SANDAG *External Truck Model*

SANDAG

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1 Introduction

In 2008, the San Diego Association of Governments (SANDAG) implemented a two level truck model for San Diego County. The national level model represents nationwide truck travel based on the Freight Analysis Framework (FAF) version 2, also called FAF². The local level model represents truck flows based on a methodology developed for the Southern California Association of Governments (SCAG). Currently, SANDAG is replacing the local level model with a tour-based commercial vehicle model. A revised version of the FAF data, called FAF³, was released in 2010. The purpose of this study is to provide updated external truck trips based on FAF³ and include recent improvements of the long-distance model.

External truck trips are generated based on commodity flow data provided by the Freight Analysis Framework (FAF). FAF is published by the Federal Highway Administration of the U.S. Department of Transportation (Federal Highway Administration 2008). The size of the FAF zones in the Southwest of the U.S is shown in *Figure **1***. Fortunately, San Diego is represented as a single FAF zone.

Figure 1: Geography of FAF zones in the Southwest of the U.S.

The external truck model consists of three steps (Figure 2). The national model uses FAF[3] data to generate a nationwide truck trip table. This trip table is assigned to a nationwide network in the subarea analysis step, and truck flows between SANDAG external stations and San Diego County are extracted. The final step disaggregates the internal end of truck trips to SANDAG TAZs using employment data. The final output is a truck trip table between external stations and TAZs.

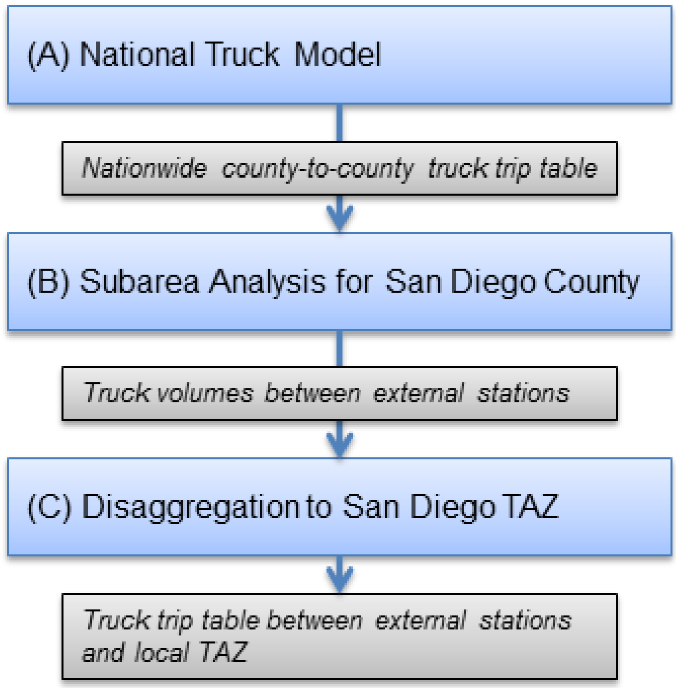

Figure 2: Flowchart of external model system

The national truck model and the disaggregation to TAZs are implemented in Java, while the subarea analysis is implemented in GISDK for TransCAD. The following sections describe each module in more detail.

2 National Truck Model

The resolution of the FAF[3] data with 123 zones within the U.S. is too coarse to analyze freight flows. For example, the metropolitan area of Los Angeles is represented by a single FAF zone. Assigning truck flows from and to this zone to a single point (zonal centroid) would lead to highly unrealistic truck travel patterns. Therefore, a method has been developed to disaggregate freight flows from 123 FAF zones to 3,138 U.S. counties using employment by type. An overview of the truck model design is shown in *Figure **3***. First, the FAF[3] data are disaggregated to counties across the entire U.S. using employment by 12 types and make/use coefficients that were derived from input/output coefficients. Following, commodity flows in tons are converted into truck trips using average payload factors. Finally, empty truck trips are added to the national truck trip table.

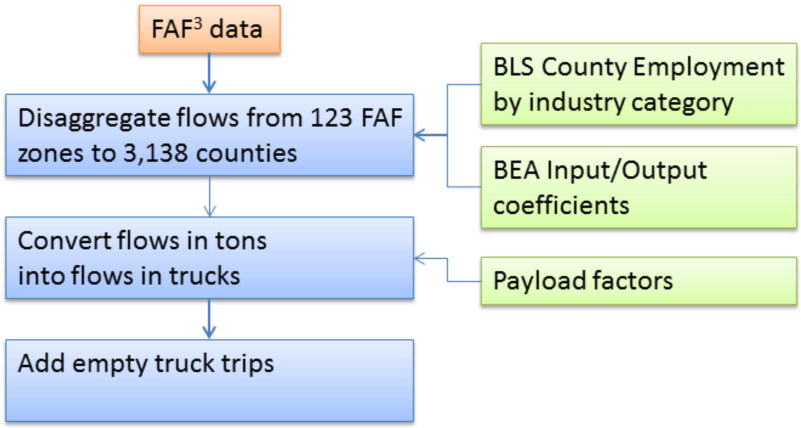

Figure 3: Truck Model flowchart

Two truck types are distinguished for this truck model, single-unit trucks (FHWA vehicle classes 5 to 7) and multi-unit trucks (FHWA vehicle classes 8 to 14). While single-unit trucks tend to serve shorter distances, multi-unit trucks are predominately used for long-distance trucks. Both truck types tend to serve different origins and destinations. This distinction is also relevant for the assignment. Multi-unit trucks take up more space on the highway system and need more time to accelerate. The model accounts for these differences between single-unit and multi-unit trucks by using different passenger-car equivalent factors (PCE) in the assignment.

2.1 Input Data

The third generation of the FAF data, called FAF^3, was released in summer 2010 and contains flows between 123 domestic FAF zones and 8 international FAF regions. The data can be downloaded free of charge[1]. FAF^3 data provide commodity flows in tons and dollars by

- FAF zones (123 domestic + 8 international zones)
- Mode (7 types: Truck, Rail, Water, Air, Multiple modes & mail, Pipeline, Other & unknown)
- Standard Classification of Transported Goods (SCTG) commodity (43 types)
- Port of entry/exit for international flows (i.e. border crossing, marine port or airport)

The base year is 2007, and freight flow forecasts are provided for the years 2015 to 2040 in five-year increments. At the time of the implementation of this model, the most recent version of FAF^3 was 3.4, which has been used consistently throughout this study. The FAF data contain different modes and mode combinations. For this project, the mode Truck was extracted for highway assignment.

Further data required for the truck model include the Vehicle Inventory and Use Survey (VIUS) conducted in 2002. This survey, published by the U.S. Census Bureau, provides the data of

[1] http://faf.ornl.gov/fafweb/

trucks and their usage[2]. County-level BLS data for employment by type[3] as well as BEA Input/Output coefficients[4] were used for FAF[3] data disaggregation. Finally, truck traffic counts were used for model validation.

2.2 Commodity flow disaggregation

The disaggregation from FAF zones to counties is based on county employment by 12 industry categories. The categories include[5]

- Agriculture
- Construction Natural Resources and Mining
- Manufacturing
- Trade Transportation and Utilities
- Information
- Financial Activities
- Professional and Business Services
- Education and Health Services
- Leisure and Hospitality
- Other Services
- Government
- Coal mining

These employment types serve to ensure that certain commodities are only produced or consumed by appropriate employment types. For example, SCTG25 (logs and other wood in the rough) is produced in those zones that have agriculture employment (as a proxy for forestry activity). This commodity is shipped to those zones that have employment in industries consuming this commodity, particularly manufacturing.

The following equation shows the calculation to disaggregate from FAF zones to counties. A flow of commodity *com* from FAF zone *a* to FAF zone *b* is split into flows from county *i* (which is located in FAF zone *a*) to county *j* (which is located in FAF zone *b*) by:

$$flow_{i,j,com} = flow_{FAF_a,FAF_b} \cdot \frac{weight_{i,com} \cdot weight_{j,com}}{\sum_{M \in FAF_a} \sum_{N \in FAF_b} weight_{m,com} \cdot weight_{n,com}} \tag{1}$$

2 http://www.census.gov/svsd/www/vius/products.html

3 ftp://ftp.bls.gov/pub/special.requests/cew/2010/county_high_level/

4 http://www.bea.gov/industry/io_benchmark.htm

5 Agriculture employment at the county level was obtained from the U.S. Department of Agriculture (USDA) upon request. Coal mining activity by county was obtained from the U.S. Department of Labor, Mine Safety and Health Administration Form 7000-2, "Quarterly Mine Employment and Coal Production Report." All other employment data are available for download from the Bureau of Labor Statistics at ftp://ftp.bls.gov/pub/special.requests/cew/2010/county_high_level/

where $flow_{i,j,com}$ is flow of commodity *com* from county *i* to county *j*
i is a county located in FAF_a
j is a county located in FAF_b
M are all counties located in FAF_a
N are all counties located in FAF_b

To disaggregate flows from FAF zones to counties, weights are calculated based on employment in 12 categories and make/use coefficients. These weights are commodity-specific. They are calculated by:

Production

$$weight_{i,com} = \sum_{ind} \left(empl_{i,ind} \cdot mc_{ind,com} \right) \tag{2a}$$

Consumption

$$weight_{j,com} = \sum_{ind} \left(empl_{j,ind} \cdot uc_{ind,com} \right) \tag{2b}$$

where $emp_{i,ind}$ is the employment in county *i* in industry *ind*
$mc_{ind,com}$ make coefficient describing how many goods of commodity *com* are produced by industry *ind*
$uc_{ind,com}$ use coefficient describing how many goods of commodity *com* are consumed by industry *ind*

Table 1 shows the make coefficients applied. Many cells in this table are set to 0, as most commodities are produced by a very few industries only. No value was available for the commodities SCTG09 (tobacco products) and SCTG15 (Coal). They were assumed to be produced by agricultural employment and coal mines, respectively. As only the relative importance of each industry for a single commodity is required, it is irrelevant which value the make coefficient for this commodities has, as long as the industry that produces this commodity is set to a value greater than 0 and all other industries are set to 0. For simplicity, these values were set to 1.

Table 1: Make coefficients by industry and commodity for disaggregation to counties

Commodity	Agriculture	Construction Natural Resources and Mining	Manufacturing	Trade Transportation and Utilities	Information	Financial Activities	Professional and Business Services	Education and Health Services	Leisure and Hospitality	Other Services	Government	Coal Production
SCTG01	811.6238	0	0	0	0	0	0	0	0	0	0	0
SCTG02	198.234	0	0	0	0	0	0	0	0	0	0	0
SCTG03	3669.689	324.679	0	0	0	0	0	0	0	0	0	0
SCTG04	159.456	0	114.4688	0	0	0	0	0	0	0	0	0
SCTG05	0	220.2534	786.7564	0	0	0	0	0	0	0	0	0
SCTG06	0	0	1289.469	0	0	0	0	0	0	0	0	0
SCTG07	205.8607	0	6551.506	0	0	0	0	0	0	0	0	0
SCTG08	0	0	1150.509	0	0	0	0	0	0	0	0	0
SCTG09	1	0	0	0	0	0	0	0	0	0	0	0
SCTG10	0	211.2682	4.254867	0	0	0	0	0	0	0	0	0

SCTG11	0	25.07928	0.643628	0	0	0	0	0	0	0	0	0
SCTG12	0	142.1159	3.647224	0	0	0	0	0	0	0	0	0
SCTG13	0	95.63332	3.740241	0	0	0	0	0	0	0	0	0
SCTG14	0	42.32755	0	0	0	0	0	0	0	0	0	0
SCTG15	0	0	0	0	0	0	0	0	0	0	0	1
SCTG16	0	138.1041	0	0	0	0	0	0	0	0	0	0
SCTG17	0	12.86544	46.14806	0	0	0	0	0	0	0	0	0
SCTG18	0	12.86544	46.14806	0	0	0	0	0	0	0	0	0
SCTG19	0	156.6388	222.981	0	0	0	0	0	0	0	0	0
SCTG20	0	7.601936	1133.067	0	0	0	0	0	0	0	0	0
SCTG21	0	0	393.104	0	0	0	0	0	0	0	0	0
SCTG22	0	0	267.6962	0	0	0	0	0	0	0	0	0
SCTG23	0	0	1082.518	0	0	0	0	0	0	0	0	0
SCTG24	0	0	1839.762	0	0	0	0	0	0	0	0	0
SCTG25	93.52182	5031.908	0	0	0	0	0	0	0	0	0	0
SCTG26	0	0	7578.98	0	0	0	0	0	0	0	0	0
SCTG27	0	0	392.5042	0	0	0	0	0	0	0	0	0
SCTG28	0	0	3254.577	0	0	0	0	0	0	0	0	0
SCTG29	0	0	621.0631	0	561.9978	0	0	0	0	0	0	0
SCTG30	0	0	747.4527	0	0	0	0	0	0	0	0	0
SCTG31	0	9.26281	1439.455	0	0	0	0	0	0	0	0	0
SCTG32	0	0	3039.151	0	0	0	0	0	0	0	0	0
SCTG33	0	0	4198.737	0	0	0	0	0	0	0	0	0
SCTG34	0	0.067042	3546.295	0	0	0	0	0	0	0	0	0
SCTG35	0	0	12377.87	0	0	0	0	0	0	0	0	0
SCTG36	0	0	6003.092	0	0	0	0	0	0	0	0	0
SCTG37	0	0	1785.718	0	0	0	0	0	0	0	0	0
SCTG38	0	0	3133.745	0	0	0	0	0	0	0	0	0
SCTG39	0	0	711.9008	0	0	0	0	0	0	0	0	0
SCTG40	0	0	1088.497	0	0	0	0	0	0	0	0	0
SCTG41	0	0	29.10704	0	0	0	8.608894	0	1.052104	0	0	0
SCTG42	0.06671	0.083488	0.84238	0	0.007296	0	0.000112	0	1.37E-05	0	0	0
SCTG43	0.06671	0.083488	0.84238	0	0.007296	0	0.000112	0	1.37E-05	0	0	0

Table 2 shows this reference in the opposite direction, defining which industry consumes which commodities. No data were available for coal mining, and thus values were set 0.

Table 2: Use coefficients by industry and commodity for disaggregation to counties

Commodity	Agriculture	Construction Natural Resources and Mining	Manufacturing	Trade Transportation and Utilities	Information	Financial Activities	Professional and Business Services	Education and Health Services	Leisure and Hospitality	Other Services	Government	Coal Production
SCTG01	166.435	17.245	11.188	53.064	0.302	38.968	47.149	1.006	0.576	0.900	0.005	0
SCTG02	2.810	15.474	8.045	13.610	0.077	27.222	1.234	0.583	0.110	0.314	0.003	0
SCTG03	107.551	364.139	105.791	254.524	1.904	244.535	37.352	8.192	3.078	7.577	0.083	0
SCTG04	6.897	9.206	17.855	24.754	0.371	15.793	21.956	0.353	0.796	0.754	0.075	0
SCTG05	190.286	17.154	60.307	86.094	1.577	16.482	51.845	9.624	3.631	4.639	0.372	0
SCTG06	27.336	6.590	57.220	206.179	2.855	27.893	143.396	0.003	6.097	6.524	0.975	0
SCTG07	854.169	32.833	727.346	813.944	8.477	110.607	425.561	0.240	17.500	27.404	2.900	0
SCTG08	44.799	2.731	104.258	160.917	1.376	18.414	90.234	0.018	1.568	2.816	0.737	0
SCTG09	0	0	1	0	0	0	0	0	0	0	0	0
SCTG10	0.324	0.865	1.807	19.680	0.264	7.645	12.375	0	0.216	0.163	0.001	0
SCTG11	0.052	0.068	0.367	2.275	0.040	0.995	1.792	0	0.025	0.021	0.000	0
SCTG12	0.292	0.387	2.082	12.892	0.229	5.640	10.157	0	0.142	0.121	0.003	0
SCTG13	0.210	0.239	1.519	10.447	0.156	4.044	7.079	0	0.100	0.095	0.003	0
SCTG14	0.089	0.542	0.770	2.783	0.018	0.521	1.312	0	0.006	0.015	0.014	0
SCTG15	0	0	1	0	0	0	0	0	0	0	0	0
SCTG16	0	29.419	5.266	9.619	0.327	17.924	21.549	0.001	0.021	0.244	0.023	0
SCTG17	0	9.008	0.214	1.174	0.010	0.096	0.497	0.001	0.062	0.077	0.005	0
SCTG18	0	9.008	0.214	1.174	0.010	0.096	0.497	0.001	0.062	0.077	0.005	0
SCTG19	0	39.411	10.691	19.568	0.464	19.295	27.091	0.002	0.292	0.769	0.044	0
SCTG20	5.555	13.295	124.747	139.427	1.435	12.000	77.454	0.003	2.795	7.177	0.885	0

SCTG21	0.007	1.855	54.918	42.271	0.786	4.598	78.362	0.003	0.446	1.722	0.433	0
SCTG22	0	3.925	23.736	68.574	0.277	3.438	15.388	0	0.427	2.835	0.050	0
SCTG23	0	4.172	130.089	86.738	1.423	13.165	120.219	0.004	2.092	3.189	1.221	0
SCTG24	0	10.627	170.388	142.135	4.403	35.618	115.278	0.012	10.806	10.390	1.100	0
SCTG25	1.192	878.051	14.600	168.838	1.950	31.229	38.998	0.773	0.534	44.291	0.150	0
SCTG26	4.259	1365.980	1013.975	728.073	25.935	98.436	321.878	0.021	44.158	43.052	2.766	0
SCTG27	0	26.306	24.780	29.872	0.252	2.135	12.691	0	0.753	2.351	0.645	0
SCTG28	0	261.436	262.769	546.635	6.113	33.556	181.616	0.022	12.418	32.699	17.244	0
SCTG29	0	7.170	63.615	148.933	25.280	85.811	228.676	0.421	18.980	13.978	0.422	0
SCTG30	1.170	2.023	44.320	82.125	2.876	18.842	78.851	0.001	4.451	2.527	0.466	0
SCTG31	0	18.751	79.061	234.383	4.730	28.820	89.890	0.005	8.515	13.631	1.069	0
SCTG32	0	51.646	107.547	463.198	3.766	40.219	126.145	0.009	7.868	22.837	32.057	0
SCTG33	0	27.968	189.055	340.033	13.608	98.218	261.766	0.020	20.462	28.936	12.457	0
SCTG34	0	12.003	206.897	278.454	10.373	81.719	223.908	0.019	16.051	12.579	1.080	0
SCTG35	0	53.889	1573.704	1204.984	99.194	191.424	1229.759	0.128	24.231	52.272	4.103	0
SCTG36	0	18.271	487.881	633.439	24.787	40.352	211.107	0.003	4.341	16.792	1.637	0
SCTG37	0	3.937	149.155	123.491	4.757	24.415	126.213	0.012	5.082	4.041	0.303	0
SCTG38	0	9.804	353.619	223.215	45.386	83.781	274.954	0.036	19.310	13.489	0.724	0
SCTG39	0	3.566	103.988	73.693	3.811	24.405	51.922	0.006	5.501	3.778	0.340	0
SCTG40	0.547	2.891	64.723	85.161	6.569	30.395	82.098	0.007	6.542	3.279	0.293	0
SCTG41	0	0	0	1	0	0	0	0	0	0	0	0
SCTG42	0.054	0.128	0.244	0.289	0.012	0.059	0.186	0.001	0.010	0.015	0.003	0
SCTG43	0.054	0.128	0.244	0.289	0.012	0.059	0.186	0.001	0.010	0.015	0.003	0

The disaggregated commodity flows in short tons need to be transformed into truck trips. Depending on the commodity, a different amount of goods fits on a single truck. FAF provides payload factors that were applied to convert flows from tons into trucks. FAF distinguishes five truck types, which were aggregated to the two truck types used in this model (single-unit [FAF category 1] and multi-unit trucks [FAF category 2 through 5]). First, the share of truck types by distance class is calculated based on *Table **3***.

Table 3: Share of truck type by distance class

Minimum Range (miles)	**Maximum Range (miles)**	**Single Unit**	**Truck Trailer**	**Combination Semitrailer**	**Combination Double**	**Combination Triple**
0	50	0.793201	0.070139	0.130465	0.006179	0.0000167
51	100	0.577445	0.058172	0.344653	0.019608	0
101	200	0.313468	0.045762	0.565269	0.074434	0.000452
201	500	0.142467	0.027288	0.751628	0.075218	0.002031
501	10000	0.06466	0.0149	0.879727	0.034143	0.004225

For every truck type, tons are converted into trucks separately. As an example, Table 4 shows payload factors for single-unit truck[6]. These payload factors describe how many trucks for one ton of goods are carried by single-unit trucks on the average. Multiplying these values with the tons traveling provides number of trucks needed to carry this flow. The nine body types (auto, livestock, bulk, flatbed, tank, day van, reefer, logging and other) are not used further but aggregated to a single truck type, in this case single-unit trucks.

[6] Payload factors for all FAF truck types can be found at http://faf.ornl.gov/fafweb/Data/Freight_Traffic_Analysis/faf_fta.pdf, pages A-1 to A-5

Table 4: Payload factors for single unit trucks by commodity

Commodity	Auto	Livestock	Bulk	Flatbed	Tank	Day Van	Reefer	Logging	Other
1	0	0	0.0066	0.04922	0.00111	0.00419	0.00173	0	0
2	0	0	0.02675	0.0086	0.00103	0.00032	0.00003	0	0.00003
3	0	0	0.01069	0.01981	0.00102	0.00996	0.00942	0	0.00147
4	0	0	0.01463	0.02657	0.00562	0.00334	0.00137	0	0.00034
5	0	0	0.00004	0.00089	0	0.03835	0.04837	0	0.00033
6	0	0	0	0.00025	0	0.15767	0.00216	0	0.00011
7	0	0	0.00001	0.00032	0.00073	0.02096	0.02048	0	0.02192
8	0	0	0	0.00002	0	0.02133	0.00286	0	0.02956
9	0	0	0	0	0	0.06785	0.04242	0	0.01498
10	0	0	0.01399	0.01865	0.00029	0.00115	0	0	0.00185
11	0	0	0.02362	0.00638	0	0.00107	0	0	0.00058
12	0	0	0.02337	0.00292	0	0	0	0.00002	0.00034
13	0	0	0.02393	0.00255	0.00119	0.0008	0.00002	0	0.00048
14	0	0	0.01773	0.01261	0	0	0	0	0
15	0	0	0.01973	0.00307	0	0	0	0	0.001
16	0	0	0.00685	0.02455	0.01041	0.00086	0	0	0.01333
17	0	0	0	0.00186	0.02298	0.02755	0	0	0.00225
18	0	0	0.00026	0.00328	0.03386	0.00038	0	0	0.00261
19	0	0	0.00116	0.01074	0.0466	0.00273	0	0	0.00122
20	0	0	0.00171	0.02421	0.0146	0.01697	0	0	0.00266
21	0	0	0	0	0	0.10537	0.0122	0	0
22	0	0	0.01074	0.00974	0.01882	0.00302	0	0	0.00063
23	0	0	0.00145	0.01277	0.00987	0.03153	0	0	0.00539
24	0	0	0.00109	0.04904	0.00199	0.04913	0.00147	0	0.00863
25	0	0	0.0177	0.0167	0	0.00013	0	0.00831	0.00291
26	0	0	0.01437	0.03091	0.00002	0.01721	0	0.00017	0.00205
27	0	0	0	0.00142	0	0.07422	0	0	0
28	0	0	0.00262	0.00222	0	0.06609	0.00109	0	0.00223
29	0	0	0	0.00909	0	0.0857	0	0	0.00038
30	0	0	0.00154	0.0146	0	0.09299	0.00181	0	0.00251
31	0	0	0.00404	0.00588	0.00034	0.00436	0	0	0.01456
32	0	0	0.00076	0.06023	0	0.01594	0	0	0.01038
33	0	0	0.004	0.03186	0.00005	0.02246	0	0.00005	0.02908
34	0	0	0.00271	0.03187	0	0.03959	0	0.00002	0.00814
35	0	0	0.00033	0.01488	0	0.08017	0.00164	0	0.01258
36	0	0	0.00041	0.0073	0	0.00756	0	0	0.0548
37	0	0	0.00649	0.0228	0	0.00782	0	0	0.0141
38	0	0	0.00064	0.04872	0	0.11375	0	0	0.0006
39	0	0	0.00007	0.00432	0	0.11805	0.00166	0	0.00382
40	0	0	0.00027	0.01702	0.00117	0.07196	0.00051	0	0.01452
41	0	0	0.01372	0.00869	0.00221	0.00069	0.00011	0	0.01908
42	0	0	0.00215	0.01208	0.02291	0.00117	0	0	0.00181
43	0	0	0	0.00415	0	0.09378	0	0	0

To retain some information on commodities carried, six commodity groups were defined. In addition, empty trucks are written out separately. For each of these groups, single-unit and multi-unit trucks are distinguished, generating a total of 14 vehicle classes [calculated as (6+1) * 2]. These commodity groups are kept separately through the assignment (described in section 3), which allows allocating truck trips by commodity group to SANDAG employment when flows are further disaggregated to zones (described in section 4).

Table 5: Definition of Commodity Groups

Commodity Group	SCTG	Commodity
1 Waste, Other, Unknown	40	Misc. mfg. prods.
	41	Waste/scrap
	43	Mixed freight
	99	Unknown
2 Gravel, Sand, Minerals, Ores, Logs	10	Building stone
	11	Natural sands
	12	Gravel
	13	Nonmetallic minerals
	14	Metallic ores
	25	Logs
	31	Nonmetal min. prods.
3 Chemical products	18	Fuel oils
	19	Coal-n.e.c.
	22	Fertilizers
	23	Chemical prods.
	24	Plastics/rubber
4 Food-related and consumer products	1	Live animals/fish
	2	Cereal grains
	3	Other ag prods.
	4	Animal feed
	5	Meat/seafood
	6	Milled grain prods.
	7	Other foodstuffs
	8	Alcoholic beverages
	9	Tobacco prods.
	21	Pharmaceuticals
	27	Newsprint/paper
	28	Paper articles
	29	Printed prods.
	30	Textiles/leather
5 Machinery, Metals, Wood	26	Wood prods.
	32	Base metals
	33	Articles-base metal
	34	Machinery
	35	Electronics
	36	Motorized vehicles
	37	Transport equip.
	38	Precision instruments
	39	Furniture
6 Crude petroleum, coal, gasoline	15	Coal
	16	Crude petroleum
	17	Gasoline
	20	Basic chemicals
0 Empty trucks	N/A	

The definition of commodity groups was done manually trying to achieve three goals simultaneously. SCTG commodities were grouped that

1. are similar in type
2. predominately used the same truck type
3. carry comparable average payload factors

While more commodity groups are desirable to improve the disaggregation described in section 4, the number of commodity groups is limited by the assignment. The more commodity groups are distinguished, the longer and less stable runs the assignment. Having six commodity groups that lead to 14 vehicle classes in the assignment was perceived to be a reasonable compromise.

FAF data provide commodity flows of goods transported. Some trucks, however, travel empty to pick up another shipment or to return to their base. According to data of the U.S. Census Bureau[7], an average of 19.36 percent of all truck miles is traveled by empty trucks. In addition, the empty truck model implemented for SANDAG takes into account that commodity flow data may be imbalanced, but truck flows are not. For example, to produce one ton of crude steel, 1.4 tons of iron ore, 0.8 tons of coal, 0.15 tons of limestone and 0.12 tons of recycled steel are commonly needed[8], i.e. flows in tons into and out of such a plant are highly imbalanced. While it is reasonable to assume that commodity flows are imbalanced, trucks are assumed to always be balanced, i.e. the same number of trucks shall enter and leave every zone on an average day. *Figure **4*** shows a simplified example of flows between three zones. Blue arrows show truck flows based on commodity flows that are imbalanced, and red arrows show necessary empty truck trips to balance the number of trucks entering and leaving every zone on an average day.

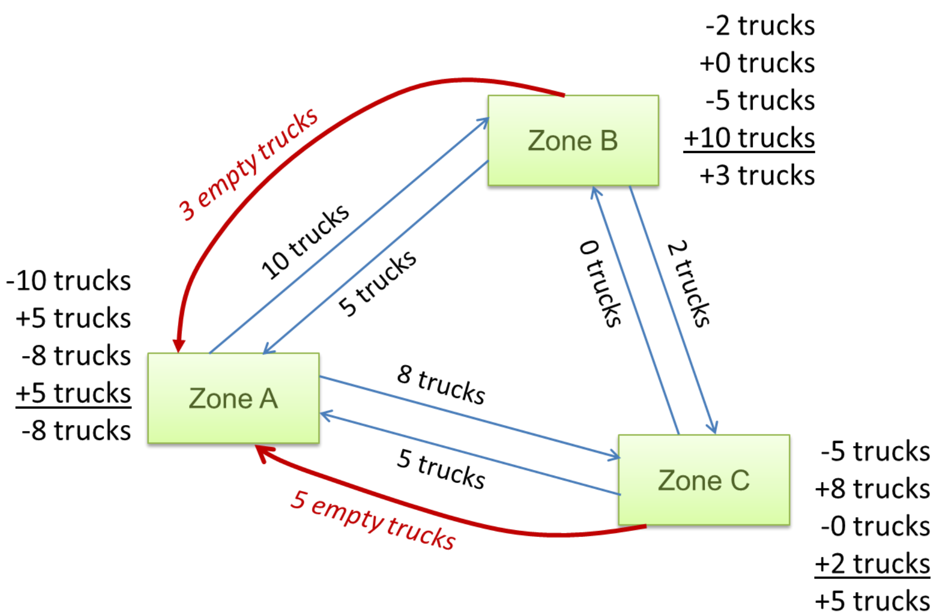

Figure 4: Example of truck flows (blue) based on commodity flows and empty trucks (red)

[7] http://www.census.gov/svsd/www/sas48-5.pdf

[8] http://worldsteel.org/dms/internetDocumentList/fact-sheets/Fact-sheet_Raw-materials2011/document/Fact%20sheet_Raw%20materials2011.pdf

All zones that have a positive balance of trucks (i.e. more trucks are entering than leaving the zone based on commodity flows) need to generate empty trucks, and their number of excess trucks are put into the empty truck trip matrix as row totals (purple cells in Figure 5). Zones with a negative balance (i.e. more trucks are leaving than entering the zone based on commodity flows) need to attract empty truck trips, and their balance is put (as positive values) as column totals into the empty truck trip matrix (yellow cells in Figure 5). To calculate these truck balances, trucks carrying commodities of six groups as defined in Table 5 were lumped together.

Positive Balance

from \ to	1001	1002	1003	...	500003	Truck balance
1001						4
1002						0
1003						12
...						
500003						0
Truck balance	0	8	0		26	

Negative Balance

Figure 5: Matrix of empty truck trips

The cells within the empty truck trip matrix are filled using a gravity model. It is assumed that empty trucks attempt to pick up another shipment in a zone close by, thus the travel time is used to calculate the impedance:

$$friction_{i,j} = \exp\left(\beta \cdot \mathrm{d}_{i,j}\right) \quad (3)$$

where $friction_{i,j}$ is the friction for empty truck trips from zone i to zone j
β is the friction parameter, currently set to -0.1
$d_{i,j}$ is the distance from zone i to zone j

A matrix balancing process is used to distribute empty truck trips across the empty truck trip table. Empty trucks are balanced separately for single-unit and multi-unit trucks. These empty trucks are added to the truck trip table of loaded trucks. The first and the second row in

Table ***6*** show the number of trucks generated based on commodity flows and the number of trucks generated to balance flows into and out of every zone. The number of empty truck trips necessary to balance truck trips by zone is lower than the 19.36 percent empty trucks according the U.S. census bureau. Therefore, another 8 percent of empty trucks needs to be added to account for the larger number of observed empty truck trips. These additional empty truck trips are added globally, i.e. all truck trips are scaled up to match the observed empty truck trip rate.

Table 6: Truck trips generated nationwide based on commodity flows and empty trucks

Purpose	Trucks	Share
Trucks based on commodity flows (FAF3)	1,725,928	81%
Trucks returning empty for balancing	246,010	11%
Additional empty truck trips (Census data)	168,350	8%
Total trucks trips	2,140,288	100%

This is an interesting finding by itself. If all trucking companies were perfectly organized and cooperated on the distribution of shipments between trucks that are available close-by, only 11 percent empty truck trips would be necessary. But because there is competition between trucking companies and because of imperfect information on where empty shipments are available, a much higher empty-truck rate is observed. Granted, this is a simplified empty-truck model, and the 11 percent empty-truck rate may not be achievable for two reasons: On the one hand, the model works with fractional numbers, i.e. the model may send 0.5 trucks from zone a to zone b, which is acceptable for a trip-based model that simulates an average day. On the other hand, only two truck types are distinguished, and trucks for different purposes, such as flatbed, livestock or reefer trucks, are not distinguished. Nonetheless, the model suggests that the number of empty trucks on the U.S. highway network is higher than what would be needed to serve all freight flows.

Finally, yearly trucks need to be converted into daily trucks to represent an average weekday. FAF provides commodity flows per year, and they need to be broken down into daily flows. As there are slightly more trucks traveling on weekdays than on weekends, a weekday conversion factor needs to be added.

$$trucks_{daily} = \frac{trucks_{yearly}}{365.25} \cdot \frac{AAWDT}{AADT} \quad (4)$$

where $trucks_{daily}$ is the number of daily truck trips
$trucks_{yearly}$ is the number of yearly truck trips
AAWDT is the average annual weekday truck count
AADT is the average annual daily truck count

Based on ATR (Automatic Traffic Recorder) truck count data the ratio *AAWDT/AADT* was estimated to be 1.02159, meaning that the average weekday has just 2.159 percent more traffic than the average weekend day. This reflects the nature of long-distance truck travel that is not affected much by the course of the week.

County-to-county truck flows can be assigned to a U.S.-wide network covering the continuous 48 states. *Figure **6*** shows the assignment of truck flows across the U.S.

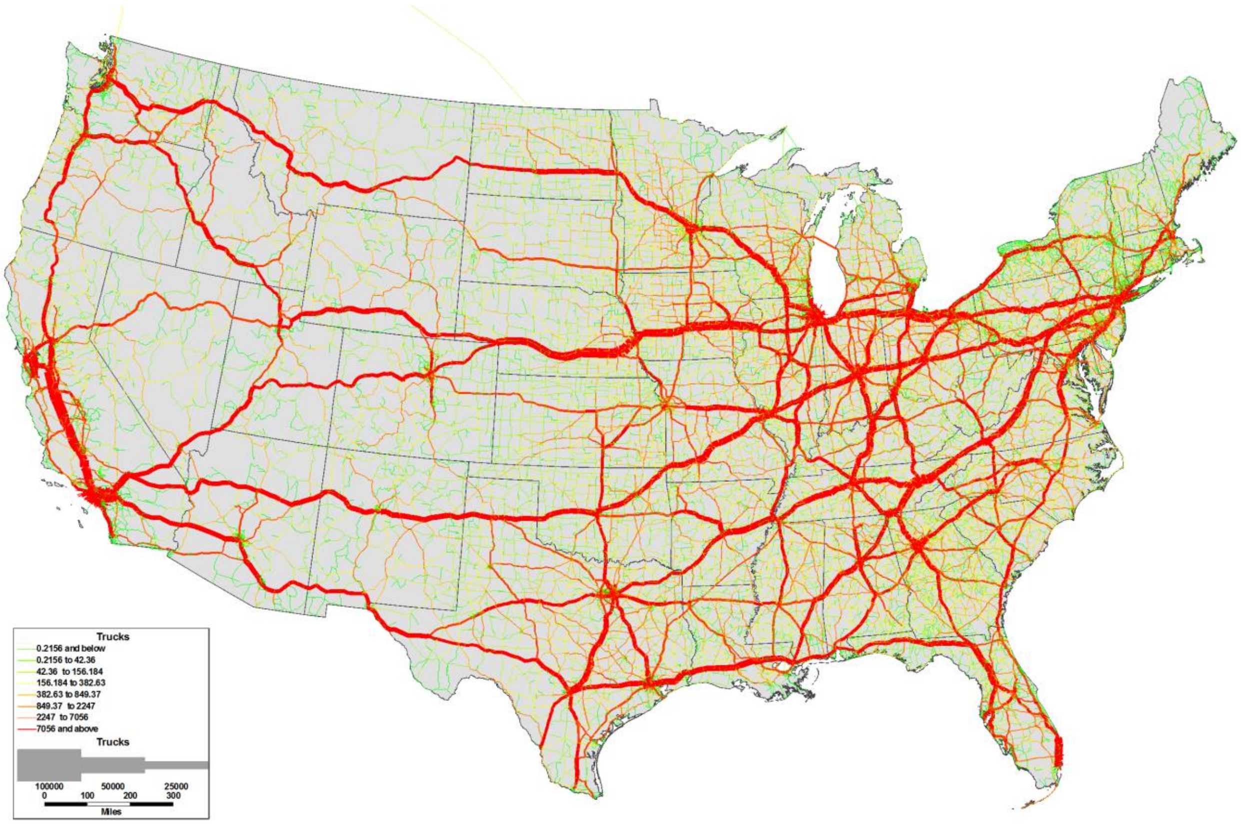

Figure 6: US-wide assignment of truck flows

This assignment step is not needed for the model flow of the SANDAG External Truck Model. This assignment was only done to validate the model and make reasonability checks. In production mode for SANDAG, this assignment step will be omitted.

2.3 Calibration

The model has been calibrated to match truck count data provided by SANDAG. Truck counts were collected from four datasets: Cordon counts, PEMS counts, Caltrans count and Port counts. Only count data at external stations were considered, as those were considered to be long-distance flows that are included in the FAF data. Counts within San Diego County were dropped from the calibration, as those counts cover both short- and long-distance trucks. *Figure **7*** shows the national network is dark blue and the SANDAG network in a lighter blue. SANDAG external stations are marked with red circles and labeled with external zone numbers. Some external stations, such as 11 or 5, are not included in the national network, and therefore, cannot receive any truck traffic. They have been excluded from the calibration and validation process. Count data were available for those external stations that were named in black in *Figure **7***; no count data were available for external stations with a grey name in *Figure **7***.

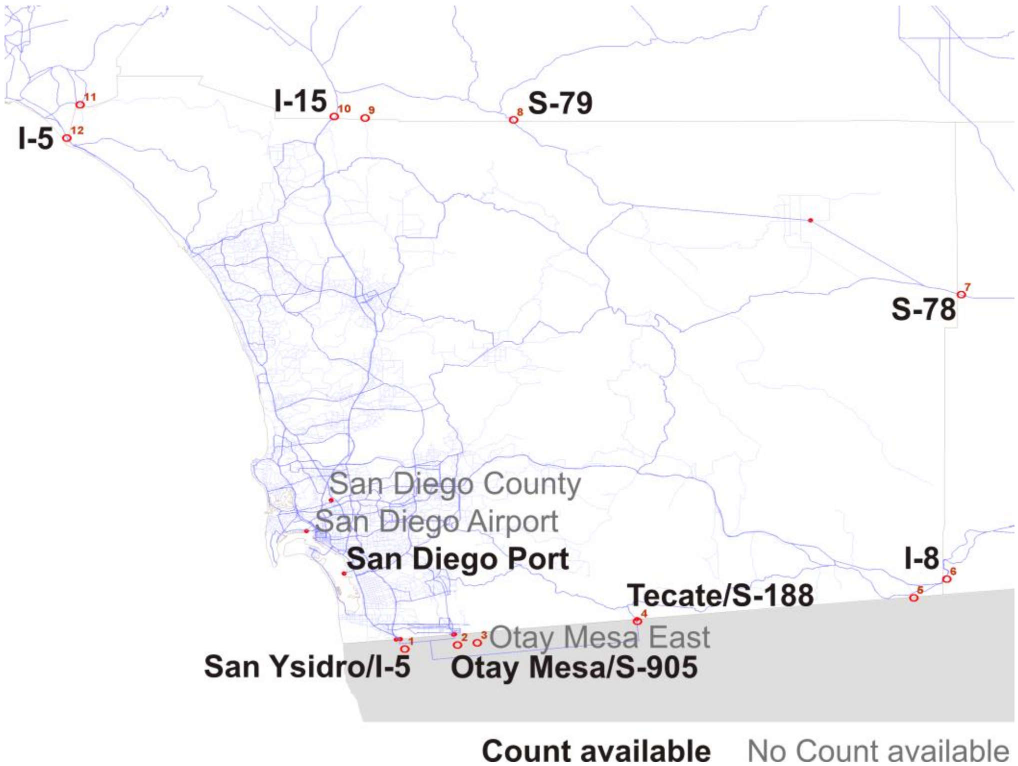

Figure 7: External stations with and without count data

During initial calibration efforts state routes 78 and 79, in the northeast corner of San Diego County, were not attracting truck trips. Trucks are assigned to the network using the shortest travel times. These two state routes did not have the shortest travel times between any of the surrounding centroids to the San Diego County centroid thus no truck trips were being assigned to them. In an effort to disperse truck trips appropriately within the county, San Diego County was split into two counties, internally called San Diego County and San Diego Phantom County.

To split the county, a new centroid was added to the network and the county employment was split based on the percent share of employment in the SANDAG TAZ data. Based on the truck counts on SR78 and SR79, the phantom county needs to produce and/or attract approximately 900 truck trips. These 900 trips amount to about 4.2% of the total truck trips entering the study area. The TAZ employment density, shown in *Figure **8***, was mapped to help with TAZ selection and to minimizing the effects on the remaining roadways.

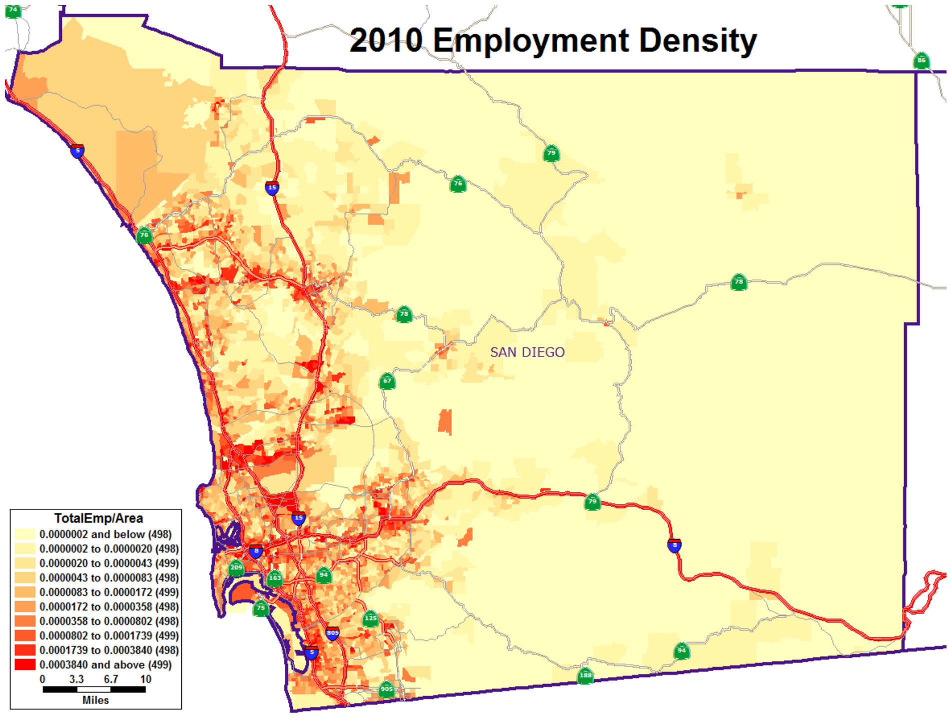

Figure 8: 2010 TAZ Employment Density

Ultimately, the phantom county, shown in Figure 9, has 127 TAZs which comprise approximately 4.4% of the total employment. *Table **7*** shows the percent employment that was applied to the county employment.

Table 7: Percent Employment Share

County	FIPS	Employment	Share
San Diego County	6073	1,339,116	95.58%
San Diego Phantom County	6074	61,989	4.42%
Total Employment		1,401,105	100.00%

Without any other calibration measures, splitting the county yielded 3.6% of the total truck trips traveling on SR78 and SR79 while only minimally affected other roadways

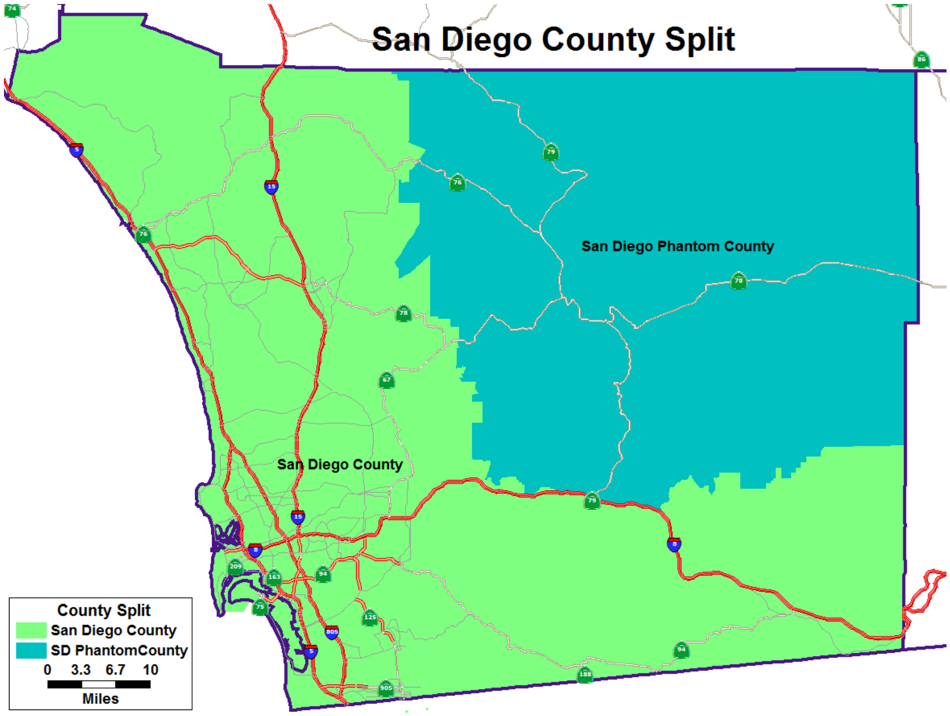

Figure 9: San Diego County Split

Figure ***10*** shows the validation results after over 30 rounds of calibration. Blue bars show model volumes, and green bars show count volumes. For one station (I-15), counts from two sources were available. Most external stations are closely matched. I-8 is slightly too high, while S-78 is too low. Given the coarseness of the zone system (counties) and the network, true origins and destinations could not be represented exactly. Hence, some deviations of flows crossing the eastern border of San Diego County were unavoidable.

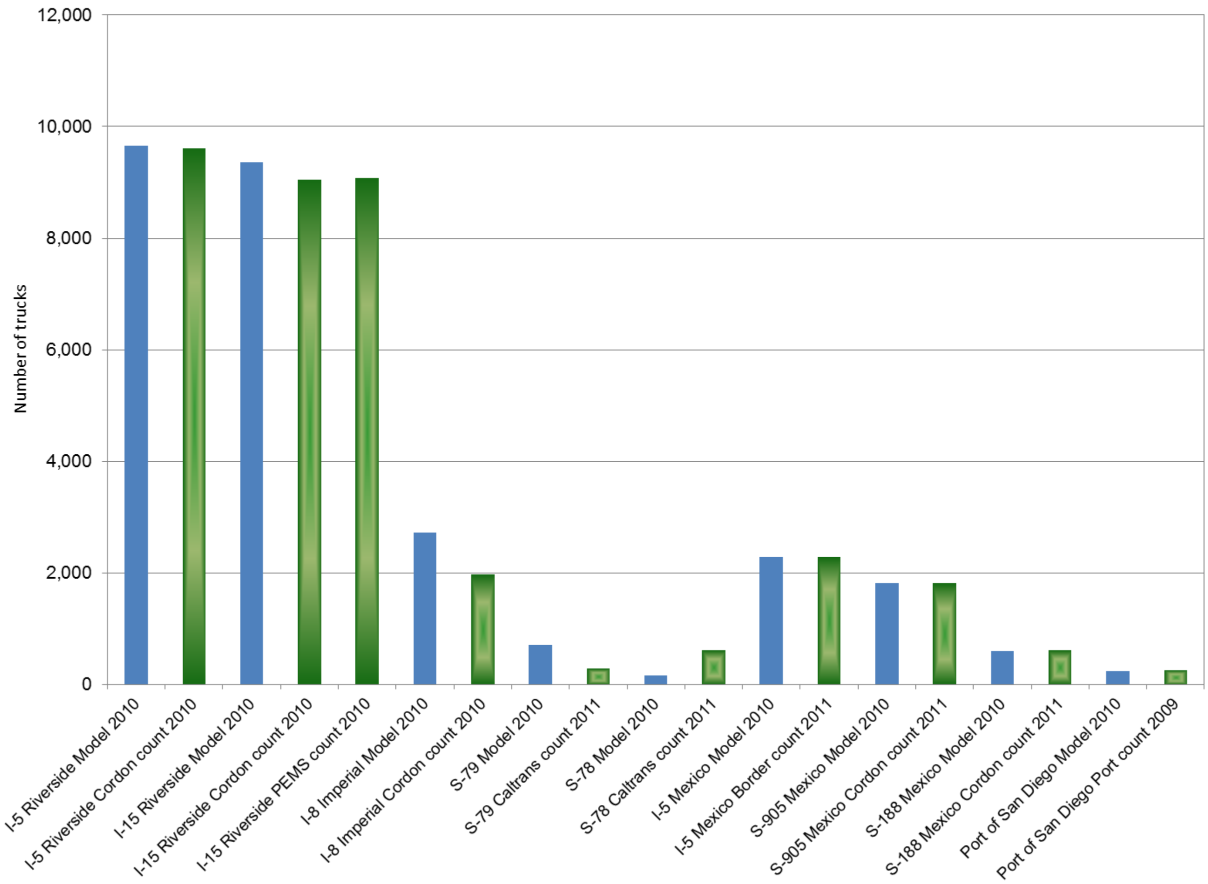

Figure 10: Validation of external stations

3 Subarea Analysis for San Diego County

A subarea analysis was implemented to extract truck flows traveling into, out of or through San Diego County. A TransCAD GISDK script was written that is organized in five steps:

1. Macro "createTripTable": Read in truck trip table from National Truck Model (described in section 2) in comma-separated values (csv) format.
2. Macro "createMatrixIndex": Reference zone index of the National Truck Model, which are county FIPS codes, to node IDs on the national network.
3. Macro "assignFlows": Conduct a subarea analysis for San Diego County. 14 vehicle types are assigned (six commodity groups plus empty trucks for single-unit and multi-unit trucks). Single-unit trucks are assigned with a Passenger-Car Equivalent (PCE) factor of 1.5, and for multi-unit trucks this value is 2.2. A User Equilibrium assignment is used. Alpha was set to 0.2 and beta to 4 in the volume-delay function. The assignment iterates until a relative gap of 0.0001 or below or a maximum number of 50 iterations (whichever comes first) has been reached. In the base case, equilibrium is reached after 31 iterations.
4. Macro "exportSubareaMatrix": The resulting subarea matrix in TransCAD matrix format (*.mtx) is exported to a DBF file.

The subarea analysis runs under an hour on a 12-core computer. The resulting matrix file contains 14 trip matrices with truck trips between external stations and four internal nodes, including external-to-external flows.

4 Disaggregation to San Diego TAZ

Flows provided by the subarea analysis are further disaggregated to SANDAG TAZ. Flows to and from the two internal centroids San Diego County and San Diego Phantom County are disaggregated to 4,988 TAZ. Trip ends at external stations, at the airport and at the marine port are not further disaggregated. Given that the flows are provided by six commodity groups, truck flows can be allocated to zones with employment categories that consume or produce a given commodity group. Empty trucks are allocated to the sum of productions and attractions of all employment types.

Three different types of flow are distinguished.

1. External-to-external trucks: Flows are preserved, and external stations of the national network are translated into SANDAG external zones. External stations include the airport and the marine port.
2. Internal-to-internal trucks: Flows are ignored, as FAF is known to underrepresent short-distance flows. Such internal flows will be provided by the SANDAG local truck model.
3. Internal-to-externals and external-to-internal flows: The external trip end is translated from external stations of the national network to SANDAG external zones. The internal trip end is disaggregated to TAZ.

Figure 11 shows the external stations of the national network (in red) in reference to SANDAG external TAZ (in blue). External stations 3, 5, 9 and 11 are not included in the national network, and therefore, do not receive any truck traffic.

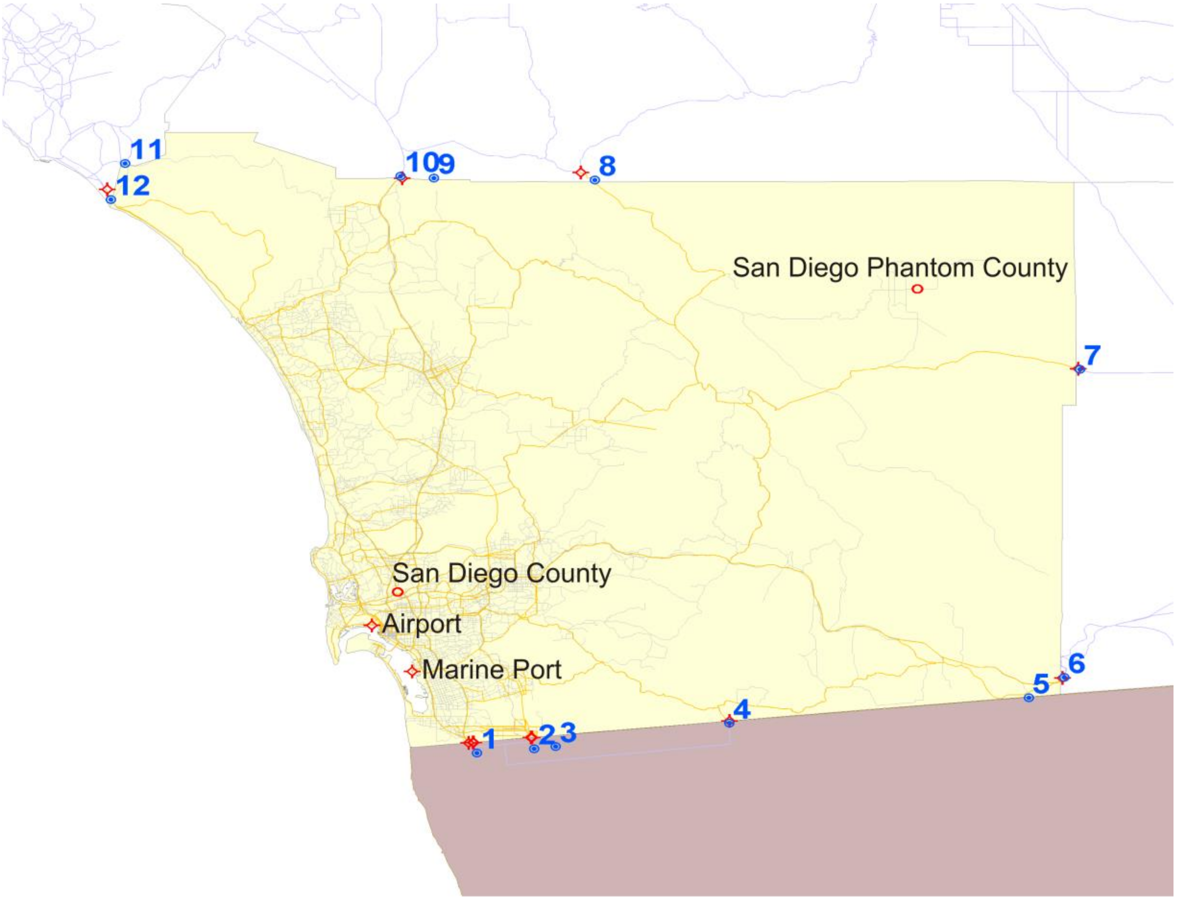

Figure 11: Translation of external stations from national network to SANDAG TAZ

Table 8 contains the complete list of external stations. The I-5/San Ysidro border with Mexico has three external stations in the national network, but only one in the SANDAG zone system. Flows through this border entrance are summed up into SANDAG external zone 1.

Table 8: List of external stations

External Station	Name	SANDAG External Station	Border Station
421169	I-5 South	1	Yes
421177	San Ysidro	1	Yes
421057	unknown	1	Yes
422216	Otay (S-905)	2	Yes
422232	Otay East (S-905)	3	Yes
446270	Tecate (S-188)	4	Yes
455692	I-8 East	6	No
455836	S-78 East	7	No
449048	S-79 North	8	No
442866	I-15 North	10	No
404214	I-5 North	12	No

For disaggregation to SANDAG TAZ, equations 1, 2a and 2b are used accordingly. Make/Use coefficients shown in Table 1 and Table 2 are aggregated based on the commodity group definition shown in Table 5. SANDAG employment categories were associated to the twelve employment categories at the national level. The commodity aggregation is calculated endogenously, allowing the user to change the allocation of SCTG commodities to commodity groups.

The output of this disaggregation step is a trip table for external truck trips between TAZ and external stations by two truck types (single-unit and multi-unit) and six commodity groups plus empty trucks, adding up to 14 vehicle types (Table 9).

Table 9: Descriptions of fields in output truck trip table

Field	Description	
orig	Origin TAZ or external station	
dest	Destination TAZ or external station	
sutEmpty	Single-unit trucks	Empty trucks
sut1		Commodity Group 1
sut2		Commodity Group 2
sut3		Commodity Group 3
sut4		Commodity Group 4
sut5		Commodity Group 5
sut6		Commodity Group 6
mutEmpty	Multi-unit trucks	Empty trucks
mut1		Commodity Group 1
mut2		Commodity Group 2
mut3		Commodity Group 3
mut4		Commodity Group 4
mut5		Commodity Group 5
mut6		Commodity Group 6

Finally, trip tables are split by time of day. The only dataset that contains hourly count for 24 hours is the Weigh-In-Motion (WIM) count dataset. Unfortunately, none of the WIM stations was located on or near a SANDAG external station, which is why WIM data were not used in model calibration. Using a WIM station that captures a lot of short-distance truck travel distorts the time-of-day distribution of long-distance trips. While short-distance truck trips have a time-of-day distribution that resembles urban auto traffic (commonly only slightly less pronounced towards the peak hours), long-distance truck trips tend to travel around the clock, with less variation between hours. In lack of better data, time-of-day distributions at WIM station 116210 on I-8 were used. With approximately 27 miles from the border with Imperial County, this WIM stations is further inside the county than desirable but provides the best dataset available.

Border crossings close over night for truck traffic. Therefore, no trucks are simulated as traveling to or from the border crossing at night. Table 10 shows the percent shares applied for splitting daily flows into five time periods.

Table 10: Time-of-day shares for border and non-border truck flows

				Share non-border traffic		Share border traffic	
Period	**Description**	**Begin time**	**End time**	**SUT**	**MUT**	**SUT**	**MUT**
1	Early	3:00 A.M.	5:59 A.M.	5.8%	10.1%		
2	A.M. Peak	6:00 A.M.	8:59 A.M.	15.1%	14.3%	18.7%	20.9%
3	Midday	9:00 A.M.	3:29 P.M.	45.3%	37.8%	56.1%	55.0%
4	P.M. Peak	3:30 P.M.	6:59 P.M.	20.4%	16.5%	25.2%	24.1%
5	Evening	7:00 P.M.	2:59 A.M.	13.4%	21.3%		
				100.0%	100.0%	100.0%	100.0%

Whenever a flow includes a border crossing, the night periods are set to zero and flows are split between periods 2, 3 and 4. All other flows are split across the five time periods. The resulting trip table aggregates the six commodity groups and empty trucks to two truck types (single-unit trucks and multi-unit trucks) by five time periods.

5 Users Guide

The User's Guide provides instructions to setup the model on a PC and to implement future year model runs.

5.1 Model setup

The model requires two pieces of software to be installed. First, Java Version 7 needs to be installed. Java can be downloaded free of charge[9]. Secondly, TransCAD needs to be installed. The model has been tested with TransCAD Version 5.

The provided directory sandag_truckModel can be stored anywhere on a PC. The directory structure is shown in Figure 12. Two subdirectories called <step1_step3> and <step2> structure the files, with the former used to execute the disaggregation from FAF zones to counties (compare section 2) and from counties to TAZ (compare section 4) and the latter being used for the subarea analysis (compare section 3). Steps 1 and 3 use Java, while step 2 is run in TransCAD.

[9] http://www.java.com/en/download/manual.jsp

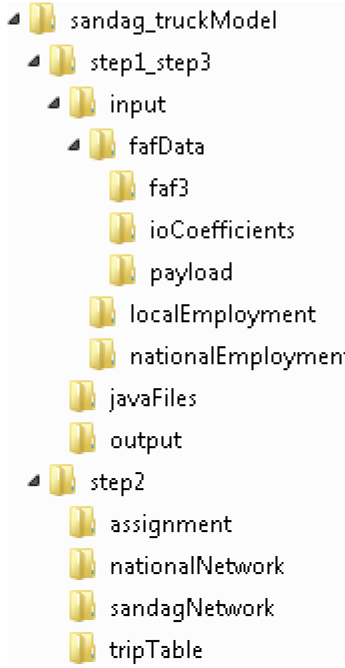

Figure 12: Directory structure of the SANDAG Truck Model

The subdirectory <step1_step3> contains two batch files that facilitate running the model from a command prompt line. There batch files link to the java installation by setting the PATH, and this PATH needs to be updated if the model is moved to another computer or if the Java installation is replaced with a different one.

The batch file <runExternalTruckModel2010_step1.bat> has the following commands:

```
set PATH=C:\Program Files\Java\jdk1.7.0_01\bin
set CLASSPATH=javaFiles;javaFiles\sandag_tm.jar

java -Xmx6000m -Djava.util.logging.config.file=log4j.xml
com.pb.sandag_tm.sandag_tm javaFiles\sandag_tm.properties
counties 2010
```

In this file, the first row pointing to the Java installation needs to be updated whenever the program is installed on a new computer. The PATH needs to point to the /bin/ directory in the Java installation. The second batch file called <runExternalTruckModel2010_step3.bat> looks similar and has the following commands:

```
set PATH=C:\Program Files\Java\jdk1.7.0_01\bin
set CLASSPATH=javaFiles;javaFiles\sandag_tm.jar

java -Xmx6000m -Djava.util.logging.config.file=log4j.xml
com.pb.sandag_tm.sandag_tm javaFiles\sandag_tm.properties zones
2010
```

Likewise, the first row pointing to the Java installation directory needs to be updated whenever the model is moved to a different computer.

5.2 Running the model

The provided model setup has been prepared to generate truck trips for the year 2010. The batch files make running the model easy. Once Java and TransCAD are installed and the first line in each batch file has been revised, the model is run in three simple steps.

1. To disaggregate from FAF zones to counties (compare section 2), open a command prompt window, navigate to the directory \sandag_truckModel\step1_step3\ and start the model by calling the first batch file called <runExternalTruckModel2010_step1.bat>. Wait until this model run has finished, which takes approximately 10 minutes on a 12-core computer.
2. To run the subarea analysis (compare section 3) open TransCAD and compile the GISDK macro called \sandag_truckModel\step2\runExternalTruckModel2010_step2.rsc. Run this script in TransCAD by calling the macro truckModel. This run completes in approximately 45 min on a 12-core computer.
3. To disaggregate from counties and external stations to TAZ and external stations (compare section 4), open a command prompt window, navigate to the directory \sandag_truckModel\step1_step3\ and run this step by calling the other batch file called <runExternalTruckModel2010_step3.bat>. The model will complete in less than one minute on a 12-core computer.

The output file can be found in the directory \sandag_truckModel\step1_step3\output\ and is called <zoneToExternalStationTripTable_2010.csv>. The layout of this output file is shown in Table 11. The first two columns specify the origin and destination zone in SANDAG TAZ IDs. Columns 3 through 7 show the number of single-unit trucks (SUT) by the five time periods, and columns 8 through 12 show the number of multi-unit trucks (MUT) by the five time periods.

Table 11: Structure of the output file zoneToExternalStationTripTable_2010.csv

orig	dest	SUT Early	SUT A.M. Peak	SUT Midday	SUT P.M. Peak	SUT Evening	MUT Early	MUT A.M. Peak	MUT Midday	MUT P.M. Peak	MUT Evening
8	3139	7.28E-05	1.89E-04	5.67E-04	2.55E-04	1.68E-04	3.67E-05	5.20E-05	1.37E-04	5.99E-05	7.72E-05
8	3135	6.38E-04	0.001654	0.004971	0.002235	0.001471	3.26E-04	4.62E-04	0.001216	5.32E-04	6.86E-04
8	3136	4.73E-04	0.001226	0.003684	0.001656	0.00109	2.50E-04	3.54E-04	9.33E-04	4.08E-04	5.26E-04
…											

This file can be imported into a TransCAD matrix and added to the multi-class assignment of the SANDAG travel demand model.

5.3 Running future years

The model is prepared to run scenarios for the years 2007 to 2040, which are the years provided by the FAF dataset. While FAF provides data points in five-year increments only, the model is built to linearly interpolate between years provided by FAF. While the FAF-based model is prepared to run future years, a few files need to be updated. These files are listed below.

\sandag_truckModel\step1_step3\runExternalTruckModel2010_step1.bat: This file specifies the year for which FAF data shall be extracted. Open this file and change the year in the fourth line (last four characters in this file).

Optional update: \sandag_truckModel_test1\step1_step3\input\nationalEmployment\: The national county-level employment data has been provided for the years 2007 (Agriculture) and 2010 (all other industries). These data are only used to proportionally allocate FAF flows. Should future county-level employment data become available, these files may be updated. However, the absolute growth in every FAF zone is given by FAF data, and only the allocation to counties within each FAF zones is effected by these employment data. In most cases, updating the county employment data will affect truck flows only marginally.

\sandag_truckModel_test1\step2\runExternalTruckModel2010_step2.rsc: In line 4 of this TransCAD GISDK script, the year is specified by <year = "2010">. This line needs to be updated for future year model runs, and the script needs to be recompiled in TransCAD.

\sandag_truckModel\step1_step3\runExternalTruckModel2010_step3.bat: This file specifies the year for which trucks are disaggregated to TAZ. Open this file and change the year in the fourth line (last four characters in this file).

\sandag_truckModel_test1\step1_step3\input\localEmployment\employment_mke_2010.csv: The local TAZ employment data need to be updated to the year of interest. The new employment file needs to be named <employment_mke_YYYY.csv>, where YYYY has to be the four digit year to be modeled. The model will find the correct employment files using the year that has been specified in runExternalTruckModel2010_step3.bat.