

## **Simulation of intrazonal traffic flows: The end of lost trips**

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**Abstract:** Commonly, intrazonal trips are disregarded in transportation modeling. This is acceptable if the zone size is small, and thus the number of intrazonal trips is close to 0. In regional models with larger zones, however, ignoring intrazonal trips may significantly underestimate congestion. This paper describes a method to assign intrazonal truck trips to the U.S. highway network. Origin and destination zones are counties that contain a noteworthy share of intrazonal truck trips. Employment is assumed to be a close proxy for truck trip generation. The employment of every county is interpolated to 2.5 million raster cells of one square mile covering the lower 48 States of the U.S. This contiguous surface of employment density is used to assign intrazonal truck flows to the highway network within every county. This assures that urban areas get the congestion due to local traffic as found in reality. Consequently, long-distance truck paths avoid congested urban areas, resulting in more realistic travel time and distance.

**Keyword:** Truck simulation, freight modeling, intrazonal trips

### **1. INTRODUCTION**

Travel models simulate trips from an origin zone to a destination zone. The assignment of trips from one zone to another works well as long as the origin and destination are in different zones. A trip within one zone is lost, as travel models commonly are unable to handle spatial detail below the zonal level. Most models solve this shortcoming by defining zones with a small size. The smaller the zone size, the smaller the number of trips with origin and destination in the same zone. Simulation time, however, tends to grow exponentially with number of zones. In particular for regional models, the number of zones that can be handled within reasonable run times is a relevant constraint.

A truck model was developed for the lower 48 States of the U.S. The Freight Analysis Framework 2 (FAF2), published by the Federal Highway Administration (FHWA), provides estimates of commodity flows by mode of transport between 130 FAF regions within the U.S. To increase the spatial resolution, flows were further disaggregated to flows between the 3,241 counties in the U.S. Average payload factors by commodity were used to transform goods flows from tons into truck trips. Assignment of flows from counties to counties produces an overall reasonable distribution of truck trips. However, about 1.5 million daily truck trips with origin and destination in the same FAF region are lost in a traditional travel model assignment. Consequently, the level of congestion in urban areas is underestimated. Lacking the congestion attributable to local truck trips, most long-distance truck paths are

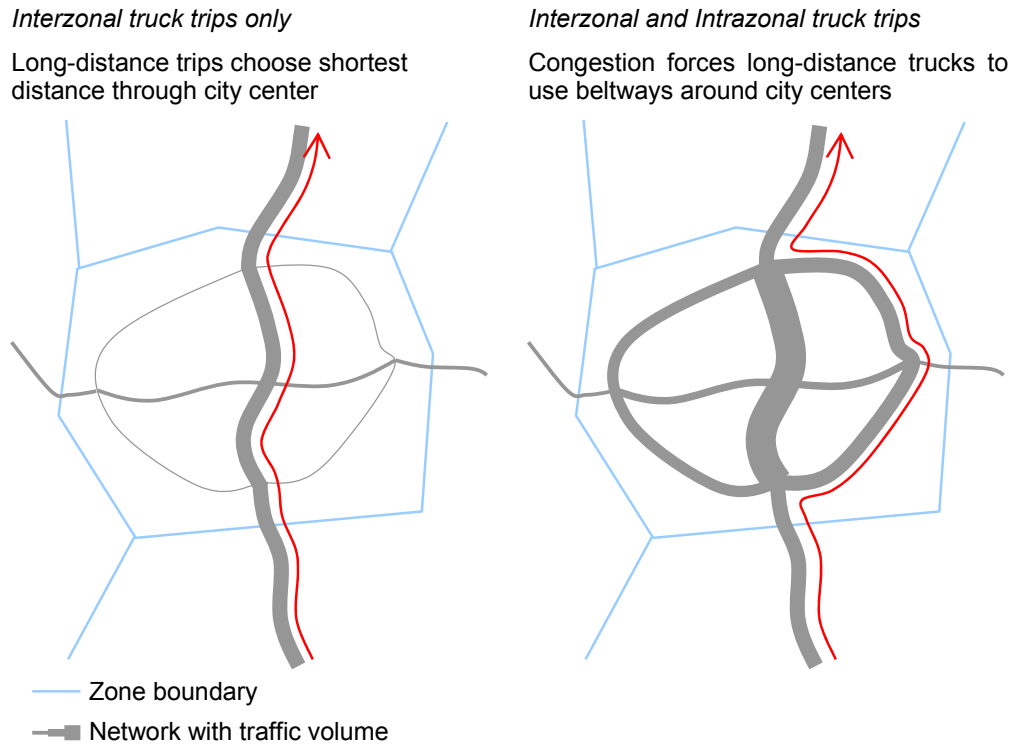


Figure 1 Change of travel flows by adding intrazonal truck trips

assigned right through the cities, rather than avoiding urban centers and using beltways (Figure 1). To generate real-world congestion in urban areas, intrazonal truck trips need to be incorporated.

So far, the only modeling procedure that is able to fully represent intrazonal flows is microsimulation. In a full microsimulation, flows may be generated and assigned from an origin premise to a destination premise. In other words, the microsimulation is able to treat every origin and every destination as a separate zone, eliminating the problem of intrazonal truck trips. Unfortunately, building a large-scale microsimulation freight model is complex, and only a few applications have been implemented successfully so far (Donnelly, 2007; Hunt and Stefan, 2007). Even though these two tour-based microscopic models handle the larger regions of State of Oregon and City of Calgary, no comparable microsimulation has proven to be feasible as the national level.

This paper develops a method that is significantly less complex than a microsimulation but still allows assigning inter- and intrazonal flows over the entire U.S. Using employment density, intrazonal truck trips are assigned to the network. Congestion levels generated in urban centers are simulated more realistically than in models ignoring intrazonal trips.

## 2. MODEL OVERVIEW

The truck model is based on freight flows given by the Freight Analysis Framework, Version 2 (FAF2), published by the Federal Highway Administration (2002). The FAF2 provides annual freight flows in tons and dollar value between 130 FAF regions all over the U.S. for the year 2002, as well as forecasts from 2010 to 2035 in

five years increments. Seven modes of transport are distinguished. Goods are classified as one of 43 commodities. Based on commodity-specific payload factors (Battelle 2002: 29), these flows are transformed from tons into annual truck trips of four truck types. Average shares of these four different truck sizes were derived from census data (U.S. Department of Commerce 2004: 43). Furthermore, an average empty backhaul rate of 19.4 percent of all truck miles traveled (estimated based on U.S. Census Bureau 2008: 14) was added to all truck flows.

The FAF data contains flows between 130 FAF regions within the U.S., of which many cover an entire state (such as Maine, Mississippi or Montana). Flows from and to these states would appear as if everything was produced and consumed in one location in the state's center (or the polygon's centroid). To distribute flows over the entire state, employment was used to disaggregate flows to the county level. Figure 2 shows FAF zones and counties for the Southwest U.S. A very few FAF zones, such as San Diego (California) or Tucson (Arizona) correspond to individual counties. Most FAF zones, however, contain a larger number of counties to which truck flows are disaggregated. This disaggregation is based on total employment within each county. Counties with a larger number of employees are assumed to generate and attract more truck trips. Thus, truck flows are disaggregated proportionally to employment.

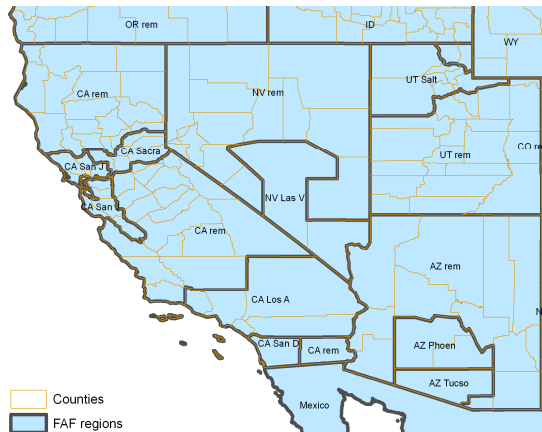


Figure 2 FAF regions and counties

The FAF provides annual flow data. Within the model, an average weekday is simulated, thus the annual flows need to be transformed to annual average weekday traffic (AAWDT). Simply dividing the flows by 365.25 days per year would underestimate the average weekday flow, as truck volumes tend to be higher on a weekday than on a weekend. Virginia DOT (2007) provides detailed traffic counts including average day and average weekday counts. Analyzing five selected counties that shall resemble an average density in the U.S. (Fairfax, Lee, Prince George, Stafford and Washington County) resulted in AAWDT that is 4.8477 percent higher than the AADT (annual average day traffic) counts. Thus, traffic flows calculated from the FAF data are divided by 365.25 days and increased by 4.85 percent to represent an average weekday.

A daily capacity for every highway link had to be estimated. In the absence of true data the capacity was estimated based on the highway class and the number of lanes. While Interstate highways (both Urban Interstate and Rural Interstate) are assumed to have a capacity of 2,400 vehicles per hour per lane (vphpl), all other highways are assumed to have a capacity of 1,700 vphpl. The daily capacity is assumed to be ten times higher than the hourly capacity, as most transportation demand arises during daylight hours. The free-flow speed, which is the average speed a single truck could drive if unimpeded by other vehicles (but including traffic signal delay, speed adjustments due to slope, etc.), is assumed to be 65 miles per hour on Interstate highways and 55 miles per hour on all other highways.

Since trucks are not the only vehicles on the roadways, autos need to be added as a

background volume on the highway network. In rural areas, a Level of Service (LOS) C is assumed, with a corresponding volume-to-capacity (V/C) ratio of 0.6 that is filled by cars. In other words, if the total capacity of a highway link is assumed to be 1,700 vphpl, auto flows equal to 60 percent of this capacity are assumed. In urban areas, highways are assumed to be more congested, and the highway is expected to operate between LOS D and E, such that the background volume of autos corresponds to a V/C ratio of 0.9.

### Assignment of interzonal flows

An assignment of a truck flow from county A to county B requires a point in the origin and destination counties where the trip begins and ends. The geographic centroid of every county was chosen in a first attempt. It turns out that some of these centroids do not well represent the spatial pattern within their counties. The left part of Figure 3 shows the geographic centroid for counties in southern California. San Diego, Riverside and San Bernardino counties, for instance, have their economic center in the western part of the county. Further east these counties become fairly rural and sparsely populated. Placing the centroid in the geographic center underestimates truck flows in the economic center and overestimates them in rural areas. As an alternative, the county centroid was placed in the center of the largest city in every county (right part of Figure 3). In San Diego County, for instance, the largest city is San Diego, representing the economic center of the county much better than the geographic center.

Figure 5 shows the flows assigned to the entire highway network of the lower 48 States of the U.S. The map shows the main truck flows between Los Angeles and the Bay Area on the West Coast and between major cities east of the Mississippi River, such as Chicago, New York, Dallas/Fort Worth and Atlanta.

Truck volumes have been validated for the Atlanta (Georgia) and San Diego (California) metropolitan areas. These two cases allow the analysis of model performance in two very different areas and under different environments. Figure 4 shows how well the model is matching truck counts in these two regions. A major difficulty in validating truck trips is the limited availability of truck count data. Often, only daily truck counts are available. Such counts include biases due to traffic accidents, special sports events, construction sites, or other deviations on this particular day. The model aims at simulating an annual average weekday. The comparison of one-day counts and model results gives only limited information about model performance. The left diagram in Figure 4 shows a fairly good match for the Atlanta region, with some locations over and others underestimating truck volumes.

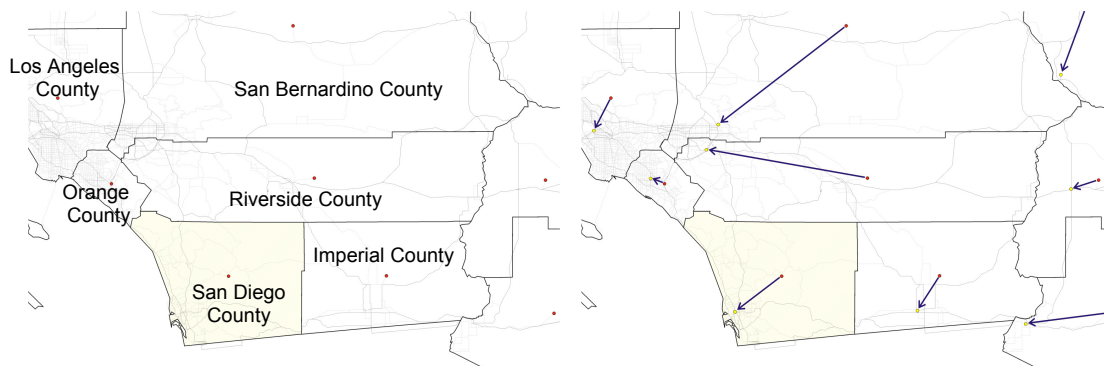


Figure 3 County centroids for regional assignment

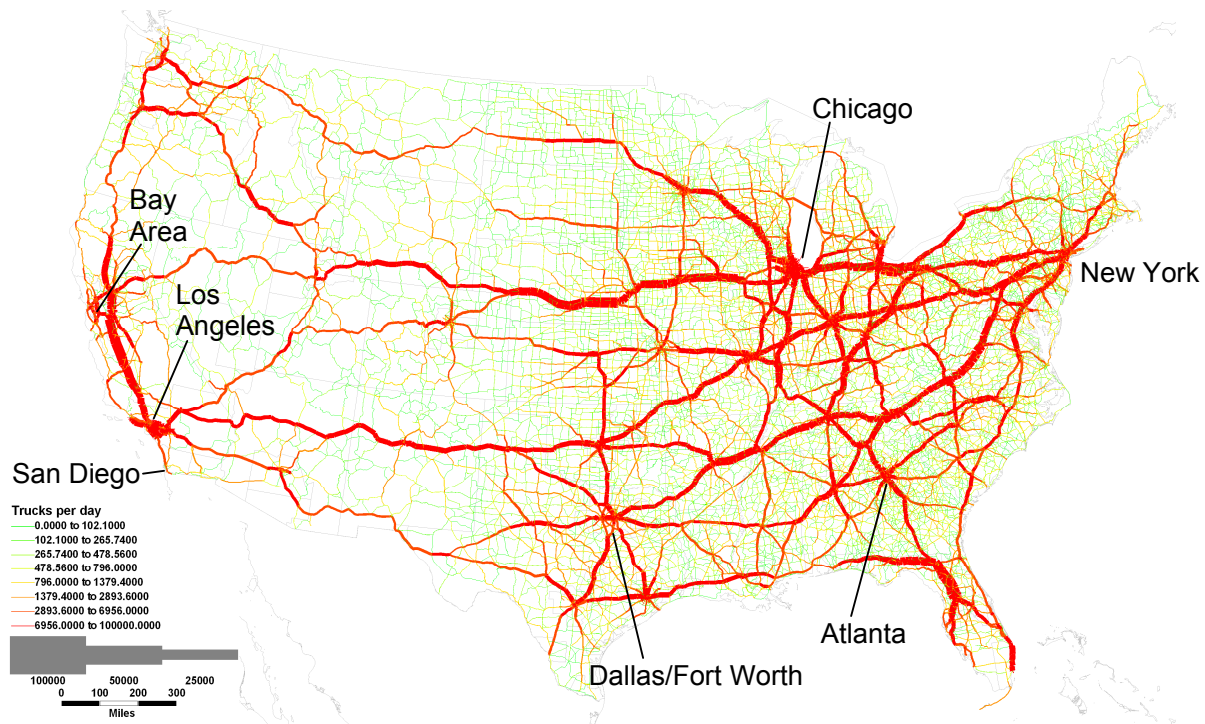


Figure 5 Truck trips in 2002 assigned to the U.S. highway network

As these counts were a one-day count, the match between count data and model results is believed to be sufficient. The right diagram in Figure 4 compares simulated volumes with truck counts in San Diego County. These counts are highly reliable as they are an average value from daily counts (retrieved from Weigh-In-Motion stations). Unfortunately, the counts define trucks by number of axles, while the model defines trucks by weight. This different truck definition probably explains most of the deviations.

Overall, the simulated volumes seem to resemble observed intercity truck flows well. However, flows in most densely populated areas are underestimated. Though this seems to be irrelevant from a regional standpoint, not depicting congestion in urban centers results in unrealistic routing of long-distance trucks through urban centers. As an example, Figure 6 shows the assignment of truck flows to the Atlanta region. The major highways going through the region (I20, I75 and I85) result in assignments of high traffic volumes through the city center. In contrast, the beltway

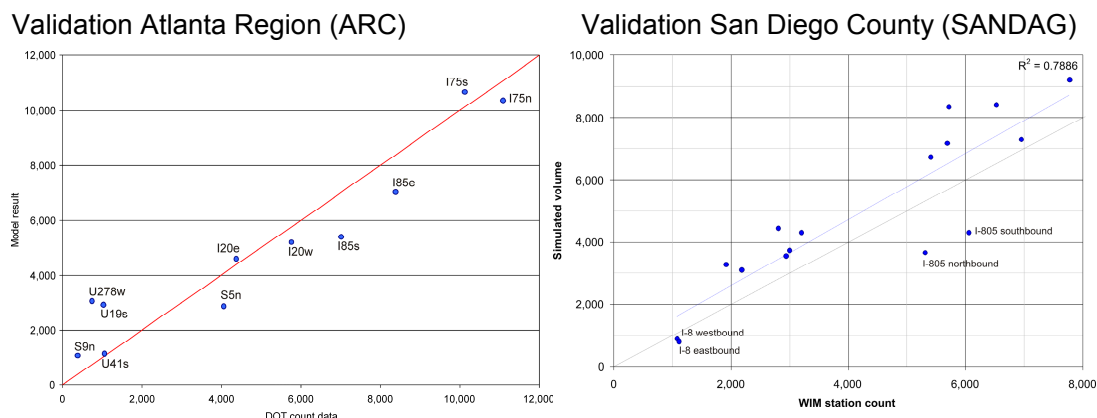


Figure 4 Validation of truck flows in the regions of Atlanta and San Diego

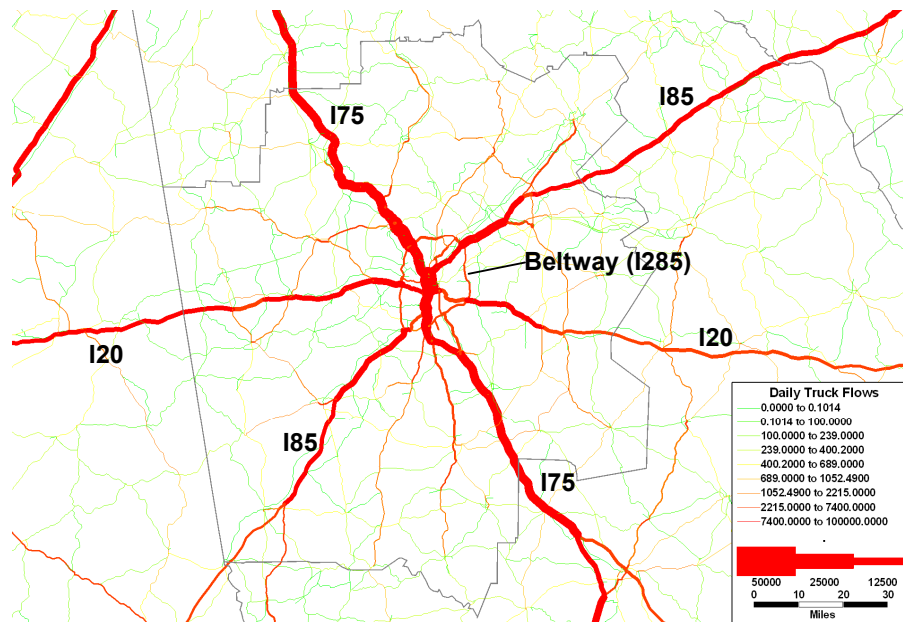


Figure 6 Assignment detail in the Atlanta region

(I-285) appears to be almost free of truck traffic. The traffic volumes on the highways outside of Atlanta match the traffic counts, but the volumes on the beltway are substantially too low. The model allocates too many trucks to routes through the center rather than choosing routes on the beltway that avoids congestion in downtown Atlanta. The dark line shows the boundary of the FAF zone for Atlanta. According to the FAF data, 32,900 intrazonal truck trips are generated within this FAF zone, but as intrazonal trips they are not assigned to the network. If these trips were added to the network congestion would be much higher (and more realistic), forcing through trips to use the beltway instead.

### 3. INTRAZONAL TRUCK FLOWS

Section 2 described the model in its first implementation. Overall, truck volumes match fairly closely with truck counts, but urban centers still portray too little congestion. A flow from Atlanta to Atlanta cannot be assigned to the network, since origin and destination are the same centroid. By developing a procedure to add intrazonal truck trips to the network, congestion levels in urban agglomerations are expected to become closer to observed volumes.

One possibility to limit the loss of intrazonal truck trips would be to reduce the size of the zones. The smaller the zone size, the smaller the number of trips that have both origin and destination in the same zone. However, working with a truck model at the national level prohibits increasing the number of zones too much. Every additional zone increases the run time of the model, and it becomes cumbersome and error-prone to collect the right employment data for every added zone below the county level.

Alternatively, an interpolation procedure was developed to account for intrazonal truck trips. The left side of Figure 7 shows the method to create truck trips between counties as described in section 2, and the right part summarizes the procedure to generate intrazonal truck trips.



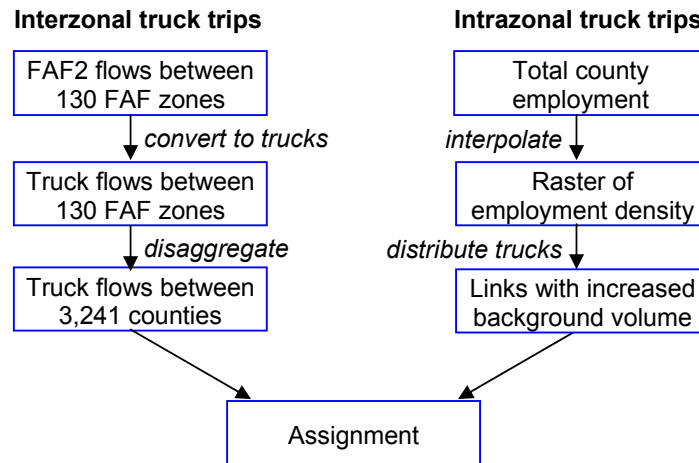


Figure 7 Model concept

The area of the United States was rasterized to 2.5 million raster cells of 1 mile by 1 mile. The county employment density is interpolated between these raster cells using Inverse Distance Weighting (IDW). This raster of employment density is used as surrogate for activity density or likelihood to generate truck trips. Figure 8 shows county employment densities that were interpolated for the Atlanta region. The city center as well as subcenters can be identified in these square-mile raster cells. These employment densities are an indicator where intrazonal truck trips are most likely to occur.

In a first approach, intrazonal truck trips within every county were allocated to the network. It turned out, however, that the highway network had a different density in every county, leading to unexpected changes in intrazonal truck trip density from one county to the next one. To reduce this boundary effect, intrazonal truck trips within every FAF region were allocated to the highway network. This effect does still exist, but 130 FAF zones have fewer miles of boundaries than 3,241 counties. Therefore, intrazonal freight flows were allocated to the highway network at the FAF zone level, while interzonal freight flows were disaggregated from FAF zones to counties.

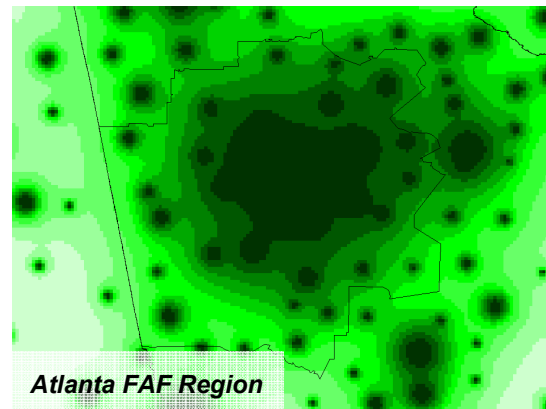


Figure 8 Interpolated employment

The estimation the correct number of intrazonal truck trips proved to be noteworthy difficulty. While the FAF2 forecast are believed to be fairly reliable for long distance trips, it is broadly acknowledged that FAF2 underestimates short distance trips. No data set was available that could provide the correct number of intrazonal truck trips in every FAF zone. To obtain a point of comparison, the number of local truck trips simulated in three different projects was used as a reference point. Table 1 shows the number of intrazonal truck trips of six FAF zones in different parts of the U.S. The intrazonal volumes derived from the FAF data are contrasted with the number of intrazonal truck trips simulated in the three simulation models for San Diego County, the Los Angeles region and the Maryland region. Obviously, the results of the models are simulated numbers and, therefore, only an estimate of truck volumes.

Nevertheless, the models allow an independent comparison with the FAF2 data.

Consistently, the intrazonal truck volumes in all three models are much higher than the intrazonal truck trips that were estimated based FAF2 data. For lack of other independent data, intrazonal truck trips based on FAF2 data are multiplied by ten in this study. Obviously, this is a crude adjustment that is based on very limited comprehension of intrazonal truck traffic. Until more reliable data on intrazonal truck trips become available, ten-fold inflated FAF2 data are used as a placeholder.

Table 1: Intrazonal truck volume comparison

Region	Daily Intrazonal Truck Volume		Factor
	FAF2 data	SANDAG Model <sup>1</sup>	
CA San Diego	14,114	137,379	9.7

Region	Daily Intrazonal Truck Volume		Factor
	FAF2 data	SCAG Model <sup>2</sup>	
CA Los Angeles	83,417	861,784	10.3

Region	Daily Intrazonal Truck Volume		Factor
	FAF2 data	MStM Model <sup>3</sup>	
Delaware	5,808	67,142	11.6
Washington DC	286	58,336	203.8
Baltimore	15,357	220,084	14.3
VA DC area	8,103	169,068	20.9

The number of intrazonal truck trips has to be translated into actual miles driven. Obviously, in a smaller zone such as Atlanta, the average intrazonal truck trip has a shorter distance than in a very large zone, such as the FAF zone of the State of Montana. In lack of observed data, it is assumed that intrazonal trucks travel on average half the average diameter of a zone. This distance is calculated based on the total area of a given zone:

$$d_i = \sqrt{a_i / \pi}$$

Equation 1

$d_i$  average distance of intrazonal truck trips in zone  $i$   
 $a_i$  area of zone  $i$   
 $\pi$  Pi = 3.14159

The actual number of miles that need to be assigned to the network is calculated by:

$$t_i = FAF_i \cdot d_i \cdot \delta$$

Equation 2

$t_i$  intrazonal traveled truck miles in zone  $i$   
 $FAF_i$  Number of intrazonal truck trips based on FAF2 data  
 $d_i$  average distance (as calculated in Equation 1)  
 $\delta$  correction factor (currently set to 10)

The estimated intrazonal traveled truck miles are allocated to the highway network within the corresponding FAF zone. Every highway link is associated with the

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<sup>1</sup>: San Diego Truck Model, <sup>2</sup>: Southern Assoc. of Governments Truck Model <sup>3</sup>: Maryland Statewide Model



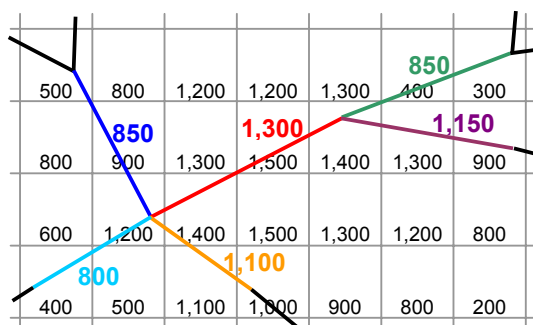


Figure 9: Weight assignment for links

employment density of its location. If the start node and the end node of a highway link are located in different FAF zones, the link is ignored since this link cannot carry intrazonal flows. For all other links, the raster cell of the start node and the raster cell of the end node are identified and the average employment density of the two raster cells is assigned to the link. In the example of Figure 9, the small numbers show employment densities of raster cells, and the colored numbers show the densities assigned to every link. This is the

weight the link receives as likelihood to carry intrazonal truck trips. Finally, all intrazonal truck trips within one FAF zone are distributed over all links in that county in proportion to the respective employment density.

As a result, no intrazonal truck trip is lost. Every intrazonal trip is allocated on an intrazonal link. Figure 10 shows intrazonal truck volumes assigned to the highway network for the Atlanta region. The distribution of trips resembles the employment densities shown in Figure 8. City centers with a higher employment density receive more intrazonal truck trips, and areas with a low activity density receive very few intrazonal truck trips only.

The intrazonal truck trips are put on the network as background volume. They are added to the auto background volume. The subsequent assignment of interzonal truck trips takes this total background volume into account when calculating travel times and flows. Consequently, autos and intrazonal trucks both contribute to the level of congestion, particularly in urban centers.

Figure 11 shows the assignment of regional truck trips after the intrazonal truck trips have been added as background volume to the network. This figure needs to be analyzed in comparison to Figure 6. The Beltway receives much more traffic, since

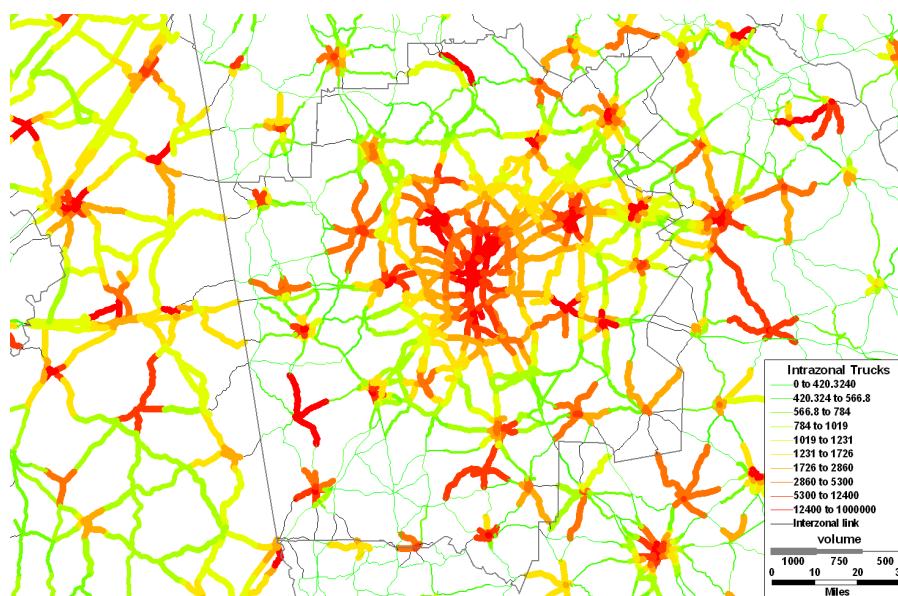


Figure 10: Intrazonal truck trips assigned to the highway network

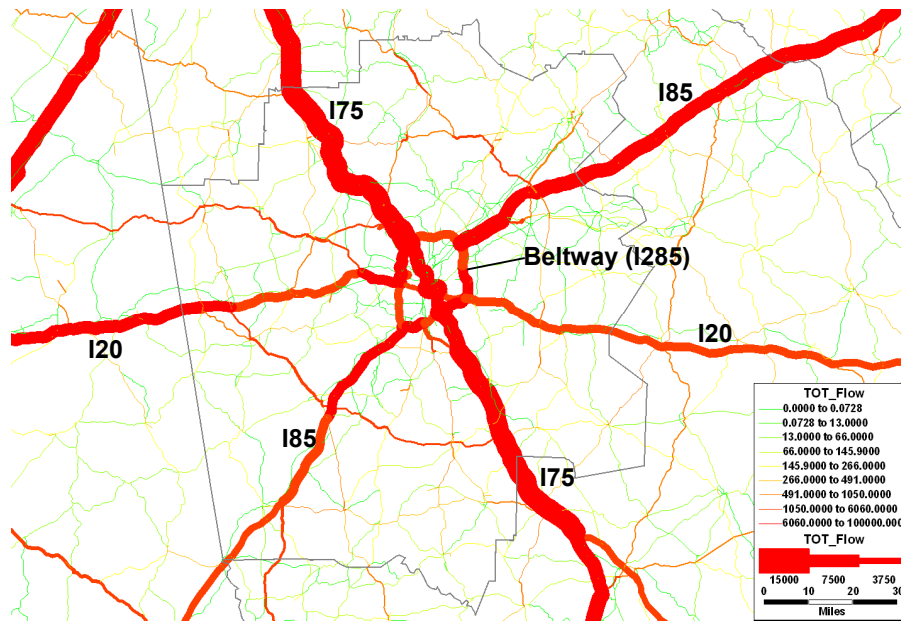


Figure 11: Intra and Interzonal Truck Trips

congestion in Atlanta Downtown diverts long-distance truck trips from the direct route through the city center to the circumferential ring road I 285.

#### 4. CONCLUDING REMARKS

In urban agglomerations, about 6 percent of all vehicles are trucks. On some highway links in more rural areas, the share of trucks may be as high as 50 percent. Including truck trips into a person travel model completes the picture by simulating all vehicle classes endogenously. Many trucks, however, travel over long distances. Capturing these truck trips requires covering a larger study area for truck simulation than for a person travel model. To be able to cover a larger area for truck trips, the zone size in truck simulation has to be fairly large. And with larger zone sizes, the loss of intrazonal truck trips becomes relevant.

The different patterns of personal and freight traffic calls for a multi-layer approach, where the study area and the level of detail is different for every modeling task. Most person trips are within a fairly small distance, which requires a relatively small but detailed study area. Truck trips, in contrast, tend to cover long distances, and naturally the level of detail has to be lower for very large truck study areas. Missing intrazonal truck trips, however, was identified as a significant shortcoming in using a highly coarse zone system.

As in many projects that deal with modeling freight and truck flows, the limited understanding of truck travel behavior is a significant limitation. A key shortcoming is the lack of understanding how many intrazonal truck trips should be expected within every FAF region. A comparison with four independent urban truck models revealed a significant underestimation of intrazonal truck trips by the FAF2 data, and inflating FAF2 data ten times still appears to be a conservative adjustment. No true estimation of intrazonal truck trips was attempted in this study. It would be desirable to calculate the number and distance of intrazonal truck trips based on the

distribution and size of population and employment within a FAF zone. However, it is a complex task to estimate the number of intrazonal truck trips, excluding the trips that cross the border of a FAF zone.

A serious proof of concept calls for comparing simulated truck volumes with observed truck counts. As indicated at the end of section 2, truck model validation is highly limited by lack of available truck count data. Lacking a consistent definition of trucks, which sometimes are counted by axles and sometimes by weight classes, further complicates the comparison of model results with count data. In most cases, trucks are only counted for a single day once every five years, making count volumes highly vulnerable to special circumstances on that count day. The conclusion stating that assigned volumes in Figure 11 are more realistic than volumes in Figure 6 remains hypothetical and is only based on theoretical assumptions and knowledge of the study area. Missing reliable count data on the beltway and on highways in the city center prohibits a thorough validation of simulated truck volumes.

The proposed method presented in this paper allocates intrazonal truck trips to the network based on employment densities. Without a doubt, this approach handles intrazonal truck trips fairly technically, rather than building a behavioral model that simulates the motivation for intrazonal truck trips. However, it was aimed at developing a model that is significantly simpler than complex microsimulation models which commonly require a large amount of data and increase run times significantly, particularly when modeling very large study areas. This approach is a compromise between developing a sophisticated behavioral model and the need of simulating trucks with an acceptable level of detail at the national level. The level of sophistication of this model will be further adjusted in future developments according to the needs arising in truck trip simulations.

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