USER'S GUIDE FOR SAM AV MODULE

Guide for the Texas Statewide Analysis Model with Autonomous Vehicles, Shared-Autonomous Vehicles & Autonomous Trucks.

11/30/2023
University of Texas at Austin
Dr. Kara Kockelman, Maithreyi Vellimana, Priyanka Paithankar

Sponsored by the Texas Department of Transportation
5-7081 P1

Table of Contents

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This document serves as a comprehensive guide on how to use the SAM AV Module within the context of the 5-7081-01 implementation project. This module is a variation SAM-V4 model (Statewide Analysis Model) modified to include autonomous vehicles (AVs), shared autonomous vehicles (SAVs) and autonomous trucks (ATrucks).

This project introduces autonomous passenger and freight vehicles to the Texas Statewide Analysis Model (SAM) to assess their impact on Texas travel patterns, focusing on freight trips and long-distance passenger travel in the year 2040. SAM, a statewide travel demand model maintained by Texas Department of Transportation (TxDOT), serves as a tool to evaluate intercity transportation projects in Texas. The SAM model, designed to operate in TransCAD 8.0, underwent modifications for this project to create "SAM AV Module". This module is a TransCAD-based package containing the modified geographic Information System Developer's Kit (GISDK) scripts and input files tailored to run the model. This User Guide will walk you through the operation of the SAM AV Module, offering details on the model changes and essential background information.

This User Guide is not intended to provide instructions on SAM-V4 or TransCAD (Open **TransCAD** > **Help** > **TransCAD User's Guide**), as detailed documentation already exists.

GUIDE LAYOUT

The User Guide is broken into two parts. Part 1 is titled "Using the SAM AV Module" and takes users through a step-by-step process to run the SAM-AV module. Part 2 is titled "Understanding the SAM AV Module" and expands on new model specifications and parameters, and details of SAM V4's modifications.

PART 1: USING THE SAM AV MODULE

This section outlines the procedure to execute the modified TransCAD module, with the assumption that the user is familiar with running default SAM-V4 models. It also provides overview on using the Geographic Information System Developer's Kit (GISDK) debugger and creating custom interfaces, both of which are invaluable tools during GISDK code modification and execution.

Detailed instructions for installing and running the SAM-V4 model can be found in the SAM documentation's *SAMV4 Operator Manual*.

1.1. GUIDELINES TO USE SAM AV MODULE

The following section provides step-by-step instructions for the implementation of the SAM AV Module:

1. Save the unzipped “SAM AV Module” in your local directory.
2. Navigate to **Tools** > **GIS Developer’s Kit** > **Setup Add-ins,** as shown in Figure 1**,** to display **Setup Add-ins** dialog box.

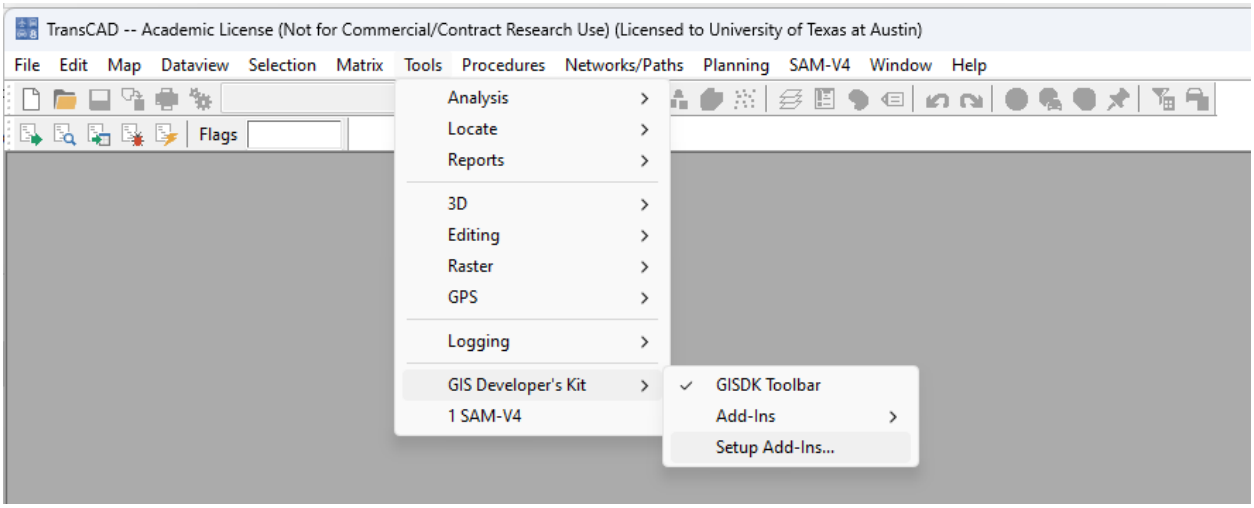


Figure 1. Locating SAM-V4 'Setup Add-ins'

3. Create a new add-in by selecting the **Add** button on the right-hand side of the dialog box.
4. As shown in **Figure 2**, provide an appropriate name in the **Description** information box. Under **Name**, enter “SAM-V4-ModelMenu” resembling the default SAM interface. For **UI Database**, select the “sam_av” interface located within the “SAM AV Module” folder, which integrates SAM code modified to include AVs, SAVs and ATrucks.

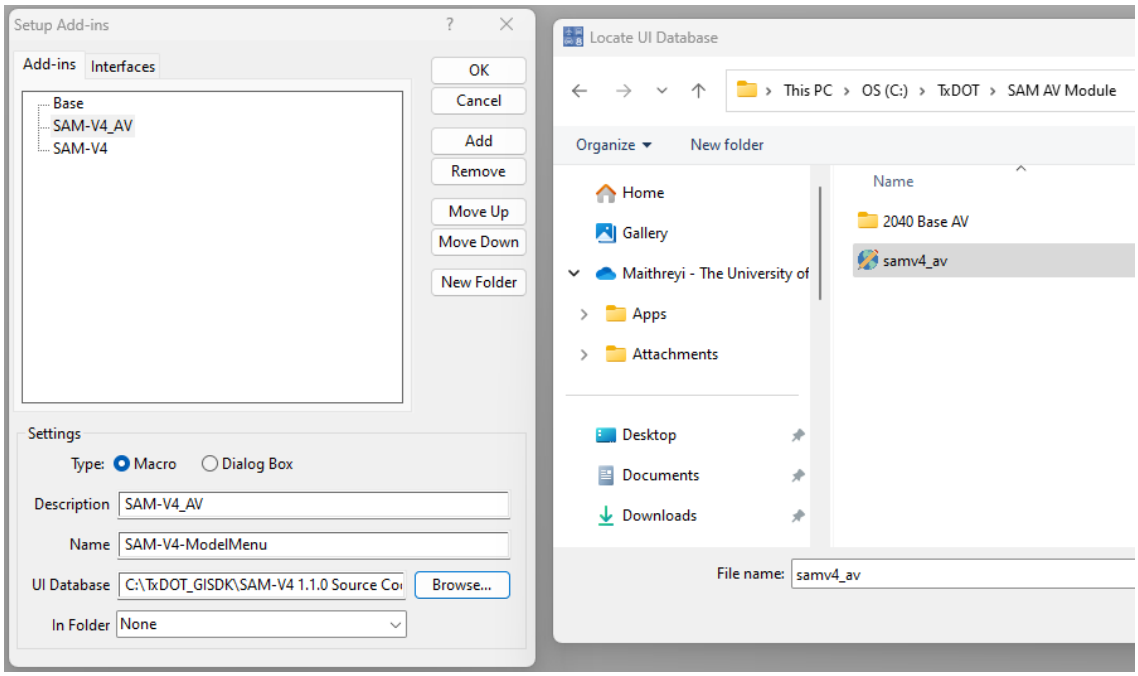


Figure 2. SAM-V4 Add-In Setup

5. Click the **OK** button to complete the add-in setup process.
6. Next, under **Tools** > **GIS Developer's Kit** > **Add-in**s, select the newly created add-in. Similar to running the default SAM model, this action will generate a "SAM-V4" option on top in the TransCAD Menu, as shown in Figure 3.

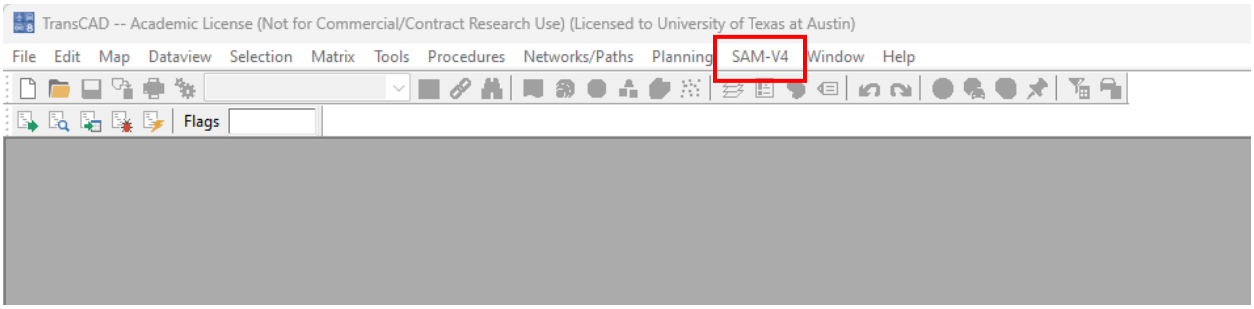


Figure 3. "SAM-V4" Menu

7. Selecting **Model Interface** under it will load the interface.

Additionally, ensure to copy the "2040 Base AV" folder provided in the "SAM AV Module" folder to the "SAM-V4" folder with the "TxDOT" folder. "SAM-V4" is the folder created in your C drive during SAM installation containing the Weekend and Weekday input-output structure and input files for the years 2015 and beyond. Once the interface is open, follow these steps, similar to running any SAM model:

1. Click on **Setup**, which opens up the **Model Scenario Manager** shown in Figure 4. Then duplicate one of the scenarios to create a new scenario. Provide an appropriate name and update the folder path by double-clicking on the folder tab. Select the correct folder, in this case, "2040 Base AV" folder.

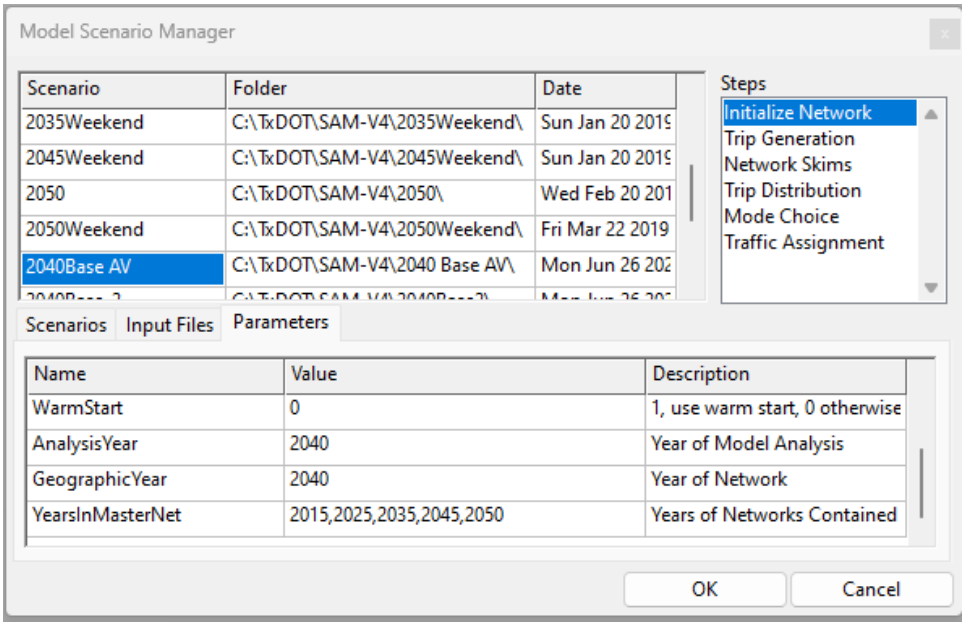


Figure 4. Model Scenario Manager Dialog Box

2. Then select the **Initialize Network** step in the **Steps** list and click the **Parameters** tab.
3. Change **AnalysisYear** and **GeographicYear** under the **Parameters** tab to the desired non-default year, this this case 2040 (as shown in Figure 4).
4. To run the model, navigate outside the setup options, select the desired scenario (e.g., "2040 Base AV"), and initiate the model run.

1.2. ADDITIONAL SUPPORT

This section provides a brief overview of using the GISDK Debugger tool and creating custom interfaces. Detailed instructions are available in the SAM documentation.

GISDK DEBUGGER

The GISDK Debugger serves as an invaluable tool for the identification and resolution of potential coding errors, as well as the meticulous examination of inputs and outputs at various procedural stages. A detailed guide on leveraging this functionality is conveniently located within the TransCAD guide, accessible through the Help menu (**Help** > **GISDK Help**).
Quick guide on how to use it:

1. In the GIDSK Toolbar (**Tools > GIS Developer's Kit** > **GISDK Toolbar**), select the Debugger button. Within the GIDSK Toolbar (located at **Tools** > **GIS Developer's Kit** > **GISDK Toolbar**), select the debugger button highlighted in the Figure 5 below.

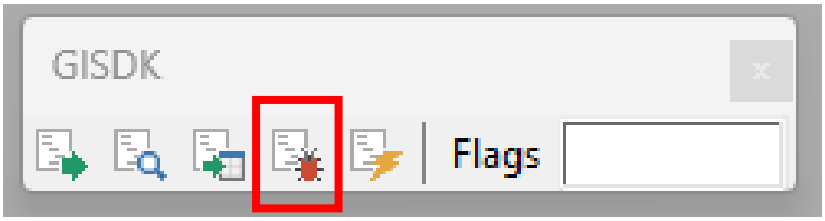


Figure 5. Debugger button on GISDK Toolbar

2. Select the GISDK rsc script of concern.
3. Implement breakpoints at sections requiring code interruption for detailed examination. Please note that it does not work on commented lines.
4. Subsequently, during the model execution, the process will halt at the designated breakpoints. Then you can systematically run the code line by line, inspecting inputs and outputs. Figure 6 shows an example of a debugger window.

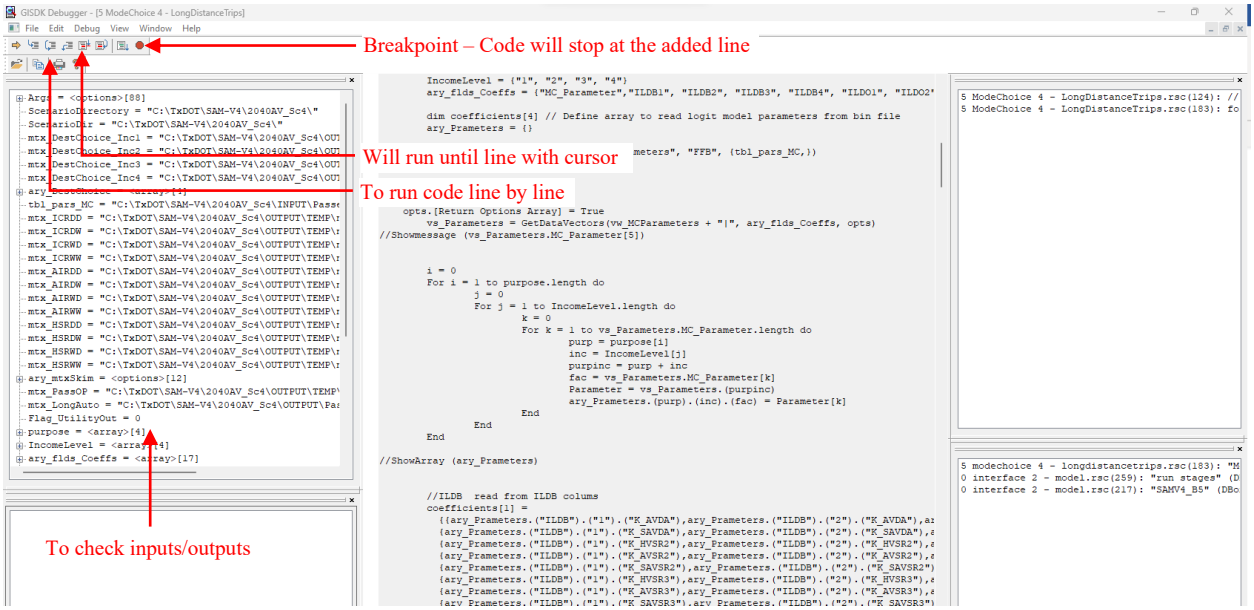


Figure 6. GISDK Debugger Window

SAM CUSTOM INTERFACE

To execute the SAM model through GISDK scripts, a custom user interfaces is required. The steps for this process are outlined below:

1. Within the directory containing all GISDK scripts, locate the .lst file. Ensure that the folder path in this file accurately reflects the path to your script folder.
2. Launch TransCAD and navigate to the GISDK Toolbar. Click on the "Compile to UI" button.
3. Select the updated .lst file and assign a name for the interface. It is essential to update this interface anytime modifications are made to the code, ensuring that it accurately reflects the latest changes.
4. Subsequently, follow the instructions provided in the *SAM Operator Manual* for running the model.

Note: Make sure to copy “SAM_mod” files that are in the Interface folder for the original SAM model folder with all the input files from 2015-2050.

PART 2: UNDERSTANDING THE SAM AV MODULE

To integrate AVs, SAVs, and ATrucks as additional transportation modes within SAM, significant modifications were made to the mode choice component of the model. In this document, we refer to this modified model as the "AV/ATruck" scenario. This model underwent substantial adjustments using the GISDK within the TransCAD software. GISDK serves as a valuable tool that automates repetitive tasks and enhances the customization of the TransCAD process. Within SAM, a comprehensive set of 38 scripts guides the four-step process. For this

particular scenario, the scripts and input files related to trip generation, skim creation, mode choice (includes passenger short-distance and long-distance mode choice, as well as freight mode choice), traffic assignment, and report generation were carefully edited. Modified scripts are highlighted below in Figure 7. These modifications are discussed in further detail in the subsequent sections.

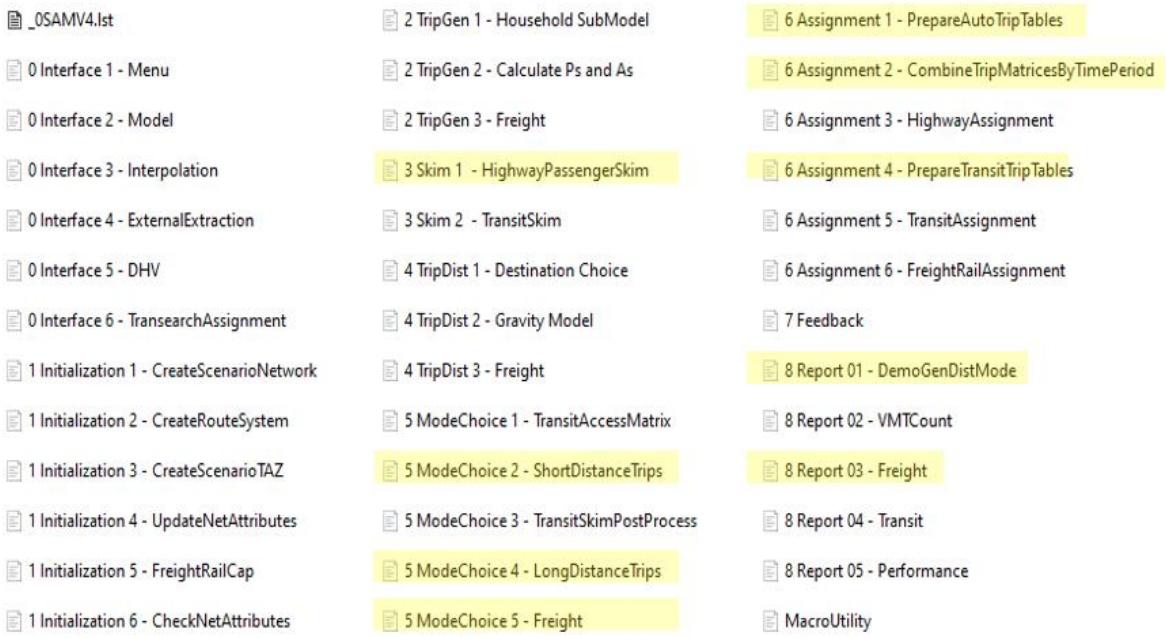


Figure 7. SAM-V4 GISDK Scripts

2.1. PASSENGER MODEL

To accommodate the anticipated rise in Vehicle Miles-Traveled (VMT) resulting from the introduction of AVs and SAVs, a 15% increase in all passenger trip production rates has been assumed and incorporated in the SAM-AV Module. This reflects a long-term growth in trip counts (by Year 2040 here) by improving travel access for elderly individuals, those without driver's licenses, and those with mobility impairments, based on Harper et al.'s (2016) detailed estimates based on differences in travel between these special groups and their counterparts.

SAM AV Module Update - This update involved the modification of the *'ProdRates'* bin file located under **INPUT** > **PASSENGER** > **TRIP_GEN**. Production rates for all person-trip purposes have been uniformly increased by 15%. For instance, the new *'ProdRate_HBW'* column was adjusted to old *ProdRate_HBW* * 1.15. Figure 8 shows bin file with the updated values where the old production rate columns have the suffix "_old".

Figure 8. Updated Production Rates

State	MSA	IncomeGroup	HouseholdSize	ProdRate_HBW_old	ProdRate_HBW	ProdRate_HBO_old	ProdRate_HBO	ProdRate_HBS_old	ProdRate_HBS	ProdRate_NHB_old	ProdRate_NHB	ProdRate_ILD
1	1	1	1	0.25800	0.29670	1.35300	1.55595	0.00000	0.00000	1.00300	1.15345	0.0
1	1	1	2	0.87300	1.00395	3.15500	3.62825	0.08600	0.09890	1.60200	1.84230	0.0
1	1	1	3	1.24600	1.43290	4.99300	5.74195	0.75100	0.86365	1.88000	2.16200	0.0
1	1	1	4	1.34200	1.54330	7.13600	8.20640	1.80100	2.07115	3.01600	3.46840	0.0
1	1	2	1	0.66500	0.76475	1.79500	2.06425	0.00000	0.00000	1.30800	1.50420	0.0
1	1	2	2	1.19300	1.37195	3.47300	3.99395	0.08600	0.09890	2.01700	2.31955	0.0
1	1	2	3	1.92400	2.21260	5.08400	5.84660	1.15800	1.33170	4.01000	4.61150	0.0
1	1	2	4	2.16300	2.48745	7.73400	8.89410	3.54200	4.07330	4.12600	4.74490	0.1
1	1	3	1	1.12400	1.29260	1.64100	1.88715	0.00000	0.00000	1.66200	1.91130	0.0
1	1	3	2	1.48100	1.70315	2.95600	3.39940	0.05900	0.06785	4.01000	4.61150	0.0
1	1	3	3	2.57500	2.96125	4.62100	5.31415	2.12400	2.44260	4.22700	4.86105	0.0
1	1	3	4	2.64800	3.04520	7.64700	8.79405	2.90200	3.33730	5.61200	6.45380	0.2
1	1	4	1	1.51200	1.73880	1.63500	1.88025	0.00000	0.00000	1.67000	1.92050	0.1
1	1	4	2	1.79800	2.06770	2.99400	3.44310	0.05300	0.06095	3.21800	3.70070	0.1
1	1	4	3	2.92700	3.36605	4.30700	4.95305	2.12400	2.44260	4.45000	5.11750	0.1
1	1	4	4	2.94300	3.38445	9.41200	10.82380	2.90200	3.33730	7.55200	8.68480	0.2
1	2	1	1	0.42700	0.49105	1.97800	2.27470	0.00000	0.00000	1.45300	1.67095	0.0
1	2	1	2	0.87500	1.00625	4.34400	4.99560	0.23900	0.27485	1.60200	1.84230	0.0
1	2	1	3	1.28300	1.47545	4.48600	5.15890	0.67900	0.78085	1.88000	2.16200	0.0
1	2	1	4	2.08700	2.40005	6.41800	7.38070	3.51800	4.04570	3.62700	4.17105	0.0
1	2	2	1	0.58200	0.66930	1.75900	2.02285	0.00000	0.00000	1.69800	1.95270	0.0
1	2	2	2	1.27200	1.46280	3.90400	4.48960	0.08700	0.10005	2.01700	2.31955	0.0
1	2	2	3	1.79200	2.06080	4.41400	5.07610	0.91300	1.04995	2.42400	2.78760	0.0
1	2	2	4	2.54200	2.92330	8.37800	9.63470	2.93800	3.37870	4.34200	4.99330	0.0
1	2	3	1	0.88300	1.01545	1.73300	1.99295	0.00000	0.00000	1.19000	1.36850	0.0
1	2	3	2	1.32100	1.51915	3.07100	3.53165	0.03200	0.03680	2.48300	2.85545	0.0
1	2	3	3	2.07800	2.38970	5.28900	6.08235	0.51800	0.59570	2.82200	3.24530	0.0
1	2	3	4	2.30300	2.64845	7.44100	8.55715	2.72400	3.13260	4.71300	5.41995	0.1
1	2	4	1	1.17000	1.34550	1.70900	1.96535	0.00000	0.00000	1.55000	1.78250	0.0
1	2	4	2	1.79800	2.06770	3.19300	3.67195	0.03200	0.03680	2.42100	2.78415	0.0
1	2	4	3	1.91500	2.20225	6.22300	7.15645	0.81200	0.93380	4.45000	5.11750	0.0
1	2	4	4	2.76400	3.17860	7.55100	8.68365	3.19000	3.66850	5.46100	6.28015	0.1
1	3	1	1	0.32000	0.36800	1.57400	1.81010	0.00000	0.00000	0.99900	1.14885	0.0
1	3	1	2	0.84900	0.97635	2.76100	3.17515	0.29000	0.33350	1.59500	1.83425	0.0
1	3	1	3	1.52200	1.75030	4.05700	4.66555	1.26400	1.45360	2.83600	3.26140	0.0
1	3	1	4	1.77400	2.04010	6.17400	7.10010	2.95900	3.40285	3.23300	3.71795	0.0
1	3	2	1	0.64400	0.74060	1.57600	1.81240	0.00000	0.00000	1.35900	1.56285	0.0
1	3	2	2	1.21100	1.39265	3.08600	3.54890	0.16400	0.18860	2.01100	2.31265	0.0
1	3	2	3	1.68700	1.94005	4.73400	5.44410	1.17000	1.34550	3.14700	3.61905	0.0
1	3	2	4	1.91300	2.19995	6.30400	7.24960	3.11600	3.58340	3.89200	4.47580	0.0
1	3	3	1	0.86300	0.99245	1.64800	1.89520	0.00000	0.00000	1.62600	1.86990	0.0
1	3	3	2	1.35900	1.56285	3.10800	3.57420	0.12200	0.14030	2.20400	2.53460	0.0
1	3	3	3	1.82900	2.10335	4.76800	5.48320	1.12700	1.29605	3.12100	3.58915	0.0
1	3	3	4	2.33600	2.68640	6.83900	7.86485	3.03400	3.48910	4.24900	4.88635	0.0
1	3	4	1	0.91500	1.05225	1.52700	1.75605	0.00000	0.00000	1.41100	1.62265	0.0
1	3	4	2	1.57500	1.81125	2.99700	3.44655	0.03100	0.03565	2.29700	2.64155	0.0

SAM uses distinct approaches for short-distance and long-distance passenger trips. The following sections elaborates the modifications made to accommodate this scenario.

SHORT-DISTANCE MODE CHOICE

For short-distance trips, SAM applies mode shares based on transit availability for different trip purposes and income groups. Within SAM-V4, four distinct modes are considered for short distance trips: Drive-alone (DA), Shared-Ride 2 (SR2) and Shared-Ride 3 or more people (SR3+) and “Other” modes. The “Other” category includes modes such as bus, urban rail, ferries, and any other transportation modes not captured by the survey questionnaire. SAM-V4 applies different factors based on three area types: "No Transit Available area," "Bus Available Area", and "Urban Rail Available Area". Figure 9 highlights TAZs according to their transit availability. Zone pairs where one of the zones has no transit access is considered a “No Transit Available Area”. When both zones have urban rail access, it is classified as “Urban Rail Available Area”. Similarly, for zone pairs where both have transit access but at least one zone has only bus access, it is considered “Bus Available Area”.

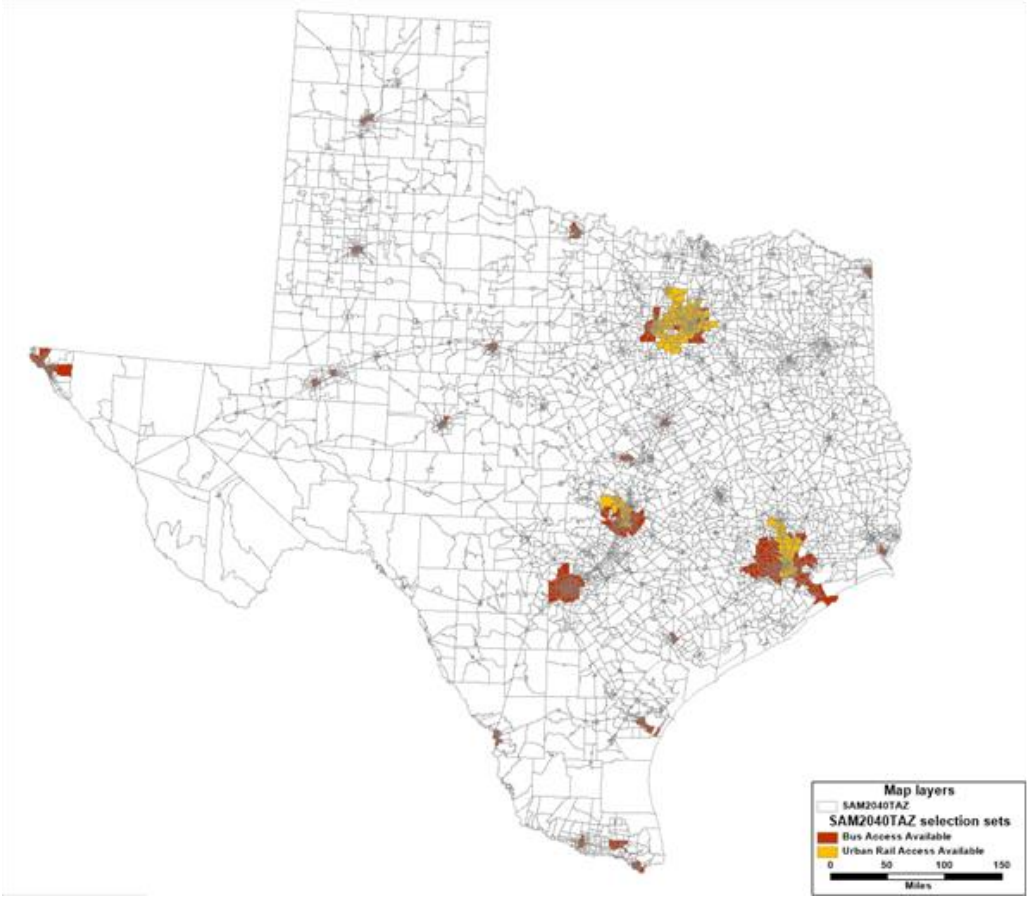


Figure 9. 2040 SAM-V4 Transit Availability by TAZ

In areas where no transit is available, a distribution of 40% for human-driven vehicles (HVs), 40% for AVs, and 20% for SAVs was assumed for DA, SR2, and SR3+. Similarly, in areas with transit availability (bus and urban rail available areas), the distribution of 40% for HVs, 40% for AVs, and 20% for SAVs was assumed for DA, SR2, and SR3+, mirroring the previous case. Additionally, a 50% reduction in the mode shares from "Other" modes to SAVs was considered in these areas. Zhao et al. (2018) forecasted two-thirds of all auto users opting for AVs or SAVs. Litman (2020) forecasts predicted 30% U.S. fleet in 2040 to be AVs, while other research predicts AVs comprising anywhere from 25% to 87% (based on different assumptions) of U.S fleet in 2045 (Bansal and Kockelman, 2016). Huang et al. (2021) survey results for trips between 75 and 500 miles indicate approximately a 23%, 28%, and 17% split for HVs, AVs, and SAVs for business trips, and a 37%, 15% and 34% split for HVs, AVs, and SAVs for non-business trips. These studies were used as reference for developing the assumptions outlined above.

SAM AV Module Update – The '*ModeShareSplit*' bin file, within **INPUT** > **PASSENGER** > **MODE** path, and the '*5 ModeChoice 2 – ShortDistanceTrips*' GISDK script was modified to achieve this.

Table 1 shows the updated mode splits after including the new modes. The GISDK script was modified to include the newly added modes.

Table 1. AV/ATruck Scenario Mode Share Splits for Short-Distance Trips (<50 miles)

No Transit Available Area											
Income Level	Trip Purpose	DA			SR2+			SR3+			Other
		HV	AV	SAV	HV	AV	SAV	HV	AV	SAV	
1	HBW	0.316	0.316	0.158	0.064	0.064	0.032	0.02	0.02	0.01	-
	HBO	0.184	0.184	0.092	0.116	0.116	0.058	0.1	0.1	0.05	-
	NHB	0.184	0.184	0.092	0.12	0.12	0.06	0.096	0.096	0.048	-
	HBS	0.048	0.048	0.024	0.092	0.092	0.046	0.144	0.144	0.072	0.29
2	HBW	0.332	0.332	0.166	0.048	0.048	0.024	0.024	0.024	0.012	-
	HBO	0.18	0.18	0.09	0.124	0.124	0.062	0.096	0.096	0.048	-
	NHB	0.196	0.196	0.098	0.112	0.112	0.056	0.092	0.092	0.046	-
	HBS	0.056	0.056	0.028	0.128	0.128	0.064	0.136	0.136	0.068	0.21
3	HBW	0.344	0.344	0.172	0.044	0.044	0.022	0.012	0.012	0.006	-
	HBO	0.192	0.192	0.096	0.128	0.128	0.064	0.084	0.084	0.042	-
	NHB	0.216	0.216	0.108	0.108	0.108	0.054	0.076	0.076	0.038	-
	HBS	0.048	0.048	0.024	0.128	0.128	0.064	0.144	0.144	0.072	0.2
4	HBW	0.356	0.356	0.178	0.036	0.036	0.018	0.004	0.004	0.002	-
	HBO	0.176	0.176	0.088	0.12	0.12	0.06	0.104	0.104	0.052	-
	NHB	0.212	0.212	0.106	0.104	0.104	0.052	0.084	0.084	0.042	-
	HBS	0.064	0.064	0.032	0.124	0.124	0.062	0.156	0.156	0.078	0.14
All	NHBV	0.14	0.14	0.07	0.116	0.116	0.058	0.144	0.144	0.072	-
Bus Available Area											
Income Level	Trip Purpose	DA			SR2+			SR3+			Other
		HV	AV	SAV	HV	AV	SAV	HV	AV	SAV	
1	HBW	0.280	0.280	0.157	0.064	0.064	0.049	0.020	0.020	0.027	0.050
	HBO	0.136	0.136	0.086	0.116	0.116	0.076	0.100	0.100	0.068	0.055
	NHB	0.144	0.144	0.089	0.120	0.120	0.077	0.096	0.096	0.065	0.050
	HBS	0.048	0.048	0.072	0.092	0.092	0.094	0.144	0.144	0.120	0.145
2	HBW	0.304	0.304	0.164	0.048	0.048	0.036	0.024	0.024	0.024	0.035
	HBO	0.160	0.160	0.088	0.124	0.124	0.070	0.096	0.096	0.056	0.025
	NHB	0.168	0.168	0.097	0.112	0.112	0.069	0.092	0.092	0.059	0.040
	HBS	0.056	0.056	0.063	0.128	0.128	0.099	0.136	0.136	0.103	0.105
3	HBW	0.332	0.332	0.171	0.044	0.044	0.027	0.012	0.012	0.011	0.015
	HBO	0.180	0.180	0.095	0.128	0.128	0.069	0.084	0.084	0.047	0.015
	NHB	0.196	0.196	0.106	0.108	0.108	0.062	0.076	0.076	0.046	0.025
	HBS	0.048	0.048	0.057	0.128	0.128	0.097	0.144	0.144	0.105	0.100
4	HBW	0.340	0.340	0.177	0.036	0.036	0.025	0.004	0.004	0.009	0.020

	HBO	0.172	0.172	0.088	0.120	0.120	0.062	0.104	0.104	0.054	0.005
	NHB	0.196	0.196	0.105	0.104	0.104	0.059	0.084	0.084	0.049	0.020
	HBS	0.064	0.064	0.055	0.124	0.124	0.085	0.156	0.156	0.101	0.070
All	NHBV	0.132	0.132	0.069	0.116	0.116	0.061	0.144	0.144	0.075	0.010
Urban Rail Available Area											
Income Level	Trip Purpose	DA			SR2+			SR3+			Other
		HV	AV	SAV	HV	AV	SAV	HV	AV	SAV	
1	HBW	0.264	0.264	0.154	0.064	0.064	0.054	0.020	0.020	0.032	0.065
	HBO	0.124	0.124	0.087	0.116	0.116	0.083	0.100	0.100	0.075	0.075
	NHB	0.132	0.132	0.088	0.120	0.120	0.082	0.096	0.096	0.070	0.065
	HBS	0.048	0.048	0.072	0.092	0.092	0.094	0.144	0.144	0.120	0.145
2	HBW	0.288	0.288	0.161	0.048	0.048	0.041	0.024	0.024	0.029	0.050
	HBO	0.152	0.152	0.088	0.124	0.124	0.074	0.096	0.096	0.060	0.035
	NHB	0.156	0.156	0.095	0.112	0.112	0.073	0.092	0.092	0.063	0.050
	HBS	0.056	0.056	0.063	0.128	0.128	0.099	0.136	0.136	0.103	0.105
3	HBW	0.324	0.324	0.170	0.044	0.044	0.030	0.012	0.012	0.014	0.025
	HBO	0.172	0.172	0.093	0.128	0.128	0.071	0.084	0.084	0.049	0.020
	NHB	0.192	0.192	0.106	0.108	0.108	0.064	0.076	0.076	0.048	0.030
	HBS	0.048	0.048	0.057	0.128	0.128	0.097	0.144	0.144	0.105	0.100
4	HBW	0.332	0.332	0.176	0.036	0.036	0.028	0.004	0.004	0.012	0.030
	HBO	0.168	0.168	0.087	0.120	0.120	0.063	0.104	0.104	0.055	0.010
	NHB	0.180	0.180	0.102	0.104	0.104	0.064	0.084	0.084	0.054	0.035
	HBS	0.064	0.064	0.055	0.124	0.124	0.085	0.156	0.156	0.101	0.070
All	NHBV	0.120	0.120	0.068	0.116	0.116	0.066	0.144	0.144	0.080	0.025

LONG-DISTANCE MODE CHOICE

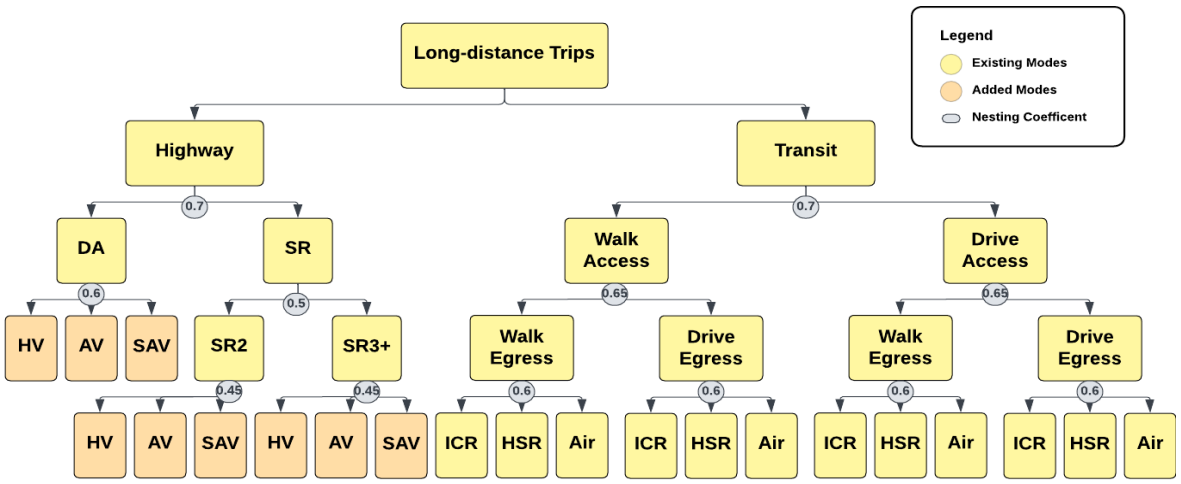
For trips greater than 50 miles, SAM's nested logit model was modified to include HVs, AVs, and SAVs. These modes were nested under DA, SR2 and SR3+. The nesting order was determined so because individuals are more inclined to determine the mode of transportation based on the size of their party, rather than selecting a mode first and then considering the number of people traveling with them. The operating cost rates for the long-distance mode choice model used to calculate operating cost between each zone pair, for both the default SAM model and the AV/ATruck scenario, are shown on Table 2. Figure 10 presents the updated nesting structure with the assumed nesting coefficients. The specific mode choice constants (ASCs) and explanatory variable coefficients assumed for the model, along with those set by default in the base model, are presented in Table 3. The IVTT coefficients for AVs and SAVs were reduced by 20%. This was done in order to reflect reduction in their VOTT ($/hr) by 20% due to alleviating driving burden and improving quality of travel. VOTT values for HVs, AVs and SAVs are shown in Table 4. These parameters were selected based on the

SAM-V4 base model and a similar model calibrated in the Huang et al. (2020) Texas megaregion study. These were estimated for each long-distance trip purpose and some for different income groups. Income groups in SAM-V4 are categorized into four based on household income (in 2015 dollars). Household income under $25,000 was grouped under category 1, followed by category 2 for household income ranging between $25,000 and $49,999. Households with income between $50,000 and $99,999 fell under category 3, and household income over $100,000 was grouped under category 4 (Alliance Transportation Group, 2019).

Table 2. Long-Distance Passenger Mode Choice Operating Cost Rates

NO AV/ATRUCK SCENARIO (Default SAM-V4 Model)			
Mode		***Business (ILDB & ILLB)***	***Non-Business (ILDO & ILLO)***
Auto Operating Cost ($/mile)		0.346	0.17
AV/ATRUCK SCENARIO			
Mode		***Business (ILDB & ILLB)***	***Non-Business (ILDO & ILLO)***
Operating Cost ($/mile)	HV	0.346	0.17
	AV	0.6	0.6
	SAV	1	1

Figure 10. AV/ATruck Scenario Long-Distance Mode Choice Nested-Logit Structure and Nesting Coefficients



**DA – Drive Alone, SR – Share Ride, ICR – Intercity Rail, HSR – High Speed Rail*

Table 3. Passenger Model Parameters (ASCs & Constants)

NO AV/ATRUCK SCENARIO (Default SAM-V4 Model)						
	Mode		***ILDB***	***ILDO***	***ILLB***	***ILLO***
ASC	Drive Alone (DA)		N/A	N/A	N/A	N/A
	Shared-Ride 2 (SR2)		-1.5	-0.1	-3	-0.8
	SR 3+ (SR3+)		-2	-0.2	-4.2	-2
	High-Speed Rail (HSR)		-1.1	-2.5	2.5	-0.4
	Intercity Rail (ICR)		-5	-3.8	-5	-2.5
	Air		-1.1	-2.5	2.5	0
Variable Coefficient	In-Vehicle Time		-0.02	-0.01	-0.02	-0.01
	Out-of-Vehicle Time		-0.02	-0.01	-0.02	-0.01
	Travel Cost	Income I	-0.1664	-0.1109	-0.1664	-0.1109
		Income II	-0.0555	-0.037	-0.0555	-0.037
		Income III	-0.0277	-0.0185	-0.0277	-0.0185
		Income IV	-0.0166	-0.0111	-0.0166	-0.0111
AV/ATRUCK SCENARIO						
	Mode		***ILDB***	***ILDO***	***ILLB***	***ILLO***
ASC	DA	Human-Driven Vehicles (HV)	N/A	N/A	N/A	N/A
		Autonomous Vehicles (AV)	-0.05	-0.05	-0.05	-0.05
		Shared Autonomous Vehicles (SAV)	-0.2	-0.2	-0.2	-0.2
	SR2	HV	-1.5	-0.1	-3	-0.8
		AV	-1.55	-0.15	-3.05	-0.85
		SAV	-1.7	-0.3	-3.2	-1
	SR3+	HV	-2	-0.2	-4.2	-2
		AV	-2.05	-0.25	-4.25	-2.05
		SAV	-2.2	-0.4	-4.4	-2.2
	High-Speed Rail (HSR)		-1.1	-2.5	2.5	-0.4
	Intercity Rail (ICR)		-5	-3.8	-5	-2.5
	Air		-1.1	-2.5	2.5	-0.4
Variable Coefficient	In-vehicle Time_HV		-0.02	-0.01	-0.02	-0.01
	In-vehicle Time_AV/SAV		-0.016	-0.008	-0.016	-0.008
	Out-of-vehicle Time		-0.02	-0.01	-0.02	-0.01
	Travel Cost	Income I	-0.1664	-0.1109	-0.1664	-0.1109
		Income II	-0.0555	-0.037	-0.0555	-0.037
		Income III	-0.0277	-0.0185	-0.0277	-0.0185
		Income IV	-0.0166	-0.0111	-0.0166	-0.0111

Note: ILD = infrequent, long-distance (>50 mile) passenger trips. under 400 miles. ILL = extra-long trips (> 400 miles each way). B = business trips, and O = non-business or "other" trips.

Table 4. Passenger Modes VOT

AV/ATRUCK SCENARIO VOT ($/hr)								
	ILDB		***ILDO***		***ILLB***		***ILLO***	
	HV	***AV/SAV***	***HV***	***AV/SAV***	***HV***	***AV/SAV***	***HV***	***AV/SAV***
Income I	7.2	5.76	5.4	4.32	7.2	5.76	5.4	4.32
Income II	21.6	17.28	16.2	12.96	21.6	17.28	16.2	12.96
Income III	43.3	34.64	32.4	25.92	43.3	34.64	32.4	25.92
Income IV	72.3	57.84	54.1	43.28	72.3	57.84	54	43.2

SAM AV Module Update – These updates are reflected in *'AutoOperatCost'*, *'MC_Parameters'* input files (**INPUT>PASSENGER>MODE**). The '*3 Skim 1 - HighwayPassengerSkim'*, *'5 ModeChoice 4 – LongDistanceTrips*' rsc script was also updated to include these new modes.

2.2. FREIGHT MODE CHOICE

The freight mode choice was updated to include ATrucks as a new category. These ATrucks are nested under the broader truck mode, separating automated trucks (ATrucks) from human-driven trucks (HTrucks). The Texas megaregion study conducted by Huang et al. (2020) is again used as a starting point for the model parameters, assuming a nesting coefficient of 0.7 for HTruck and ATrucks to reflect the relative substitutability between the two modes. The operating costs for ATrucks were assumed to be 1.5 times those of HTrucks per-mile (to account for automation equipment cost and additional training expenses for humans supervising the truck). The ATrucks travel time skim was assumed to be 0.42 times that of HTrucks to reflect the ability of automated trucks to drive 24 hours a day. The time coefficient for 11 out of 15 commodities in SAM-V4 default are 0. Therefore, for these groups, only the operating cost is increased. The updated mode choice structure for this scenario, along with the nesting coefficient, is shown in Figure 11. SAM-V4 freight mode choice model uses an incremental logit structure that builds upon existing base share. However, with the introduction of ATrucks and the associated changes in the model structure, the calculations for mode shares needed to be updated.

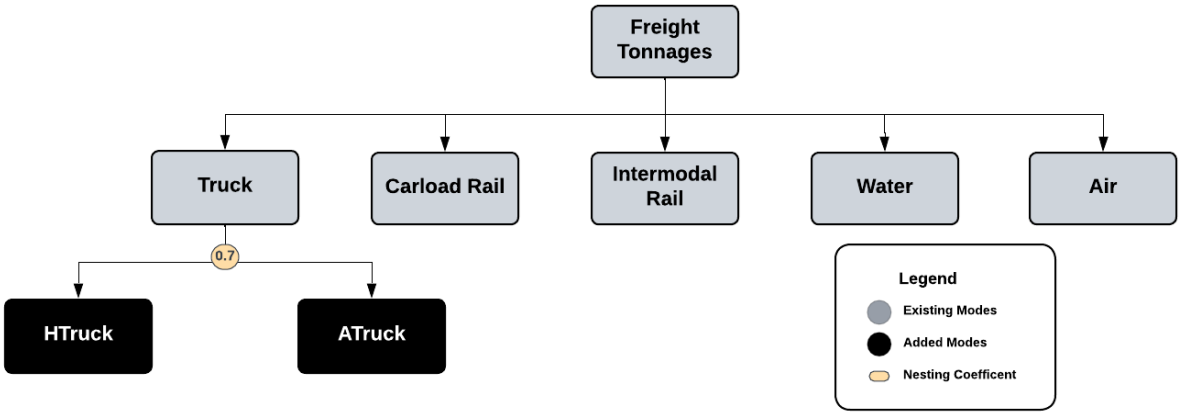


Figure 11. AV/ATruck Scenario Mode Choice Structure and Nesting Coefficient

To begin, the utilities of HTrucks and ATrucks for every commodity group and zone pair were computed using the explanatory variables and modal constant terms, similar to the approach followed in the base model. The utility calculation for ATrucks is shown as an example below:

$$U_{ij}^{ATruck,k} = ASC^{ATruck,k} + \beta_t^{ATruck} * Travel\ Time_{ij} + \beta_c^{ATruck} * (Cost\ Rate\ per\ ton - mile * Distance_{ij})$$

where $ASC^{ATruck,k}$ is the alternate specific constant, β_t^{ATruck} is the time coefficient and β_c^{ATruck} is the cost coefficient for ATrucks, for commodity *k* from zone *i* to *j*.

Next, the utility of the truck mode was determined by calculating the logsum of the utilities of HTrucks and ATrucks, taking the nesting coefficient into consideration. The formula for this calculation is expressed below:

$$U_{ij}^{Truck,k} = \theta * \log\left(e^{\left(\frac{U_{ij}^{HTruck,k}}{\theta}\right)} + e^{\left(\frac{U_{ij}^{ATruck,k}}{\theta}\right)}\right)$$

where θ = Nesting Coefficient and U_{ij} = Utility for specified mode for commodity *k* from zone *i* to *j*.

Following this, the new truck share or probability was calculated using the same methodology as the base model, using the base mode shares. The incremental logit model form as followed in the base or no AV scenario model is shown below:

For every mode *m*, in commodity group *k*, from zone *i* to *j*:

$$New\ Mode\ Share_{ij}^{m,k} = \frac{Existing\ Mode\ Share_{ij}^{m,k} * e^{\Delta U_{ij}^{m,k}}}{\sum\left(Existing\ Mode\ Share_{ij}^{m,k} * e^{\Delta U_{ij}^{m,k}}\right) for\ all\ m\ in\ k}$$

where $\Delta U_{ij}^{m,k}$ = Change in Utility

For Truck mode, the change in utility is determined by comparing the newly calculated utility of the truck mode, which involves taking the logsum of HTrucks and ATrucks, with the previous utility of the truck mode, before introduction of new mode (and nest). The shares of ATrucks and HTrucks (for every zone pair) were then derived from the total number of truck trips (which is calculated by multiplying the new truck share with total number of trips from each zone *i* to zone *j*) as shown below:

$$ATruck\ Share_{ij}^{k} = Total\ Truck\ Trips * \frac{e^{\left(\frac{U_{ij}^{ATruck,k}}{\theta}\right)}}{e^{\left(\frac{U_{ij}^{HTruck,k}}{\theta}\right)} + e^{\left(\frac{U_{ij}^{ATruck,k}}{\theta}\right)}}$$

$$HTruck\ Share_{ij}^{k} = Total\ Truck\ Trips * \frac{e^{\left(\frac{U_{ij}^{HTruck,k}}{\theta}\right)}}{e^{\left(\frac{U_{ij}^{HTruck,k}}{\theta}\right)} + e^{\left(\frac{U_{ij}^{ATruck,k}}{\theta}\right)}}$$

where θ = Nesting Coefficient and U_{ij} = Utility for specified mode for commodity k from zone i to j.

<u>SAM AV Module Update</u> – The '*5 ModeChoice 5 – Freight*' script was updated to accommodate ATrucks, with modifications made to the incremental logit structure, as detailed in the previous section. The "*BaseShare*" bin file within the **INPUT** > **FREIGHT** > **MODE** directory was updated to include matrix cores for ATrucks. Matrix cores with base share for the 15 commodity groups for ATrucks were duplicated from Truck matrix cores. This was done to maintain consistency in code after inclusion of new ATrucks mode while iterating through the different modes. Figure 12 highlights the duplicated ATrucks matrices added to base share input file, increasing the number of modes from five to six.

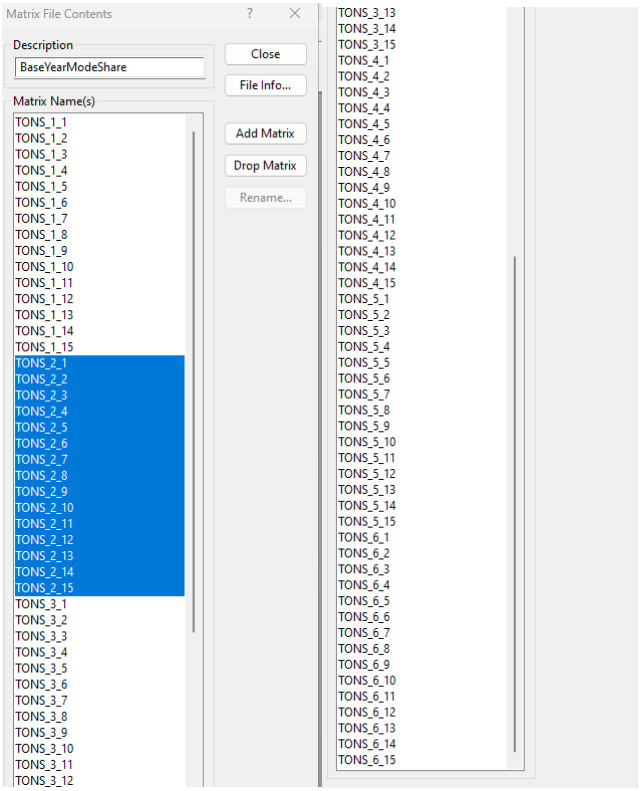


Figure 12. Modified Base Shares Input File Contents

2.3. TRAFFIC ASSIGNMENT

Person-trips produced in the mode choice step are converted to vehicle trips before traffic assignment. Auto occupancy factors are fixed for different modes for this step. DA and SR2 have occupancy of 1 and 2, respectively. Auto occupancy rates for SR3+ trips are applied in SAM based on trip purpose and income group, based on the National Household Travel Survey (NHTS). Given that SAVs operate without the need for parking and without passengers, the trips where the vehicle is unoccupied (such as when en route to pick up a new passenger or after dropping off a previous one) are accounted for by reducing auto occupancy rates of SAVs by 20%. This modification was done to reflect empty VMT in the travel demand model and is based off of studies by Simoni et al. (2019), Gurumurthy et al. (2019), de Souza et al. (2020) and Bischoff and Maciejewski (2016).

SAM AV Module Update – GISDK scripts associated to traffic assignment ('*6 Assignment 1 – PrepareAutoTripTables*', '*6 Assignment 2 – CombineTripMatricesByTimePeriod*', '*6 Assignment 4 – PrepareTransitTripTables*') and report generation ('*8 Report 01 – DemoGenDistMode*', '*8 Report 03 – Freight*') were modified due to added modes and updates to previous step script. An '*AutoOccupancy_SAV*' bin file similar to 'AutoOccupany' file in the **INPUT** > **ASSIGNMENT** folder was created to reflect this 20% reduction for SAV occupancy. Figure 13 displays two bin files with the auto occupancy rates, providing a visual representation of the different rates applied to SAVs from other passenger modes (HVs and AVs) for the purpose of accommodating unoccupied VMT.

Dataview1 - AutoOccupancy

TripPurpose	inc1	inc2	inc3	inc4
HBW	3.10	3.35	3.61	3.50
HBO	3.57	3.41	3.40	3.44
HBS	3.39	3.48	3.41	3.38
NHB	3.52	3.39	3.50	3.48
NHBV	3.47	3.47	3.47	3.47
ILDB	3.77	3.16	4.79	3.03
ILDO	3.28	3.92	4.58	4.12
ILLB	3.77	3.16	4.79	3.03
ILLO	3.28	3.92	4.58	4.12

Dataview2 - AutoOccupancy_SAV

TripPurpose	inc1	inc2	inc3	inc4
HBW	2.48	2.68	2.89	2.80
HBO	2.86	2.73	2.72	2.75
HBS	2.71	2.78	2.73	2.70
NHB	2.82	2.71	2.80	2.78
NHBV	2.78	2.78	2.78	2.78
ILDB	3.02	2.53	3.83	2.42
ILDO	2.62	3.14	3.66	3.30
ILLB	3.02	2.53	3.83	2.42
ILLO	2.62	3.14	3.66	3.30

Figure 13. Modified Auto Occupancy Rates for SAVs

REFERENCES

Alliance Transportation Group. (2019) *Model Development Report Package*, developed on behalf of the Texas Department of Transportation.

Bansal, P., & Kockelman, K.M. (2017) Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies. *Transportation Research Part A: Policy and Practice.* 95. 49-63. 10.1016/j.tra.2016.10.013.

Bischoff, J., & Maciejewski, M. (2016). Simulation of city-wide replacement of private cars with autonomous taxis in Berlin. *Procedia computer science*, *83*, 237-244.

de Souza, F., Gurumurthy, K. M., Auld, J., & Kockelman, K. M. (2020). A repositioning method for shared autonomous vehicles operation. *Procedia Computer Science*, *170*, 791-798.

Gurumurthy, K. M., Kockelman, K. M., & Simoni, M. D. (2019). Benefits and Costs of Ride-Sharing in Shared Automated Vehicles across Austin, Texas: Opportunities for Congestion Pricing. Transportation Research Record, 2673(6), 548-556. https://doi.org/10.1177/0361198119850785

Harper, C. D., Hendrickson, C. T., Mangones, S., & Samaras, C. (2016). Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. *Transportation research part C: emerging technologies*, *72*, 1-9.

Huang, Y., Kockelman, K.M., & Quarles, N. (2020) How will self-driving vehicles affect U.S. megaregion traffic? The case of the Texas Triangle. *Research in Transportation Economics*. 84. 101003. 10.1016/j.retrec.2020.101003.

Huang, Y., Zuniga-Garcia, N., & Kockelman, K.M. (2021) Long-distance travel impacts of automated vehicles: A survey of American households. https://www.caee.utexas.edu/prof/kockelman/public_html/TRB22LD-AVUSSURVEY.pdf

Litman, T. (2020). Autonomous vehicle implementation predictions: Implications for transport planning.

Simoni, M. D., Kockelman, K. M., Gurumurthy, K. M., & Bischoff, J. (2019). Congestion pricing in a world of self-driving vehicles: An analysis of different strategies in alternative future scenarios. *Transportation Research Part C: Emerging Technologies*, *98*, 167-185.