Valid Modeling of the I-35 Capital Express Central Project

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Qualifications

I received a B.S. in Mathematics from Worcester Polytechnic Institute (1977) and an M.S. in Engineering Sciences from Dartmouth College (1982). My studies at Dartmouth College included graduate courses in transportation modeling.

I have 33 years of professional experience in transportation modeling and transportation planning including 14 years at RSG Inc. (1987-2001) and 19 years at Smart Mobility Inc. (2001-now).

My primary professional focus is regional travel demand modeling and related transportation planning. I am a nationally known expert in this field and have completed projects in over 30 states including work for the U.S. government, state Departments of Transportation, Metropolitan Planning Organizations, cities and non-profit organizations. One of my particularly notable projects is a $250,000 project with the California Air Resources Board where I led a team including the University of California in reviewing the state's regional travel demand models.

I have many peer-reviewed publications and conference presentations, including presentations at national Transportation Research Board conferences in 2017, 2018 and 2019.

I am an Associate Member of the Transportation Research Board.

My resume is attached as Appendix B.

Executive Summary

Valid modeling of the I-35 Capital Express Central Project is required for the public to be assured that the benefits and impacts of the project are properly disclosed, and that prudent investments are made. Valid modeling requires:

1) Impossibly high traffic volumes must not be assumed – There is a maximum traffic throughput per hour for every roadway. For I-35 in central Austin, this maximum throughput has been reached during peak periods, and therefore peak period traffic volumes cannot increase significantly. The preliminary analysis done for TxDOT assumes that traffic will grow another 47% by 2045 and 66% by 2050 – whether the roadway is widened or not. This is ridiculous. Any subsequent analysis predicated on either of these assumptions would be worthless.

2) Modeled I-35 peak period speeds must be realistic – The Capital Area Metropolitan Planning Organization (CAMPO) regional travel demand model overestimates current and future I-35 peak period traffic volumes, in part, because it also overestimates I-35 congested speeds. Realistic speed modeling is needed for realistic traffic volume modeling.

3) Over-capacity modeled traffic must not be considered "demand" – The CAMPO model overestimates congested speeds and traffic volumes. However, the assigned traffic volumes are still much lower than the true "latent demand" that would occur without any congestion. This latent demand is so great that no amount of I-35 widening can satisfy all of it.

4) Overcapacity traffic volumes must not be input to Dynamic Traffic Assignment (DTA) or microsimulation – Freeway widening studies often obscure over-capacity traffic assignment problems by filtering them through another more detailed model. This is a case of "garbage in – garbage out." Invalid model inputs result in invalid model outputs.

5) Modeling must show that un-tolled I-35 lanes will be congested in both the No Build and Build alternatives – Given the high amount of latent demand in the I-35 corridor, traffic will divert from lower-speed streets to I-35 until the travel times are the same, i.e. until I-35 is congested.

6) An alternative where all lanes are tolled must be analyzed – A moderate toll on all lanes is the only way to satisfy the project Purpose and Need that is focused on congestion and delay. Therefore, at least one alternative where all lanes are tolled should be fully analyzed.

7) Horizon year modeling assumptions for downtown Austin must be plausible – The 2045 CAMPO assumptions concerning downtown Austin's jobs, housing and high auto mode share are impossible. There would not be enough road capacity for the workers to leave the downtown. Some combination of changes in jobs, housing and/or mode share is needed for modeling to be realistic.

8) Modeling must consider impacts to downtown Austin streets – No trip begins or ends on I-35. If widening I-35 results in higher entering and exiting traffic volumes downtown, this also means higher volumes on intersecting streets. These impacts should be considered direct impacts of the project and be analyzed.

1) Impossibly High Traffic Volumes Must Not Be Assumed

The *Purpose and Need Draft Technical Report* (October 2020) states:

> *By 2045, traffic is expected to reach 303,700 vpd [vehicles per day], an increase of approximately 47% over 2019.*

This is one of the primary justifications for the project and it is **misinformation**. In the congested parts of I-35, peak period traffic throughput will not increase above current levels unless the road is widened because it cannot increase above capacity. There is an absolute traffic capacity per hour that already has been reached. There could possibly be increases in off-peak traffic volumes – but not enough that daily traffic would increase by 47%.

The CAMPO regional travel demand model has a pretense of being capacity constrained. However, as is documented below, it is not. The I-35 traffic forecasts that have been developed by HDR and Alliance Transportation Group for TxDOT[1] do not even have pretend to be capacity constrained, but simply apply arbitrary growth rates to existing daily traffic volumes. Nevertheless, the HDR report references the CAMPO model traffic growth rates as validation. Therefore, I first address the CAMPO model and then the HDR/ATC forecasts.

The CAMPO regional travel model includes an hourly capacity value for each roadway segment. Modeling best practice is to use "ultimate capacity", i.e. the "maximum volume that should be assigned to a link by the forecasting model."[2] Assigned volumes that exceed capacity are errors, and assigned volumes that greatly exceed capacity are serious model errors. Alan Horowitz, one of the most respected experts in travel demand modeling wrote:

> *I am quite familiar with alternatives that assign traffic well beyond a volume-to-capacity ratios (v/c) of 1, and I cannot fathom why anybody would take any of this seriously, either as a realistic representation of the future or as a strawman case study…*
>
> *… do not publish any alternative/scenarios with facilities loaded beyond a v/c ratio of 1.1.[3] (Horowitz 2019)*

As shown in Figure 1, the CAMPO model assigns many important roadways including I-35 in excess of 1.1, even in the 2015 model base year.

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[1] Best, Matthew, HDR. Memorandum to Adam Kaliszewski, DOT, regarding Mobility35 Capital Express: Traffic Projections Methodology Memoradum, January 2, 2020.

[2] Cambridge Systematics, Vanassse Hangen Brustlin, Gallop, Bhat, C.R., Shapiro Transportation Consulting and Martin/Alexious/Bryson. Travel Demand Forecasting: Parameters and Techniques, National Cooperative Highway Research Program Report 716, 2012.

[3] Horowitz, Alan. Posting on the Travel Model Improvement Program (TMIP) listserv, March 2019.

Figure 1: CAMPO 2015 Model Afternoon Peak Period Volume-to-Capacity Ratio Exceeding 1.1 (RED)

The red lines represent roadway segments that are assigned more than 110% of capacity for the entire 3-hour afternoon peak period (3:30 – 6:30 p.m.) All the model traffic assignments for the red links, including I-35, are impossibly high, and should not be used as a basis for planning.

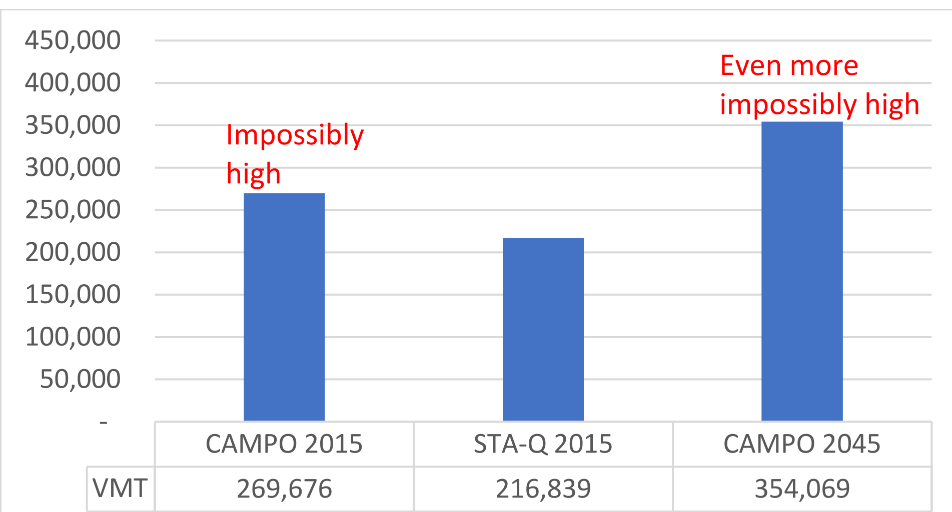
The CAMPO model relies on 40-year-old Static Assignment Algorithm (STA) that was adopted when computers were less powerful than today's smart phones. STA treats every road segment as independent of other road segments. In peak periods, traffic on I-35 is characterized by queues behind bottlenecks. In STA there are no queues behind bottlenecks, and the CAMPO model cannot capture backups at the merges on I-35 or accurately model conditions during the peak of rush hour traffic.

In my peer-reviewed journal article: *Forecasting the impossible: The status quo of estimating traffic flows with static traffic assignment and the future of dynamic traffic assignment*[4], I document that STA always produces impossibly high freeway traffic volumes in congested networks and cannot be relied on for planning. The only solution is to replace STA with a more modern Dynamic Traffic Assignment (DTA) algorithm. Alan Horowitz also wrote: "*Choose DTA over STA whenever possible.*"[5]

Implementing DTA in the CAMPO model will be a significant effort which was not possible within this review. However, I implemented an intermediate STA-Q model that calculated real-world delays more accurately than the CAMPO model. (Details on the STA-Q model are provided in Appendix A.) As shown in Figure 3, the STA-Q model eliminates most of the roadway segments with V/C greater than 1.1 in the 2015 model, including all the I-35 segments.

The over-capacity CAMPO model assignments for I-35 shown in Figure 1 are impossible. The STA-Q assignments are more realistic. Figure 2 shows vehicle miles traveled (VMT) for the I-35 general purpose freeway lanes for the 8-mile section between Routes 71 and 290 for the afternoon peak periods.

Figure 2: 2015 Model Afternoon Peak Period (3:30-6:30) VMT



If the CAMPO model properly constrained traffic volumes to capacity, the 2015 modeled VMT would be in the same range as the STA-Q value. Furthermore, the 2045 modeled VMT would also be in the same range of as the 2015 STA-Q value because I-35 is already at capacity during the afternoon peak period, and traffic throughput cannot increase significantly.

[4] Marshall, Norman. Forecasting the impossible: The status quo of estimating traffic flows with static traffic assignment and the future of dynamic traffic assignment, *Research in Transportation Business & Management*, Volume 29, 2018, 85-92. https://www.sciencedirect.com/science/article/pii/S2210539517301232?via%3Dihub

[5] Horowitz, Alan. Posting on the Travel Model Improvement Program (TMIP) listserv, March 2019.

Figure 3: STA-Q 2015 Model Afternoon Peak Period Volume-to-Capacity Ratio Exceeding 1.1 (RED)

As shown in Figure 3, traffic assignments of over 110% of capacity are almost eliminated in the 2015 afternoon peak period.

As has been documented above, the CAMPO model is not useful for planning because it assigns traffic volumes greater than 110% of capacity to important roadways including I-35. Nevertheless, the traffic forecasting approach that TxDOT has adopted is even worse.

The January 2020 HDR memo to TxDOT indicates that Alliance Transportation Group proposed growth rates for this project in 2018 and that these rates were approved by TxDOT (p. 9). For the central part of the corridor, a compound growth rate of 1.5 per year has been adopted for the period 2016 – 2050. This represents at assumption of 66% percent growth. Considering a 3-lane section of I-35 that is congested today during peak periods, accommodating 66% more traffic would require 5 congested lanes in 2050. But it is assumed that these vehicles that would fill 5 lanes of congested traffic will somehow squeeze into the existing 3 lanes in the No Build alternative. This is ludicrous and makes any subsequent analysis worthless.

As is documented in Appendix A, the maximum sustained traffic throughput is likely substantially below 100% of the capacity value assumed in both the CAMPO and STA-Q models and well below the 110% value used as a threshold in Figures 1 and 3. A realistic freeway capacity should be established in the I-35 study, and not exceeded in the traffic forecasts.

Modeling Requirement #1: Impossibly high traffic volumes must not be assumed.

2) Modeled I-35 Peak Period Speeds Must Be Realistic

The *Purpose and Need Draft Technical Report* (October 2020) states:

> *I-35 within Travis County is located within a heavily urbanized area that consistently ranks within the Top 3 Most Congested Roadways in Texas, currently #2, as measured by Texas Transportation Institute (TTI) in 2019, and roadways with the highest Annual Congestion Costs at more than $200M (TTI 2019).*

The "more than $200M" is misinformation. As discussed in Section 5, un-tolled urban freeways will always become congested during peak periods, so measuring them against hypothetical uncongested conditions is pointless because it is impossible to eliminate the delay. In general, the wider these freeways are, and the more traffic is carried, the more "delay" there will be.

However, the TTI data provide useful information about congested I-35 speeds. In the most recent 2020 TTI accounting (December 2020), data are based on INRIX real-time speed data for calendar year 2019.[6] The data have a high degree of variability in peak period travel times on this section of I-35, including:

- Mean travel time 2.88 times free-flow travel time,
- 95th percentile travel time 5.14 times free-flow travel time.

TTI calls the 95th percentile multiplier the "Planning Time Index" suggesting that travelers with critical arrival times need to allow this much time.

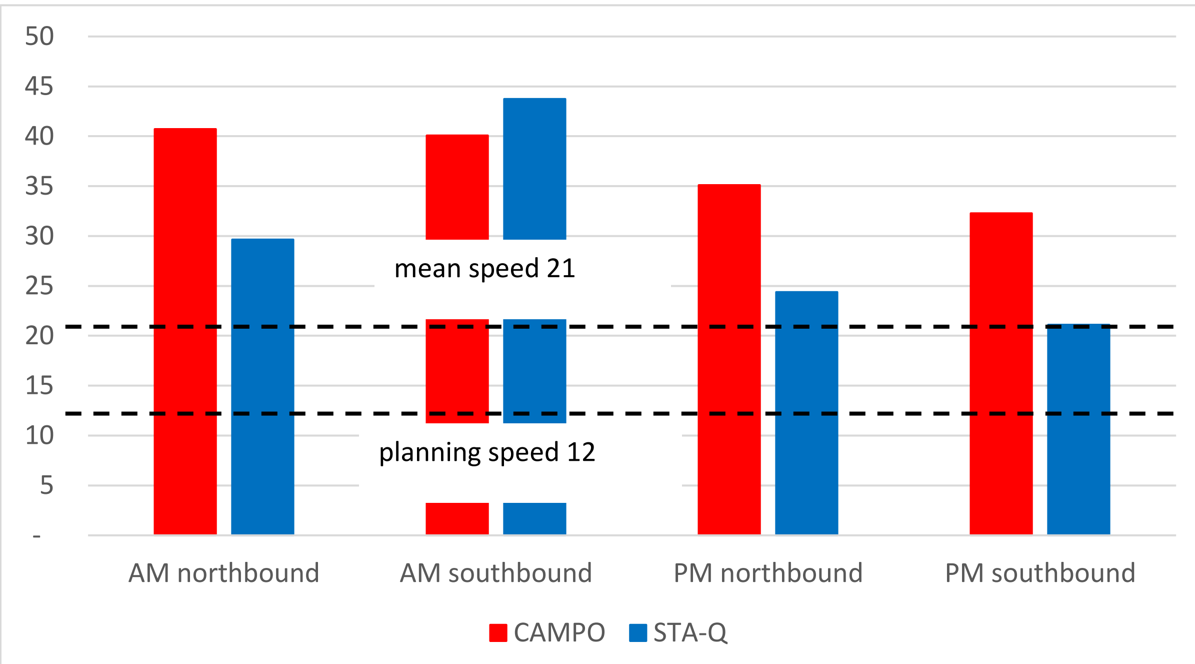
[6] Texas A&M Transportation Institute. Technical Memorandum Analysis Procedures and Mobility Performance Measures: 100 Most Congested Texas Road Sections. November 2020.

These delay multipliers can be translated into average speeds:[7]

- Mean speed 21 mph,
- 95th percentile "planning" travel time 12 mph.

In the CAMPO model, travelers choose their destinations and routes based on model speeds. In order to model these decisions accurately, the speeds need to match reality, i.e. somewhere between the planning speed of 12 mph and the mean speed of 21 mph. As shown in Figure 4, the CAMPO model speeds are much higher. The STA-Q speeds are closer, especially for the afternoon peak period.

Figure 4: CAMPO and STA-Q 2015 Modeled I-35 Morning and Afternoon Peak Period Speeds Compared to Data



The CAMPO model simultaneously overestimates peak period traffic volumes on congested I-35 (as documented in the previous section) and overestimates peak period speeds on congested I-35. Without correcting these deficiencies, the model is not useful for I-35 planning.

Modeling Requirement #2: Modeled peak period I-35 speeds must be realistic.

[7] TTI gives a free-flow speed for this section of I-35 of 60.7 mph.

3) Over-Capacity Modeled Traffic Must Not Be Considered "Demand"

The over-capacity traffic assignments in the CAMPO model are errors. Sometimes, roadway widening proponents try to spin these errors as indicative of the true underlying traffic demand. This is wrong.

Demand is not a point, as anyone who has taken Economics 101 has had hammered into them repeatedly; demand is a curve with more demand when the price is lower and less demand when the price is higher. For un-tolled roads, this "price" is primarily based on the value of travel time. The generalized price for toll roads includes both cost and time. As shown in this illustration from the Federal Highway administration, there is a market equilibrium balance between demand and price/supply (Figure 5).

Figure 5: Market Equilibrium User Costs and Traffic Volumes (FHWA)[8]

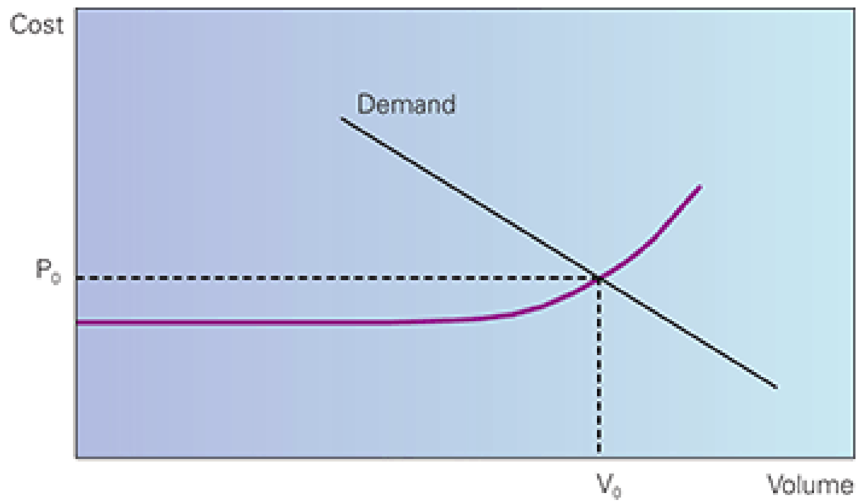


Exhibit 4. Equilibrium user costs and traffic volumes.
P = price. V = volume.

Source: Federal Highway Administration, 2017.

The narrative accompanying the figure reproduced above states:

> When supply and demand are in balance, a market is said to be in *equilibrium*. This is often represented as the intersection of a supply curve and a demand curve, which determines the market-clearing price and quantity (see Exhibit 4). At this point, everyone who purchases the good is willing to (collectively) buy that amount at that price, and producers are willing to supply that quantity at that price. If either the supply or demand curves shift, the market price and quantity will also change.
>
> For highway travel, demand is determined as described above. The "supply" curve, however, is essentially represented by the generalized cost curve. The intersection of these two curves determines how high traffic volumes will be and what the associated average highway-user costs will be at that volume level. When the level of demand is

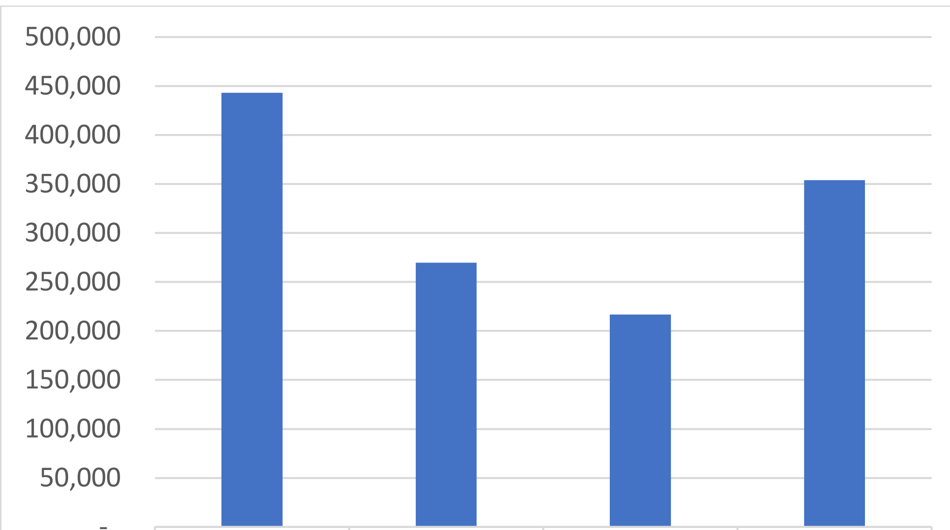
[8] Federal Highway Administration. Economics: Pricing, Demand, and Economic Efficiency – A Primer. 2017. https://ops.fhwa.dot.gov/publications/fhwahop08041/cp_prim4_03.htm

low relative to the capacity of the road, it will be uncongested, and prices will be relatively constant even as volumes increase (the "flat" part of the user cost curve in Exhibit 4). However, when demand levels are high and the road is congested, both user costs and traffic volumes will be higher, potentially rising sharply as demand continues to increase.

At any speed (supply), there is a corresponding demand. If the CAMPO model estimates speed correctly, it should also estimate demand correctly. The over-capacity assignments result from overestimated model speeds.

If speed is increased as a result of widening (i.e. a drop in "price"), a new equilibrium is reached with higher demand. If delays could be eliminated completely, the maximum demand would be reached. The CAMPO model can be used to estimate this "latent" demand.[9] As shown in Figure 6, this 2015 "demand" is higher than even the exaggerated 2045 CAMPO model forecast. This is evidence that "latent demand" for I-35 can never be satisfied through expansion.

Figure 6: 2015 Model Afternoon Peak Period VMT – Including 2015 Latent Demand if I-35 Had No Delays



	CAMPO 2015 latent demand	CAMPO 2015	STA-Q 2015	CAMPO 2045
VMT	443,120	269,676	216,839	354,069

The CAMPO model outputs do not estimate latent demand. Instead, they estimate demand at an unrealistic speed (price) that is somewhere between the real speed and the free-flow speed. This arbitrary and unrealistic demand point is useless for planning purposes.

Modeling Requirement 3: Over-capacity modeled traffic must not be considered "demand."

[9] Latent demand estimated with an "all-or-nothing" assignment.

4) Overcapacity Traffic Volumes Must Not Be Input to DTA or Microsimulation

The CAMPO regional travel demand model is characterized as a "macro" model. The primary analysis for the I-35 project will likely be done in a microsimulation ("micro") model that covers only a small part of the geographic region covered by the CAMPO model. It is possible that the study may also employ an intermediate "meso" model with Dynamic Traffic Assignment (DTA) – again for a subarea much smaller than the full region.

These DTA and microsimulation models are capacity constrained. When over-capacity traffic volumes (or over-capacity subarea trip tables) are input into them, the downstream models can only report that the inputs are impossible and generate error messages. Sometimes, these error messages are spun as being indicative of latent demand. As discussed in Section 1.3, this claim is false.

This is an example of an old computer adage – "garbage in – garbage out." The two-model process is analogous to money laundering. Bad macro model forecasts are filtered through the micro model and come out as very detailed precise-looking numbers. However, the underlying macro model forecasts (or arbitrary trend forecasts as approved by TxDOT) are invalid, and the micro model outputs also are invalid.

Modeling Requirement 4: Overcapacity traffic volumes must not be input to DTA or microsimulation.

5) Modeling Must Show that Un-Tolled I-35 Lanes Will Be Congested in Both the No Build and Build Alternatives

In 1992 Anthony Downs coined the term *triple convergence* to describe how peak period traffic congestion is inevitable because drivers will compensate for capacity increases by (a) shifting routes, (b) shifting travel time of travel, and (c) shifting travel mode (Downs 1992). After capacity expansion, the new equilibrium will be just as congested as the old equilibrium. Downs describes how drivers will choose "limited-access roads that are faster than local streets if they are not congested", but the attractiveness of such routes will cause them to become congested "to the point where they have no advantage over the alternate routes" (i.e. over arterial and local street routes). Managed lanes do not change this fundamental economic law.

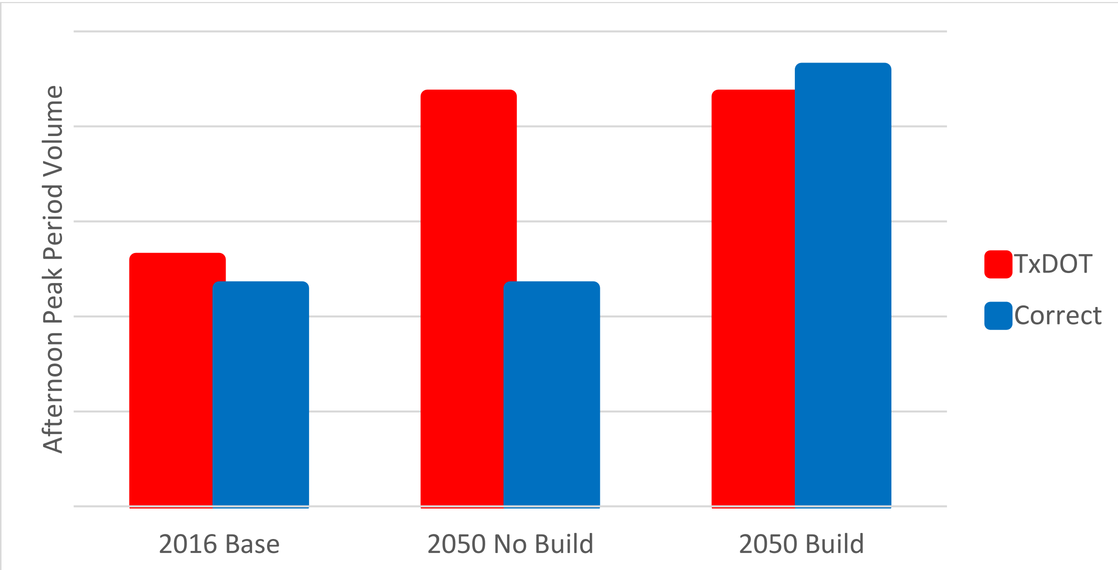
Valid modeling can capture these effects, but the invalid approach TxDOT apparently plans to use does not.

Table 1: Correct Alternatives Modeling for I-35 Free Travel Lane Volumes

	TxDOT	Correct
2016 Base	Over-capacity volumes	Existing volumes
2050 No Build	Over-capacity + 66%	Like current volumes
2050 Build	Over-capacity + 66% + maybe a bit more	Enough traffic growth that freeway lanes become congested "to the point where they have no advantage over the alternate routes."

In the TXDOT approach there is little difference between No Build and Build traffic volumes. In the correct approach, there is a huge difference as shown in Figure 7.

Figure 7 Correct Alternatives Modeling for I-35 Free Travel Lane Volumes



If the TXDOT microsimulation modeling has similar traffic volumes inputs for the 2050 No Build and Build alternatives, it is likely to show severe congestion for the No Build alternative and reduced congestion in the Build alternative. It would be invalid to conclude that this is representative of reality.

Modeling Requirement 5: Modeling must show that un-tolled I-35 lanes will congested in both the No Build and Build Alternatives.

6) An Alternative Where All Lanes Are Tolled Must Be Analyzed

It will be impossible to build enough I-35 lanes to eliminate congestion because the true latent demand as shown in Figure 6 is almost twice the traffic volume today, and even higher in the future.

Therefore, the only way to counter the triple convergence effect is to toll all lanes. This would make the generalized cost of the high-speed lanes equal to the generalized cost of the parallel low-speed lanes. This basic traffic law has been accepted when planning managed toll lanes but also needs to be accepted when planning any type of freeway expansion.

Similarly, tolling is the only way to truly address the project Purpose and Need which includes addressing “severe traffic congestion” and delay on I-35.

If all lanes are tolled, the tolls need not be as high as they are for managed lanes such as those on Mopac. I tested tolling all freeway lanes in the Austin region with the STA-Q model at two different toll levels – 20 cents a mile and 40 cents a mile (50 cents and $1 per mile for trucks). I applied the tolls for the entire 24 hours.[10].

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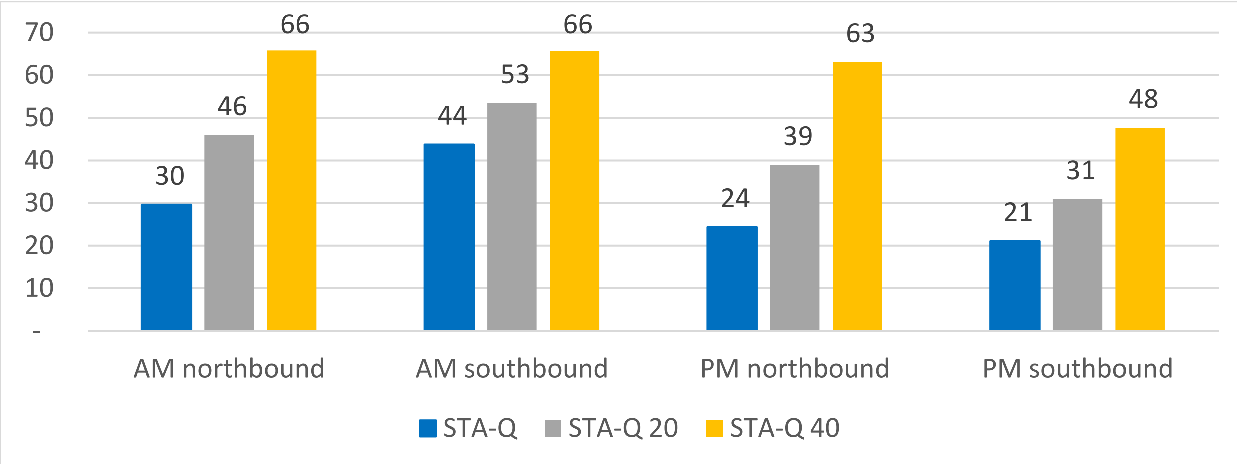
[10] It is likely that the optimal toll strategy would involve higher peak period tolls and lower off-peak tolls. However, testing variable tolls would require revamping the CAMPO model to provide correct feedback signals to non-work trips where the model chooses travel destinations based on off-peak travel times and costs.

Figure 8 shows modeled I-35 speeds for the two toll alternatives.

Figure 8: 2015 Modeled I-35 Morning and Afternoon Peak Period Speeds for Free, 20 Cent Per Mile and 40 Cent Per Mile Alternatives



As shown in Figure 8, a moderate 20 cent per mile toll significantly improves I-35 peak period speeds. The 40 cent per mile toll results in free-flow speeds except for the afternoon peak period in the southbound direction. Tolling all lanes is the only way for the project to satisfy its Purpose and Need of addressing congestion and delay.

Express toll lanes have much higher toll rates in peak periods – forcing people to choose between extremely high tolls and extreme congestion. This gives an advantage to higher-income travelers. These moderate tolls on all lanes are a much fairer way to institute pricing.

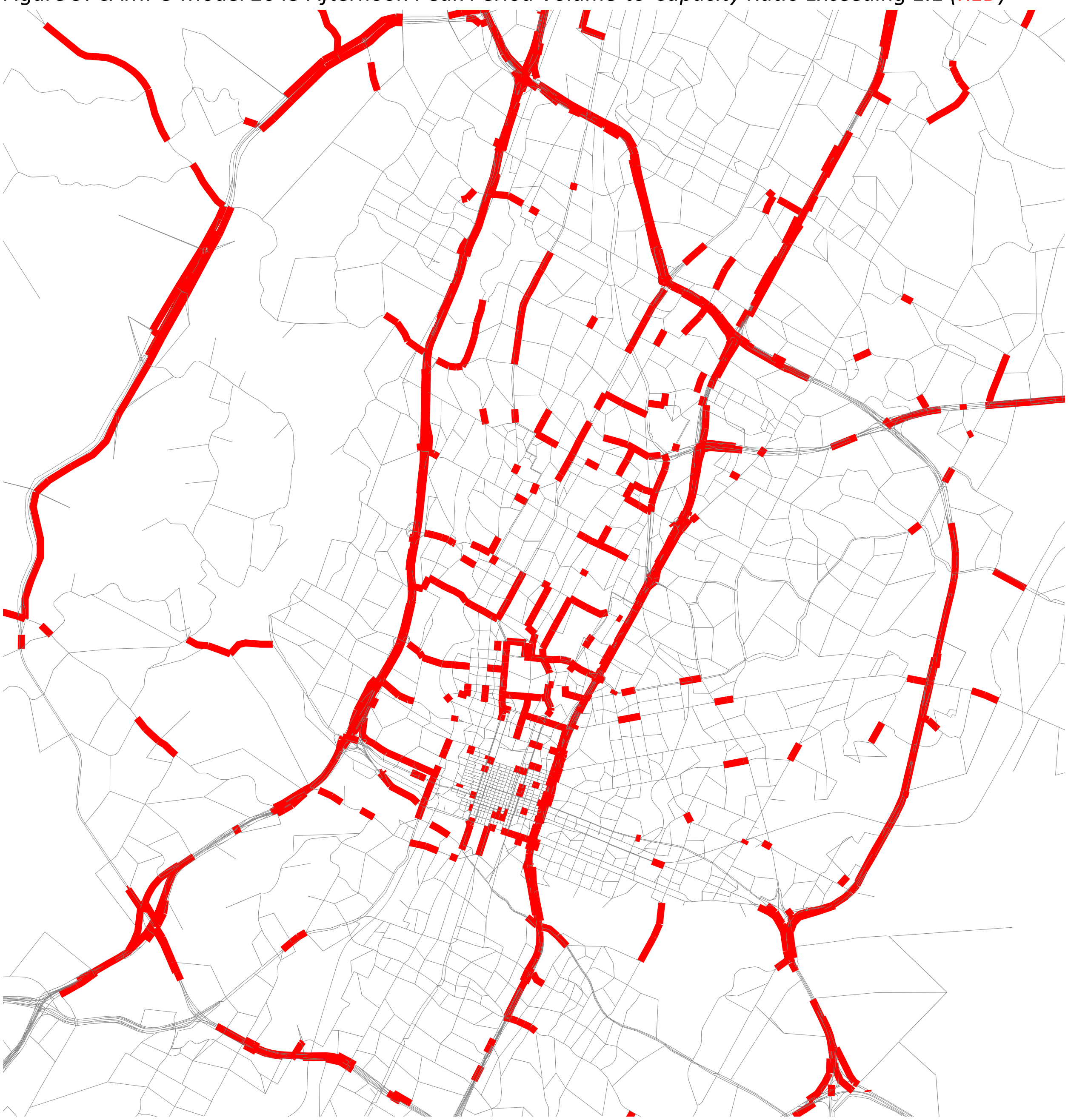
Tolling all lanes would raise a lot of revenue. As collection costs would be low with modern technology, most of the money could be returned to the community in the form of lower taxes and/or in multimodal transportation investments. To ensure equitable access, the credit-based congestion pricing concept that the Texas A&M Transportation Institute and the UT Center for Transportation Research have studied to deploy in the Austin region could be used.

Modeling Requirement 6: An alternative where all lanes are tolled must be analyzed.

7) Horizon Year Modeling Assumptions for Downtown Austin Must Be Plausible

So far, I have only presented CAMPO and STA-Q model outputs for the 2015 base year rather than for the 2045 CAMPO horizon year. This is because the 2045 CAMPO modeling assumptions are implausible. In Section 1, I documented that assigned volume-to-capacity ratios of greater than 1.0 are impossible, and that assignments greater than 1.1 should not be used for planning. Figure 9 shows that all major roadways in the 2045 CAMPO model in central Austin have volume-to-capacity ratios greater than 1.1 in 2045.

Figure 9: CAMPO Model 2045 Afternoon Peak Period Volume-to-Capacity Ratio Exceeding 1.1 (RED)



The STA-Q 2015 model eliminated most of the V/C > 110% roadways by reassigning traffic to less congested streets, but this is not possible given the 2045 model inputs. As shown in Figure 10, the 2045 STA-Q model has many fewer road segments with V/C greater than 110% than in the CAMPO model, but many critical links in downtown Austin remain impossibly over capacity as shown in a more detailed map in Figure 11.

Figure 10: STA-Q Model 2045 Afternoon Peak Period Volume-to-Capacity Ratio Exceeding 1.1 (RED)

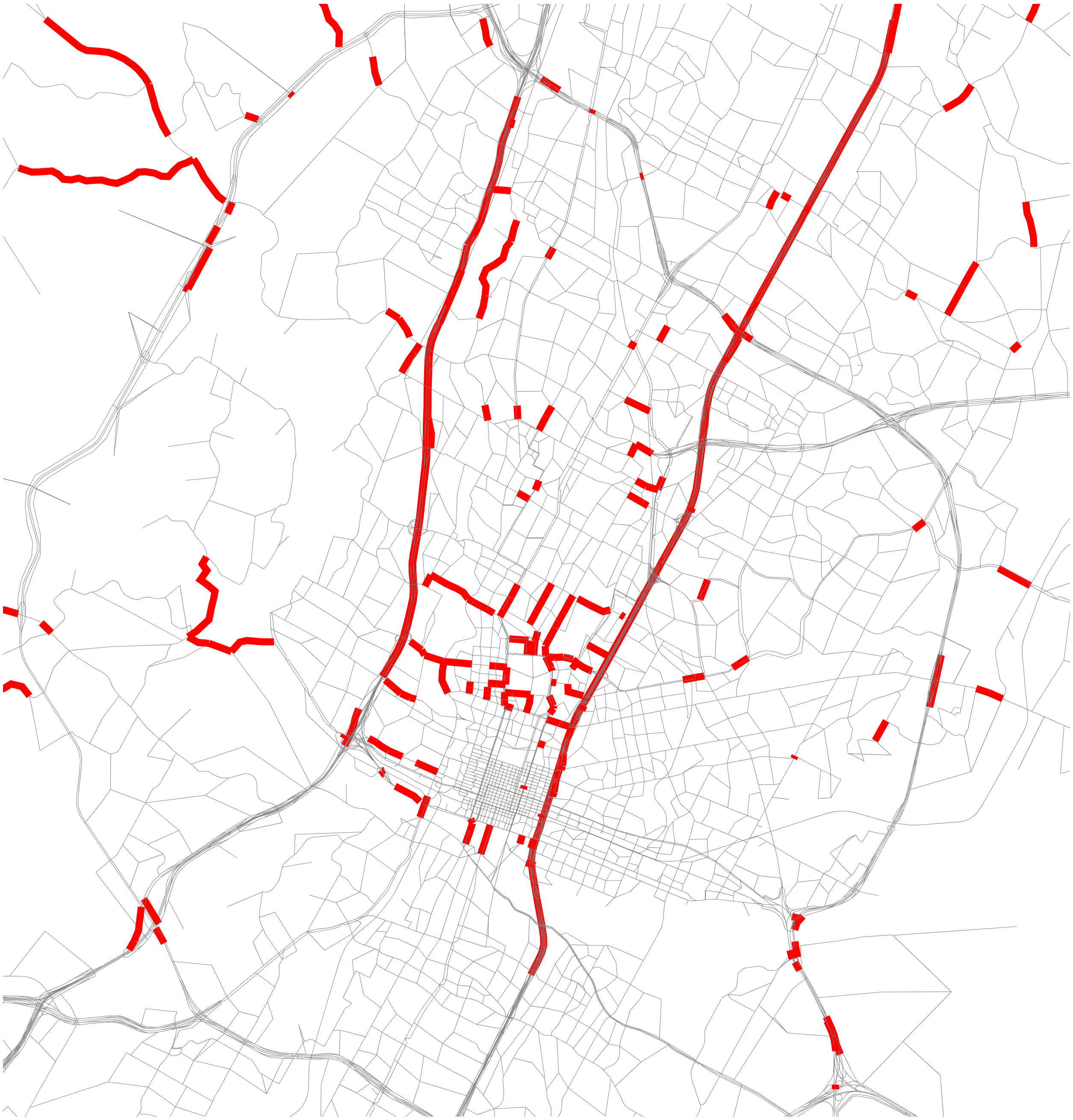


Figure 11: STA-Q Model 2045 Afternoon Peak Period Volume-to-Capacity Ratio Exceeding 1.1 Downtown Austin (RED)

To the south, all roadways crossing the river have V/C > 110% including:

- Mopac
- Lamar
- First,
- Congress,
- I-35 main line
- I-35 frontage

To the west, the streets and roads with V/C > 110% include:

- 29th
- 24th
- Enfield
- 6th
- Cesar Chavez

To the north the streets and roads with V/C > 110% include:

- Mopac
- Lamar
- Guadalupe
- Duval
- I-35 main line
- I-35 frontage

All these V/C exceeding 110% assignments are impossible. The underlying problem is that the assumptions about future downtown jobs and housing are incompatible with the modeled auto mode share. It is impossible in either the CAMPO or STA-Q model for the downtown workers to leave their workplaces and head for home during the afternoon 3-hour peak period. It is probable that these implausible assumptions will carry over into the TxDOT 2050 modeling. The jobs and housing downtown should be adjusted, or alternatively, downtown travel mode must shift significantly away from auto mode to transit, and to walk and bicycle modes. This would require major investments in transit. No amount of I-35 widening can solve this problem.

Unless 2050 downtown auto work trips can be accommodated somewhere on the road network, realistic modeling is impossible. This sort of jobs/road network imbalance would never occur in the real world because workplaces would stop adding jobs downtown before it did.

Addressing the downtown Austin over-capacity issue is a minimal requirement for modeling the central section of I-35. Ideally, the TxDOT modeling also should address the many other over-capacity areas in the CAMPO 2045 model including:

- Much of Williamson County and especially Round Rock, SH 45 and intersecting roads, US 183
- SR 71 east of US 183
- Lockhart
- San Marcos,
- The hill country between San Marcos and Dripping Springs (where there aren't enough roadways to support the assumed development
- SR 71 west of US 290

As with downtown Austin, the assumed growth in these areas is not possible given the planned roadway system. While the Austin region has doubled its population roughly every 20 years for a long time, this will need to stop sometime this century. Otherwise the Austin region's population would exceed the current population of the entire state of Texas by the year 2100 (nonsensical). The STA-Q modeling indicates that even one more doubling will not be possible without drastic changes in travel behavior.

The region cannot support a doubling in VMT with the planned roadway system; therefore, growth must be accompanied with significant reductions in VMT per capita. This could be accomplished through a combination of more compact growth and reprioritization of transportation investments away from freeway capacity to transit and walk and bike infrastructure.

Modeling Requirement 7: Modeling assumptions for downtown Austin must be plausible.

8) Modeling Must Consider Impacts to Downtown Austin Streets

No trip begins or ends on I-35. If widening I-35 results in higher entering and exiting traffic volumes downtown, this also means higher volumes intersecting streets. These impacts should be considered direct impacts of the project and be analyzed. The detailed model area should be like that shown in Figure 11 above – including the river to the south, Mopac to the west, and at least as far as 45th Street to the north.

I illustrate how ramp assumptions can affect traffic on local streets by modeling an alternative where most I-35 ramps between Routes 71 and 290 were eliminated. The only ramps kept are a single northbound on-ramp and a single southbound off-ramp north of 12th Street to link to the northern section with four freeway lanes in each direction.

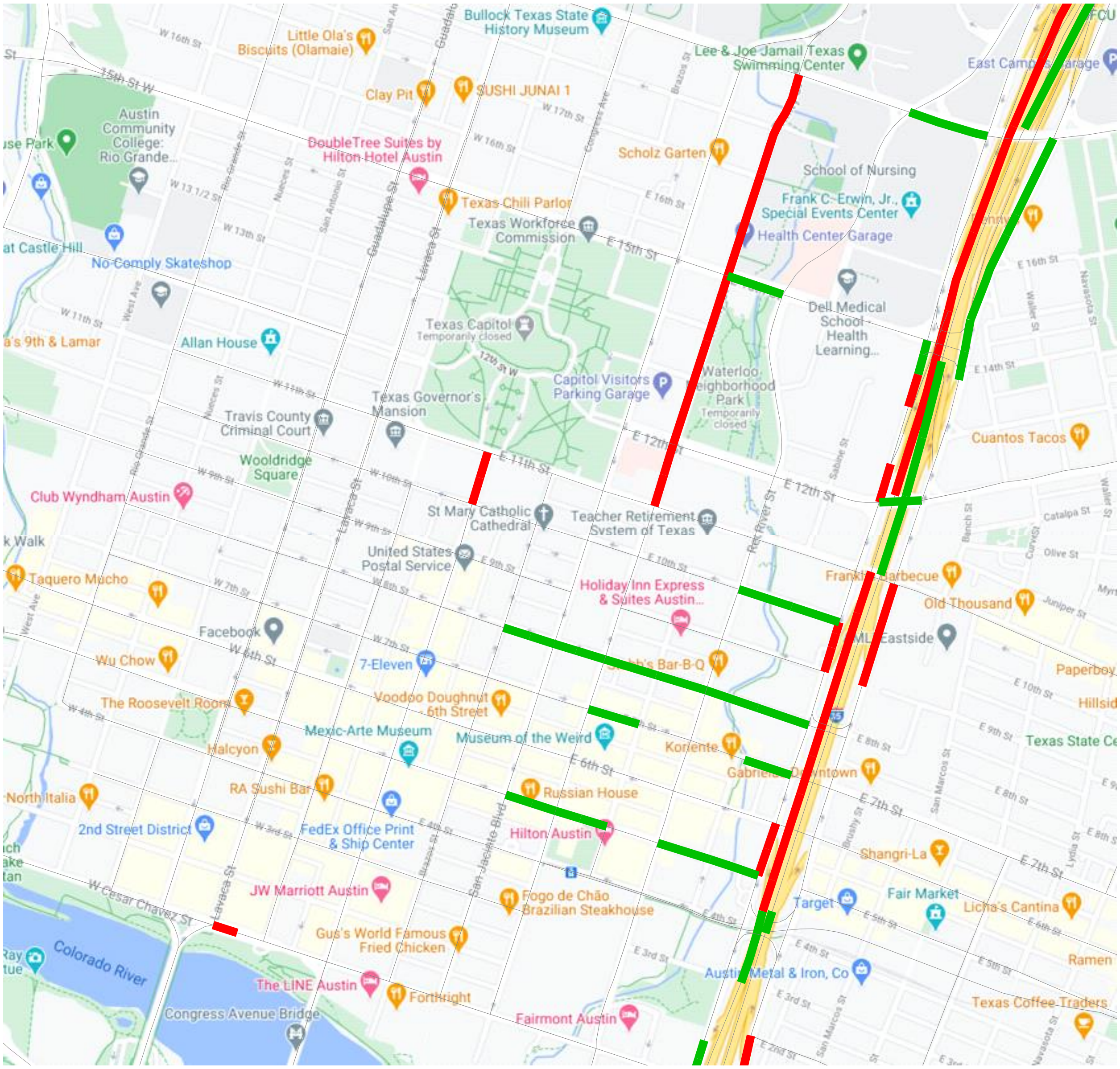
Reducing the number of ramps would greatly improve I-35 operations because the merges and associated lane changes and weaves reduce effective capacity considerably. When I-35 is modeled without tolls, travelers jump on and off the freeway lanes, but generally only gain a few seconds in peak travel times because the freeway lanes are congested. When I-35 is modeled with tolls, ramp volumes are considerably lower as it would not pay for travelers to jump on and off the freeway lanes so frequently.

Eliminating almost all the ramps has only moderate impacts on I-35 in the modeling. Travelers in the model sort themselves out between the freeway lanes and the frontage roads south of SR 71 or north of US 183, and the volumes and speeds do not change significantly on either the freeway lanes or frontage roads as compared to the modeling with the current ramp configuration. Therefore, the ramp removal alternative does not perform significantly better or worse than the complicated set of ramps that exist today. There is enough latent demand for I-35 that the free lanes will continue to be congested even if a significant number of ramps are removed. Some travelers shift to other routes, but other travelers replace them.

However, as shown in Figure 12, the ramp changes would have some significant, and mostly beneficial, impacts on Austin Streets. In the afternoon peak period, there would be a significant increase in Trinity Street northbound traffic leaving downtown as well as significant traffic decreases on multiple east-west streets near to I-35.

Modeling Requirement 8: Modeling must consider impacts to downtown Austin streets.

Figure 12: STA-Q Model with Most I-35 Ramps Removed PM Peak Period Increase of Greater than 1000 Vehicles (RED), Decrease of More than 1000 Vehicles (GREEN)



Appendix A: Capacity, STA, DTA and STA-Q

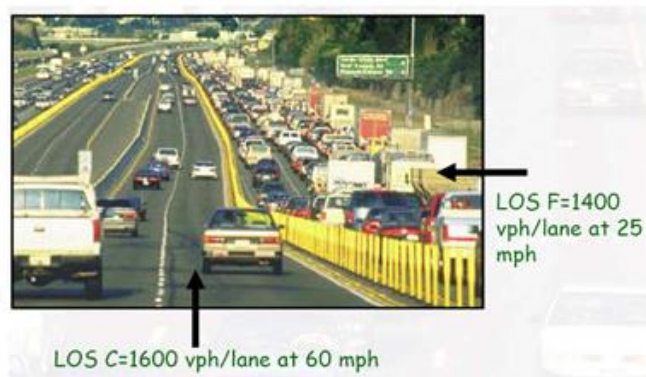
Capacity

Section 1 describes how roadways cannot carry traffic volumes in excess of capacity and introduces a threshold of 110% of capacity beyond which model outputs are invalid. The maximum sustained traffic flow on I-35 likely is significantly less than 100% of modeled capacity.

Freeway capacity in the CAMPO travel demand model varies slightly by area type ranging from 2,130 vehicles per lane per hour in rural areas to 2,170 vehicles per hour in the Central Business District (CBD).[11]

While traffic volumes can reach these levels for short periods, traffic at this level is unstable and often breaks down to stop-and-go conditions with significantly lower throughput. Once traffic breakdown occurs (as is common on I-35), vehicle throughput can be well below the maximum capacity as illustrated in this photo where congested traffic has a throughput of only 1400 vehicles per lane per hour in stop-and-go conditions vs. the adjacent managed lanes carrying 1600 vehicles per lane per hour at freeway speeds while appearing to be almost empty by comparison.

Figure A1: SR 91, Orange County, California[12]



For this reason, managed lanes are maintained at much lower traffic levels that the capacity assumed in the CAMPO model as described in a Federal Highway Administration (FHWA) document[13]:

> *The capacity a single directional lane can carry does not assure travel reliability as the flow rates become unstable at this point, and speeds and throughput can suddenly deteriorate… Managing flow below capacity can better assure travel benefits. Ongoing research sponsored by NCHRP is defining the appropriate values associated with different managed flow rates. In the meantime, the "rule of thumb" various states have adopted is a maximum managed flow threshold of approximately 1600 to 1650 vehicles/hour/lane (vphpl) for a single managed lane, assuming a vehicle mix composed largely of passenger cars, some buses and no heavy trucks. This value generally supports conditions corresponding to LOS C or better for most conditions. Observed maximum flow rates on geometrically restricted HOV lanes typically range from 1500 vphpl to 1750 vphpl. Multi-lane treatments may obtain somewhat higher values approaching*

[11] Alliance Transportation Group. CAMPO TDM Development Report. Table 5, p. 12. 2019.
[12] FHWA Federal Highway Administration (FHWA). Freeway and Operations Handbook Chapter 8 Managed Lanes, January 2011..
[13] FHWA.

1700 to 1900 vphpl since there is less friction in flow and no constraints caused by the slowest moving vehicle.

Figure A2 reproduced from a University of Texas report illustrates the complex relationships between capacity, traffic volume, and travel time. Important things to note in Figure A2 are:

1) True capacity represented with the vertical black line cannot be exceeded
2) In uncongested conditions (the lower left quadrant), as traffic volume increases, travel time increases.
3) In congested conditions (the upper left quadrant), longer travel times generally are correlated with less traffic throughput.

Point #3 is counterintuitive and the relational between travel time and throughput is not strictly causal. In many cases, the stop-and-go conditions represented with extremely high travel times result from downstream bottlenecks rather than the volume on that link. This is a fundamental problem with Static Traffic Assignment (STA); road segments are not independent of each other.

Figure A2: Relationships Between Capacity, Volume and Travel Time[14]

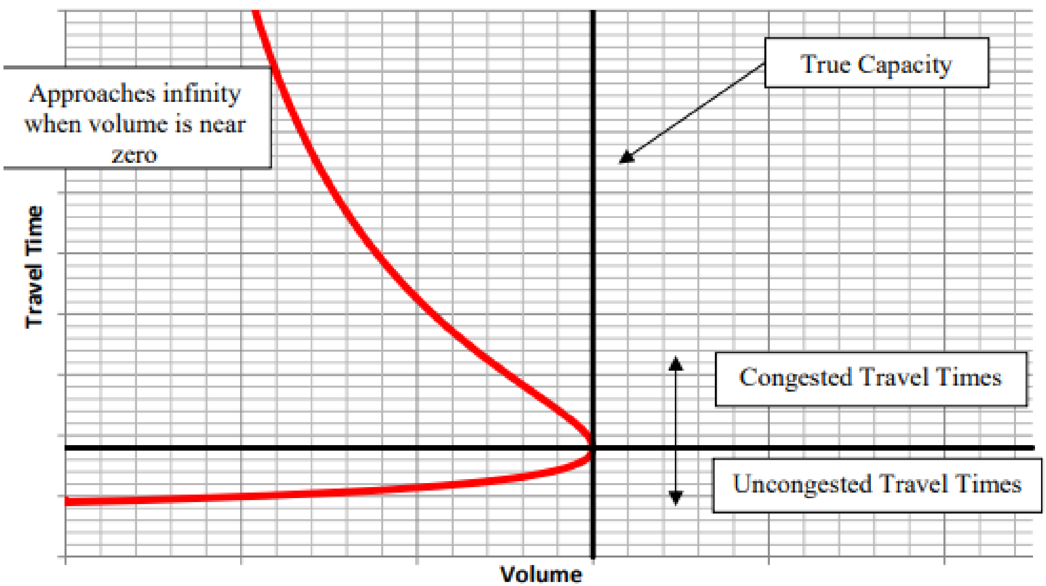


Figure 9.1: Travel time and link volume relationship used in DTA

The maximum I-35 capacity that can be sustained for a 3-hour peak period is probably significantly less than 2000 vehicles per lane per hour. Therefore, the CAMPO model capacity values are likely too high, and there is no reason to set an even higher threshold of 110% of the CAMPO model capacity as was done in the Section 1 graphics. The true capacity number should be established within the I-35 study and used as an upper limit for forecasts.

[14] J.C. Duthie, N Nesamuddin, N Juri, T Rambha, C Melson, C Pool, S. Boyles, W. Waller and R. Kumar. Investigating Regional Traffic Assignment Modeling for Improved Bottleneck Analysis: Final Report, University of Texas Center for Transportation Research, 2013.

Static Traffic Assignment (STA) Deficiencies

The CAMPO regional travel demand uses a 40-year-old Static Traffic Assignment (STA) algorithm. Another graphic from the same UT technical report illustrates why STA cannot properly account for congestion delays. An STA model has no capacity constraint but instead adds a delay based on the volume-to-capacity ratio.

Figure A3: STA Is Not Capacity Constrained[15]

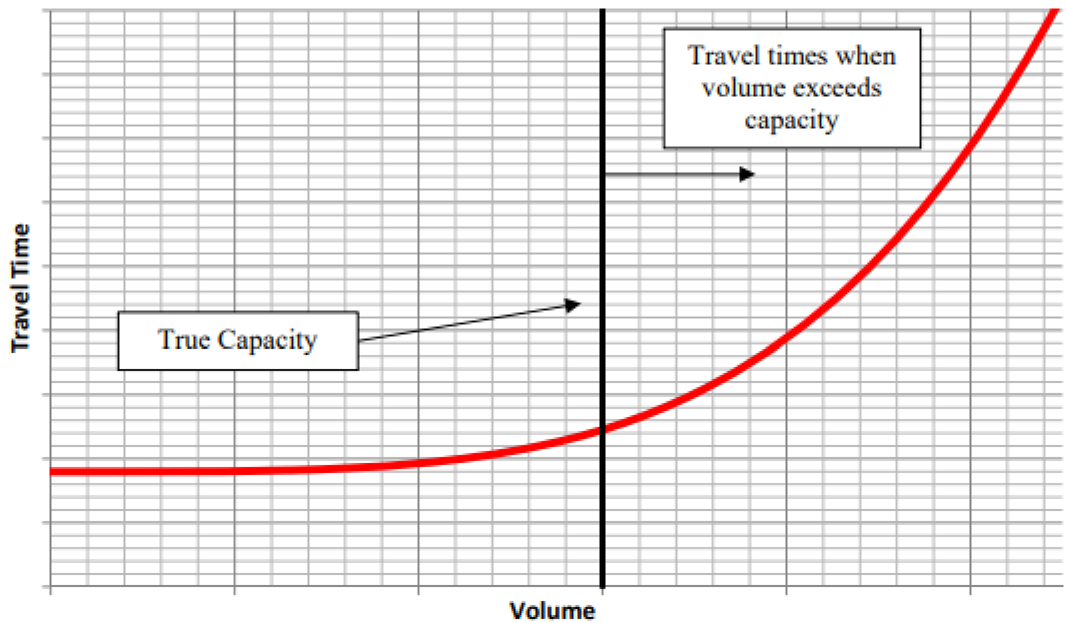


Figure 9.2: Travel time and link volume relationship used in STA—The BPR Function

The travel time multiplier is calculated from the model's volume-to-delay function coefficients. The CAMPO model assumes the free-flow speed on I-35 in the study area varies from 65 mph to 72 mph. At 100% of model capacity, the model assumes that I-35 operates at 33-36 mph. At 110% of model capacity, the model assumes that I-35 operates at 23-26 mph. As documented in Section 2, actual I-35 speeds are:

- Mean speed 21 mph,
- 95th percentile "planning" travel time 12 mph.

Therefore, even at 110% of modeled capacity, the CAMPO model speeds are higher than the actual speeds.

Furthermore, these problems are much worse for modeled freeway ramps. The CAMPO model assumes that ramps in the study area have free-flow speeds of 25-35 mph. At 100% of capacity, the modeled ramp speeds are 22-30 mph and at 110% of capacity, the modeled ramp speeds are 20-29 mph. Given that a typical ramp is only about 700 feet in length, the delay calculated for a single ramp at 110% of

[15] J.C. Duthie, N Nesamuddin, N Juri, T Rambha, C Melson, C Pool, S. Boyles, W. Waller and R. Kumar. Investigating Regional Traffic Assignment Modeling for Improved Bottleneck Analysis: Final Report, University of Texas Center for Transportation Research, 2013.

capacity is less than 5 seconds. In the CAMPO 2015 model, there is a ramp assigned with V/C = 1.44 with a total travel time of 17 seconds and a delay of only 9 seconds – essentially no delay at all.

Dynamic Traffic Assignment (DTA)

In my peer-reviewed journal article: *Forecasting the impossible: The status quo of estimating traffic flows with static traffic assignment and the future of dynamic traffic assignment*[16]*,* I document that STA always produces impossibly high freeway traffic volumes in congested networks and cannot be relied on for planning. The only solution is to replace STA with a more modern Dynamic Traffic Assignment (DTA) algorithm. Rather than assign traffic volumes above 100% of capacity, traffic in a DTA model spills back onto upstream roadway segments. The delays in these resulting queues are realistically estimated. Leading modeling expert Alan Horowitz wrote: "*Choose DTA over STA whenever possible.*"[17]

CAMPO and TxDOT should replace STA with DTA in all regional modeling applications as soon as possible.

STA-Q

The capacity can be considered as the maximum possible discharge volume for a road segment. The CAMPO regional travel demand model has 3-hour morning and afternoon peak periods. In general, traffic volumes are lower than the average throughput at the beginning and end of the peak period, and higher than average in the middle of the peak period. If a segment averages V/C = 1 across the entire hour peak period, this implies that the traffic volume entering the link in the middle of the time period is higher than capacity, and a queue will form behind the segment.

The problems with STA cannot be eliminated, but Dr. Xuesong Zhou of Arizona State University has observed that a modified STA can roughly approximate these queue delays. I am calling this STA-Q (for queue).

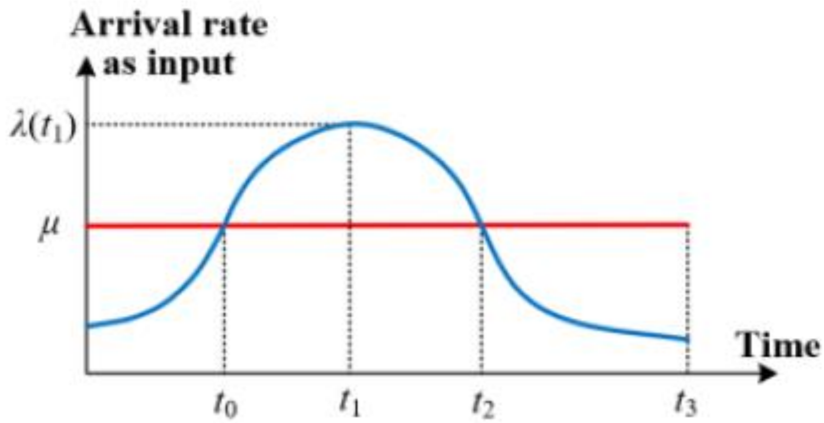
I have borrowed some graphics from Dr. Zhou's team to illustrate queue concepts. Figure A4 illustrates the generalized evolution of a bottleneck over time assuming a constant discharge rate μ (shown in **red**) and vehicles arriving $\lambda(t)$ (shown in **blue**). There are four distinct stages:

1) before time t_0, $\lambda(t) < \mu$ and there is no bottleneck
2) between t_0 and t_2, $\lambda(t) > \mu$ and the queue lengthens
3) between t_2 and t_3, $\lambda(t) < \mu$ queue shortens and clears at time t_3
4) after time t_3, $\lambda(t) < \mu$ and there is no queue

[16] Marshall, Norman. Forecasting the impossible: The status quo of estimating traffic flows with static traffic assignment and the future of dynamic traffic assignment, *Research in Transportation Business & Management*, Volume 29, 2018, 85-92. https://www.sciencedirect.com/science/article/pii/S2210539517301232?via%3Dihub

[17] Horowitz, Alan. Posting on the Travel Model Improvement Program (TMIP) listserv, March 2019.

Figure A4: Temporal Stages of a Bottleneck



The maximum arrival rate occurs at time t_1. The maximum queue is at time t_2. The area between times t_0 and t_2 between the blue and red lines represents the accumulated queued vehicles and this is equal to the area between times t_2 and t_3 and between the red and blue lines which represents the vehicles cleared from the queue.

Figure 2 provides a different representation of the same bottleneck with a focus on the queue length which is 0 for $t <= t_0$ and for $t>=t_3$.

Figure A5: Queue Length Representation

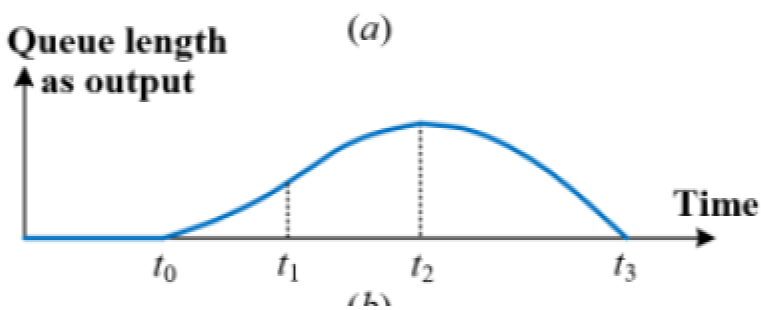
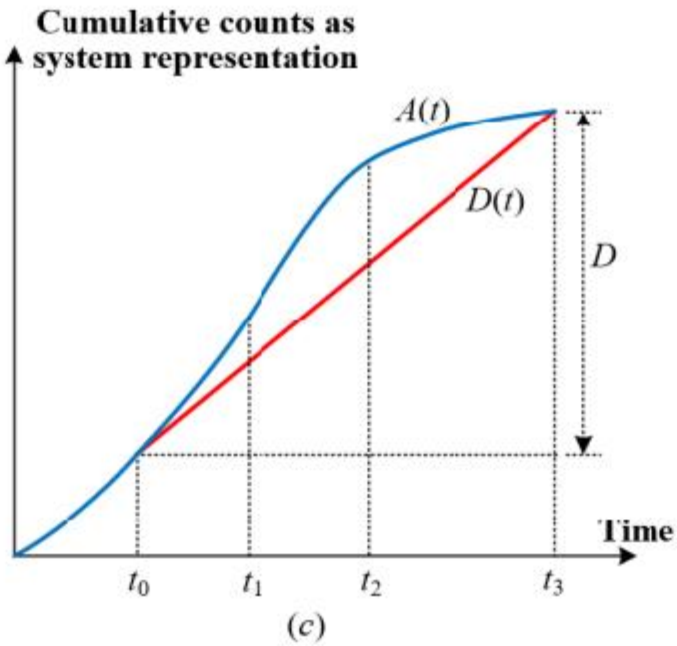


Figure A6 shows a third representation of the same bottleneck with a focus on the cumulative arrivals A(t) (blue) and the cumulative departures D(t). At times t_0 and t_2, A(t) = D(t).

Figure A6: Cumulative Counts Representation



Between times t_0 and $t_{2,}$ the vertical difference between the cumulative arrival and departure curses at time t is the queue length Q(t), and delay at time t is w(t) = Q(t)/μ. In a 3-hour peak period, this queue delay could be many minutes.

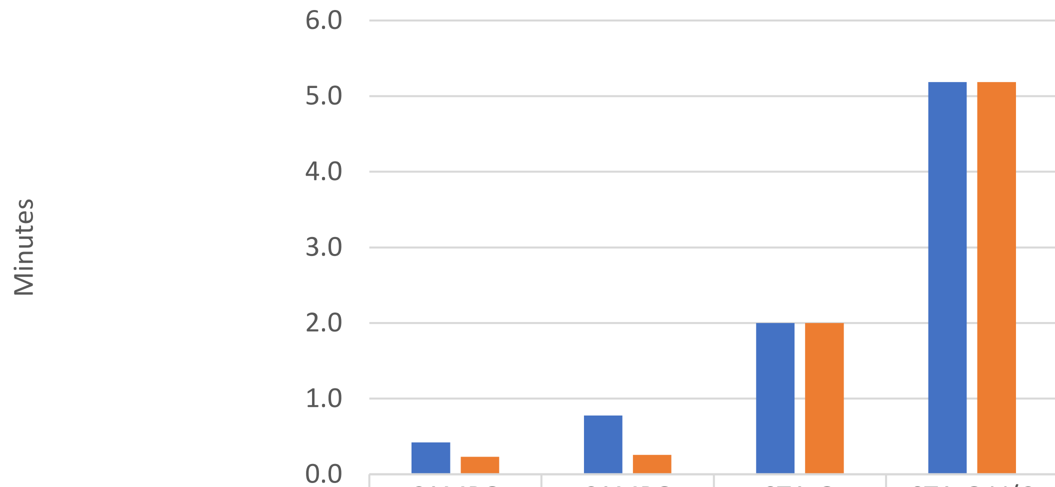
The STA volume-to-delay function is controlled by two parameters assigned to each road segment – alpha and beta. STA-Q keeps the alpha and beta coefficients so that it can be implemented with standard travel demand modeling software. However, it modifies the alpha parameter on a road segment by road segment basis.

In conventional STA, it is assumed that the delay function is a multiplier of free-flow travel time. For short road segments, including most ramps, the free-flow travel times are short. Therefore, even very high volume-to-capacity values translate into unrealistically short delays. The time delay for a queue behind a bottleneck does not depend on the length of the road segment, and the queue delay time should be modeled as independent of the segment length or free-flow time. To make the calculated delays independent of length, the STA-Q alpha parameter is divided by the free-flow travel time. The Austin region STA-Q model has been parameterized so that the modeled queue delay at V/C = 1 is 2 minutes for any road segment – regardless of functional type, length, or free-flow speed.

The beta exponent is 10.0. This makes the modeled queue delay at V/C = 1.1 equal to 5.2 minutes for any road segment – regardless of functional type, length, or free-flow speed.

Figure A7 compares the calculated CAMPO and STA-Q model delays for two typical road segments: 1) a freeway segment ½ mile in length, and 2) a ramp 700 feet in length.

Figure A7: Comparison of CAMPO an STA-Q Road Segment Delays at V/C = 1 and V/C = 1.1



	CAMPO V/C=1	CAMPO V/C = 1.1	STA-Q V/C=1	STA-Q V/C = 1.1
1/2 mile freeway segment	0.4	0.8	2.0	5.2
700-foot ramp	0.2	0.3	2.0	5.2

The alpha parameter for the ½ mile freeway segment is 2 / 0.5 = 4.0. The alpha parameter for the 700-foot ramp is 2 / (700/5280) = 15.1

In the CAMPO model, I-35 model segments are generally quite short because the mainline freeway segments are split by so many ramps. As each roadway segment is independent in STA, an extended stretch of high V/C segments will result in adding multiple delays. In the 2015 model, this largely prevents V/C > 1.1 segments.

Appendix B: Norman L. Marshall Resume

NORMAN L. MARSHALL, PRESIDENT

nmarshall@smartmobility.com

EDUCATION:

Master of Science in Engineering Sciences, Dartmouth College, Hanover, NH, 1982
Bachelor of Science in Mathematics, Worcester Polytechnic Institute, Worcester, MA, 1977

PROFESSIONAL EXPERIENCE: (33 Years, 19 at Smart Mobility, Inc.)

Norm Marshall helped found Smart Mobility, Inc. in 2001. Prior to this, he was at RSG for 14 years where he developed a national practice in travel demand modeling. He specializes in analyzing the relationships between the built environment and travel behavior and doing planning that coordinates multi-modal transportation with land use and community needs.

Regional Land Use/Transportation Scenario Planning

Portland Area Comprehensive Transportation System (PACTS) – the Portland Maine Metropolitan Planning Organization. Updating regional travel demand model with new data (including AirSage), adding a truck model, and multiclass Dynamic Traffic Assignment (DTA) including differentiation between cash toll and transponder payments.

Vermont Agency of Transportation-Enhanced statewide travel demand model to evaluate travel impacts of closures and delays resulting from severe storm events. Model uses innovate Monte Carlo simulations process to account for combinations of failures.

California Air Resources Board – Led team including the University of California in $250k project that reviewed the ability of the new generation of regional activity-based models and land use models to accurately account for greenhouse gas emissions from alternative scenarios including more compact walkable land use and roadway pricing. This work included hands-on testing of the most complex travel demand models in use in the U.S. today.

Chicago Metropolis Plan and Chicago Metropolis Freight Plan (6-county region)— developed alternative transportation scenarios, made enhancements in the regional travel demand model, and used the enhanced model to evaluate alternative scenarios including development of alternative regional transit concepts. Developed multi-class assignment model and used it to analyze freight alternatives including congestion pricing and other peak shifting strategies.

Envision Central Texas Vision (5-countyregion)—implemented many enhancements in regional model including multiple time periods, feedback from congestion to trip distribution and mode choice, new life style trip production rates, auto availability model sensitive to urban design variables, non-motorized trip model sensitive to urban design variables, and mode choice model sensitive to urban design variables and with higher values of time (more accurate for “choice” riders). Analyzed set land use/transportation scenarios including developing transit concepts to match the different land use scenarios.

Municipal Planning

City of Grand Rapids – Michigan Street Corridor – developed peak period subarea model including non-motorized trips based on urban form. Model is being used to develop traffic volumes for several alternatives that are being additional analyzed using the City's Synchro model

City of Omaha – Modified regional travel demand model to properly account for non-motorized trips, transit trips and shorter auto trips that would result from more compact mixed-use development. Scenarios with different roadway, transit, and land use alternatives were modeled.

City of Dublin (Columbus region) – Modified regional travel demand model to properly account for non-motorized trips and shorter auto trips that would result from more compact mixed-use development. The model was applied in analyses for a new downtown to be constructed in the Bridge Street corridor on both sides of an historic village center.

City of Portland, Maine – Implemented model improvements that better account for non-motorized trips and interactions between land use and transportation and applied the enhanced model to two subarea studies.

City of Honolulu – Kaka'ako Transit Oriented Development (TOD) – applied regional travel demand model in estimating impacts of proposed TOD including estimating internal trip capture.

City of Burlington (Vermont) Transportation Plan – Led team that developing Transportation Plan focused on supporting increased population and employment without increases in traffic by focusing investments and policies on transit, walking, biking and Transportation Demand Management.

Transit Planning

Regional Transportation Authority (Chicago) and Chicago Metropolis 2020 – evaluated alternative 2020 and 2030 system-wide transit scenarios including deterioration and enhance/expand under alternative land use and energy pricing assumptions in support of initiatives for increased public funding.

Capital Metropolitan Transportation Authority (Austin, TX) Transit Vision – analyzed the regional effects of implementing the transit vision in concert with an aggressive transit-oriented development plan developed by Calthorpe Associates. Transit vision includes commuter rail and BRT.

Bus Rapid Transit for Northern Virginia HOT Lanes (Breakthrough Technologies, Inc and Environmental Defense.) – analyzed alternative Bus Rapid Transit (BRT) strategies for proposed privately-developing High Occupancy Toll lanes on I-95 and I-495 (Capital Beltway) including different service alternatives (point-to-point services, trunk lines intersecting connecting routes at in-line stations, and hybrid).

Roadway Corridor Planning

I-30 Little Rock Arkansas – Developed enhanced version of regional travel demand model that integrates TransCAD with open source Dynamic Traffic Assignment (DTA) software, and used to model I-30 alternatives. This model models freeway bottlenecks much more accurately than the base TransCAD model.

South Evacuation Lifeline (SELL) – In work for the South Carolina Coastal Conservation League, used Dynamic Travel Assignment (DTA) to estimate evaluation times with different transportation alternatives in coastal South Caroline including a new proposed freeway.

Hudson River Crossing Study (Capital District Transportation Committee and NYSDOT) – Analyzing long term capacity needs for Hudson River bridges which a special focus on the I-90 Patroon Island Bridge where a microsimulation VISSIM model was developed and applied.

PUBLICATIONS AND PRESENTATIONS (partial list)

DTA Love: Co-leader of workshop on Dynamic Traffic Assignment at the June 2019 Transportation Research Board Planning Applications Conference.

Forecasting the Impossible: The Status Quo of Estimating Traffic Flows with Static Traffic Assignment and the Future of Dynamic Traffic Assignment. *Research in Transportation Business and Management* 2018.

Assessing Freeway Expansion Projects with Regional Dynamic Traffic Assignment. Presented at the August 2018 Transportation Research Board Tools of the Trade Conference on Transportation Planning for Small and Medium Sized Communities.

Vermont Statewide Resilience Modeling. With Joseph Segale, James Sullivan and Roy Schiff. Presented at the May 2017 Transportation Research Board Planning Applications Conference.

Assessing Freeway Expansion Projects with Regional Dynamic Traffic Assignment. Presented at the May 2017 Transportation Research Board Planning Applications Conference.

Pre-Destination Choice Walk Mode Choice Modeling. Presented at the May 2017 Transportation Research Board Planning Applications Conference.

A Statistical Model of Regional Traffic Congestion in the United States. Presented at the 2016 Annual Meeting of the Transportation Research Board.

MEMBERSHIP/AFFILIATIONS

Associate Member, Transportation Research Board (TRB)

Member and Co-Leader Project for Transportation Modeling Reform, Congress for the New Urbanism (CNU)