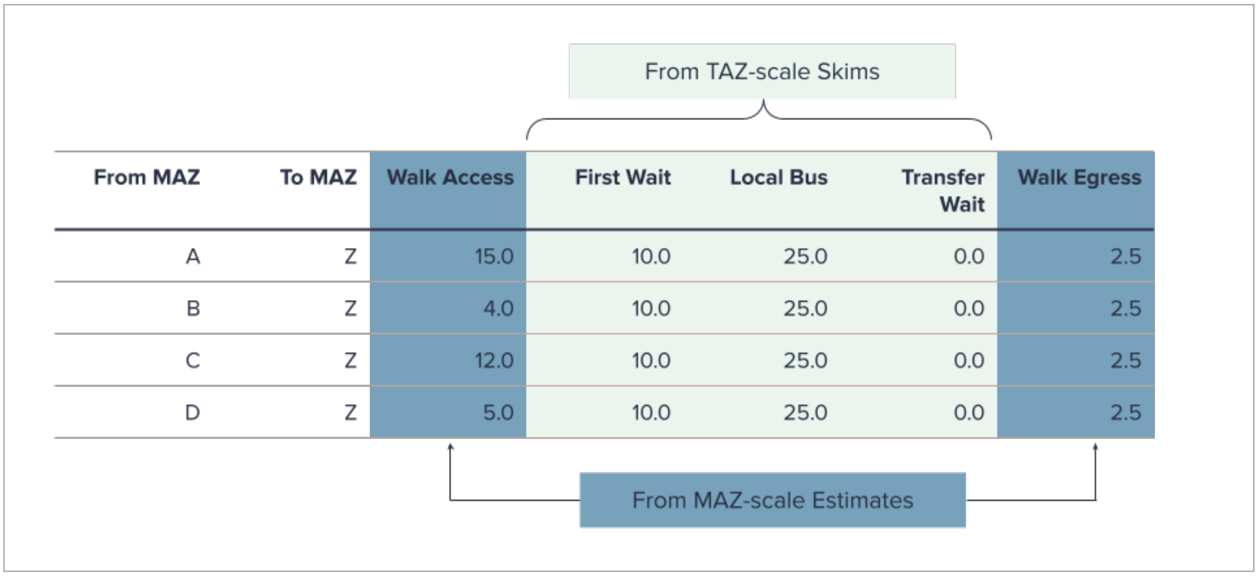


Figure 9: MAZ to Stop Connections

All of this information is then assembled to create MAZ-to-MAZ level-of-service information using the MAZ-scale walk access estimates, the transit attributes from the TAZ-scale paths, and MAZ-scale walk egress estimates (created in a manner identical to the above walk access estimates); this construction is shown in Figure 10 below. Transit attributes such as the initial wait time and in-vehicle time are taken from the TAZ-scale paths and are the same across each MAZ (that share a TAZ). The walk access/egress estimates are taken from the MAZ-scale analysis and are the same for all paths leaving from (or arriving to) the same MAZ. Separate walk access/egress estimates can be created for any number of transit paths, including segmentation by time of day.



From MAZ	To MAZ	Walk Access	First Wait	Local Bus	Transfer Wait	Walk Egress
A	Z	15.0	10.0	25.0	0.0	2.5
B	Z	4.0	10.0	25.0	0.0	2.5
C	Z	12.0	10.0	25.0	0.0	2.5
D	Z	5.0	10.0	25.0	0.0	2.5

Figure 10: Alternative to MAZ-to-MAZ Skim Construction

The outcome of this procedure is, importantly, *not* consistent MAZ-to-MAZ *paths*. Meaning, a user cannot trace a movement from the origin MAZ to the destination MAZ through the network. Rather, it creates approximations of MAZ-scale access and egress estimates that are better than TAZ-scale estimates and pairs them with TAZ-scale transit path details. The result is MAZ-to-MAZ *skims* or level-of-service matrices. But these skims are not consistent with the paths through the network; they are an approximation.

The TAP approach does create MAZ-to-MAZ *paths* and, under the right circumstances (see the Assessment section for additional discussion), will create consistent skims. Meaning, an analyst can extract out the complete details for the MAZ-to-MAZ movement, which goes from origin MAZ to transit stop to boarding TAP to alighting TAP to transit stop to destination MAZ.

In select cases, the spatial bias of the TAP approach and this alternative will be similar. In others, as discussed in the Assessment section, one approach should be superior to the other. The purpose of this paper is to understand, quantify, and discuss the relative merits of these two approaches.

Walk Access/Egress Estimation Algorithm

The proposed algorithm for estimating walk access and egress is described in this subsection. In the existing travel models that use a similar non-TAP approach, the manner of determining the walk access/egress estimates varies. We take a fresh look at this problem and propose a solution that takes advantage of information provided by the TAZ-scale transit assignment and MAZ-scale transit demand. The proposed approach is not currently used in existing travel models, but instead builds off the non-TAP approach used in other travel models that use MAZs.

We note that this approach which, effectively, updates walk times using sub-TAZ information, is not novel. The travel modeling community has for many years used approaches such as segmenting demand for each origin TAZ into (spatially implicit) "cannot walk", "short walk" and "long walk" categories, and using a static value for the walk access time for each of these markets (e.g., 5 minutes, or less if the connector is shorter, for short walk; 10 minutes, or less if the connector is shorter, for long walk). A parallel construction is used for walk egress. The differences here are that the walk times are informed by explicit MAZ geographies, TAZ-scale transit boardings, and MAZ-scale transit demand.

Two algorithms are used to describe the process. The first describes the creation of MAZ-scale access/egress estimates, used in mode choice; the second describes the creation of TAZ-scale access/egress connectors, used in path building and assignment. The proposed algorithms are applied separately for each of the travel model's time periods and transit paths. It uses readily available information from (a) the spatial analysis of MAZs and stops, (b) the TAZ-scale transit assignment, and (c) the MAZ-scale transit demand.

MAZ-scale Walk Access/Egress Impedance Algorithm

In order to show the mode choice models approximations of MAZ-to-MAZ paths, an algorithm is needed to compute, for each MAZ, estimates of walk access time and egress time. These values can then be used in mode choice models. The algorithm, which is applied separately for each time period and transit path, is as follows:

1. For each MAZ, identify transit stops within a walk shed of ½ a mile. If we assume a typical walk speed of 3 miles per hour, the maximum walk time is 10 minutes.
2. For each identified transit stop, record the walk time along the pedestrian network from the MAZ centroid to each transit stop, assuming a walk speed of 3 miles per hour.
3. Define a linear splines function to translate the walk time into a walk impedance as follows: $Impedance = 1.0 \cdot w + 2.0 \cdot x + 3.0 \cdot y + 5.0 \cdot z$, where:
    - w is minimum(time, 2.5 minutes)
    - x is 0 if time < 2.5 minutes, otherwise minimum(time - 2.5 minutes, 2.5 minutes)
    - y is 0 if time < 5 minutes, otherwise minimum(time - 5 minutes, 5 minutes)
    - z is 0 if time < 7.5 minutes, otherwise time - 7.5 minutes

    The weights in the above equation are arbitrary and calibrating them to observed data would be difficult (see commentary on key limitations below).

4. Obtain the share of demand allocated to each transit stop from each origin TAZ from the TAZ-scale assignment (i.e., the volume on each walk access connector) in the previous iteration of the model.
5. Use the product of (i) the TAZ-scale assignment boarding share and (ii) the ratio of the walk time and walk impedance, as weights in a weighted average of walk time to compute the MAZ-specific walk access time as shown in the following formula:

    $Walk\ Time_m = \frac{\sum_i \ \omega_{m,i} \cdot time_{m,i}}{\sum_i \ \omega_{m,i}}$, where

    - *m* is an index for each MAZ
    - *i* is an index for each transit stop within a half-mile of MAZ *m*
    - $time_{m,i}$ is the time to walk between the MAZ centroid and the transit stop
    - ω is the weight computed using the following formula:

$$\omega_{m,i} = boarding\ share_{z,i} \cdot \frac{time_{m,i}}{impedance_{m,i}},$$ where

- z is the TAZ that contains MAZ m

6. Repeat steps 4 and 5 in the egress direction. The resulting walk access and egress times, by time of day and transit path, are the walk times that will be shown to the mode choice models.

TAZ-scale Walk Access/Egress Connector Impedance

In order to build transit paths and assign transit trips, TAZ-scale connectors between TAZ centroids and transit stops are needed. The algorithm to create these is as follows:

1. Translate the MAZ-centroid-to-stop connections from Step 1 in the MAZ-scale algorithm to TAZ-centroid-to-stop connections, i.e., the set of MAZ connections determine the connectivity of the TAZ. The TAZ connectors are needed for the TAZ-scale transit skimming/assignment.
2. For each TAZ, use the weighted average walk access time between MAZs and each transit stop (i.e., the outcome from the MAZ-scale algorithm) as the walk access time between the TAZ and each transit stop. The weight in this calculation is the MAZ-scale transit demand (for the origin end of trips) from the previous model iteration.
3. For each TAZ, use the weighted average walk egress time between MAZs and each transit stop as the walk egress time between the TAZ and each transit stop. The weight in this calculation is the MAZ-scale transit demand (for the destination end of trips) from the previous model iteration.

Example

To illustrate the approach, consider an example MAZ that has access to two transit stops, with the following characteristics:

- Stop i
  - Walk access time: 5.0 minutes
  - TAZ-scale boarding share: 25 percent
- Stop ii
  - Walk access time: 10.0 minutes
  - TAZ-scale boarding share: 75 percent

The calculations are as follows:

$$\omega_i = 0.25 \cdot \frac{5.0}{7.5} = 0.17$$

$$\omega_{ii} = 0.75 \cdot \frac{10.0}{35.0} = 0.21$$

$$Walk\ Access\ Time = \frac{0.17 \cdot 5.0 + 0.21 \cdot 10.0}{0.17 + 0.21} = 7.8\ minutes$$

If this MAZ were the only MAZ in the TAZ, then the TAZ-scale assignment will use walk access connectors between the TAZ and Stop i of cost 5.0 minutes, and TAZ and Stop ii of cost 10.0 minutes. If multiple MAZs are present in this TAZ, then we use a weighted average, in which the weight for each MAZ is the MAZ-scale transit demand from the previous iteration.

To better explain the approach, these and other calculations are provided in a spreadsheet here.

The key features of this formulation are as follows:

- It takes advantage of the boarding share for each stop from the TAZ-scale assignment to inform the weighting of walk access times, which nudges the walk times and assignments towards consistency at the TAZ level.
- It uses MAZ-scale walk sheds to determine the TAZ-scale walk access connectors.
- It correctly labels MAZs without access to transit in the resulting skims.
- It uses MAZ-scale demand to weight the TAZ-scale walk access times, which will nudge the TAZ assignment to align with MAZ-scale demand.
- By introducing the time/impedance ratio in the weighting, it uses the MAZ geographies to favor walk access paths that are close to each MAZ centroid.
- It ignores transit stops that are not used by the transit assignment.
- It ignores MAZs that have no transit demand in the TAZ-scale transit assignment.

The key limitations of this approach are as follows:

- The TAZ-scale assignment has no understanding of demand to/from each MAZ and can therefore only use TAZ-scale assignment outcomes to inform the weighting of walk access/egress estimates. To the extent the TAZ demand varies across MAZs in a manner inconsistent with the impedance-informed weighting approach, the walk access estimates will be incorrect.
- The impedance formulation used to nudge the walk access estimates towards closer stops is arbitrary and cannot be generalized. Meaning, even if the curve was calibrated to match observed data, there is no reason to expect it to be generally true across the region; it would simply be an artifact of the MAZ and TAZ structures used in the training data.
- To the extent the TAZ demand varies across MAZs in a manner inconsistent with the impedance-informed weighting approach, the TAZ-scale paths will be inconsistent with the walk access/egress connections, i.e., the walk access estimates will be based on stops not used in the TAZ-scale paths.
- The MAZ-scale estimates are informed by the TAZ-scale outcomes and the TAZ-scale outcomes are informed by the MAZ-scale estimates. As such, you need to start with some set of initial conditions, which can either be naive (e.g., assume equal demand at each transit stop) or via a so-called “warm start” assignment. It is common in travel models to, as a first step, estimate a plausible set of congested roadway times using a demand matrix from a similar model run. The same can be done here on the transit side to create initial TAZ-scale outcomes to begin the iterative process.

While variations of this approach can be imagined and readily implemented, we believe this approach is reasonable and appropriate to serve as a counterfactual for assessing the value of a TAP-based approach.

Assessment

The preceding sections of this document introduced the TAP-based approach to transit path building and discussed the approach’s pros and cons. We then introduced and discussed an alternative to TAPs that uses MAZ-scale information. We refer to this method as the “non-TAP approach” henceforth. In this section, we ask: when do these two approaches give similar and dissimilar information? When the information is dissimilar, which is a more accurate representation of transit access/egress?

As noted in the Alternative to TAPs discussion, any number of alternative formulations are possible, including using TAZs or MAZs directly. We narrow our examination by comparing a single non-TAP approach, as introduced above. An interesting follow-up study would be to examine alternative formulations, including using TAZs or MAZs directly.

The analysis will be carried out along two tracks. In the first track, we will compare level-of-service matrices (or skims) generated using the same inputs for the TAP and non-TAP approaches. In the context of a travel model, if the skims are the same between the two approaches, the behavioral models should generate the same outcomes. Even if the skims and the resulting demand estimates are the same, it is possible for the transit assignment results to differ. As such, we will also compare the assignment outcomes across the TAP and non-TAP approach. This approach is discussed in detail in the Statistical Assessment subsection below.

The statistical assessment of skims and assignment outcomes will tell us whether, in a typical travel model application, the two approaches are likely to generate the same outcomes. This approach may miss outcomes that are important, but not statistically notable or otherwise highlighted in the statistical analysis. To address these concerns, a second analysis track will also be pursued. This examination starts with a hypothesis formation exercise, asking: given our knowledge of the TAP and non-TAP approaches, in what specific situations will the information provided by these approaches differ? The details of the hypothesis formation are discussed in the next subsection. With these hypotheses in hand and the statistical assessment complete, we will then examine each of the hypotheses to see whether we can confirm or refute each hypothesis with available evidence.

A common element across the two assessment tracks is the need for tools to conduct skimming and assignment for the TAP and non-TAP approaches. Our analysis uses the travel model developed and maintained by the Metropolitan Transportation Commission (MTC). MTC serves as the Metropolitan Planning Organization (MPO) for the nine county San Francisco Bay Area region. Specifically, we use MTC's Travel Model Two, version 1 (TM2.1), which uses the TAP approach and has procedures in place that carry out skimming and assignment. We have created a version of select TM2.1 components that use the non-TAP approach to skim building discussed in this document, as well as procedures to carry out a TAZ-scale assignment. We therefore have procedures to create comparable skims and assignment estimates for the TAP and non-TAP approaches using the same network inputs.

Computational Performance

The present study will fall short of doing a complete assessment of the computing time needed to run MTC's TM2.1 with the TAP and non-TAP approaches for the following reasons:

- The resident passenger travel component of TM2.1 is integrated with the TAP-based MAZ-to-MAZ transit path building procedures. We cannot, therefore, readily configure the modeling system to use the non-TAP skims.
- TM2.1's iterative procedures to conduct congested transit assignments with TAPs is, at the time of writing, a work in progress. We therefore do not yet know the computational time of these procedures.

We can say, however, that the non-TAP approach will run faster than the TAP-based approach for the following reasons:

- Given the comparable size of TAPs and TAZs, the burden of reading and storing TAZ-scale skims is comparable to reading and storing TAPs.
- To obtain the MAZ-to-MAZ level-of-service information needed by the travel model components, the TAP-based approach requires a call to an algorithm that searches for and determines an optimal MAZ-to-MAZ path. In the non-TAP approach, all that's needed is assembling the MAZ-scale walk access/egress times from a vector of data and the TAZ-scale information from a matrix of data. The latter tasks should take less computing time than the former.
- When running a congested assignment, the TAP approach requires the TAP-based assignment (executed in Emme) to be run iteratively with the MAZ-scale determination of optimal TAP pairs (executed in custom software). In the non-TAP approach, the TAZ-scale assignment (executed in Emme) needs only be run once — if, as noted above, all of the transit demand generated by the demand model is assigned to a common set of transit paths. The latter task should take less computing time than the former.

Burden

As noted in the Drawbacks of TAPs section, agency and consulting teams in the handful of regions where TAPs are deployed have found them difficult to use — in network coding and debugging. As noted in the above subsection, we expect congested assignment to take longer to run with TAPs than without them, though this claim is speculative and subject to configuring a non-TAP approach that avoids feedback between mode choice-level transit path choices and transit assignment. The burden, therefore, is on the TAP-based approach to demonstrate superior outcomes regarding accurately representing MAZ-scale access and egress and/or MAZ-to-MAZ paths. If the two approaches give similar results, the non-TAP-based approach is preferred.

Hypothesis Formation

Based on our understanding of the TAP and non-TAP approaches to building MAZ-to-MAZ skims, we formulate a set of hypotheses regarding when we expect the two approaches to give similar results and when we expect the approaches to give dissimilar results. There has not been, to our knowledge, a systematic assessment of the TAP and non-TAP approaches.

Hypothesis #1: Two TAPs, Far Apart, Disparate Travel Patterns

Consider an MAZ with a TAP to the east and south, as shown in the figure below.

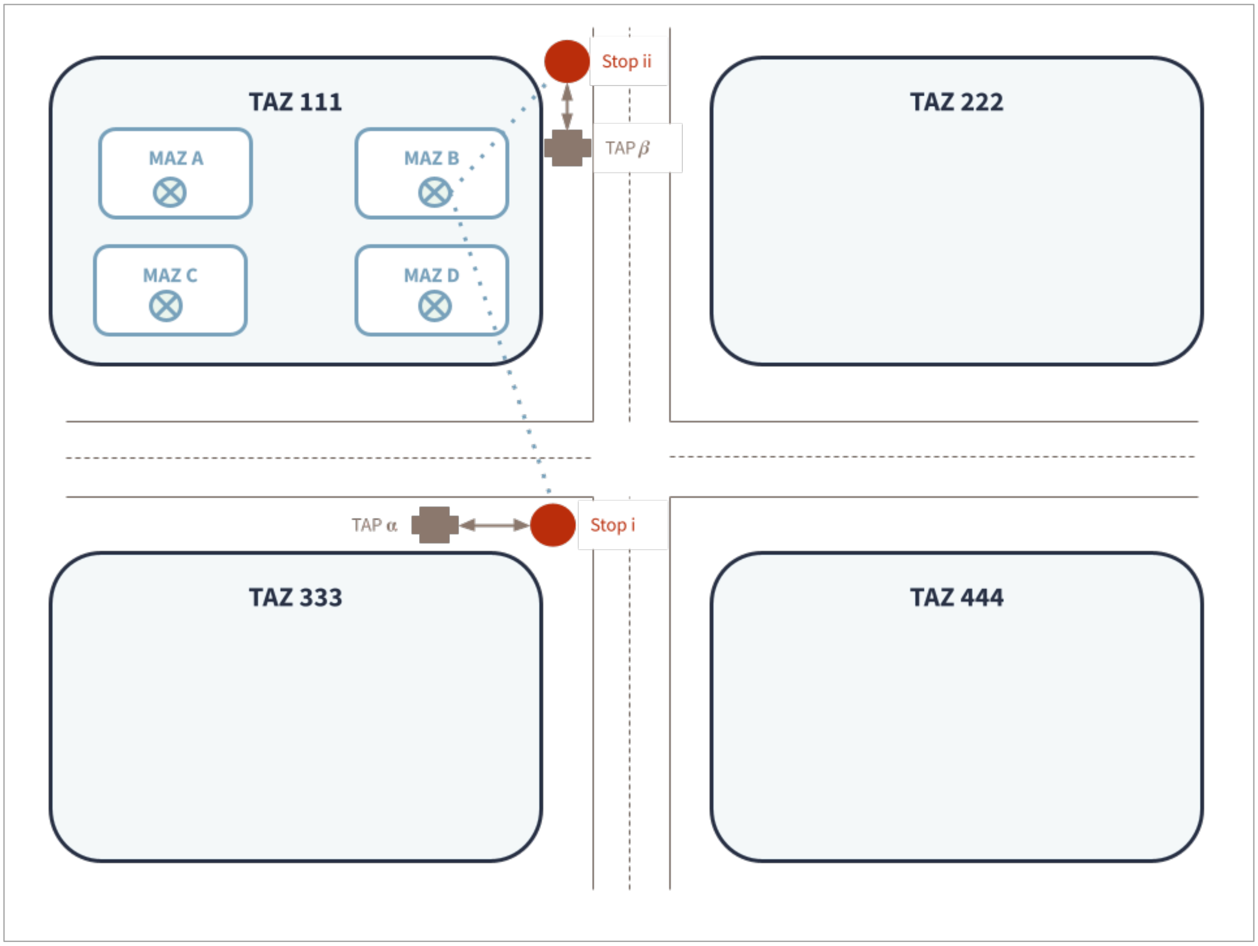


Figure 11: MAZ with Connections to Two TAPs

Let us further assume that travelers departing MAZ B during the morning commute period are, by and large, traveling eastbound, say to the central business district, and not northbound. However, travelers departing TAZ 111 are traveling both eastbound and northbound, in similar amounts. In this case, the TAP approach should accurately route passengers through TAP α and therefore accurately estimate the walk access time to go from MAZ B to Stop i. Because TAP α and Stop i are paired only with each other, the introduction of TAPs is not distorting other walk access paths. In cases like this, the TAP approach should outperform the non-TAP approach. In the non-TAP approach, the weighted walk time, between MAZ B and Stop i and MAZ B and Stop ii, would be used to approximate the walk access time for all trips departing from MAZ B. Because the TAZ-scale demand is roughly equal between these stops, the walk time would be averaged across the links to Stop i and Stop ii, which would underestimate the impedance of walking to Stop i. The non-TAP-based approach should, therefore, systematically underestimate walk access impedance and overestimate transit usage.

In the assignment step, the non-TAP approach will assign all demand for this TAZ based on the TAZ-scale demand, using TAZ-scale walk access connectors based on the MAZ-scale demand from the previous iteration of the model. As such, the boardings in the assignment would differ between the TAP and non-TAP approaches. The specifics of these differences will depend on the demand patterns for each of the MAZs.

The conditions of this case are as follows:

- An MAZ with connections to multiple TAPs.
- MAZ connections to TAPs with walk distances that are significantly different from each other.
- TAPs are connected to transit stops in a manner that does not distort the walk access paths of other MAZs, ideally with a one-to-one TAP-to-stop relationship.
- MAZ travelers disproportionately use TAPs in a manner that is inconsistent with the TAZ-scale demand outcomes.

We should be able to sequentially filter an MAZ-to-MAZ dataset using the above criteria, reporting the number of cases with each step. If we can locate these cases, we will describe a real-world example of this use case. This analysis will be limited to the estimated demand provided by TM2.1, as it provides a level of coverage (each simulation provides for well over a million synthetic trips) not provided by the region's on-board survey data. The analysis is therefore limited by the understanding of disparate demand being an estimate, rather than observed.

Hypothesis #2: Buses are Close, Trains are Not

Consider an MAZ with a cluster of bus stops directly adjacent to the MAZ's boundary and a rail stop a fair distance from the boundary, as shown in the figure below.

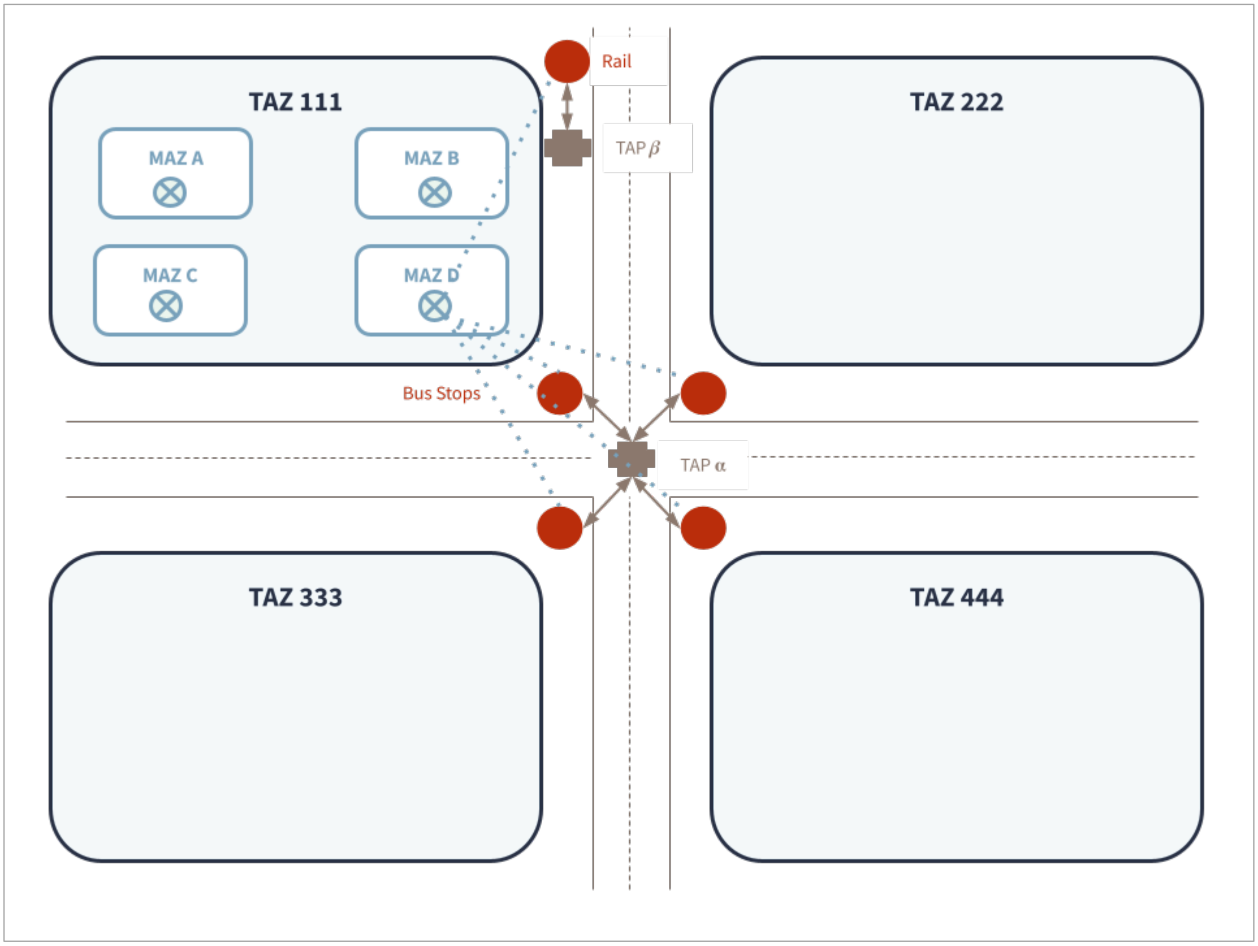


Figure 12: Single MAZ with Access to TAPs served by Bus and Rail

Similar to Hypothesis #1, the TAP-based approach should perform well in this case, provided both bus and rail services are available in the subject path. To the extent the rail line provides superior connections to the destinations of travelers going from this MAZ, the TAP-based approach should accurately route travelers through TAP β, using the connection to the rail station as the appropriate estimate of walk access impedance.

The non-TAP-based approach will assume that all paths leaving the MAZ will have the same walk access impedance, which, as described in the Walk Access/Egress Estimation Algorithm, will be a function of the TAZ-scale demand and the impedance to each stop. This algorithm may overvalue the close bus stops, which would, in turn, result in a short walk access time, which would understate the impedance of walking to the rail station, potentially overestimating rail usage.

As described in Hypothesis #1, the assignment of demand in the two approaches should also differ, as the non-TAP approach will conduct a TAZ-scale assignment.

The conditions necessary to identify these cases are like those in Hypothesis #1 and are as follows:

- A transit path that allows both rail and local bus service to compete.
- An MAZ with connections to multiple TAPs, with one TAP serving rail.
- MAZ connections to TAPs with walk distances that are significantly different from each other.
- TAPs are connected to transit stops in a manner that does not distort the walk access paths of other MAZs, ideally with a one-to-one TAP-stop relationship.
- MAZ-scale demand estimates that differ from TAZ-scale demand estimates.

We can use spatial analysis to identify these MAZs and then assess the skims to check the prevalence of these estimates. As before, after we identify cases in the travel model, we will describe a real-world counterpart to illustrate the use case.

Hypothesis #3: Sparse TAPs, Exaggerated Transit Access

Consider the sparse transit network shown in the figure below. As noted in the spatial bias discussion of TAPs, TAPs in this case are likely to exaggerate the quality of transit service in these locations, as the zero-cost transit stop to TAP connections allow travelers from MAZ B to access transit service at Stop i and allow travelers from MAZ K to access transit service at Stop ii. The non-TAP-based approach should get this right, accurately representing the walk access and path details. Similarly in the assignment step, the non-TAP approach should assign demand to transit services that can be reached from each MAZ, whereas the TAP approach will allow access to transit services that cannot be reached by each MAZ.

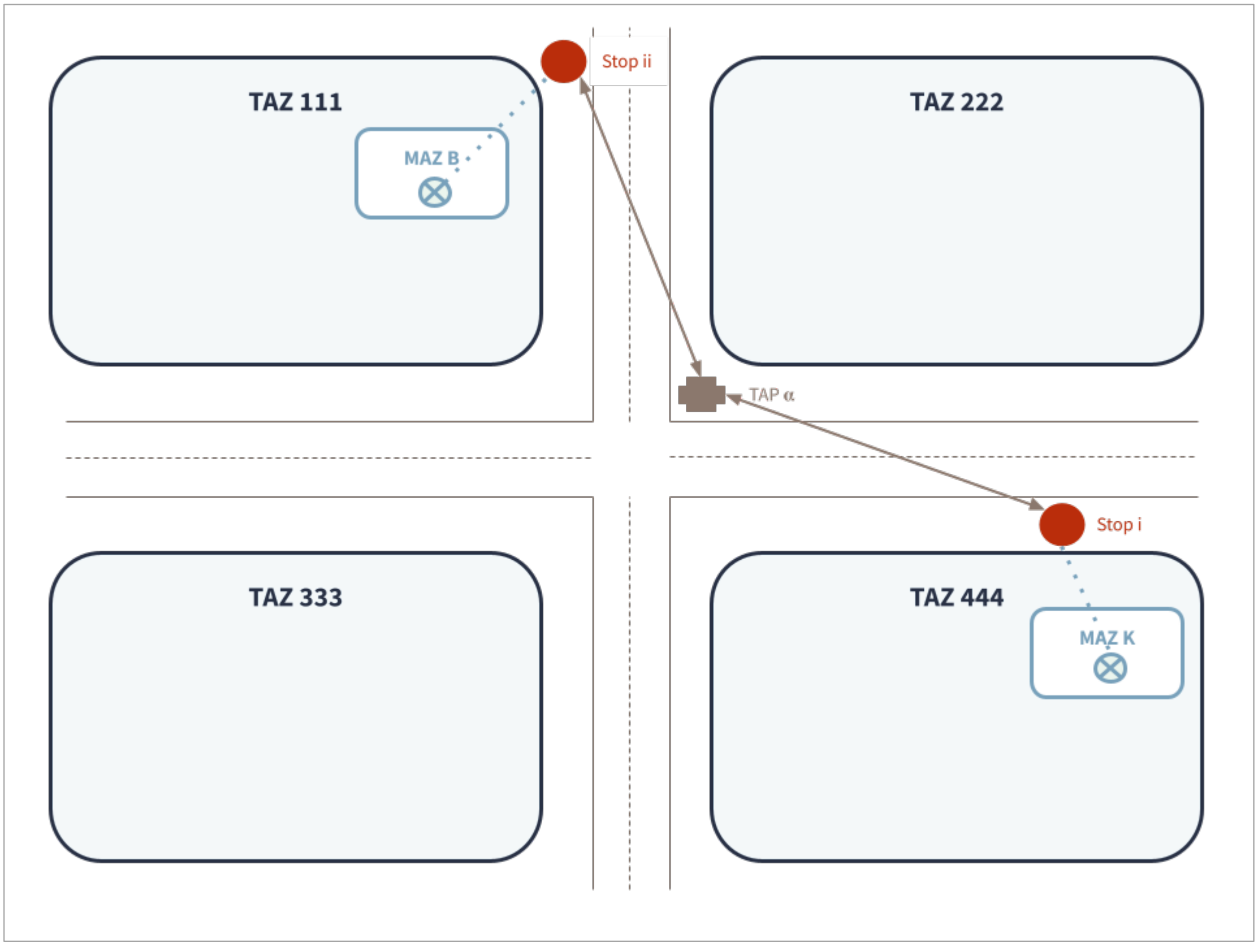


Figure 13: Sparse Transit Network with Single TAP

The conditions necessary for these problems to occur are as follows:

- Long TAP to transit stop connections.
- TAPs with more than one connection to a transit stop.
- Paths between MAZs and transit stops (via TAPs) that are farther than the assumed maximum walk distance.

Mechanically, we can identify these paths by first selecting TAPs with long connections to transit stops and then selecting the TAPs that are connected with the selected stops. We can then examine the TAP-to-TAP paths to determine the degree to which these MAZs are using transit stops within walkable distances. If these cases are found, real world examples will be provided.

Hypothesis #4: A River Runs through It

Consider a TAZ that has a barrier such as a creek bed or steep hillside that prevents travelers from exiting the TAZ in all directions, as illustrated in the figure below.

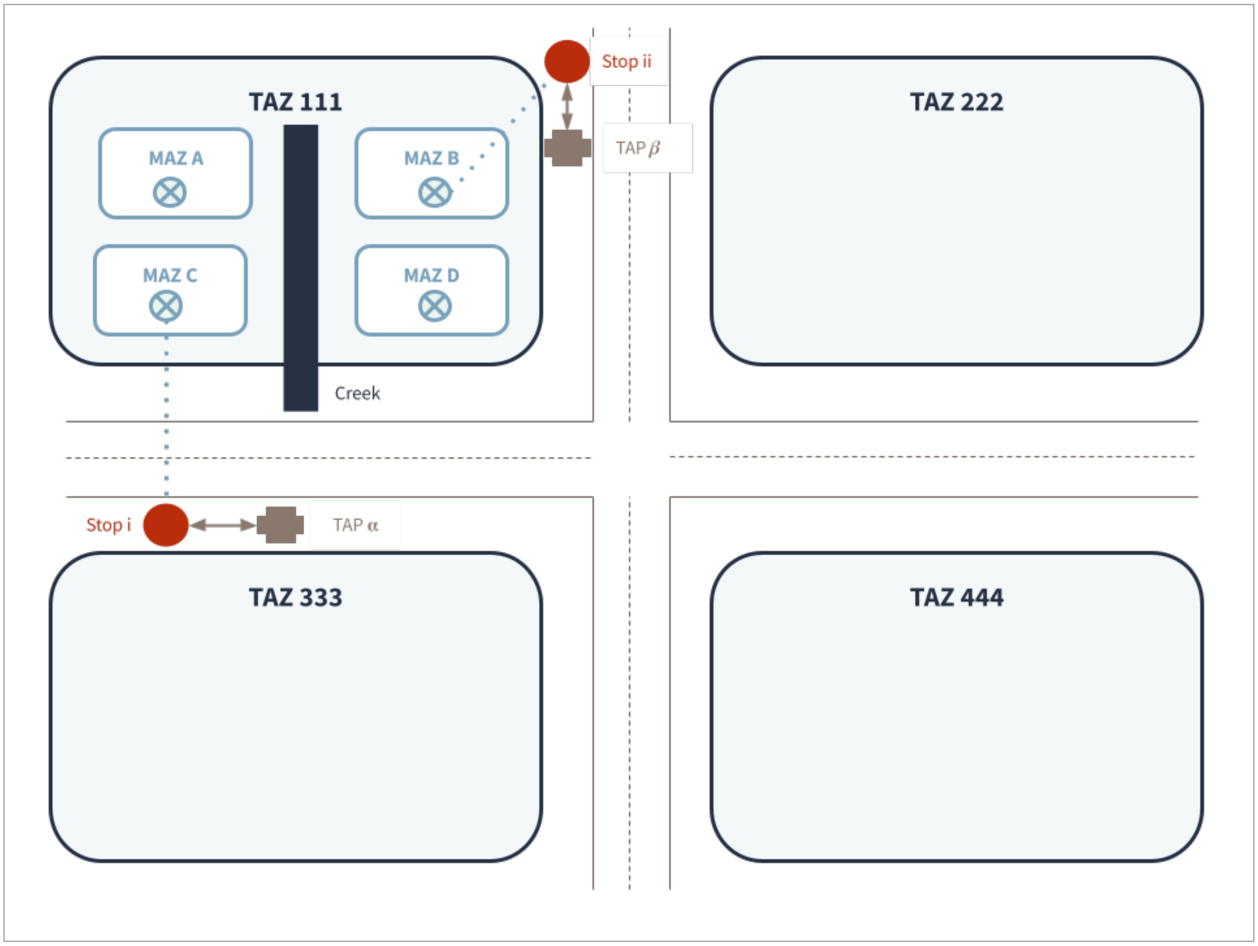


Figure 14: TAZ with Physical Barrier (Creek) Reducing Access

Provided that an accurate pedestrian network is used to connect MAZ centroids to transit stops, the TAP-based approach should accurately represent the access to Stop i, but not Stop ii, from MAZ C and the access to Stop ii, but not Stop i, from MAZ B.

Again provided that an accurate pedestrian network is used to connect MAZ centroids to transit stops, the non-TAP based approach should also accurately represent the connections between MAZ C and Stop i, as well as MAZ B and Stop ii. When computing the weighted walk time for MAZ C, only the connection to Stop i will be considered. There is no difference, therefore, between the connectivity between MAZs and transit stops in the TAP and non-TAP approaches.

There will be a difference, however, in the assignment outcomes between the TAP and non-TAP approaches. In the TAP approach, all transit demand from MAZ B will use Stop ii and all transit demand from MAZ C will use Stop i. This is not the case in the non-TAP approach. In the non-TAP approach, the TAZ-scale assignment will be used to apportion all transit demand between Stop i and Stop ii. It is possible, therefore, for all the transit demand to use Stop i or Stop ii.

In this case, the TAP and non-TAP approaches should give the same skim results, but different assignment results. The conditions necessary for this problem to occur are as follows:

- TAZs in which member MAZs have disparate access to transit stops. For example, a TAZ in which one MAZ has access to a single transit stop and a second MAZ has access to a separate transit stop.
- TAZ assignments that do not accurately allocate MAZ demand to the transit stops that are connected to each MAZ.

Statistical Assessment

MTC, in partnership with the region's numerous transit agencies, conducts routine on-board transit surveys. One outcome of these surveys is a rich database of detailed movements made by transit riders along with expansion weights or factors that estimate the approximate number of riders each surveyed rider represents. We use these records to inform the statistical assessment of the TAP and non-TAP approaches.

MTC's travel model segments the day into the following five time-of-day categories:

- Early morning, 3 am to 6 am;
- Morning commute, 6 am to 10 am;
- Midday, 10 am to 3 pm;
- Evening commute, 3 pm to 7 pm; and,
- Evening/night, 7 pm to 3 am the next day.

MTC's travel model (TM2.1) builds three sets of TAP-to-TAP paths, segmented by transit technology, as follows:

- Set 1: Local bus service only
- Set 2: "Premium" (or non local bus) services only
- Set 3: Premium plus local bus (i.e., paths that include both Premium and local bus services)

For each skim set and time-of-day combination, MTC's custom travel model software returns the N best MAZ-to-MAZ transit paths, with the user able to set a value of N. For the balance of this discussion, we use the single best path returned by the travel model's path builder. Within MTC's travel model, the best four paths are retained (independent of the skim set) and the single best path is selected probabilistically.

The first examination focuses on skims. If any two transit skimming approaches give comparable results, then the trips generated by the behavioral models should also be comparable. MTC's travel model builds walk and drive access skims. We limit our analysis here to walk access, as the purpose of the TAP-based approach is to create improved estimates of walk access and egress using the MAZ geographies. There is no reason to expect different outcomes when comparing TAP- and non-TAP-based approaches to drive access path building, aside from the walk egress leg, whose differences will be captured in the walk access assessment (see Walk and Drive Access section for additional discussion).

The travel model has ~40,000 MAZs, so we have a total of 40,000 x 40,000 x 3 (skim sets) x 5 (time of day categories) outcomes to compare across the skimming techniques. However, these interchanges are not equally relevant. Skim differences for interchange/skim set/time-of-day categories that have many transit riders are more important than differences for categories that have no transit riders. This is where the on-board survey is useful. By examining the MAZ pairs, by time of day and skim set, that are used by travelers in the on-board survey, we narrow and focus the analysis. The analysis will therefore start with the on-board survey records, then append the skim outcomes from the TAP-based and non-TAP-based approach to each record.

An ideal approach would first tune the parameters in the TAP-based approach to match observed data and then tune the parameters in the non-TAP approach to match observed data. The approach taken here started with a work-in-progress set of parameters for a TAP-based approach. We then made minor adjustments to the non-TAP approach such that the TAP and non-TAP outcomes were similar.

Table 1 below summarizes the skim tables appended to each of the on-board survey records, comparing the TAP and non-TAP means and medians. Important notes from the table are as follows:

- The "perceived time" applies perception factors for walking, waiting, and transferring, using the Emme settings for the TAP and non-TAP approaches. Please note that the TAP approach considers a broader set of perceptions in determining the best TAP pair for each MAZ pair that are not reflected in Table 1.
- The "MAZ Walk Access" and "MAZ Walk Egress" fields for the non-TAP approach, which operates at the TAZ level, uses the approach described in the MAZ-scale Walk Access/Egress Impedance Algorithm.
- The table only summarizes paths with non-zero in-vehicle times that are found for on-board survey records in both approaches.

Skim Table	Mean TAP	Mean Non-TAP	Mean Difference	Median TAP	Median Non-TAP
Perceived Time	80.1	71.1	3.4	61.9	57.7
Time	41.1	36.7	0.8	32.6	30.4
Wait Time	10.2	6.9	3.2	6.0	5.0
In-vehicle Time	14.8	13.7	1.1	11.5	10.2
MAZ Walk Access	6.6	5.8	0.2	4.9	5.7
MAZ Walk Egress	6.8	5.8	0.2	5.0	5.7
Initial Wait Time	7.2	6.4	0.8	5.0	4.9
Transfers	0.3	0.1	0.3	0.0	0.0
Transfer Wait	3.0	0.5	2.4	0.0	0.0
Auxiliary Walk†	2.8	7.0	-4.3	0.0	2.5
† — As discussed in the text below, the definition of "auxiliary walk" is not consistent across the two approaches.					

Table 1: TAP and Non-TAP Skim Differences by Skim Table (N = 68,173)

Table 1 shows that the two approaches can be tuned to generate very similar outcomes. The median total times between the two approaches are 32.6 and 30.4 minutes, respectively. Further, the mean and median values across skim tables are very similar. Figure 15 and Figure 16 below show scatter plots of the TAP and non-TAP approach for total time and total in-vehicle time, with each dot representing an on-board survey record.

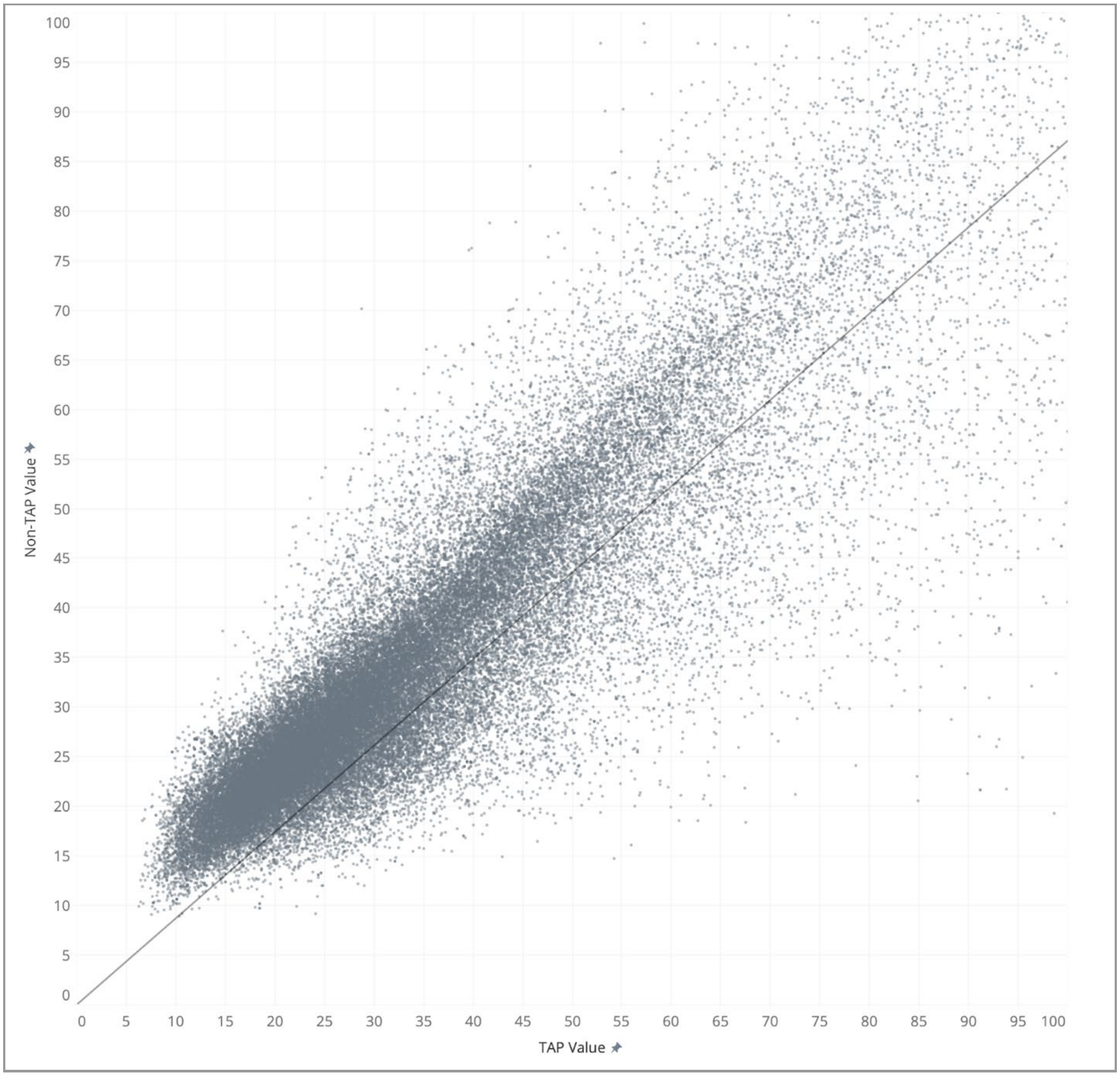


Figure 15: Scatter Plot of Total Time (N = 68,173; R^2 = 0.91)

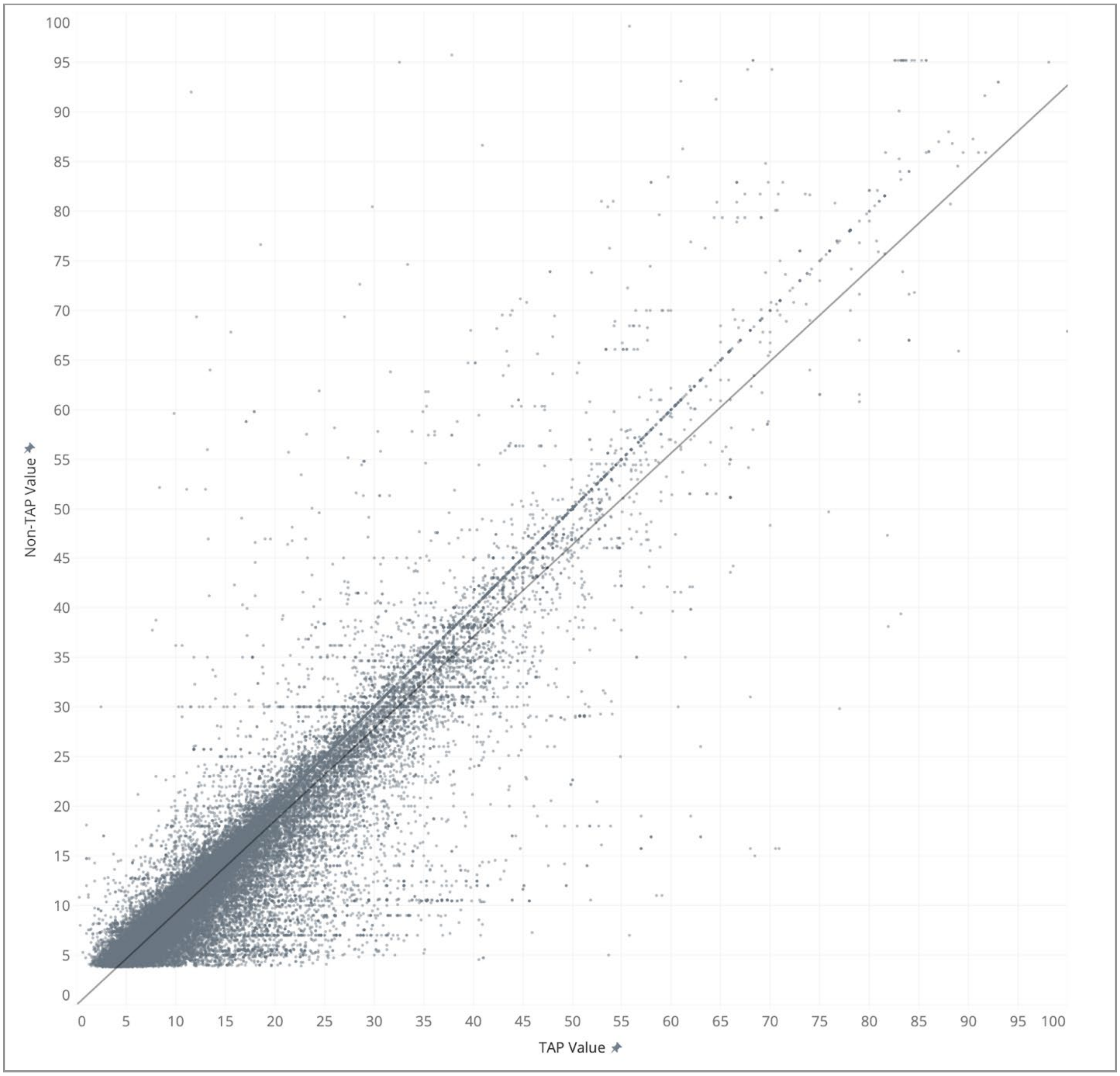


Figure 16: Scatter Plot of In-vehicle Time (N = 68,173)

The largest difference in Table 1 is the value for "auxiliary walk". In the TAP approach, the walk access/egress rules are determined outside the transit assignment step, with MAZs connected only to specific TAPs (via transit stops). To ameliorate cliff effects, the TAP approach takes a broad view on connectivity, considering stops within a 25-minute walk. Cliff effects persist, however, but only at the margins: if a highly attractive transit stop is located a 26-minute walk from the MAZ, it will not be considered.

In the non-TAP approach, travelers are allowed to walk any distance to a desirable transit stop. Mechanically, this is done by first traversing the TAZ connectors, the impedance of which is informed by the MAZ geographies (see the TAZ-scale Walk Access/Egress Impedance Algorithm for details), and then walking along the roadway network in search of optimal transit routes. The 7.0 mean minutes for "Auxiliary Walk" in Table 1 reflects both the time spent walking to transfer between routes and time spent walking on the roadway network after leaving the TAZ. The 2.8 mean minutes for "Auxiliary Walk" in Table 1 in the TAP approach column reflects only time spent walking when transferring.

The practical differences between these two approaches should be small, as illustrated by the small differences in total time shown in Table 1. While the TAP approach has the potential to introduce cliff effects, the impact of these effects can be minimized by increasing the maximum walk distance (which will have a small increase on the computational time), as has been done in the MTC application. The non-TAP approach avoids cliff effects but requires model users to be mindful of the representation of pedestrian infrastructure, as movements are made on the network directly. Allowing travelers to walk on the network to find better transit paths will also have a small impact on the computational time.

As shown in Table 2, the non-TAP approach finds a larger share of viable paths for the on-board survey records than the TAP approach. Of the 97,842 walk to transit on-board survey records, paths were found using both approaches for about 68,000 records, in neither for about 2,700, only in the TAP approach for ~7,700, and only in the non-TAP approach for ~19,000. This makes sense given the non-TAP approach's allowance of walking on the network to find a viable transit stop. Practically, the maximum walk distance could be expanded in the TAP approach to reduce this difference.

Operator	Both	Neither	Only TAP	Only Non-TAP	Total
SF Muni	32,495	304	4,565	5,182	42,546
BART	13,710	1,546	548	6,138	21,942
VTA	8,343	170	811	2,455	11,779
AC Transit	8,861	272	847	1,793	11,773
Caltrain	795	53	28	1,727	2,603
SamTrans	1,679	42	297	513	2,531
Golden Gate Transit	980	85	34	934	2,033
Santa Rosa CityBus	365	6	126	16	513
LAVTA	174	41	109	158	482
TriDelta	273	19	76	65	433
County Connection	79	29	18	126	252
Soltrans	94	51	43	53	241
Petaluma Transit	76	10	93	7	186
FAST	84	12	20	22	138
Napa Vine	90	7	34	6	137

SMART	53	15	1	52	121
ACE	5	3		50	58
City Coach	3	2	23	1	29
WestCAT	10			8	18
Marin Transit	4		1	7	12
WETA				8	8
Delta Breeze	4			3	7
Total	*68,173*	*2,671*	*7,674*	*19,324*	*97,842*

Table 2: Paths Found for On-board Survey Records by Operator

Similar skims will result in similar travel demand estimates. It is likely that similar skims will result in similar boarding estimates on individual transit routes, but it is possible for the skims to be similar and the boardings to be different. We therefore also examine the boarding patterns revealed by the transit assignment step. The analysis again uses the on-board survey data, assigning records by time of day and skim set using both the TAP and non-TAP approaches. The TAP approach requires two steps: using custom software to determine the best TAP-to-TAP path for each record and then commercial software (Emme in this case) to assign the TAP-to-TAP record. The non-TAP approach requires two steps as well: using custom software to create the TAZ-scale walk access connections and then using commercial software to assign the TAZ-scale demand.

Table 3 below summarizes boardings by operator. The non-TAP boardings are higher because, as noted previously, the parameters used in the non-TAP approach identifies viable paths for more records than does the TAP approach. Overall, however, the results are similar. The average transfer rate is similar between the two approaches and could be further aligned through adjustment of the transfer penalty in each approach. Again, these differences, based on our analysis, are seemingly not fundamental to the TAP or non-TAP approach, but rather an outcome of not fully calibrating each approach to observed data.

Operator	TAP Boardings	Non-TAP Boardings	Difference
San Francisco MUNI	655,323	576,769	-78,553
BART	312,101	359,897	47,796
AC Transit	158,283	258,715	100,432
Santa Clara VTA	120,536	172,712	52,177
samTrans	46,044	102,236	56,192
Golden Gate Transit	20,955	38,173	17,219

Caltrain	20,237	85,537	65,300
TriDelta	4,181	11,684	7,502
Santa Rosa CityBus	4,030	566	-3,464
SF Bay Ferry	3,842	1,332	-2,510
Vallejo Transit	3,582	3,048	-534
WHEELS	3,467	9,085	5,619
Stanford Marguerite	2,747	3,501	754
Golden Gate Ferry	2,583	9,944	7,361
Fairfield-Suisun Transit	1,855	1,736	-119
County Connection	1,633	24,801	23,169
WestCAT	1,527	13,490	11,963
Amtrak Capitol Corridor	1,482	6,114	4,631
Sonoma County	1,306	4,066	2,760
Napa VINE	1,201	2,406	1,206
Emery Go-Round	914	38	-876
Petaluma Transit	771	134	-637
Vacaville City Coach	431	20	-410
Union City Transit	417	3,893	3,475
ACE	354	4,920	4,567
Mountain View	109	5	-104
Marin Transit	56	633	577
Blue and Gold	26	311	285
Rio Vista Delta Breeze	3	41	38
Grand Total	*1,369,994*	*1,695,808*	*325,813*

Table 3: Summary of Boardings by Operator from Weighted On-board Survey Records

Comparisons were also made by route. Figure 17 and Figure 18 below show scatter plots of TAP and non-TAP boardings by route for routes operated by the Santa Clara Valley Transportation Authority (Santa Clara VTA) and San Francisco Municipal Transportation Agency (SF Muni), respectively. The two approaches generally assign the on-board survey demand to the same routes.

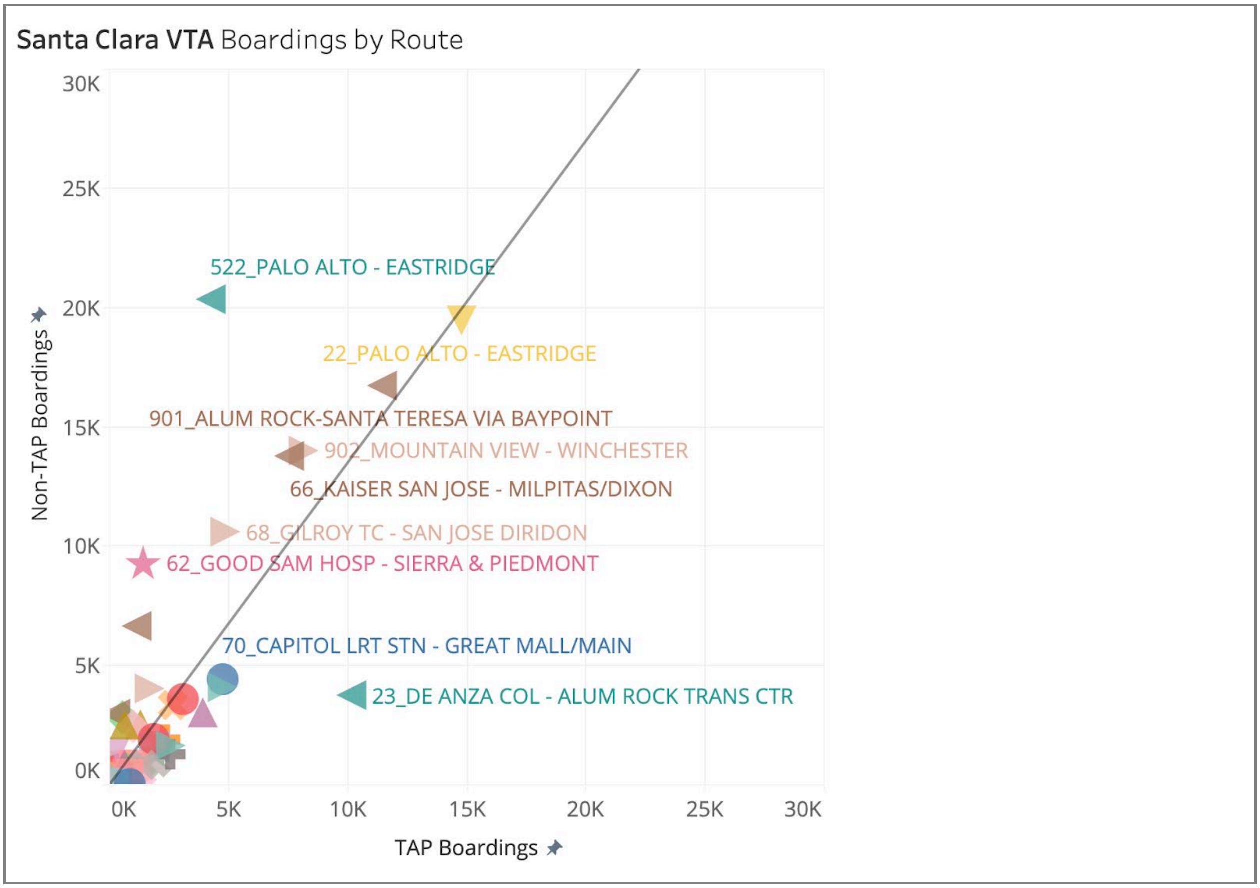


Figure 17: Scatter Plot of Santa Clara VTA Boardings by Route by Approach

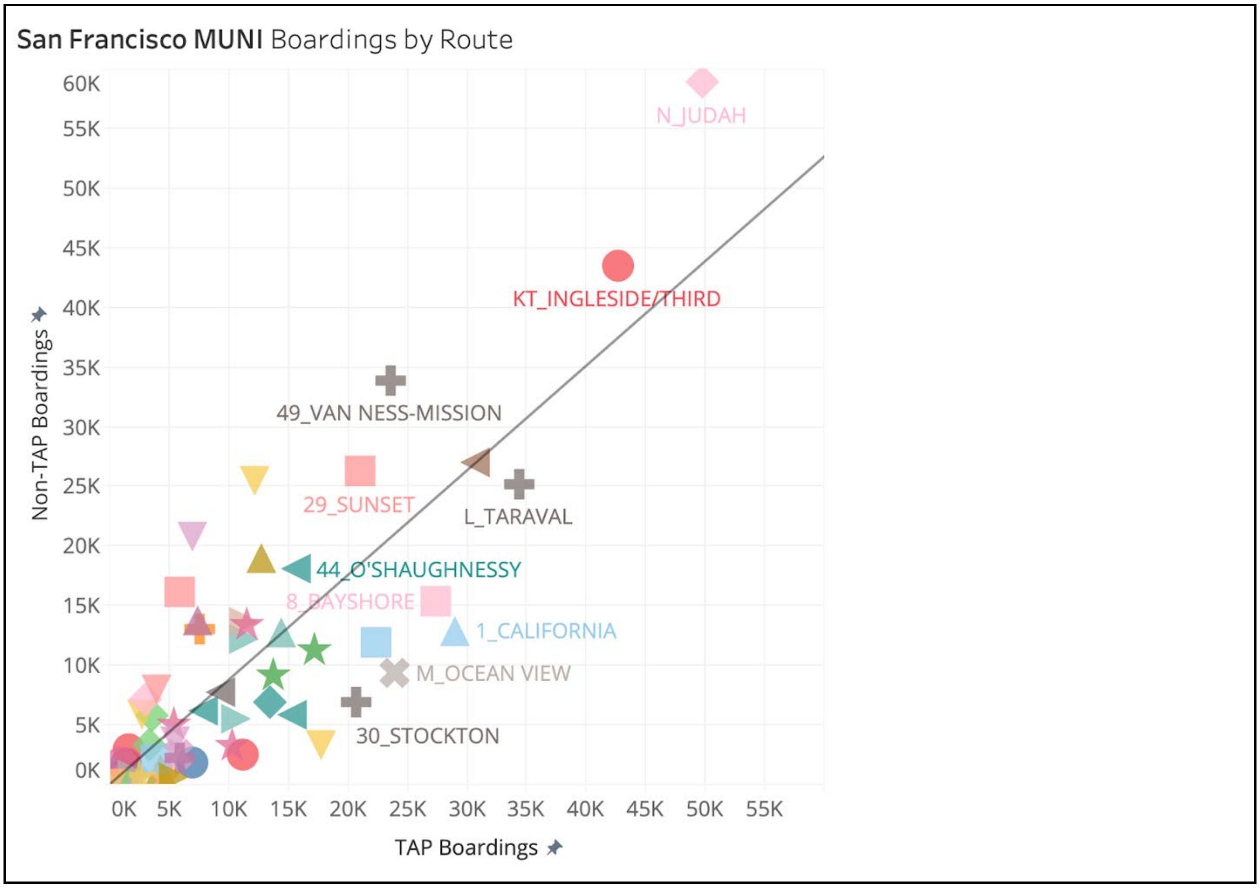


Figure 18: Scatter Plot of San Francisco Muni Boardings by Route by Approach

The statistical assessment suggests that both the TAP and non-TAP approach can be calibrated to match observed demand patterns in a region, such as the San Francisco Bay Area. As noted previously, an ideal study would fully calibrate both approaches to observed data to a consistent set of performance criteria prior to comparing them statistically. The present study started with a roughly calibrated TAP approach and tuned the non-TAP approach to approximately match the TAP outcomes. This experience suggests to us that the non-TAP approach could be readily manipulated to match observed demand patterns.

Hypothesis Assessment

The assessment of hypotheses needs a rich set of transit movements in order to find the rare cases that meet the criteria defined in each hypothesis. While the on-board survey database assembled by MTC and their partners is very large, it is insufficient for this task. We therefore use MTC's travel demand model simulation outcomes as the basis for the travel demand that informs our assessment. While not ideal due to the demand being simulated rather than observed, it should be sufficient, as it identifies edge cases in which the TAP or non-TAP approach should be superior. To the extent the edge cases in the simulation also occur in real life, which seems likely to us, the travel model is useful in this context.

Hypothesis #1: Two TAPs, Far Apart, Disparate Travel Outcomes

The first hypothesis discusses a use case in which the TAP approach will be superior to the non-TAP approach. If a single MAZ has both (a) different demand patterns from its parent TAZ and (b) significantly different walk access times to stops it is connected to, then the non-TAP approach of (i) aggregating demand to the TAZ level and then (ii) estimating MAZ-scale walk access times using TAZ-scale boarding outcomes, will misrepresent the subject MAZ's transit connectivity.

To identify these use cases in the simulation data, we walked through the steps summarized below in Table 4.

Step	Records	Quantity	Share of all MAZs
1	MAZs that are connected to multiple TAPs	38,010	95.7%
2	Of the MAZs in Step 1, the number of MAZs connected to stops with distance differences greater than 0.25 miles	20,916	52.6%
3	Of the MAZs in Step 2, the number of MAZs with non-zero walk to transit trips	16,769	42.2%
4	Of the MAZs in Step 3, the number of MAZs with more than 100 walk to transit trips.	498	1.3%
5	Of the MAZs in Step 4, the number of MAZs with very different demand patterns than TAZs	12	0.0%

Table 4: Filtering of Records Specific to Hypothesis #1

The goal of the steps outlined in Table 4 is to help us find situations in the simulation data where the TAP approach is likely to perform better than the non-TAP approach. A digression on each steps is as follows:

1. **Connected to multiple TAPs**. If an MAZ is only connected to a single TAP, it is likely to be close to a single transit stop or a cluster of transit stops located in close proximity. In this case, it's likely that both the TAP and non-TAP approach estimate the walk access time correctly. It may, however, be possible in this situation for the non-TAP approach to assign the demand from this MAZ to a stop that cannot be reached by this MAZ, which is the subject of Hypothesis #4.
2. **Disparate walk access distances**. If, for a given MAZ, the walk distances to each of the stops it is connected to are the same, the non-TAP approach of estimating the walk distance will be correct. If, however, the walk distances are very different, the TAP approach becomes valuable.
3. **Non-zero walk to transit trips**. MAZs must have transit demand for the details of the transit connections to be important.
4. **More than 100 transit trips**. We select an arbitrarily large cut-off point to identify MAZs that have a sufficiently large amount of transit demand that we can, in Step 5, determine if the MAZ-scale demand is different from the TAZ-scale demand.
5. **Different demand patterns**. We use the χ^2 test applied at MTC's 22-district geographies to identify MAZs that have demand patterns different from the TAZ demand patterns. An example contingency table for MAZ 10600 and TAZ 343 are summarized in Table 5 below. We use a χ^2 statistic of 50 as an arbitrarily large cut-off point for differences in demand.

District	MAZ-scale Demand	TAZ-scale Demand
1 — Downtown San Francisco	358	695

2 — Northwest San Francisco	4	241
3 — Southeast San Francisco	6	230
4 — Northern San Mateo County	0	33
22 — Marin County	0	5

Table 5: Example Contingency Table for Hypothesis #1, MAZ 10600 (χ^2 = 199.6)

This filtering process identified MAZ 10600 in the MTC model as an MAZ likely to benefit from the TAP approach. The location of the MAZ is shown in Figure 19 below. The MAZ is occupied by a Galileo Academy of Science and Technology, which is a large public high school in San Francisco. The TAZ includes residential and commercial land uses as well, including popular tourist attractions. It would therefore make sense that the transit patterns to/from this MAZ differ from the patterns for the broader TAZ.

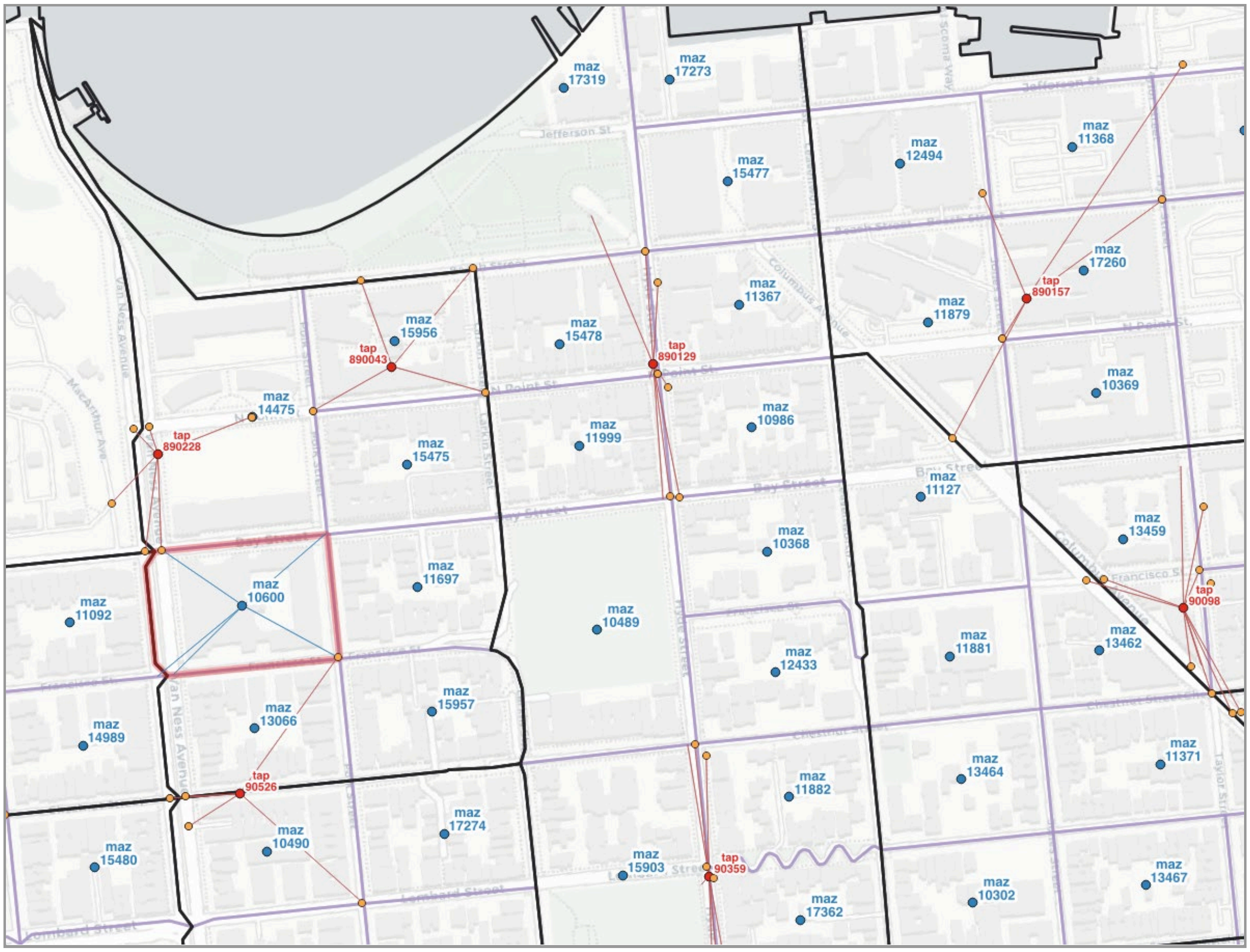


Figure 19: MAZ 10600 (red boundary), within TAZ 343 (dark black boundary), with MAZ centroids in blue, TAPs in red, and transit stops in orange

In the TAP approach, the MAZ-scale demand is allocated to TAPs. Table 6 below summarizes the TAP approach's allocation of demand during the morning commute time period (selected as illustrative) as well as the walk access times assumed for each TAP. This example illustrates both the advantages and disadvantages of using TAPs. The advantage is the heterogeneity of the transit paths identified for this MAZ. The disadvantage is that, once you arrive at a TAP, you can move at zero cost to any other stops that are connected to the TAP, which exaggerates the walk access shed.

TAP	Morning Commute Demand (trips)	Morning Commute Walk Access Time (minutes)
90526	5	3.2
890129	2	6.7
890157	1	11.0
890228	8	2.2
90526	5	3.2

Table 6: TAP Allocation of Demand from MAZ 10600

In the non-TAP approach, this MAZ is assigned a uniform value by time of day, by skim set. For this MAZ, the walk access estimate is between 3.7 minutes and 4.2 minutes (across skim sets). However, as noted in the Statistical Assessment section, the non-TAP approach allows for additional walk access time on the network to reach the optimal stop in the TAZ-scale assignment. Because the non-TAP approach mixes TAZ- and MAZ-scale estimates, the true MAZ walk access time will often be distorted.

A second example, for MAZ 16727, is shown in Table 7 and Figure 20 below, which is in San Francisco's central business district. This MAZ is located within a TAZ that has similar land use. The contingency table has a large χ^2 statistic because of the amount of transit travel to his MAZ and TAZ, which suggests there may be benefits to the TAP approach, which has the potential to sort out demand patterns for small geographies.

District	MAZ-scale Demand	TAZ-scale Demand
1 — Downtown San Francisco	36	713
2 — Northwest San Francisco	21	869
3 — Southeast San Francisco	15	956
4 — Northern San Mateo County	11	136
5 — Southern San Mateo County	0	1
6 — Northwest Santa Clara County	0	2
13 — Southern Alameda County	1	3

14 — Northern Alameda County	31	145
15 — Downtown Oakland	0	48
16 — Western Contra Costa County	3	14
17 — Central Contra Costa County	0	1
22 — Marin County	0	4

Table 7: Example Contingency Table for Hypothesis #1, MAZ 16727 (χ^2 = 129.9)

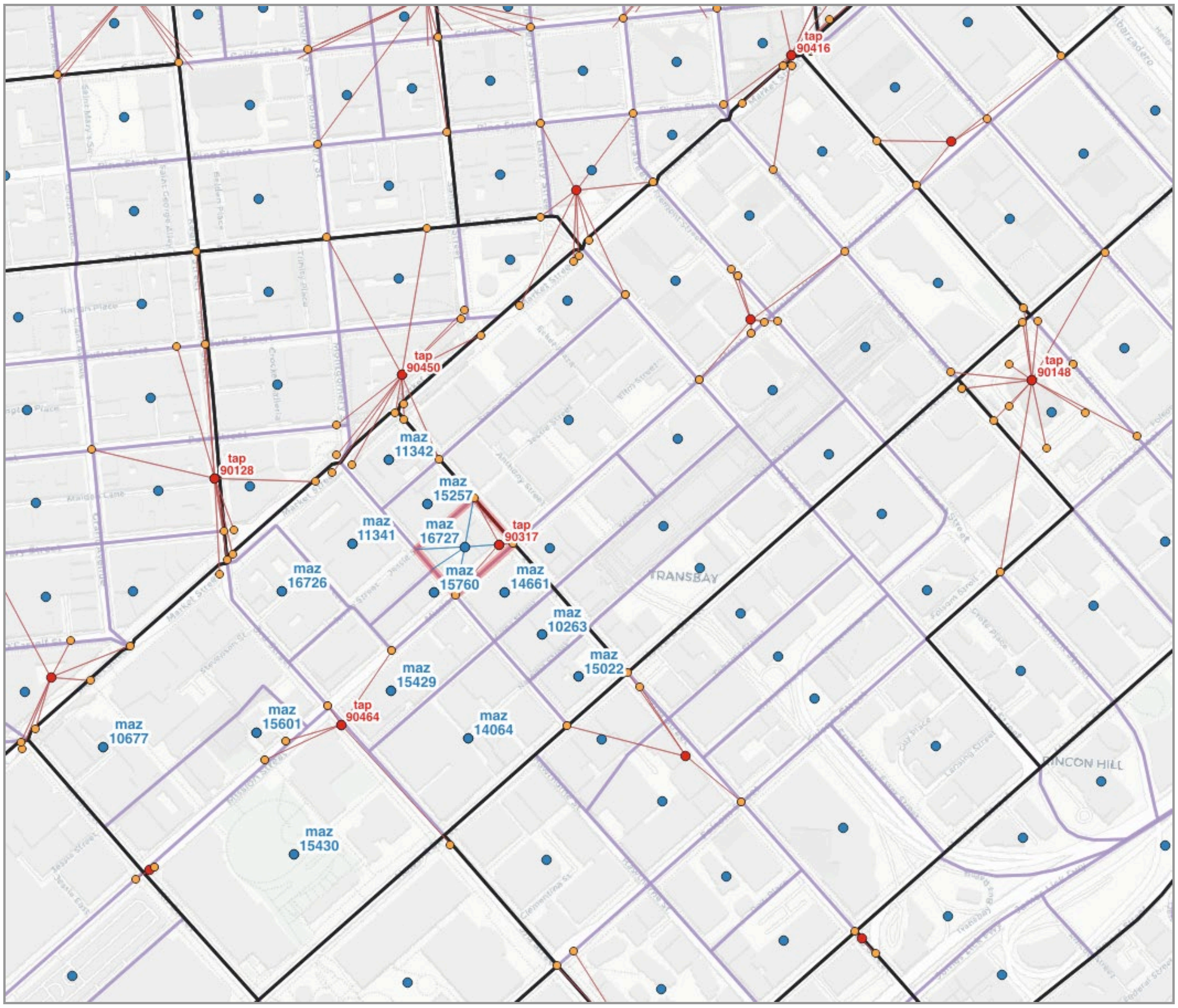


Figure 20: MAZ 16727 (red boundary), within TAZ 590 (dark black boundary), with MAZ centroids in blue, TAPs in red, and transit stops in orange

Table 8 below summarizes the allocation of demand to TAPs during the evening commute period. As in the previous example, we again see the advantages of the TAP approach in the diversity of connections at the MAZ level. However, due to the TAPs being connected to multiple stops, the true walk access time is distorted. The dominant TAP is 90450, which is connected to the Montgomery BART station and has a short walk access time of 2.8 minutes.

TAP	Morning Commute Demand (trips)	Morning Commute Walk Access Time (minutes)
90128	3	4.7
90148	3	10.8
90220	1	11
90317	2	1.7
90416	3	10.7
90450	37	2.8
90464	1	3.4

Table 8: TAP Allocation of Demand from MAZ 16727

In the non-TAP approach, this MAZ is assigned a uniform value by time of day by skim set. For this MAZ, the walk access estimate is 4.5 minutes (set 1), 2.9 minutes (set 2), 3.6 minutes (set 3) — with additional walk access possible on the network itself in the TAZ scale path building. As noted above, because the non-TAP approach mixes MAZ- and TAZ-scale walk access estimates, the true MAZ walk times will be distorted. In this case, the estimate is close to the dominant TAP value of 2.8 minutes, but fails to capture the heterogeneity of the TAP approach.

In order to find these examples, we used the χ^2 statistic to identify MAZs with different demand patterns than TAZs. There are two key problems with this approach, as follows:

- The geography used to assess differences, namely MTC's 22 districts, likely mask differences in travel patterns that happen at a smaller scale; and,
- Statistical significance is not an obviously helpful guidepost, as we are interested in practical, not statistical differences.

Despite these shortcomings, the χ^2 statistic does allow us to readily identify situations in which the TAP approach has the potential to be superior to the non-TAP approach, which is the goal of the analysis. However, it makes it difficult to generalize differences between the two approaches, given the *ad hoc* nature of the details used to identify these use cases.

The distribution of the χ^2 statistic is shown in Figure 21 below. The distribution suggests the difference between the MAZ and TAZ demand is generally small, as indicated by the concentration of data near low values of the χ^2 statistic. The distribution does show a long tail, however, indicating numerous places in which the MAZ and TAZ demand differ. In these cases, the travel model may or may not realistically represent the differences in demand patterns. For example, in the Galileo High School example shown above, the distribution is likely different due to the different destination choice models applied for high school travel. The demand pattern, however, did not strike MTC staff as realistic: Galileo High School likely draws students from neighborhoods across San Francisco, rather than just downtown. Further, the TAPs to which the MAZ is connected to via transit stops also connect to other transit stops, which distorts the actual walk distance from this MAZ. These short-comings ameliorate the advantages of the TAP approach in these cases.

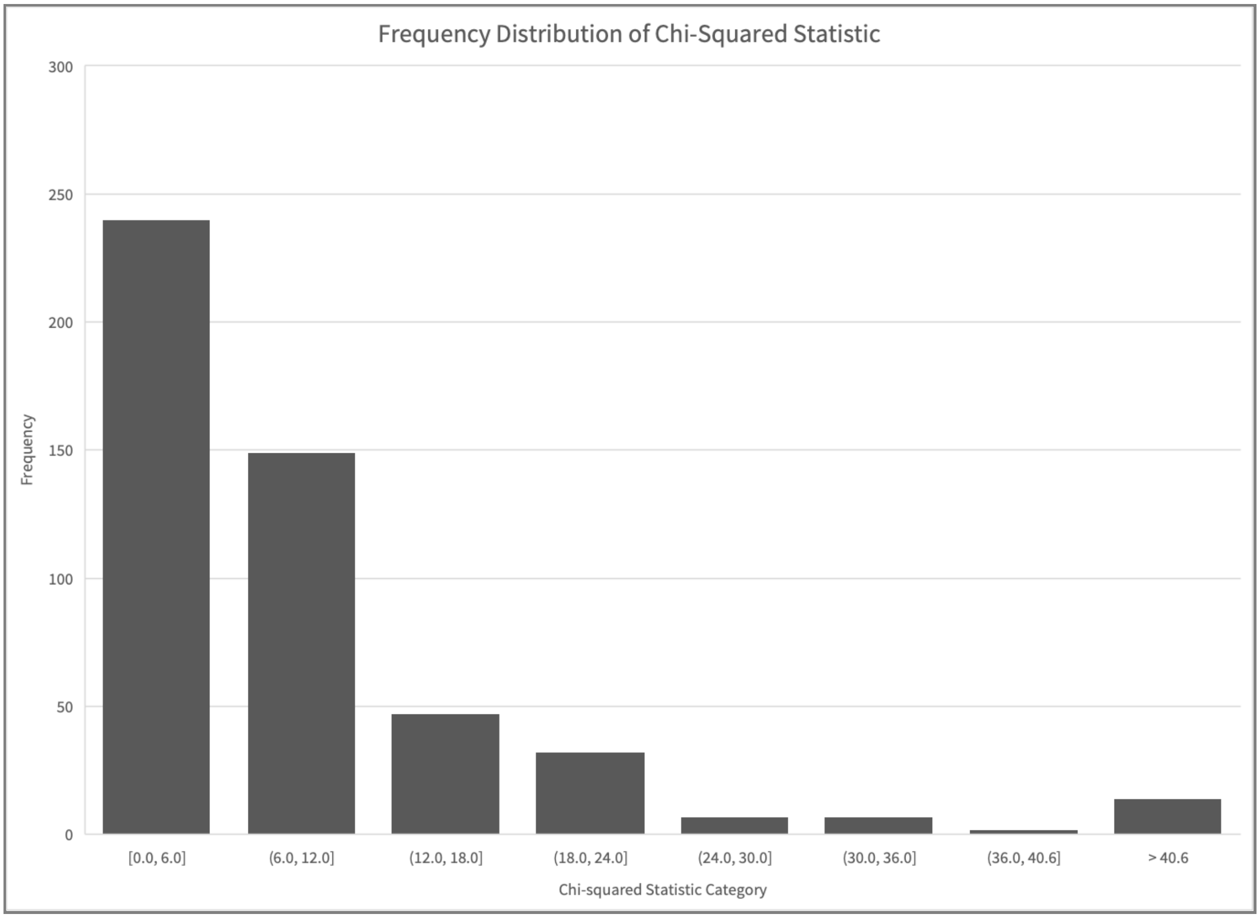


Figure 21: Frequency Distribution of the χ^2 statistic Comparing MAZ and TAZ Demand Patterns

Hypothesis #2: Buses are Close, Trains are Not

Hypothesis #2 is identical in structure to Hypothesis #1, but involves differences between bus and train access. The filtering of records for Hypothesis #2 are shown below in Table 9.

Step	Records	Quantity	Share of all MAZs
1	MAZs that are connected to at least two TAPs, with at least one accessing only bus service and at least one connecting to rail service	25,206	63.5%
2	Of the MAZs in Step 1, the number of MAZs connected to a bus TAP and a rail TAP with distance differences greater than 0.25 miles	16,411	41.3%
3	Of the MAZs in Step 2, the number of MAZs with non-zero walk to transit trips	14,087	35.6%
4	Of the MAZs in Step 3, the number of MAZs with more than 100 walk to transit trips.	494	1.2%
5	Of the MAZs in Step 4, the number of MAZs with very different demand patterns than TAZs	12	0.0%

Table 9: Filtering of Records Specific to Hypothesis #2

These steps identified the same 12 MAZs we identified in Hypothesis #1, i.e., all of the cases in Hypothesis #1 involved bus and rail connections. Two additional examples are provided to further illustrate use cases for this issue.

MAZ 15431 is shown in Figure 22 and its contingency table is shown in Table 10. The MAZ is located in Downtown San Francisco, in a mixed residential and commercial district. As with the previous example in Hypothesis #1, the large χ^2 is a function of the large amount of transit demand in this area.

District	MAZ-scale Demand	TAZ-scale Demand
1 — Downtown San Francisco	267	1103
2 — Northwest San Francisco	79	861
3 — Southeast San Francisco	50	732
4 — Northern San Mateo County	6	81
13 — Southern Alameda County	1	7
14 — Northern Alameda County	11	116
15 — Downtown Oakland	2	39
16 — Western Contra Costa County	0	18
22 — Marin County	0	5

Table 10: Example Contingency Table for Hypothesis #2, MAZ 15431 (χ^2 = 113.3)

Figure 22: MAZ 15431 (red boundary), within TAZ 401 (dark black boundary), with MAZ centroids in blue, TAPs in red, and transit stops in orange

Table 11 summarizes the allocation of demand to TAPs from this MAZ. As before, this table shows the advantage of TAPs, as it highlights the heterogeneity of demand from the MAZ. The dominant TAP is 90416, which is connected to the Embarcadero BART station and has a walk access estimate of 6.7 minutes.

TAP	Morning Commute Demand (trips)	Morning Commute Walk Access Time (minutes)
90043	29	4.7
90055	1	9.4
90113	11	5.7
90148	5	12.7
90149	3	13.0
90193	2	11.0

90254	3	7.1
90267	10	8.8
90279	9	7.2
90416	129	6.7
90450	11	8.2

Table 11: TAP Allocation of Demand from MAZ 15431

In the non-TAP approach, this MAZ is assigned a uniform value by time of day. For this MAZ, the walk access estimates are all close to 6.7 minutes (across sets 1, 2, 3). In this case, the non-TAP approach aligns with the dominant movement for this MAZ at the TAP level to the Embarcadero BART station. But the non-TAP approach will slightly overestimate the walk access time to closer transit stops that are near the MAZ boundaries, e.g., stops connected to TAP 90113.

The second example for Hypothesis #2 is MAZ 327867, which is located in Oakland's Jack London Square. The parent TAZ (see Figure 23) includes a diverse set of land uses, including Jack London Square, which has restaurants that cater to tourists, a large junior college, and residential condominiums. The large χ^2 statistic shown in Table 12 is due to the large amount of transit demand in this area.

District	MAZ-scale Demand	TAZ-scale Demand
1 — Downtown San Francisco	15	63
3 — Southeast San Francisco	1	19
4 — Northern San Mateo County	0	2
6 — Northwest Santa Clara County	0	1
12 — Eastern Alameda County	0	6
13 — Southern Alameda County	4	147
14 — Northern Alameda County	34	1628
15 — Downtown Oakland	57	519
16 — Western Contra Costa County	3	39
17 — Central Contra Costa County	0	7

Table 12: Example Contingency Table for Hypothesis #2, MAZ 327867 (χ^2 = 104.8)

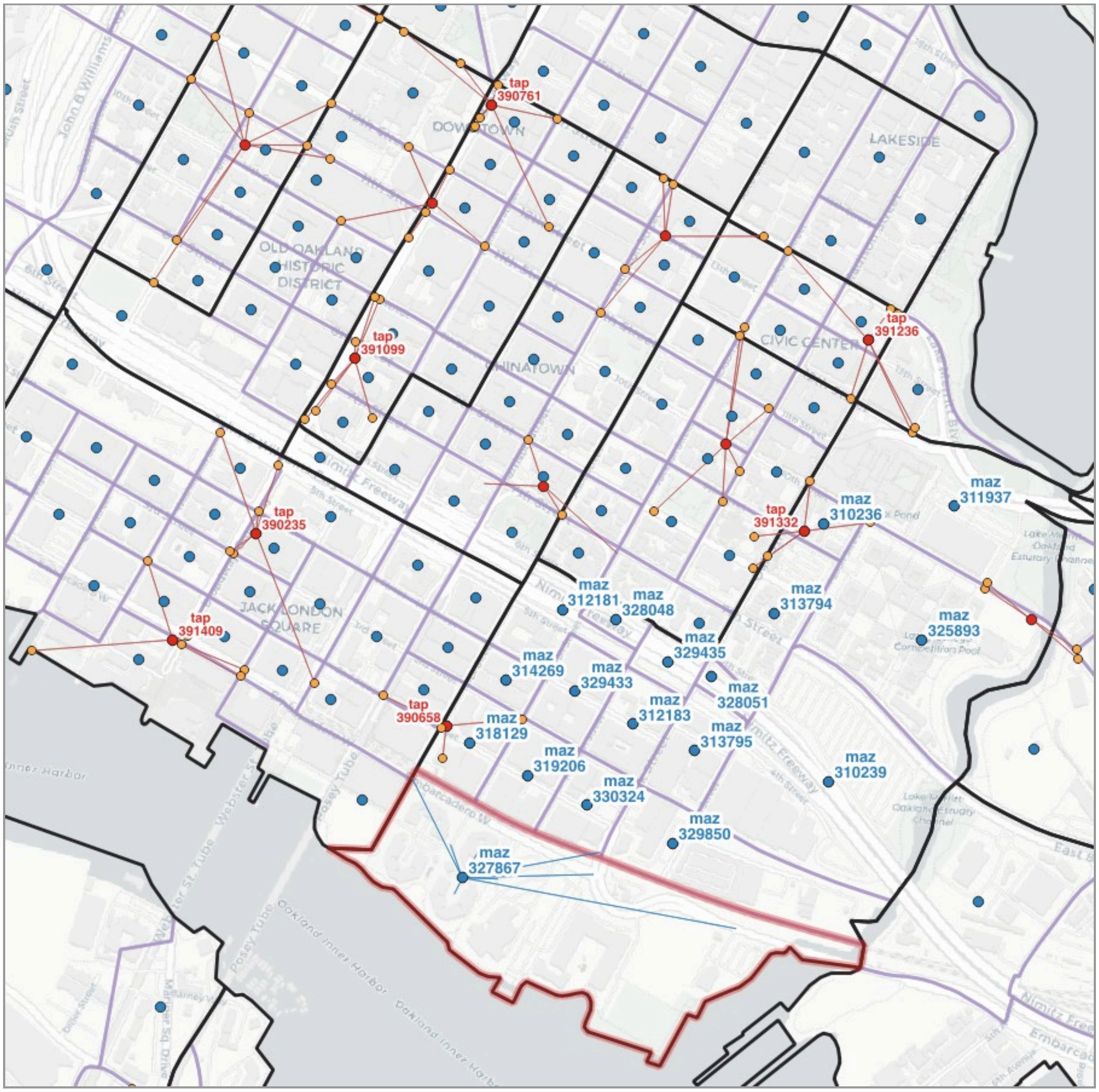


Figure 23: MAZ 327867 (red boundary), within TAZ 300855 (dark black boundary), with MAZ centroids in blue, TAPs in red, and transit stops in orange

Table 13 summarizes the morning commute demand from this MAZ to TAPs. The dominant movement is to TAP 391332, which is connected to the Lake Merritt BART station. This is about a 12.5 minute walk. The non-TAP approach estimates a uniform walk access time by time of day and skim set of, for this MAZ, of 7.2 minutes (set 1), 4.2 minutes (set 2), and 4.3 minutes (set 3). The premium only estimate, which is set 3, therefore underestimates the walk time to access Lake Merritt BART by 8 minutes. The MAZ is close to both an Amtrak station and a ferry landing, hence the low walk access time for set 3. This example best captures the value of the TAP approach: it understands the attractiveness of the train station and properly estimates the walk time needed to access it. The aggregation to TAZs in the non-TAP approach brings travelers from this MAZ much closer to the train station than they actually are.

TAP	Morning Commute Demand (trips)	Morning Commute Walk Access Time (minutes)
390235	15	10.3
390658	7	5.0
390761	1	22.3
391099	1	16.5
391236	1	17.0
391332	31	12.5
391409	2	9.1

Table 13: TAP Allocation of Demand from MAZ 327867

Hypothesis #3: Sparse TAPs, Exaggerated Transit Access

The third hypothesis examines a use case in which the TAP approach may exaggerate transit access. As shown in the figures describing Hypotheses #1 and #2, connecting multiple stops to a single TAP has the potential to distort walk access. Table 14 summarizes the number of MAZs that are able to access stops, via TAPs, that are more than ½, ¾, and one mile away. We then identify MAZs that fit this description with sizable numbers of transit trips. As the table shows, the TAP approach has the potential to mildly distort walk access times by allowing travelers to access stops via TAPs, but this distortion is unlikely to occur at long distances in places where transit is common.

Step	Records	Quantity	Share of all MAZs
1	MAZs that have connections, via TAPs, to stops that are more than 0.5 miles away	24,978	62.89%
2	MAZs that have connections, via TAPs, to stops that are more than 0.75 mile away	5,763	14.5%
3	MAZs that have connections, via TAPs, to stops that are more than 1.0 mile away	1,126	2.8%
4	MAZs identified in step 3 that have more than 100 transit trips	5	0.4%

Table 14: Filtering of Records Specific to Hypothesis #3

An example of this outcome is MAZ110068, as shown in Figure 24 below. This MAZ is located in San Mateo County, just off Highway 92 west of Foster City. Stops that are located more than a ½ mile walk from the MAZ centroid are highlighted in green; the one stop more than one mile away is highlighted in light blue (middle right of the map). Travelers can therefore access a transit stop adjacent to TAP 190124 and then use transit services that stop on the other side of Highway 92 — the stops highlighted in light green and light blue.

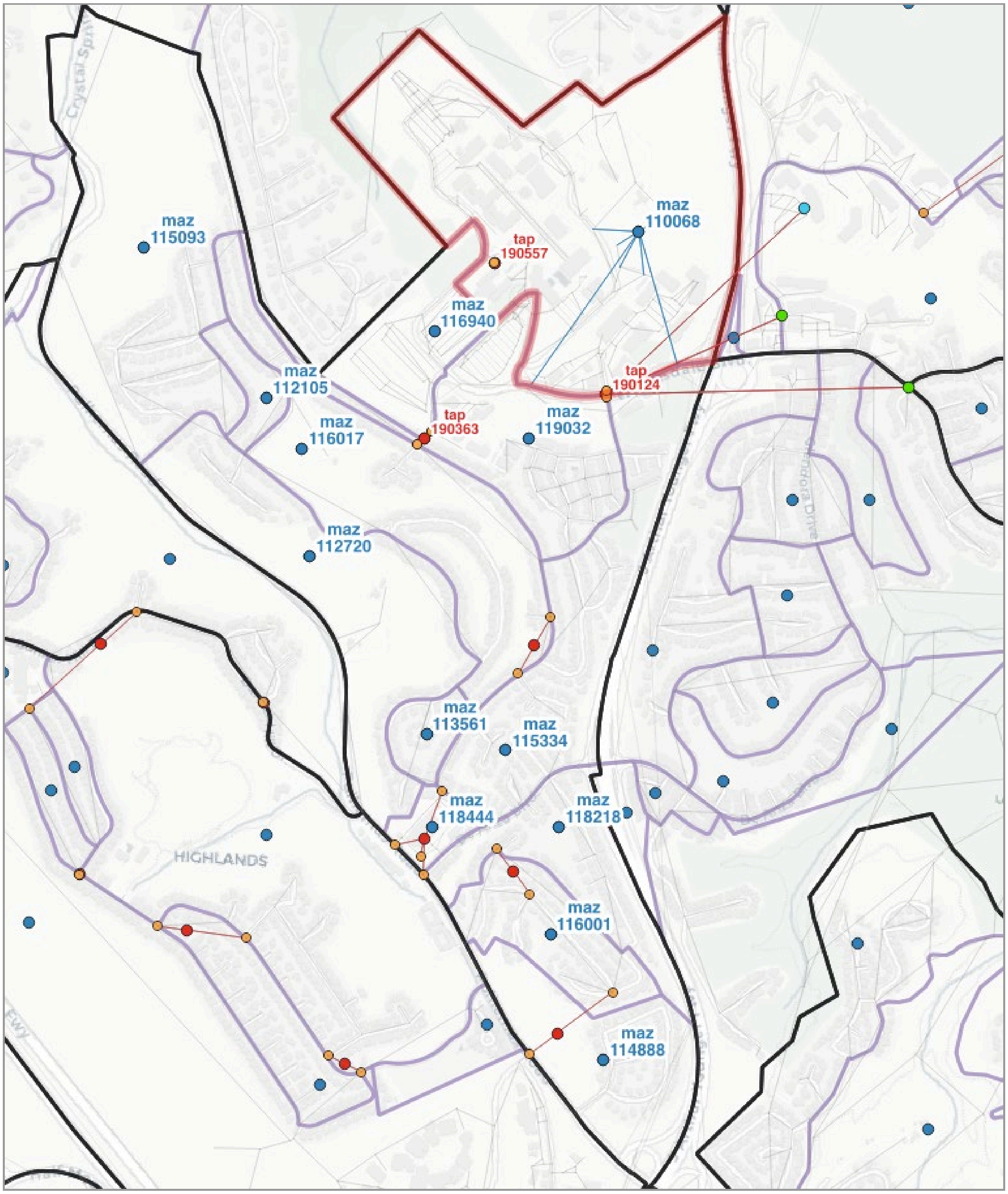


Figure 24: MAZ 110068 (red boundary), within TAZ 100311 (dark black boundary), with MAZ centroids in blue, TAPs in red, transit stops within 0.5 miles in orange, transit stops accessible via intermediate TAPs but have walking distance greater than 0.5 miles in light green, and transit stops accessible via intermediate TAPs but have walking distance greater than 1 mile in light blue

Table 15 below summarizes the daily demand from this MAZ, with most of the demand going to 190124. An examination of the transit assignment would be needed to determine what share of this demand used transit services a long distance from the TAP centroid, which was not done as part of this analysis. But this example illustrates that connecting multiple stops to TAPs has the potential to distort walk access estimates. The scale of this distortion is small, as indicated by the small number of records identified in Table 15. Further, service frequency is used to locate TAPs in the MTC model, which further minimizes this issue.

TAP	Morning Commute Demand (trips)
190124	425
190363	40

Table 15: TAP Allocation of Demand from MAZ 110068

Hypothesis #4: A River Runs Through It

While Hypothesis #1 covered cases in which the non-TAP approach had the potential to distort walk access times, this hypothesis covers cases in which the non-TAP approach has the potential to misrepresent transit access. The filtering for this hypothesis is summarized in Table 16 below.

Step	Records	Quantity	Share of all MAZs
1	TAZs that have stops connected to a subset of the TAZ's MAZ	4,301	90.8%
2	Number of TAZs in step 1 in which the MAZ walk distance to one of the stops accessible by the TAZ is over 1 mile	2,519	58.6%
3	The number of walk to transit trips that use TAZs identified in Step 2	155,778	39.0% (of walk to transit trips)

Table 16: Filtering of Records Specific to Hypothesis #4

An example of this use case is TAZ 200825, which is shown below in Figure 25. This TAZ includes Morgan Hill, a small city south of San José, but covers a huge amount of largely undeveloped land.

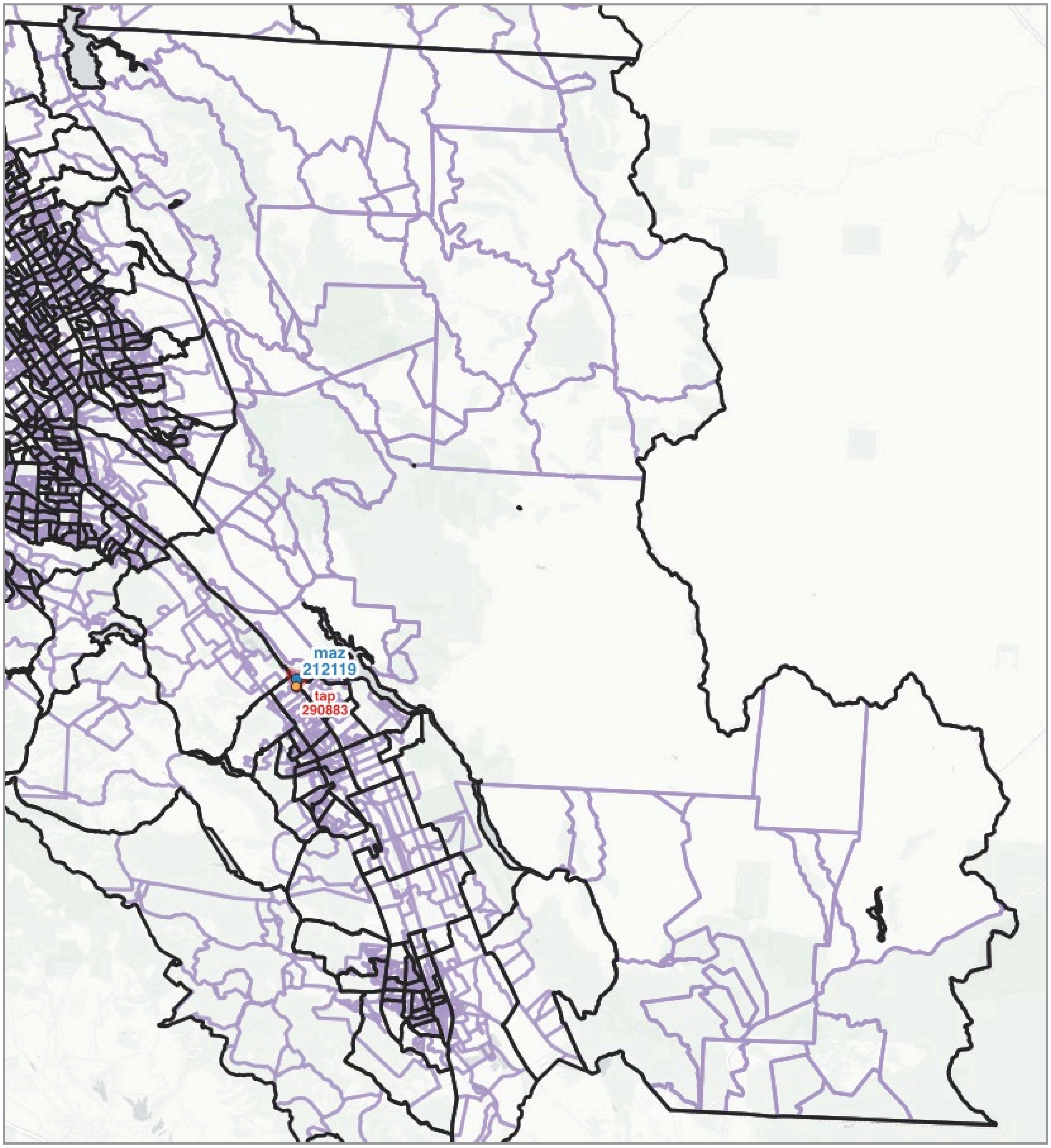


Figure 25: MAZ 212119 (red boundary), within TAZ 200825 (dark black boundary), with MAZ centroids in blue, TAPs in red, transit stops in orange

Within this large TAZ, only one MAZ, number 212119, has access to transit (see Figure 26 below). If, however, a new transit line connected to an MAZ far away from the subject MAZ, but still within the target TAZ, the non-TAP approach would allow travelers in this MAZ to connect directly to the transit service connected to the distant transit stop. In the MTC model, very large TAZs occur only in areas adjacent to large open spaces, so the scale of this problem is likely small. However, when it does occur, the error could be large.

Figure 26: MAZ 212119 (red boundary), with MAZ centroid in blue, TAP in red, transit stops in orange

Conclusions, Recommendation & Next Steps

The above analysis systematically compared two approaches for representing transit service in a travel demand model. Both approaches attempt to leverage highly detailed spatial representations of space to improve the representation of transit service. The first, which we label the "TAP" approach, uses so-called transit access points (TAPs) as abstract representations of collections of transit stops, which are used to represent MAZ-to-MAZ paths. The second, which we label the "non-TAP" approach, pairs a more common TAZ-scale assignment with refined walk access/egress estimates derived from MAZ-scale network representations.

Two categories of analyses were conducted. The first compared high level outcomes of TAP and non-TAP skims and assignments. The second compared specific use cases in which the TAP and non-TAP approach were likely to give different answers.

The first comparison of skims and assignment outcomes suggested the two approaches, when properly calibrated, can both recreate patterns observed in survey data. Both can give users sufficient flexibility in parameterizing the path building algorithms to match observed path choice behavior at a regional scale.

The second comparison identified a number of simulated outcomes when the TAP approach has the potential to more precisely represent transit paths. These situations generally occur when (a) MAZs are connected to multiple transit stops, far away from each other and (b) the demand patterns of MAZs are different from their parent TAZs. The examination of simulation outcomes from MTC suggests that the benefits of representing MAZ-scale movements is diminished by the spatial distortions caused by connecting multiple stops to a single TAP.

Recommendation

Our analysis suggests that the TAP approach is attractive when **there are many more TAZs in the travel model than transit stops**. This condition allows TAPs to be mapped one-to-one with transit stops. A one-to-one mapping reduces the potential for TAP connections to distort transit access. If there are many more TAZs than transit stops, the TAP approach can also yield computation and storage benefits with a one-to-one mapping of TAPs to transit stops.

Though not examined here and therefore a view that remains speculative and theoretical, is that the TAP approach is likely to perform better in **an uncongested transit network**. When crowding on transit vehicles occurs, a transit path building algorithm must consider the trade-off between (a) walking all the way versus riding transit and (b) boarding at various transit stops. The TAP approach's segmentation of the path building problem between commercial software (finding the best TAP-to-TAP paths) and custom software (finding the best MAZ-to-MAZ path) may be unattractive, as it requires iterating between these two software packages to find a solution. The solution may, as a result, be less stable than one found through a single optimization process that resides in the commercial software.

For MTC specifically, the representation of roadways in the MTC modeling area requires ~4,700 TAZs to provide robust regional estimates. The modeling area contains nearly 20,000 transit stops. A one-to-one mapping of transit stops to TAPs is therefore computationally inefficient. For this reason, we do not recommend MTC use the TAP approach. While the TAP approach may provide better walk access times in select instances, it will also distort walk access times in others. MTC must also contend with the usability downsides of the TAP approach. We therefore recommend that MTC use a non-TAP approach. We note, however, that the non-TAP approach is far from perfect: it will also distort walk access times in many cases, as discussed in the Hypothesis Assessment section. It is preferred because it is easier to use and computationally superior in a region with nearly four times as many transit stops as TAZs. Said another way, the non-TAP approach may be the better of two imperfect approaches for MTC.

Next Steps

A number of changes would be needed to remove TAPs from MTC's TM2.1 modeling system. Table 17 summarizes these changes, which assumes that MTC moves to the type of non-TAP approach discussed in this document.

ID	Model Component	Consideration

1	Walk connectors	The non-TAP approach to building TAZ-scale walk access connectors and MAZ-scale walk impedance estimates as described in this document are needed to replace the walk-to-TAP approach used in the TAP's virtual path builder.
2	Drive connectors	Drive access is currently described as a TAZ-to-TAP movement. With TAPs removed, transit stations that provide drive access would need to be represented as special nodes. Emme's point-to-point skimming tools can be used to build TAZ-to-drive access transit stop skims for use in the mode choice models.
3	Transfer connectors	The current MTC implementation facilitates transfers via "as-the-crow-flies" TAP-to-TAP connections. Moving to a non-TAP approach may be an opportunity to allow transfers to take place on the pedestrian network (if desired; direct as-the-crow-flies connections can also be retained). We recommend creating a background transit network that includes detailed pedestrian paths and small roads in the areas that surround rail stations (e.g., within ½ mile of rail stations) and in dense urban areas. This will allow transfer movements to utilize the underlying roadway network. QA/QC and network edits may be needed to ensure transfer movements are accurately represented.
4	Mode choice	The virtual transit path builder used by the TAP approach includes a transit path choice model of the type often found in mode choice models. While it's possible to retain this approach and implement within the mode choice model, we recommend moving to a simpler structure that uses a single best walk to transit alternative in mode choice (as well as a single best park & ride transit alternative and single best kiss & ride transit alternative). This approach would rely on Emme's path builder to identify and skim plausible paths. Technology-specific tables (e.g., heavy rail in-vehicle time skim) could be skimmed during skimming/assignment and shown to the mode choice model to facilitate calibration of technology-specific rail targets. An additional idea is to segment transit users (via different path weights) by value of time, rather than technology, which would allow the mode choice model to show different skim sets to different users based on each traveler's simulated value of time. Analysis of the on-board survey could suggest whether segmentation by value of time is supported by the data. We recommend a workshop with MTC where the pros and cons of these options are discussed.
5	Skimming/ Assignment	Three sets of path weights are currently used in MTC's model that extract local only, premium only, and all mode transit skims. As noted in the above mode choice option, one way forward is to retain this structure and move it from the virtual path builder and to the mode choice model. A second option is to remove the segmentation by technology and rely on Emme's path builder to determine the best path for each movement, considering all technologies. The analysis of the non-TAP approach in this document suggests this approach is likely to be successful in the Bay Area. A third option, also discussed above, is to carry out a single transit assignment and introduce, if warranted, segmentation by value of time, which has the possibility to allocate wealthier travelers to more expensive transit modes.

		Either the second or third approach is compatible with a congested transit assignment in which we Emme simulates trade-offs between crowded segments.
6	Transit Crowding and Capacity	The approach to representing transit crowding and capacity constraint, including constraints at park and ride lots, is embedded in the TAP infrastructure in the MTC model. A different approach is therefore needed if the TAP approach is removed. One option is to use Emme to represent crowding both at park and ride lots and on route segments. A second option is to use Emme to represent crowding on route segments, but use custom software — as is currently done — to simulate the park and ride station choice, as well as the impact of crowding/capacity limitations on that choice. We recommend a workshop with MTC where the pros and cons of these options are discussed.
7	TAZ Boundaries and Centroids	As highlighted in the document, the current TAZ structure need not be mindful of transit service, given the TAP approach. In moving to a TAZ-scale assignment, select TAZs may need to be split to better represent transit assignment.
8	ABM Software	To implement a non-TAP approach in TM2.2, which will continue to use the CT-RAMP1 Java software, modifications to the software are needed.

Table 17: Considerations for Removing TAPs from MTC's TM2 System

Acknowledgements

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