



FREIGHT ANALYSIS FRAMEWORK HIGHWAY CAPACITY ANALYSIS

METHODOLOGY REPORT

to

Office of Freight Management and Operations
U.S. Department of Transportation
Washington, D.C.

April 18, 2002



**505 King Avenue
Columbus, Ohio 43201**

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Office of Freight Management and Operations
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1 INTRODUCTION

1.1 BACKGROUND

The transportation of freight in the U.S. is predominantly an interstate activity. For example, shipments crossing state boundaries account for about 73 percent of the ton-miles and 55 percent of the value of commodity movements by truck [1]. Factors influencing freight movement by truck include: freight and logistical considerations (commodity, shipment size, package, fragility, temperature control, origin-destination patterns, delivery time requirements); infrastructure considerations (terminals and route options between origin-destination pairs); truck economic considerations (replacement cycles, resale markets, fuel economy, driver flexibility); truck operating strategies and company structures; special permitting policies and practices; regulation enforcement; and intermodal requirements.

While freight transportation has been a leading sector in terms of productivity improvement, there are growing concerns regarding the ability of the freight transportation system to support the productivity improvements. The dominant problem for the next 30 years appears to be the capacity of the highway system. Congestion within metropolitan areas, rising fuel costs, and rising labor costs threaten the efficiencies and productivity achieved by the intercity trucking industry. The same factors affect the local and regional trucking industry even more critically.

Congestion is a phenomenon related to the structure of the highway network, the management of the network, and travel demand. To some extent, management of the highway network can increase capacity or modify demand – through tolls, flow restrictions, or coordinated intelligent transportation system (ITS) efforts. Local and regional freight movements are and will continue to be dominated by trucks. The issues to consider include how many trucks, what types of trucks, and what time of day. Trucks are more likely to be victims rather than causes of congestion. Studies of the economic costs of restricting truck deliveries [2] generally conclude that the costs to carriers and consumers are greater than the benefits to commuters.

Techniques for freight transportation planning, especially at regional levels, have not been as well developed as for passenger transportation planning. To some degree, this can be attributed to the greater complexity of the freight transportation system in terms of the spatial and temporal diversity of freight generation activities and movement. The existence of multiple time zones makes it more difficult to analyze the capacity effects of the national freight transportation system. Freight transportation demand modeling must also address the multidimensional nature of freight transportation, which is not a consideration in passenger transportation modeling. In freight transportation, factors like volume, weight, and trips come under the control of a number of decision-makers (dispatchers, drivers, freight forwarders), operation regulations, and restrictions [3]. There is a dynamic interaction among them.

Literature on freight transportation planning at the national or regional level is sparse. For example, one study includes models developed for strategic analysis and planning of national freight transportation [4]. Another study describes methods that were developed for assigning

freight flow on regional networks and which were applied to the highways in the state of New Jersey [5]. Recent research efforts in freight planning tend to focus on specific states or commodity types. A statewide truck trip-forecasting model that was developed for the state of Wisconsin used input-output econometric data and the TRANPLAN transportation planning software application. In it, freight assignment was limited to only 40 links distributed throughout the state of Wisconsin [6]. In another study [3], commodity-based and vehicle-trip-based freight demand modeling techniques were examined. The study concluded that both techniques encounter challenges that are difficult to overcome. In a different study [7], a freight demand model was used to examine meat flow in the state of Iowa. The goal of this study was to develop a statewide or regional freight transportation demand model by modeling traffic for one commodity at a time. A more recent study [8] developed a model for assigning multi-commodity multi-class truck trips between various origin-destination pairs. The model was used to analyze freight traffic on the state of New Jersey highways. As part of a statewide freight planning effort in Kentucky, a modal substitution technique was used to examine freight flows throughout the state [9].

1.2 OBJECTIVES

This study is directed at conducting a national highway freight analysis designed to identify and assess the system-wide capacity deficiency elements of the nation's highway system. The primary objective of the highway capacity analysis is to develop a policy tool for

- (i) Analyzing potential policy, operational and planning issues, for example, identification of corridors with problems;
- (ii) Examining the sufficiency of the capacity of the transportation system in meeting forecast trucking demand; and
- (iii) Providing estimates of system capacity not available in the Highway Economic Requirements Systems (HERS).

The analysis is intended to provide information on a set of capacity-related performance measures for each highway link in the present as well as over the next 20 years.

1.3 OVERVIEW OF METHODOLOGY

The highway capacity analysis was constructed using four major interdependent building blocks, which are discussed in detail in the subsequent sections of this report.

1. **Establishment of freight analysis network.** The National Highway Planning Network (NHPN) [10] defines the highway network of interest for the analysis. This step includes the following:
 - Establishing freight link coverage from NHPN
 - Establishing Highway Pavement Monitoring System (HMPS) [11] and state's route information linkage for Freight Analysis Framework (FAF) link coverage

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- Calculating or estimating capacity-related inputs and network attributes such as practical capacity, free flow speed data, number of lanes, etc.
2. **Establishment of freight analysis zones.** The U.S. county boundaries of the lower 48 states define the freight analysis zones (FAZs). This step involves:
 - Establishing the FAZ centroid connectors to FAF network
 - Generating FAZ sub-centroids and associated connectors
 - Generating external border stations for import/export freight
 - Estimating or calculating the freight share for each sub-centroid connector.
 3. **Freight demand analysis.** This step involves:
 - Developing traffic flow maps based on state traffic counts
 - Converting the county-based annual freight tonnage production to equivalent daily truck trips
 - Establishing the freight assignment procedures
 - Assigning the truck trips on the FAF network
 - Calibrating the network assignment.
 4. **Capacity-related performance measures.** The purpose of this step is to determine the capacity deficiencies of the freight transportation highway network based on the supply and demand of freight (truck traffic) flows. Given that truck travel patterns are different from commuter travel patterns, it is necessary to determine the effects of truck traffic on capacity requirements of the network for truck peak hour flows. This step involves:
 - Generating reasonable performance measures such as LOS, volume to capacity ratio, travel time, link speeds, and delay to assess the infrastructure deficiency
 - Performing a time of day (TOD) analysis.

1.4 ORGANIZATION OF THE REPORT

The rest of the report is organized as follows:

- Chapter 2 Establishment of the freight analysis network.
- Chapter 3 Establishment of the freight analysis zones.
- Chapter 4 Assignment of truck trips to the network and development of traffic flow estimates.
- Chapter 5 Capacity analysis methodology.
- Chapter 6 Conclusions and potential areas for future research.

2 FREIGHT ANALYSIS NETWORK

2.1 INTRODUCTION

The primary objective of this task is to establish a freight analysis highway network using the most recent version of the National Highway Planning Network (NHPN). Other objectives are to input network impedances as of 1998 with current capacity constraints using the HPMS data as well as traffic flow data from the Traffic Monitoring Systems of the various state departments of transportation. The establishment of the freight analysis framework (FAF) highway network is described in this chapter.

2.2 BUILDING THE FREIGHT ANALYSIS FRAMEWORK (FAF) NETWORK

2.2.1 Selection of FAF Network Coverage

Capacity constraint-based freight modeling requires a significant amount of physical information about the links. This information needs to describe the network's current performance in terms of practical capacity, volume, free flow speed, and travel time. This project requires that both capacity-constrained and capacity-unconstrained assignment procedures will be utilized to assign the truck flow on the highway system. However, for the capacity-unconstrained assignments, the all-or-nothing (AON) assignment procedures do not make alternate route choices in the event of a reduction in link capacity due to link's existing or future physical performances and most often result in unrealistic travel patterns between an origin and a destination. To overcome this problem it was decided to limit the FAF network coverage to those links of NHPN whose performance data is readily available.

The NHPN was developed for and is maintained by Office of Environment and Planning within FHWA to support GIS-based traffic modeling and mapping. The latest version available for use in this study was Version 3. It represents more than 450,000 miles of public roadways including the Interstate System (IS), National Highway System (NHS), National Network (NN), and other state highways. Only approximately 350,000 miles or 78 percent of public highways are reported in the HPMS database with all the performance data. Furthermore, less than 70 percent of the links in the HPMS database match those in the NHPN version 3. Consequently, a smaller NHPN coverage was used in establishing the FAF highway network. Thus the FAF network is a subset of NHPN Version 3 and contains the following links:

- National Highway System (NHS) links
- National Network (NN) links
- Rural minor arterials for counties not served by either NN or NHS
- Urban streets as appropriate for network connectivity.

Out of 452,040 miles of NHPN network, 245,505 miles are included in the FAF network, with the following distribution,

- 46,380 miles of Interstate highways
- 162,000 miles of NHS roads (excludes Interstates)
- 35,000 miles of other National Network roads; and
- 2,125 miles of urban streets and rural minor arterials.

2.2.2 Network Preparation – Link Attribute Estimation

In this activity, the physical and performance data for each FAF link are derived that describe the vehicular flow on the public road system. The link performance data of the FAF network is derived utilizing the following data sources:

- NHPN route coverage obtained from FHWA Planning and Environment Office of Intermodal & Statewide Programs
- HPMS highway inventory database from FHWA Office of Highway Systems Performance
- Traffic and truck data from the state DOTs.

The following steps were carried out to import these databases into the FAF network:

- Establish data linkage between FAF network and HPMS database
- Establish data linkage between FAF network and state-specific traffic database
- Input traffic flow data
- Input HPMS data.

FHWA recently undertook a project to develop an NHPN-based, linear referencing, geospatial database to allow capturing the HPMS data. At the beginning of this project, the NHPN-based Linear Referencing System (LRS) had been mostly completed for all states (except Missouri). However, the geospatial data structure of NHPN route subclasses is such that it allows HPMS data visualization through the dynamic segmentation techniques where each NHPN link is transparently segmented by using the HPMS data section (normally defined by the smallest denominator of attribute data). Network analysis of the NHPN network is not practical for the following reasons:

- Limited attributes on NHPN 3.0 network that are essential for network assignment and modeling
- No one-to-one relationship between NHPN and HPMS at the network level
- Event theme shape file derived from NHPN route subclass and HPMS database does not allow network analysis, because shape file does not have the topology
- Lack of data validation between state-reported NHPN route subclasses versus HPMS route system
- Different LRS across the states

- Missing LRS references or gaps.

The challenge was to address these limitations in order to use the NHPN 3.0 network for network analysis. The following steps were implemented in addressing the problems associated with the network:

1. Transform NHPN route subclass unique LRS identification to NHPN arc coverage
2. Establish state-specific LRS and encode the LRS information onto the NHPN
3. Establish NHPN link sequential direction as a function of state-specific LRS and HPMS data sequence
4. Harmonize various LRS milepost anchor systems to county-based milepost anchor system
5. Assign beginning and ending milepost values for each FAF network's component of NHPN
6. Calibrate FAF network's milepost values with state's milepost anchor values
7. Validate HPMS data chainage direction with that of FAF LRS milepost sequence
8. Merge HPMS section data onto FAF links
9. Spread HPMS "Sample" data to FAF link universe
10. Smooth traffic/truck data across the states.

For states with missing LRS references, the following steps were taken:

1. Establish HPMS route equivalent of NHPN state route sign
2. Assign milepost values based on route sign (NHPN attribute variable "SIGN1")
3. Assign HPMS equivalent milepost anchor values at the beginning and ending route as well as at the county boundaries
4. Merge HPMS data onto the FAF links.

2.3 ESTABLISH DATA LINKAGE BETWEEN FAF NETWORK AND HPMS DATABASE

2.3.1 NHPN Route Coverage

The geospatial architecture (link, node) of NHPN is such that nodes are introduced at the change points of network attribute or functional/administration classification, at ramps and intersections, intermodal locations, or any traffic egress/access points. On the other hand, an anchor point is introduced at the end of each unique LRS section (also known as route) and subsection (also known as subroute). Therefore a unique LRS section may consist of one or more NHPN arc section. Utilizing GIS programming, the NHPN route subclass's LRSKEY is assigned to each FAF link as well as a route's milepost anchor value. A route's "LRSKEY" is a unique route identification number reported in the HPMS database and composed of a state-modified route inventory number followed by subroute number and then county code. HPMS data are collected

between these anchor points at the increasing chainage direction. Unlike the NHPN arc network, the LRS route coverage does not require nodes at each traffic exist/enter point.

Figure 2-1 illustrates the situation where LRS route A of an NHPN-route subclass changes between NHPN arc nodes X and Y. The corresponding HPMS data for this particular route also change between node X and Y, indicating probable physical changes of the roadway section, e.g., number of lanes or capacity. If the NHPN arc contained a node at location Z, then HPMS data could easily be tagged or transferred to the NHPN arc level. For this example, if the HPMS number of lanes value for LRS A and LRS B are 4 and 6 respectively, then without the arc node at location Z the probable assigned value would be 4 for entire link between node X and Y. With the node at location Z, the appropriate values would be 4 and 6 for the links between X and Z and Z and Y respectively.

Using the map network editing tools in the TransCAD GIS application software [12], additional nodes are introduced at the location of LRS anchor points for entire FAF coverage.

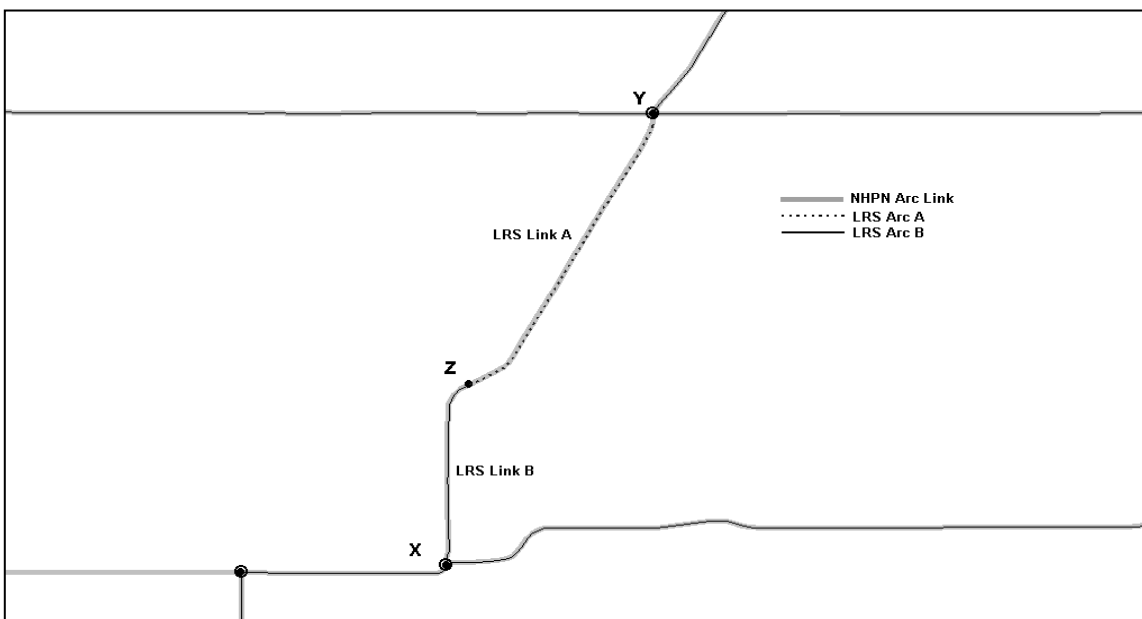


Figure 2-1. Integration of State's LRS Anchor Nodes with NHPN.

2.3.2 Establishment of FAF Link Sequence and Milepost Anchor Values

The output from the process just described is a complete link/node network with HPMS-unique route identification of "LRSKEY" and the milepost information. Each FAF link is assigned a beginning and an ending milepost and a sequence number along the direction of HPMS data collection. Table 2-1 illustrates the output attribute table after assigning appropriate link milepost anchor values and a sequence number.

Table 2-1. NHPN Milepost Sequences.

NHPN ID	LRS KEY	Route_BEGMP	Route_ENDMP	FAF Link_BEGMP	FAF Link_ENDMP	FAF Link_SEQ
162266	00000090E00063	0.000	4.169	0.000	1.380	1
155342	00000090E00063	0.000	4.169	1.380	2.830	2
155346	00000090E00063	0.000	4.169	2.830	3.190	3
155344	00000090E00063	0.000	4.169	3.190	3.570	4
155340	00000090E00063	0.000	4.169	3.570	4.410	5
155338	00000090E00063	4.169	20.280	4.410	4.740	6
155336	00000090E00063	4.169	20.280	4.740	5.080	7
155333	00000090E00063	4.169	20.280	5.080	6.010	8
153471	00000090E00063	4.169	20.280	6.010	7.840	9
153472	00000090E00063	4.169	20.280	7.840	20.500	10

2.3.3 Milepost Calibration

The FAF network mile-point anchor value is derived from NHPN 's arc mileage value reported under the attribute data field "MILE." Total mileage reported under a unique HPMS "LRSKEY" often does not match with the total cumulative mileage of all the sections with unique NHPN "LRSKEY." In other words, the ending mile-point anchor value of a given NHPN arc derived from NHPN's mileage may be higher or lower than that of HPMS database.

Visual Basic (VB) programming codes were developed to distribute mileage differences between the HPMS and the FAF arc sections. The mileage difference is proportionally distributed among the FAF links such that beginning and ending milepost matches with the equivalent HPMS route. Table 2-2 illustrates the resulted calibrated milepost of the FAF link as reported in Table 2-1.

Table 2-2. Calibrated NHPN Milepost Sequences.

FAF ID	LRS KEY	Route_BEGMP	Route_ENDMP	FAFREV_BEGMP	FAFREV_ENDMP	FAF Link Seq
162266	00000090E00063	0.000	4.169	0.000	1.304	1
155342	00000090E00063	0.000	4.169	1.304	2.674	2
155346	00000090E00063	0.000	4.169	2.674	3.014	3
155344	00000090E00063	0.000	4.169	3.014	3.373	4
155340	00000090E00063	0.000	4.169	3.373	4.169	5
155338	00000090E00063	4.169	20.280	4.169	4.499	6
155336	00000090E00063	4.169	20.280	4.499	4.839	7
155333	00000090E00063	4.169	20.280	4.839	5.770	8
153471	00000090E00063	4.169	20.280	5.770	7.602	9
153472	00000090E00063	4.169	20.280	7.602	20.280	10

A GIS program was written to assign milepost values for all routes with unique LRSKEY on FAF links regardless of linear referencing methods (county to county or state to state) adopted by

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each state. This process resulted in a uniform milepost schema that is independent of the state's LRS.

An inconsistency in the data that had to be addressed was the presence of reverse milepost anchor values. Reverse milepost anchor directions were checked and adjusted by comparing the beginning and the ending county code for each route section with the corresponding county code reported in the HPMS database.

2.4 DATA LINKAGE BETWEEN FAF NETWORK AND STATE TRAFFIC DATABASE

In some states the traffic data are collected by state road sign or state-specific route number that may have no relationship with the HPMS route system's unique LRSKEY. Therefore, additional work was needed on the FAF network to make it possible to capture state-specific data. The methodology adopted is similar to that described in the previous Section 2.3. Figures 2-2 and 2-3 show the NHPN and the FAF networks for the lower 48 states. Table 2-3 summarizes the percentage of each state's total mileage (NHPN miles) that is on the FAF network within that state. As can be seen in the table, virtually all of the NHS mileage, both Interstate and non-Interstate, is on the FAF network.

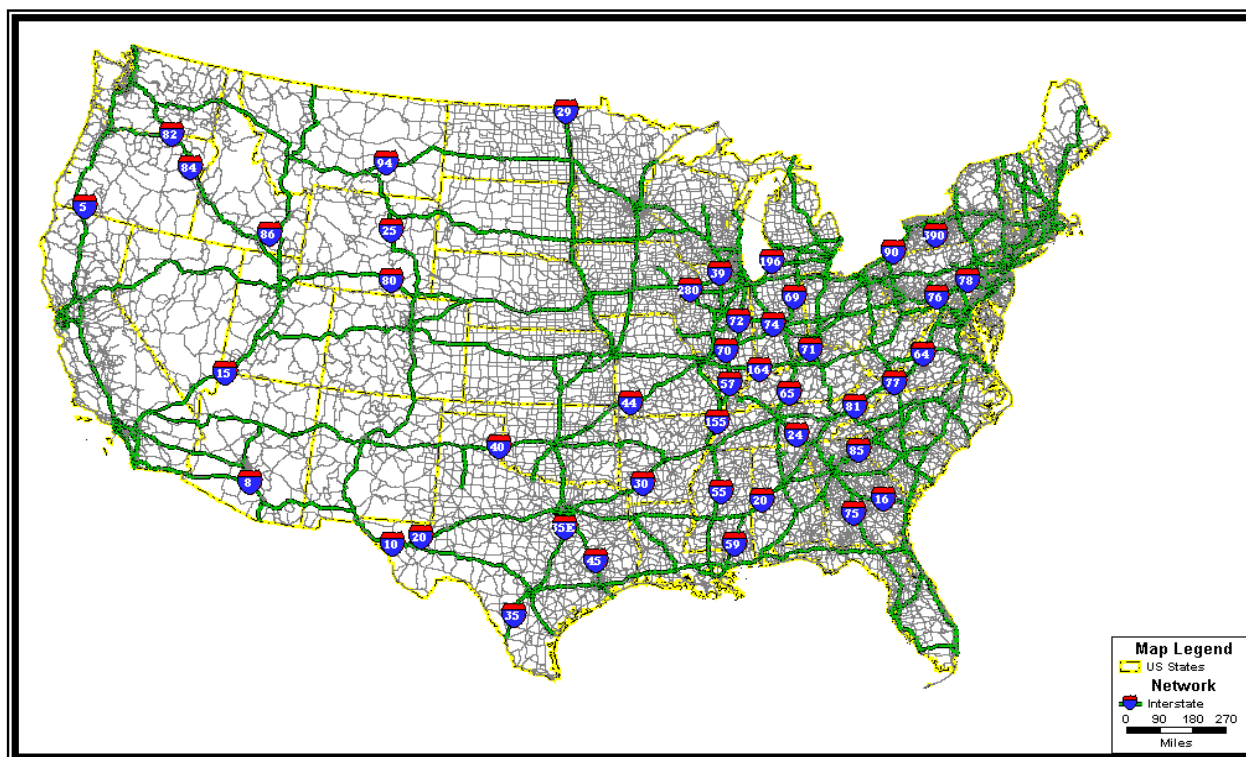


Figure 2-2. NHPN Network.

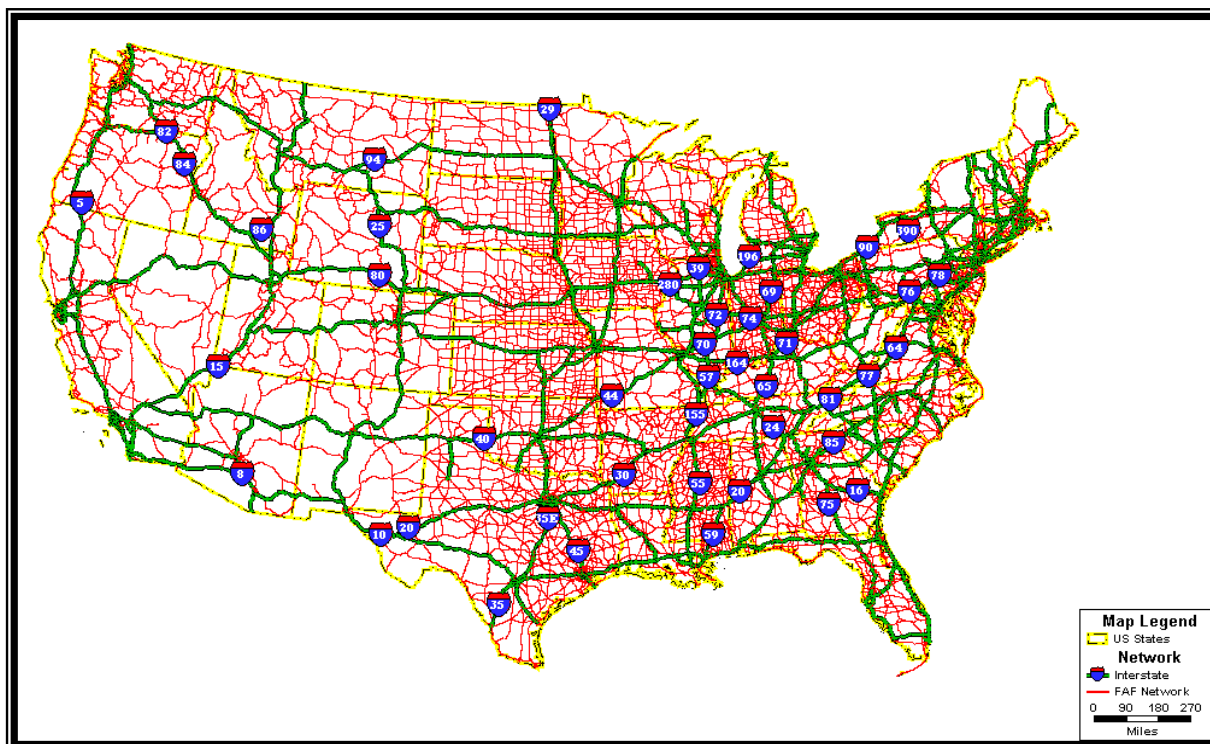


Figure 2-3. FAF Network.

Table 2-3. NHPN Mileage Captured on FAF Network of Each State.

State	NHS		Off-NHS	Total	State	NHS		Off-NHS	Total
	IS	Other				IS	Other		
AL	99%	99%	19%	49%	NC	100%	97%	16%	46%
AR	83%	101%	55%	69%	ND	100%	100%	25%	52%
AZ	100%	99%	13%	46%	NE	100%	99%	80%	87%
CA	99%	98%	5%	34%	NH	100%	99%	0%	43%
CO	100%	98%	37%	58%	NJ	100%	99%	3%	58%
CT	100%	99%	0%	36%	NM	100%	98%	9%	38%
DC	83%	33%	0%	24%	NV	100%	100%	16%	48%
DE	100%	90%	14%	49%	NY	100%	97%	3%	30%
FL	100%	99%	27%	50%	OH	100%	99%	53%	72%
GA	100%	98%	13%	37%	OK	99%	100%	49%	66%
IA	100%	96%	60%	72%	OR	100%	98%	23%	61%
ID	100%	99%	32%	63%	PA	99%	99%	4%	42%
IL	100%	99%	12%	49%	RI	100%	95%	0%	35%
IN	100%	96%	48%	66%	SC	98%	96%	10%	41%
KS	100%	98%	69%	79%	SD	100%	100%	81%	89%
KY	100%	98%	24%	52%	TN	100%	99%	21%	51%
LA	100%	97%	31%	53%	TX	100%	95%	44%	65%
MA	100%	97%	1%	54%	UT	100%	98%	50%	70%
MD	100%	100%	1%	42%	VA	100%	92%	16%	46%
ME	100%	99%	1%	31%	VT	100%	97%	6%	38%
MI	100%	98%	31%	58%	WA	100%	100%	44%	65%
MN	100%	99%	25%	47%	WI	100%	98%	19%	46%
MO	99%	90%	21%	52%	WV	100%	97%	6%	38%
MS	100%	94%	68%	76%	WY	100%	97%	33%	62%
MT	100%	100%	74%	87%	Total	100%	98%	29%	54%

3 ESTABLISHMENT OF FREIGHT ANALYSIS ZONES

3.1 INTRODUCTION

The classical traffic demand analysis requires the establishment of traffic analysis zones (TAZs) or boundaries from which the trips will originate and end via a prior established network. Typically these zones are derived from U.S. census tract, ZIP code polygon boundaries, polygon boundaries defined by Bureau of Economic Analysis (BEA), township or county boundaries, or other user-defined polygon boundaries. The size and density of a TAZ depends upon the type of trip demand modeling. Typically, a denser TAZ is required for micro planning (urban) than for macro planning (national).

For FAF freight demand analysis, the county boundaries of the lower 48 states are used to define the freight analysis zones (FAZs), and the FAF freight forecast is disaggregated to the counties. Thus, the concept of a FAZ is similar to the TAZ, but considers freight trips only.

This chapter describes the establishment of the FAZ centroid connectors to the FAF network described in Chapter 2, the generation of FAZ sub-centroids and associated connectors, external border stations for import/export freight, and estimation of the freight share for each sub-centroid connector.

3.2 CREATION OF U.S. COUNTY-BASED FREIGHT ANALYSIS CENTROIDS

As part of its efforts to simulate and subsequently forecast the impacts of freight flows on the nation's highway system and economy, the U.S. Department of Transportation has sponsored the creation of a set of county-to-county annual freight flow matrices. Typically, these matrices are loaded onto a representation of the U.S. highway network for the purposes of mapping and subsequent analysis, using a single point of geographic origination and destination within each county. While this approach may suffice for the majority of counties, it results in an unsatisfactory representation of freight movements over U.S. highways within heavily used metropolitan areas. Using a single freight activity generation and attraction point for each of these counties causes too much freight to be assigned to too few highway routes. Creating multiple freight start and end points within such counties is an obvious method for providing a more reasonable representation, including a better mapping of such flows.

“Centroid” is a term commonly used in transportation modeling to describe the geographic location at which traffic flows begin and end. The purpose of this section is to describe the creation of a set of U.S. county-based, freight traffic, sub-centroids and their attachment to a set of nodes located on the FAF freight analysis network defined in Chapter 2. The term “centroid” will be used to indicate the single, final source or sink of all traffic flows within a county. Where it is required to distribute a county's traffic to more than one traffic generation or attraction site,

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such a centroid's traffic is split among a number of "sub-centroids" suitably dispersed throughout the county of interest. Figure 3-1 shows this concept. This section is concerned with both the selection of, and assignment of traffic volumes to, each of these sub-centroid locations.

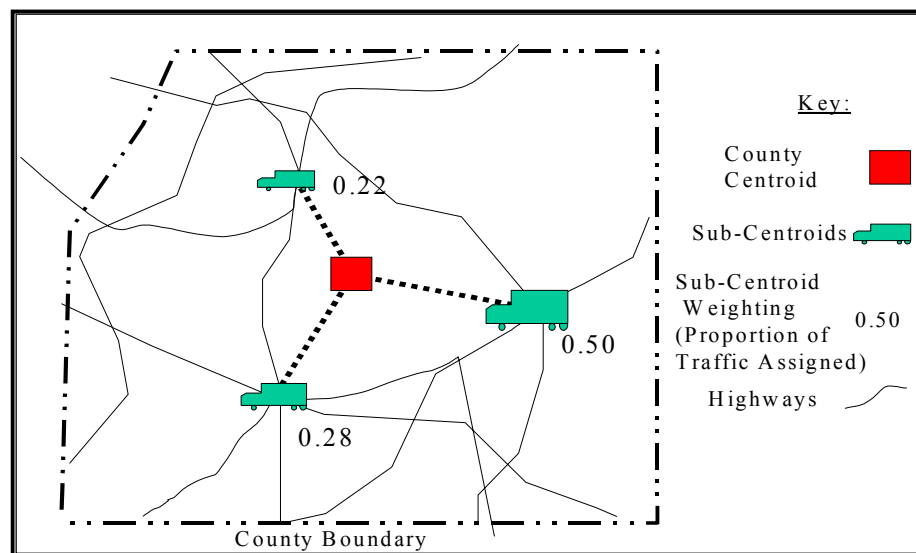


Figure 3-1. Relationship of County Centroid To Truck Traffic Sub-Centroids.

3.2.1 Overview of the Sub-Centroid Creation Process

The nature of truck freight pickup and delivery operations is such that freight is generated by, and collected at, a wide variety of geographic locations within a county. This may include large daily volumes of truck activity at seaports, at river docks, at truck-rail intermodal terminals, and at airports, as well as at major manufacturing plants and at wholesale, retail, warehousing and redistribution, and extractive industry sites. The technical problem to be addressed can be broken down into four tasks:

1. Identify and weight high-volume freight activity sites within U.S. counties
2. Develop a method for suitably aggregating these spatially separated activity sites into a small set of traffic activity sub-centroids
3. Identify and weight additional sub-centroids as necessary (special freight generators)
4. Assign the sub-centroid locations to the nearest node on the U.S. highway network.

Ideally, the process of creating truck traffic sub-centroids should start with detailed, site-specific statistics on either truck traffic volumes or on the volumes of truck traffic supporting economic activity and land use. Since the available data sets are not national in scale, it was necessary to develop an alternative approach. The method that is described below is a reasonable, generic approach that can be fine-tuned as the quality of the data improves.

3.2.2 Creating a Set of Traffic Generation/Attraction Sites

Economic activity at a sub-county level has been captured in limited forms for the nation as a whole. The most recent data set offering coverage at a reasonable level of within-county detail was the U.S. Bureau of the Census's 1997 Zip Code County Business Patterns. This data set was used to create truck freight traffic activity weights based on zip code areas. A sub-set of these zip code areas was selected as truck activity sub-centroids. The steps for generating a set of traffic generation/attraction sites are described below. Some steps involve an adaptation to available data, since we lacked the time and resources to develop a true traffic generation model.

1. The total number of employees in each zip code area, by two digit SIC (Standard Industrial Classification) Code, was estimated from data contained on the CD.

In practice it was necessary to sum up the number of establishments in various firm size intervals within each SIC category, then estimate the number employees within each size interval, and reconcile these numbers with the total employment figure reported for each zip code area.

2. Data from the 1997 Vehicle Inventory and Use Survey (VIUS) [13] were used to re-weight this location-specific employment data, according to the formula:

$$Wt(i) = \sum_g Emp(g,i) \times [VMT(g)/VMT(*)] \quad (3-1)$$

where $Wt(i)$ = the truck traffic generation/attraction weight assigned to potential sub-centroid i .

$Emp(g,i)$ = employment in industry class g at location i .

$VMT(g)$ = U.S. vehicle miles of truck travel by industry class g [13]

$VMT(*)$ = total U.S. vehicle miles of truck travel [13]

3. This VMT-weighted employment data set was matched with a second data file that contained the location (latitude and longitude) of the geographic center of these 1997 zip code areas.

This matching process required some manual effort to ensure that all zip code areas with significant employment were placed within the correct county. This was necessary because the GIS process used to capture all zip codes within a specific county is a form of "overlay" process that relies on consistency between zip code and county boundaries. Even if zip code specific centroids are used, these can cause problems if they fall outside county boundaries. This occurs mainly along the edges of coastal counties.

4. The resultant zip code centroids were assigned to a county by finding the nearest county centroid for each zip code area centroid and attaching it to that county. The resulting, geographically referenced employment file was then used as the basis for allocating freight traffic to a subset of these zip code locations within each county.

An alternative method is to carry out a zip code centroid to county area coverage calculation within a commercial GIS system. However, the method used is much faster and no less accurate. Both methods typically require some manual clean up of zip codes to counties after the programs have been run, due to misallocation problems or to county boundary problems, respectively.

5. The above-defined proxy VMT weighting was converted to annual truck freight tonnages by summing all of the truck freight flows out of plus into each county. The same truck freight origin-destination tonnage matrix was used that is going to be assigned by FHWA to the county sub-centroids. The 1998 estimates of county specific tonnages provided by Reebie Associates in August 2000, as part of the FHWA's Freight Analysis Framework project, were used.
6. An additional set of freight activity sites was added to this data file. Site information was generated from a set of latitudes and longitudes plus annual freight tonnages for 150 major U.S. seaports. This file and its annual tonnage data (for calendar year 1998) were taken from the U.S. Army Corps of Engineers Waterborne Commerce Statistics Center (WCSC) database [14]. Total tons for 1998 were used in the (very approximate) weighting process to ensure that at least one sub-centroid in each county was assigned at or near each of the country's major seaports.

These steps provided the basis for allocating the zip code areas to sub-centroids.

3.2.3 The Sub-Centroid Selection and Freight Activity Weighting Process

The next step in the process was to run this freight activity site file through a spatial location-allocation algorithm. Based on the Teitz and Bart algorithm [15, 16] this computer program allocates all N potential freight activity sites associated with a county to a smaller set of M such sites. This is done such that the weighted distance between all N-to-M sites is minimized. Figure 3-2 shows the basic idea behind this approach. The weights used here are the tonnages assigned to each of the N original zip code or port site locations. The result is spatial clustering of these tonnages into a set of M freight traffic generation/attraction sub-centroids. This process was repeated for each U.S. county, including Hawaii, Alaska, and for the two main port sites in Puerto Rico, based in each case on a user-defined value for M. Once solved for all counties, the resulting sub-centroid assignments are reported for each county as values (i.e., shares) between 0.0 and 1.0.

3.2.4 Adding Specialized Sub-Centroids (NHS-Connectors)

Once the above process was completed, an additional set of 610 freight traffic generator/attractor nodes was also scanned for possible addition to the freight traffic sub-centroids file. These nodes represent the location of the U.S. DOT's designated set of National Highway System (NHS) connectors. These are the same locations identified as important to intermodal freight activity sites by each of the 50 states, during construction of the FHWA's National Highway System network database. Where an existing sub-centroid was found to be within 5 miles of such a

connector, the connector's location was substituted for the initial sub-centroid. Where the distance to an NHS connector was more than 5 miles from any current sub-centroids within a particular county, an additional freight sub-centroid was added at the location of an NHS connector. Where two or more such NHS connectors were located within 5 miles of each other, a single connector site was selected to represent this centroid cluster.

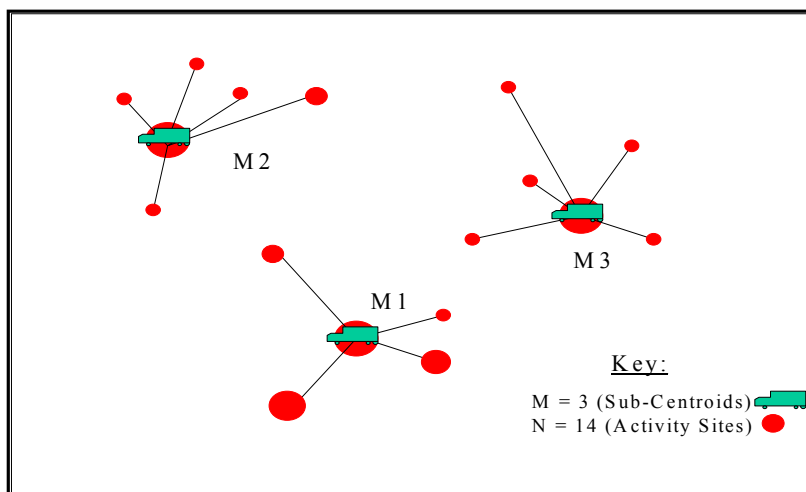


Figure 3-2. Allocation of Activity Sites To Sub-Centroids.

3.2.5 Matching Sub-Centroids to Nearest FAF Network Nodes.

The final step in the process consisted of assigning the nearest NHPN v3 node to each of the M sub-centroids selected within each county. To ensure easy connectivity to the National Highway System, this initial sub-centroid allocation was limited to NHS nodes. This was done by using the Maptitude (Caliper Corporation) GIS software [17] (specifically, by subsetting out the NHS nodes and then using the “nearest and within” option from the “select by location” menu item). The result of this exercise was not entirely satisfactory, as a significant number of counties received no sub-centroids within their boundaries, due to the distance from such counties to the nearest NHS highway node. These counties were identified as sub-centroids relocated manually within the GIS to more central, typically urban area locations.

3.2.6 Summary

The above process appears to produce a reasonable set of traffic generation sub-centroids once a set of initial freight activity sites has been constructed. The process also allows the user to experiment with the number of centroids to allocate to each county, since the location-allocation model consistently solves for all U.S. counties in under 2 minutes. However, some manual editing was required to obtain the final set of sub-centroids used in a number of single centroid, typically rural counties. Assigning sub-centroids to NHS-only nodes creates problems for geographically small counties. A significant number of counties contain no NHS nodes. In a small number of these counties, there was, indeed, no major highway node of any kind contained

within the NHPNv3 database. In cases where no NHS node was available, these single sub-centroid locations were moved to more central locations where one or more major rural highway routes intersect. For the most part, these were also the within-county locations close to the highest zip code-based employment activity locations within a county. While this process can be automated to look for within-county locations on high-capacity, non-NHS routes, if no NHS route is available, the results can vary considerably. Also, not all major rural arterials are fully connected to the NHS; for example, to ensure that each county had at least one centroid within its boundaries, the “overlay” procedure within the Maptitude GIS was used to verify this condition for all counties in the lower 48 states. To achieve this result required some additional manual inspection and subsequent movement of sub-centroids off routes located outside or along the borders of these counties. In the final analysis only two counties (the island of Nantucket, MA, and Still County, KY) failed to contain a sub-centroid (which was allocated to an adjacent county in each case).

This sub-centroids selection approach produced a set of 3,427 truck traffic centroids for the 3,111 counties in the continental U.S.

Most counties had M set equal to 1, i.e., they received a single traffic centroid. Larger counties were given M values of from 2 to 6. These counties were selected by first ranking counties on the basis of estimated annual total truck freight tonnage and then experimenting with different M values. For example, Los Angeles County received 6 traffic generator centroids, with two being selected for the Ports of Los Angeles and Long Beach each.

Figure 3-5 shows an example result for Chicago area counties. Six truck freight sub-centroids were allocated to DuPage county in this particular example (i.e., M =6). This figure shows the geographic location of the final sub-centroid selections (shown by the truck profile icon), plus the location of each county’s major, truck VMT-weighted zip code employment sites (the circular icons). Also shown are the region’s numerous inland and lakeside docks, its major truck-rail intermodal terminals, and its two major commercial airports.

3.3 ESTABLISHMENT OF EXTERNAL FREIGHT CENTROIDS

Section 3.2 described the development of internal freight centroids where trips originate and terminate within the lower 48 states. This section describes the development of external freight analysis centroids for export and import freight.

The FAF freight O-D database reports bordering states’ counties as the point of freight origin and destination. For example, freight originating (being exported) from any U.S. county and destined to Canada will terminate at the county bordering U.S.-Canada. Similarly, for import freight, the freight origin is the bordering county.

This step first identifies all ports of entry within each bordering county, estimates the total truck flow for all FAF links connecting these ports of entry, and proportionately distributes the total import/export freight for that county to each of these external centroids by the baseline truck volume at each port of entry.

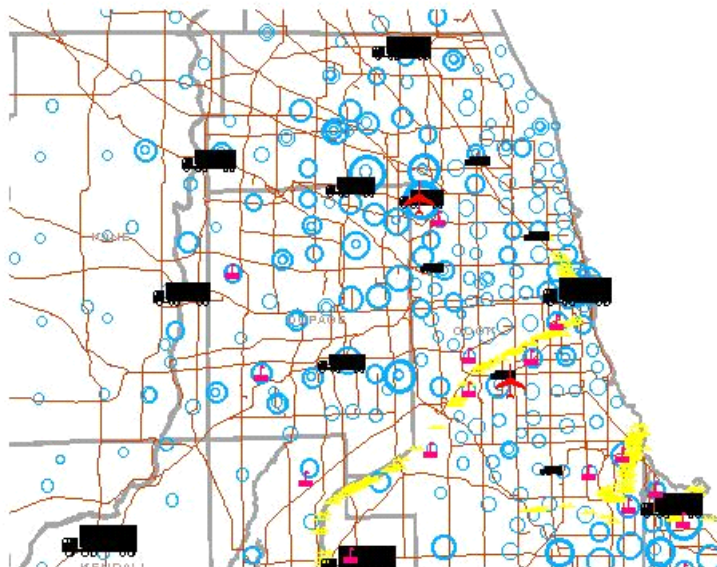


Figure 3-3. Example Sub-Centroid Selection for Chicago Counties.

Key: The (black) truck icon indicates location of a sub-centroid. Size of icon is share within a given county. The (blue) circle icon indicates location and relative size of truck VMT weighted employment sites (approx. zip code centroids). The (yellow) ship icon shows location of area's river docks and seaports. Truck-rail intermodal terminals are shown as red rectangles with a flag on top. O'Hare International and Midway Commercial Airports are also shown (red airplane icons). Also shown in the background (brown lines) is the NHPNv3 US highway network.

Extensions and improvements to this process could add a second or even a third sub-centroid to very large and unusually shaped counties, not just high freight volume counties. In the case of these latter, high freight volume counties both airport site tonnages and truck-rail inter-modal terminal site tonnages might be introduced explicitly into the sub-centroid selection process. In the example shown in Figure 3-3, these locations appear to have been reasonable well represented. However, the approximate nature of the allocation process should be borne in mind. Since the "bottom line" here is to get a reasonable distribution, or spread, of truck freight flows across a multi-county metropolitan area's highways, the value of adding these additional site details must be considered in light of the difficulties involved in getting accurate, and comparable, data on truck freight tonnages for each set of activity sites in the first place.

4 FREIGHT DEMAND ANALYSIS

4.1 INTRODUCTION

The purpose of this chapter is to describe concepts and methodologies used for assigning truck trips to the FAF highway network. The demand analysis consisted of the following steps:

1. Merge baseline traffic data onto the FAF highway network
2. Merge HPMS data on the FAF highway network
3. Prepare freight data for assignment
4. Determine network attributes
5. Assign 1998 truck trip O-D data from step 3 to the FAF highway network
6. Calibrate network using results of step 1 and assign 2010 and 2020 truck trip O-D data to calibrated network.

4.2 BASELINE TRAFFIC FLOW MAP

The purpose of the traffic flow map is to establish the baseline for calibrating the assigned freight flows; i.e., the map shows the actual volume of traffic including truck traffic on the highway network for the base year. The methodology adopted is a departure from the one adopted in developing the 1996 truck flow map as part of the comprehensive Truck Size and Weight study. In the 1996 study [18], traffic data obtained from the states were manually inputted on the NHS network. This was laborious and time-consuming. The resulting truck flow map could not be easily updated with new traffic data. For this study, the methodology adopted in developing the truck flow map used a more efficient process that can be easily updated with new data at any future date. This method requires some elaborate GIS programming that allows the traffic data to be merged with the highway network.

4.2.1 Data Source

Data for developing the traffic flow maps were obtained from the states. Every state collects traffic count data at both permanent and temporary counting stations for each road link. The latest version (1999) of highway performance monitoring system (HPMS) data was used as the initial source of traffic information. Traffic data are reported by individual states according to a format established by FHWA. In order to ensure that the most recent, comprehensive, and accurate traffic count data are used in developing the truck flow map, efforts were made to contact all 48 states. Data were received in both electronic format and hard copies. Table 4-1 shows the types and format of data obtained from the various states.

Table 4-1. Summary of Data Sources and Formats by State.

State	Data Format / Comments
Alabama	Electronic data; access format; for Interstates only
Arizona	3 electronic data files; dbf, txt, xls. Same as HPMS data.
Arkansas	2 xls data files
California	xls data files; no truck data
Colorado	Electronic data files. Data in right format
Connecticut	1999 Traffic Volume Book; no truck data; use HPMS data and hard copy to check.
Delaware	2 xls data files; hardcopy of truck data. Use HPMS truck data.
District Of Columbia	Turning movement data; use HPMS data
Florida	Data received on CD
Georgia	2 xls files (1999 and 2000 data) ; use HPMS.
Idaho	pdf format flow maps for traffic and truck--ok; 4 pdf files; Don't publish a book.
Illinois	No electronic data. Hardcopy state flow map. Use HPMS and verify with hard copy.
Indiana	No electronic data. 2000 Traffic Flow Book. Use HPMS and verify with hard copy.
Iowa	Sent book. No electronic data. Use HPMS and verify with hard copy.
Kansas	MS Access file and GIS flow maps.
Kentucky	Data from website in dbf format. Don't publish a book.
Louisiana	Data in database format. No truck data. Use HPMS truck data.
Maine	PDF file, data on CD, and traffic book.
Maryland	Data in xls format. No truck data. Use HPMS data
Massachusetts	Station based traffic data. Data in xls format. No truck data.
Michigan	2 files in pdf and one dbf format. Check mile point decimal place. Can't open file.
Minnesota	4 files in ASCII format. Convert to excel or access file.
Mississippi	Data in dbf format. Same as HPMS data.
Missouri	Data in dbf format. No truck data. Use HPMS data.
Montana	Data in xls format.
Nebraska	GIS flow map.
Nevada	PDF flow maps (traffic and truck data). Dbf format provides the station based traffic data.
New Hampshire	Data in xls format. No truck data. Use HPMS.
New Jersey	Data provided by highway functional class. Xls and pdf formats. No truck data. Use HPMS
New Mexico	Traffic book.
New York	2 zip files after work order was received.
North Carolina	No electronic data; flow maps and hardcopy of data.
North Dakota	No electronic version. 1998 Traffic Book and Flow Maps. Use HPMS and hard copy to confirm.
Ohio	Data received via e-mail. In right format
Oklahoma	No electronic data; Traffic Book and Flow Map. Use HPMS and hard copy to confirm.
Oregon	xls data file and pdf file.
Pennsylvania	Downloaded pdf file from website.
Rhode Island	Same as HPMS data. Use HPMS data
South Carolina	Same as HPMS data. Use HPMS data

State	Data Format / Comments
South Dakota	xls data file.
Tennessee	Xls data file. No truck data. Use HPMS data as well.
Texas	Traffic book/flow maps; no electronic data. Use HPMS and book to check.
Utah	2 xls and 3 pdf data files.
Vermont	4 data files in Quattro Pro format; traffic book.
Virginia	xls data file and Traffic book.
Washington	Xls and pdf data files and annual report.
West Virginia	Data xls format. Only Interstate data.
Wisconsin	No electronic data. 1999 Traffic Book. Use HPMS data and hard copy to check.
Wyoming	ASCII format, 5 files; 1999 Vehicle Miles Book.

Note: Where only hard copies of traffic flow maps or vehicle classification books are available, used HPMS data and state data to check truck volumes.

The format and quality of traffic data varied from state to state. Some states have traffic data in a format that is consistent with NHPN data structure. A few states provided only hard copies of traffic classification publications, which had to be manually keyed into the GIS network database. A few other states provided both hard copies of traffic classification/volume publications or traffic flow maps and electronic flow maps. Some states (e.g., CT, IL, IA) directed that information in the HPMS database be used in developing the traffic flow map and to use the hard copies to check the accuracy of information in the HPMS database. Some states have their traffic data on the Internet that can be easily downloaded (e.g., WA, PA). However, the format of presenting information on the Internet varies by state.

Electronic data were provided in pdf, ASCII, MS Excel or Access formats, which were generally usable in merging with the network with minimal reformatting. It was necessary to prepare data in a uniform format that could be merged with the highway network. MS Excel SQL was used to format the data.

4.2.2 Data Input

Having developed the network and reformatted the traffic data, the next step in developing the traffic flow map is to merge the data to the network. Figure 4-1 summarizes the processes involved in preparing and merging traffic data from the states with network data derived from the NHPN. The primary objective of the data conversion is to ensure consistency between the traffic data from the states and the network.

The following are some challenges encountered in merging state-provided traffic count data and other capacity-related data to the freight analysis highway network.

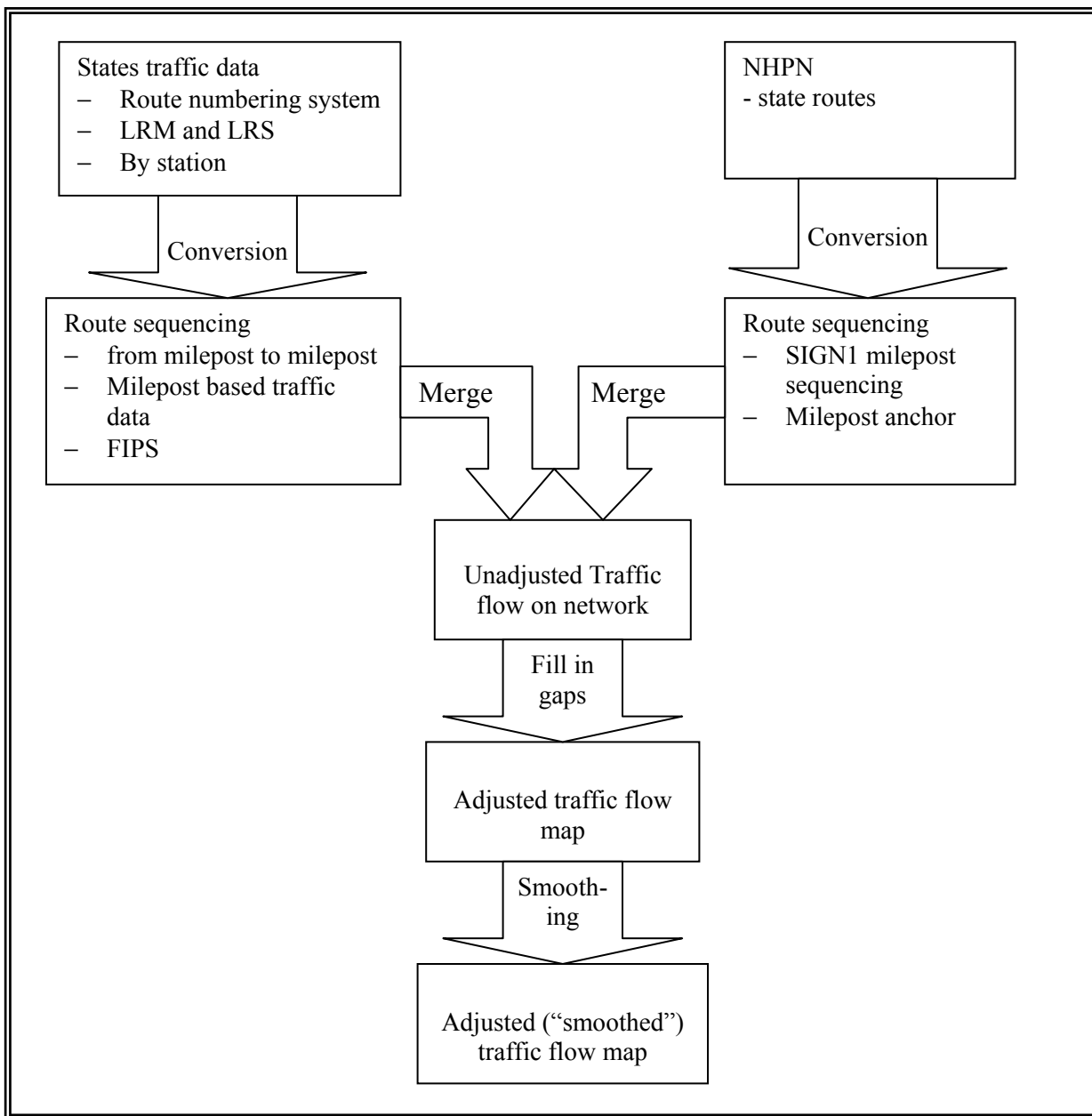


Figure 4-1. Methodology of Merging Traffic Data to Network.

4.2.2.1 Inconsistencies in Route Naming and Numbering

In order to merge the traffic data with the freight analysis network, a data collection route sequence was established to ensure homogeneity among states. The direction and system of numbering of routes (which is the basis of traffic data collection) is different among states. States use different linear referencing methods (LRMs) and therefore different route naming systems. Some states linear reference their highways in the standard format i.e., south to north

and west to east, while others linear reference their highways in the opposite direction. Furthermore, there are no consistent county or state road naming conventions. In order to address this problem, a route sequencing programming code was developed. The purpose of route sequencing is to ensure that a unique identification route number is used, and that it is continuous across county and state boundaries and consistent with the system used in NHPN Version 3.0. This process was a major and important step for merging traffic data with the freight analysis network. Some states provided traffic data in HPMS linear referencing system (LRS) sequence. In such a case, sequencing was based on HMPS route inventory information. In other situations, sequencing was based on highway sign information. Therefore, sequencing across each state was accomplished on an individual state basis.

The traffic data were then converted into a milepost-based or route number system that is homogeneous to all states. The converted data also include the state Federal Information Processing System (FIPS) code, which serves as the primary key for merging data with the highway network. After the sequencing was established, traffic data were merged with the network database to obtain an unadjusted traffic flow map. Merging was achieved with routines available in TransCAD software application [12].

4.2.2.2 Number of Segments in State Data and NHPN Links

Instances occurred where the number of segments for a highway link in the state data was different from the NHPN. In merging traffic data to the network, the concept of aggregation was used, which allows a traffic value to be inserted where differences in the number of segments occur. For example, if a link in the state's data has two segments but only one segment in NHPN, the value recorded for the NHPN link was the average of the values for the two segments indicated in the state data.

4.2.2.3 Gaps in Traffic Data

Due to differences in the construction and definition of links in NHPN and the state highway networks, gaps in traffic data were observed after merging the converted state-provided traffic data to the network. It was necessary to develop additional GIS programming code to identify and fill in the gaps in the network for which there were no traffic data. The value was either the average of two adjoining segments (for a continuous link with no node), or the value for the segment immediately preceding it (for blank segments with branch-off link following).

4.2.2.4 Quality Assurance

The purpose of quality control was to check the accuracy of merged data manually. As a quality control check, the values were manually reviewed to ensure that there are no abrupt changes in traffic volume data. If a difference in traffic value from one link to the next was greater than 20 percent, the original state data were consulted to verify if the accurate value had been merged to the network. The state-provided data served as the reference. If the values compared well with the state data, then the more common value for that link was used to ensure continuity in the

traffic volume. These abrupt changes could result from the merging process where aggregation was used. This smoothing process serves as reasonableness check of the traffic data merged with the network. The primary objective of the data conversion is to ensure consistency between the traffic data from the states and the network.

4.2.4 Truck Flow Map

The products of merging the traffic data to the highway network are GIS-based traffic flow maps. Figures 4-2 and 4-3 show the total annual average truck traffic (AADTT) and annual average daily traffic respectively, for the 1998 traffic data. Once the traffic data have been merged with the network, checked, and smoothed, the framework has been established for merging other data collected to the state LRS with the freight analysis highway network.

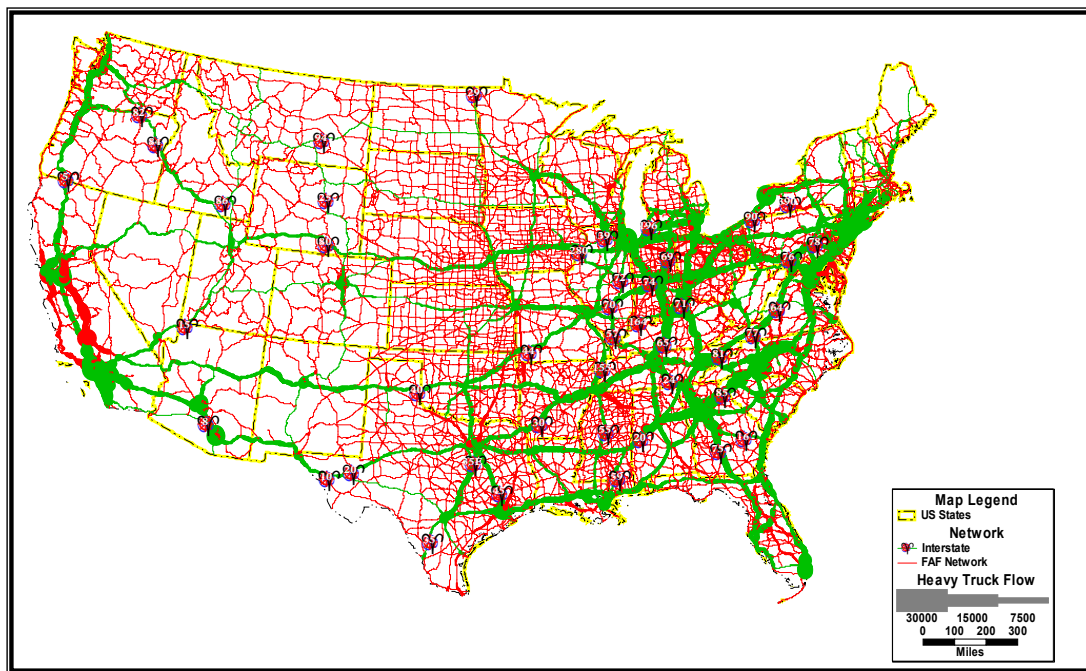


Figure 4-2. Annual Average Daily Truck Traffic (AADTT) Flow Map – 1998 Data.

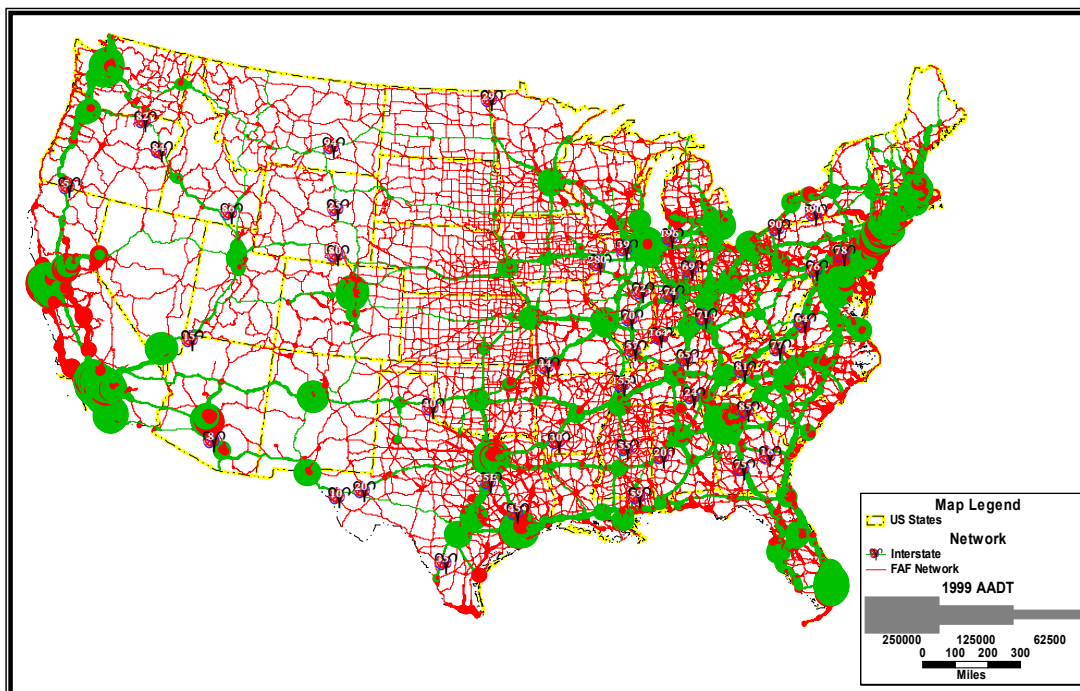


Figure 4-3. Average Annual Total Traffic (AADT) Flow Map – 1998 Data.

4.3 INPUT HPMS DATA

The HPMS database is maintained by the FHWA using data supplied by the states and updated on a regular basis. States are required to report certain information for every segment of public highways and roadways. For example, the states must report mileage, average annual daily traffic (AADT), route number, jurisdiction, functional classification, number of lanes, and pavement condition for each segment. In addition, each state must report information for a statistically valid sample of roadway sections selected on the basis of functional classification. The highway sections with additional information are called sample segments as opposed to the former segments called universe segments. The additional data required for the sample segments include detailed pavement information, geometric data, service flow ratio, truck percentage, traffic, capacity data, and environmental data.

Many needs studies ignore universe records and use only sample records by appending an expansion factor to each sample record to estimate total needs. Doing so ignores all of the specific segment information contained on the universe records. In addition, with such an approach, one database record does not correspond to an actual segment of highway but to a portion of many highway segments scattered all over the state. For this study, all records, universe and sample, are required to perform the network analysis. Data items needed but not available on the universe records were defaulted based on the sample records for the same route and the same functional classification within each state. For example, the highway capacity attribute is not available on universe records.

4.3.1 HPMS Data Input Methodology

As noted above, HPMS reports two sets of data: (1) universe data where data elements are available for every section of the FAF network and (2) sample data where data elements are available for randomly selected highway sections.

The smallest unit of a highway network can be defined by the physical length of an arc bounded by two nodes. For network analysis this arc is called a link. A unique LRS route may consist of one or more links. Each HPMS data element is reported by the LRS route's milepost value, and the smallest section of a set of data elements determines its extent. For example, the change of traffic volume for a given road section is not as frequent as pavement condition. Therefore, the extent of the smallest unit of an HPMS data element for this case would be defined by the length of the pavement section where condition changes and all other roadway attributes are also reported for this section.

The HPMS data were merged with the FAF network by averaging all of the smallest units of the HPMS data elements that belong to an FAF link as appropriate. Some data elements, for example, "Terrain," are based on the qualitative assessment of the HPMS link and do not allow for averages. For these types of data elements, the values are directly carried over using a pre-defined condition. Table 4-2 shows the capture methodology and applied conditions for the HPMS data elements.

Table 4-2. HPMS Data Elements Used in the Study.

HPMS Item No.	Variable Description	Methodology	Condition
9	Rural/Urban Designation	Carry Over	Max (of Codes)
14	National Highway System	Carry Over	Max (of Codes)
23	Designated Truck Route	Carry Over	Max (of Codes)
24	Toll	Carry Over	Max (of Codes)
28	AADT	Average	
30	Number of Lanes	Carry Over	Min (of Values)
35	Measured Pavement Roughness	Average	
36	Present Serviceability Rating	Average	
HPMS Sample Data Elements			
59	Type of Terrain	Carry Over	Max (of Codes)
63	Speed Limit	Carry Over	Min (of Values)
65A	Percent Single Unit Trucks	Average	
65B	Percent Combination Trucks	Average	
66	K-Factor	Average	
68	Peak Capacity	Average	
69	Volume/Service Flow Ratio	Average	
73	Future AADT	Average	
74	Year of Future AADT	Carry Over	

4.3.2. Spreading HPMS Section Data to FAF Network's Link

The data capture methodology applied to the universe and the sample sections are similar if LRS matching route is available for both FAF link and HPMS sections. However, an additional data spreading technique is applied for a sample data section. The spreading technique is based on the assumption that an HPMS "sample" data element of a unique LRS route (using LRSKEY) is similar for that entire route of unique LRSKEY. If no sample data element exists for a route with a unique LRSKEY, then the corresponding FAF link is left empty. The output is a database containing unique IDs of each FAF network link and its associated HPMS data elements where applicable.

4.4 DATA PREPARATION

This section describes the development of annual average daily truck origin and destination (O-D) matrices from FAF annual freight forecasts. The FAF freight forecasts are reported in annual tonnage by each county O-D pair. This section describes the methodology in converting annual freight tonnage to daily truck trips and expands those trips from county O-D pairs to equivalent sub-centroid O-D pairs using appropriate freight distribution for each O-D pair.

4.4.1 Conversion of Commodity Flows to Truck Vehicle Movements

The purpose of this step is to develop the demand freight flow county origin-county destination (O-D) matrix. This involves converting commodity flow matrices into truck trip matrices based on knowledge and assumptions relating to truck payload characteristics by commodity type. This information is required for base year 1998 and forecast years 2010 and 2020. The conversion of commodity flows from tons to truck trips involves four steps: (a) allocating commodities to truck body types that are used to transport these commodities, (b) developing truck configurations for each truck body type, (c) converting the commodity tonnage into truck trips, and (d) estimating the percent of empty truck trips. These steps are discussed in the following sections.

4.4.1.1 Allocate Commodity to Truck Body Type

"The 1998 FAF Database was used as the main data source. As described in "The Development of the Freight Analysis Framework Database and Forecast", a sister report to this document, the database displays county-to-county (FIPS-to-FIPS) commodity flows by 4-digit Standard Transportation Commodity Classification code (STCC). Truck tonnage was extracted for truckload (TL) tons, less-than-truckload (LTL) tons, and private truck (PVT) tons. The TL and PVT tons were combined as representative of total TL traffic, while the LTL tons were kept separate for special processing.

The total tonnage of freight was allocated to various truck body types. Based on information from 1987 and 1992 Truck Inventory and Use Survey (TIUS) and 1997 Vehicle Inventory and Use Survey (VIUS) analysis [20, 21], seven truck body types were selected: dry van, reefer, flat,

automobile, bulk (including hoppers and open-top gondolas), tank, and livestock. These body types were selected to represent the common truck body types operating on the highways. For each four-digit STCC (two-digit where four-digit not available), distributions of traffic by specific body types were developed. Some STCCs were attributed to one body type (STCC 2516 – Children’s Furniture – allocated 100% to Dry Van), while others were distributed to two or three different body types. This allocation was developed using the 1997 VIUS data. The final allocation of commodity to truck body type was then reviewed and adjusted based on input from industry experts.

4.4.1.2 Develop Distributions by Truck Configuration

The next step in the allocation process involved the development of distributions by truck configuration for each body type. Information from VIUS was used to develop the various allocations. For the TL portion of the analysis, truck body types were classified into 12 different truck configurations based on the number of trailers and axles. These configurations were single unit trucks, tractor semitrailer combinations, and tractor double trailer combinations. Configuration distributions were then developed for each body type based on the state of origin of the traffic.

For the LTL portion of the database, a separate configuration distribution was developed based on information obtained from VIUS. This too was based on state of origin, but did not include the secondary analysis of commodity. The final distributions were then coded as SQL tables, and the body type and commodity enhanced database was disaggregated based on these truck configurations. The database contained origin and destination FIPS, STCC4, body type, configuration, and allocated tons.

4.4.1.3 Convert Tons to Truck Trips

In converting the tonnage into trips, a series of national average payload weight distributions were developed for each body type, STCC, and configuration using data derived from VIUS. These average weight distributions became the basis of an SQL factor table that was used to convert the total tons in each O-D pair, STCC, body type, and configuration record to a specific number of loaded movements.

4.4.1.4 Estimate Empty Truck Percent

The freight traffic data were derived from commodity movements and as such do not include “empty trucks.” Empty trucks affect the capacity of the highways and therefore must be accounted for in the capacity analysis. A limitation of commodity-based models is their inability to model empty truck trips [22, 23]. Approaches for addressing this limitation include adjusting the matrix during calibration or using complementary models to depict empty trips as a function of routing choices that a commercial vehicle operator can make [23]. In a recent study [9] it was assumed that the most efficient truckers operate at 20 percent empty or less. For the analysis of empty loads, a series of backhaul percentages was developed based on truck body-type and

configuration derived from data in the VIUS analysis. These represented the relative percentage of empty movements versus loaded movements for each body type and configuration alternative. This methodology was selected because of the interchangeability and flexibility of the most common truck body type (i.e., dry van) would make it difficult to develop empties by commodity. These percentages were then applied to each of the loaded movements as an estimate of empty truck trips. “In effect, empty movements were depicted as partial reverse trips, which is a simplified assumption; in practice, the direction of an empty trip frequently is independent of the loaded direction.”

4.4.2 Refinement Truck Trips O-D pairs

The truck trips O-D matrices described in Section 4.4.1 assume a maximum gross vehicle weight (GVW) of 80,000 lbs with mean payloads of 5,980 lbs for single unit trucks, 21,100 lbs for tractor-semitrailer combinations, 27,750 lbs for double trailer combinations, and 9,700 lbs for triples. These values are significantly lower than the average payload derived from the 1997 VIUS database [13]. Based on the analysis of VIUS data [21], the average payloads for those truck types are 8,900 lbs for single unit trucks, 36,650 lbs for tractor-semitrailer combinations, 39,200 lbs double trailer combinations and 37,200 lbs for triples. The average payloads by truck type were first developed for each of the four regions used for the Comprehensive Truck Size and Weight Study [18] and took account of heavier payloads (and therefore fewer trips per ton) allowed under locally varying regulations. The average payloads by commodity type were weighted by the average annual tonnage moved for each commodity. These weighted values were then used to calculate the average payload for each truck type. In order to correct for the discrepancies in the average payloads, correction factors were developed and applied to the truck trips in the O-D matrices. The correction factors are based on the differences between the refined average payloads and those derived in Section 4.4.1. These correction factors were applied to the truck trip O-D matrices. By applying the correction factors, the numbers of truck trips between O-D pairs are reduced. Table 4-3 compares the average payloads by commodity type and truck type before and after refinement.

4.4.3 Expansion of County O-D Pairs to Freight Analysis Zone Sub-Centroids

The output of Section 4.4.2 is a revised set of truck trip O-D matrices of 3,111 by 3,111 elements as follows:

- 1998 base O-D
- 2010 forecast O-D – base, high, and low projections
- 2020 forecast O-D – base, high, and low projections.

Table 4-3. Comparison of Average Payloads by Truck Type.

Commodity	STCC	Single Unit Trucks			Semi Trailer			Double Trailers			Triples		
		Initial	Refined	% Diff	Initial	Refined	% Diff	Initial	Refined	% Diff	Initial	Refined	% Diff
Farm products	1	6.0538	12.2170	-101.81	21.3450	39.6540	-85.78	28.0836	49.3490	-75.72	9.8207	41.2500	-320.03
Logs & other products	8	7.6979	12.5140	-62.56	27.1417	46.8030	-72.44	35.7104	60.8948	-70.52	12.4878	61.5000	-392.48
Fresh Fish or Marine Product	9	6.0538			21.3450			28.0836			9.8207		
Metallic Ores	10	8.6259			30.4137			40.0153			13.9932		
Coal	11	8.6259			30.4137			40.0153			13.9932		
Mining products	14	8.6259	20.5330	-138.04	30.4137	45.3358	-49.06	40.0153	20.5478	48.65	13.9932		100.00
Ordinance or Accessories	19	7.5846			26.7424			35.1850			12.3041		
Processed foods	20	6.5434	7.7140	-17.89	23.0711	33.5216	-45.30	30.3547	35.8630	-18.15	10.6149		100.00
Tobacco Products	21	6.1817			21.7958			28.6768			10.0282		
Textile mill products	22	6.0538	4.7130	22.15	21.3450	30.2060	-41.51	28.0836	38.2855	-36.33	9.8207		100.00
Apparel or Related Products	23	4.5851			16.1665			21.2703			7.4382		
Lumber & fab. products	24	7.6979	8.3190	-8.07	27.1417	37.1468	-36.86	35.7104	48.0590	-34.58	12.4878		100.00
Furniture of hardware	25	4.1869	3.9630	5.35	14.7624	28.2844	-91.60	19.4229	34.9770	-80.08	6.7921		100.00
Paper products	26	6.7991	7.3530	-8.15	23.9728	34.3436	-43.26	31.5411	31.7543	-0.68	11.0298	12.5000	-13.33
Printed Matter	27	5.0710			17.8798			23.5244			8.2264		
Chemicals	28	6.1926	10.3780	-67.59	21.8345	38.8724	-78.03	28.7276	50.2670	-74.98	10.0459		100.00
Petroleum	29	7.8952	12.4590	-57.81	27.8374	47.2656	-69.79	36.6256	52.2540	-42.67	12.8078		100.00
Plastics &/or rubber	30	3.3831	5.8340	-72.44	11.9285	32.6092	-173.37	15.6943	29.3588	-87.07	5.4882	54.0000	-883.92
Leather or Leather Products	31	4.1504			14.6336			19.2534			6.7329		
Building materials	32	5.2464	18.7740	-257.85	18.4981	42.1238	-127.72	24.3380	48.4885	-99.23	8.5109	62.4000	-633.18
Primary metal products	33	7.2960	6.5310	10.49	25.7248	37.8534	-47.15	33.8460	54.2457	-60.27	11.8358		100.00
Fabricated metal products	34	5.2354	4.9580	5.30	18.4595	35.2550	-90.99	24.2871	26.1170	-7.53	8.4931		100.00
Machinery	35	3.9750	6.5000	-63.52	14.0153	33.1470	-136.51	18.4399	35.3570	-91.74	6.4484		100.00
Electrical Equipment	36	4.7239			16.6560			21.9143			7.6634		
Transportation equipment	37	4.1321	5.3190	-28.72	14.5692	33.2698	-128.36	19.1687	31.9243	-66.54	6.7032	12.5000	-86.48
Instrum, Photo equip, optical	38	3.5512			12.5210			16.4739			5.7609		
Misc. products of manufact.	39	5.4181	5.5920	-3.21	19.1036	33.4418	-75.06	25.1345	28.9207	-15.06	8.7895		100.00
Scrap, refuse or garbage	40	5.9807	13.2310	-121.23	21.0873	36.6138	-73.63	27.7446	45.8837	-65.38	9.7022		100.00
Mixed Cargo	41	5.8748	5.5480	5.56	20.7138	33.3048	-60.79	27.2531	32.3916	-18.85	9.5303	16.0947	-68.88
Average payload		5.9807	8.9018	-50.53	21.0873	36.6332	-80.38	27.7446	39.1994	-47.20	9.7022	37.1778	-63.07

BATTLE

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As described in Chapter 3.0, each county centroid or sub-centroid is assigned to a single or multiple network nodes with appropriate freight shares. This resulted in 3,494 node based O-D pairs from the original set of 3,111 county centroid O-D pairs. Prior to assigning this O-D matrix to the network, this matrix must be indexed with each network node's unique identification number and then expanded to the 3,494 O-D pairs. This is done by creating a look-up table that identifies the linkage among county centroid/sub-centroid with the network nodes and freight share distribution for these nodes. A Visual Basic (VB) program is written to create the expanded truck trips O-D pairs. The final O-D matrix contained 3,494 x 3,494 elements including external stations.

4.5 LINK ATTRIBUTES

This step defines the attributes of the highway links that are necessary for freight assignment. These include travel impedance functions, free flow speeds, and link capacities. These attributes determine the capacity-related performance characteristics of each link.

4.5.1 Impedance Function

Travel time on a given link is estimated by dividing its length by the travel speed on that link. Therefore, travel time for a given link changes as the travel speed fluctuates. The speed of a given link can also be affected by roadway type or other conditions as indicated earlier. Consequently, this reduced speed would introduce a penalty to the initial link travel time. Thus the impedance function of a link can be mathematically expressed as:

$$T_j = \frac{L_j}{S_j} r_j + f_j \quad (4-1)$$

where T_j = the link free flow travel time
 L_j = the length of link j in miles
 S_j = the free flow speed on link j in miles-per-hour
 r_j = travel time adjustment factors, which is a function of the number of lanes, urban bypass, traffic restriction, truck route designation, tolls, and the link reliability
 f_j = the penalty.

4.5.2 Free Flow Travel Speed

The free flow speed (FFS) of a link can be defined as the average speed of a vehicle on that link, measured under low-volume conditions when drivers tend to drive at their desired speed and are not constrained by control delay. The FFS for the FAF network link is determined by the following equations from the NCHRP Report 387, "*Planning Techniques to Estimate and Service Volume for Planning Application*," [24].

$$\text{FFS} = (0.88 * \text{Link Speed Limit} + 14); \text{ for speed limits } > 50 \text{ mph} \quad (4-2)$$

$$\text{FFS} = (0.79 * \text{Link Speed Limit} + 12); \text{ for speed limits } \leq 50 \text{ mph} \quad (4-3)$$

The link speed limit is obtained from HPMS data. The FAF network link with missing speed limit values are assumed based on the following four physical characteristics of highway segments:

1. Access control for the given highway segment
2. Median type
3. Quality of the roadway pavement (paved vs. unpaved)
4. Classification of the highway segment within or outside of an urban boundary.

Assumed speed limits for the combinations of these four characteristics are given in Table 4.4.

Table 4-4. Speed Limits (mph) for Missing HPMS Speed Data.

Functional class	Pavement type	Fully Controlled		Partially Controlled		Uncontrolled	
		With Median	Without Median	With Median	Without Median	With Median	Without Median
Rural	Paved	65	60	65	55	65	55
	Unpaved	25	15	20	15	15	10
Urban	Paved	55	45	45	35	35	25
	Unpaved	15	10	10	10	10	10

4.5.3 Travel Impedance

The total impedance of a selected highway path (i.e., truck route), denoted as T , can be expressed mathematically as the sum of all link impedances (i.e., all T_j). Assuming there are n links on the selected path, the impedance of the selected path is then equal to:

$$T = \sum_{j=1}^n T_j \quad (4-4)$$

The adjustment factors as denoted by r_j in equation 4-1 were estimated based on several road characteristics or criteria. The total adjustment factor, r , is a mathematical product of all adjustment factors that meet the criteria described below.

Number of lanes: when there are 4 or more lanes of traffic in both directions, the link travel time is reduced by 2% ($r = 0.98$).

Urban bypass: when the given link is on an urban bypass, its travel time is increased by 4% ($r = 1.04$).

Truck restrictions: when the link has known truck restrictions, the link travel time is increased by 60% ($r = 1.6$). For highway segments that prohibit trucks carrying hazardous materials, the travel time of the link is increased by 5% ($r = 1.05$).

Truck route designation: if a link is on a federal or state designated truck route, the given link's travel time is reduced by 1.5% ($r = 0.985$).

Tolls: when the given link is a toll road or bridge, its travel time is increased by 2.5% ($r = 1.025$).

Reliability: this factor is based on the assumption that travel time on links with interstate designations are more predictable to the drivers than the other links. If the given link is on the rural interstate, then the travel time is reduced by 10% ($r = 0.9$). For an urban interstate, travel time is reduced by 5% ($r = 0.95$).

For example, an FAF link is a multi-lane (4 or more) urban bypass with an urban interstate designation. The link is also part of a toll road and part of a federally designated truck route. The resultant adjustment factor of r for free flow travel time for this particular link can be estimated as:

$$\text{Adjusted } r = r_{\text{number of lanes}} \times r_{\text{urban bypass}} \times r_{\text{truck route}} \times r_{\text{tolls}} \times r_{\text{urban interstate}} \quad (4-5)$$

$$\text{Adjusted } r = 0.98 \times 1.04 \times 0.985 \times 1.025 \times 0.95 = 0.978 \quad (4-6)$$

The final adjustment of the travel impedance cost was done during the network calibration process under the FAF assignment. The network calibration was done by adjusting the link cost, capacity, or both, so that the link flow was as close as possible to the baseline traffic. The baseline is the truck traffic data on the links that are derived from the state's actual truck classification counts. The size of the network does not allow us to balance baseline truck flow with assigned truck trip (using FAF O-D freight Matrix) for each link. However, efforts were made to adjust the nation's truck flow pattern for the major route.

It should be noted that travel impedance cost is not a simple function of travel time only, and therefore caution must be taken to convert the travel cost to equivalent speed.

4.5.4 Link Capacity - HPMS

The capacity of a given link can be defined as the a maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time period under given roadway, geometric, traffic, environmental, and control conditions; this capacity is usually expressed as vehicles per hour, passenger cars per hour, or persons per hour.

The link capacity of the FAF network is obtained and estimated from the HPMS sample sections where possible. The general procedures for estimating highway capacity for 2-lane facilities,

multilane facilities—divided and undivided, freeways by design are included in Appendix N of the HPMS Manual [11].

The capacity value reported in an HPMS sample section is for one direction on multilane facilities and for both directions on 2- or 3-lane facilities and is expressed as maximum service flow rate at Level of Service (LOS) E in passenger car per hour direction (one direction for multilane & both directions for 2- or 3-lane highways). The HPMS capacity is also called “practical capacity,” because the reported capacity has been reduced to account for the presence of heavy vehicles.

Since FAF truck assignment will be based on average annual daily truck O-D matrices, HPMS capacity values need to be expanded to one directional maximum link capacity for a 24-hour period with no adjustment being made for heavy vehicles. The mathematical expression is:

$$\text{FAF link Capacity} = ((\text{HPMS Link Capacity}_{(2\text{-lanes})} \div 2) \div f_{HV}) \times 24 \text{ vehicles/direction/day} \quad (4-7)$$

Where: f_{HV} = adjustment for heavy vehicles and can be expressed as

$$f_{HV} = (1.00 / (1.00 + (P_T \times (E_T - 1.00)))) \quad (4-8)$$

Where: P_T = peak percent truck (Single and combination)
 E_T = passenger car equivalents for trucks and buses.

For example, if HPMS reports a link capacity of 3000 vehicles per hour (vph) for a segment on a 2-lane facility with a truck adjustment factor of 0.9, then the FAF capacity analysis network link will report a daily link capacity of 40,000 vehicles per direction per day.

4.5.5 Free Flow link Capacity – HCM Table

For links where HPMS capacity values are not known, the practical capacity of each link was developed using HCM 2000 methodology (Exhibit 12-11 and Exhibit 12-15). Since the capacity values under these exhibits are based on constant (5%) truck percent, the passenger equivalent capacity is first estimated using the following formula:

Capacity for Passenger car only is:

$$C = 3770 * (1 + 5\% * (\text{PCE}-1)) \text{ lane/hour} \quad (4-9)$$

This capacity is then adjusted using the baseline truck percentage as follows.

$$C_{\text{adjusted}} = (C / (1 + \text{AADTT1999}/\text{AADT1999} * (\text{PCE} - 1))) * \text{HPMS_LANE, link/hour} \quad (4-10)$$

4.6 FREIGHT ASSIGNMENT

4.6.1 Assignment Algorithm

Traffic assignment models are used to estimate the flow of traffic on a network to establish the traffic flow patterns and analyze congestion points. Intra-zonal truck movements (local traffic) are not included in the assignment process. Even though the highway capacity analysis is focused on a detailed assessment of freight flows and impacts on the highway system, highway bottlenecks are highly dependent on the interaction of total truck and passenger car traffic. Therefore passenger traffic is a key consideration in the assignment process. In this regard, freight flows are assigned with passenger traffic and non-freight (local) trucks pre-loaded on the freight analysis network. Detailed demand analysis of passenger traffic was not performed as part of the study. Rather, current passenger traffic counts and future growth rates as included in the HPMS database are used. Freight truck traffic demand analysis was carried out under the following assignment scenarios:

Capacity Constrained – Capacity constrained assignment is constrained by the highway network’s current capacity. The Stochastic User Equilibrium (SUE) traffic assignment procedure in TransCAD was used for this scenario. SUE is a generalization of user equilibrium (a modified capacity constraint approach) that assumes travelers may not have perfect information concerning network congestion and delay and/or may perceive travel costs in different ways; therefore, they may change the travel pattern by taking alternate routes as the network (or a specific link of a network) gets congested.

Capacity Unconstrained – In unconstrained assignment, freight traffic is assigned to the transportation network with no capacity constraints. The All-or-Nothing (AON) procedure will be used for this scenario. Under AON assignment, all traffic flow between an O-D pair is assigned to the shortest path connecting the origin and destination. This model utilizes only one path between every O-D pair, even though there may be other paths with the same or nearly the same travel time or cost. Traffic is assigned to links without consideration of whether there is adequate capacity or heavy congestion.

First the 1998 base year truck trip O-D matrix is assigned to the FAF highway network. This was followed by calibration.

4.6.2 Freight Assignment Calibration

The purpose of this step is to calibrate the base year demand flow so that the assigned truck trips match the actual truck volumes in the network as closely as possible. The calibration ensures that differences or discrepancies between the actual traffic flows and those estimated from freight O-D data are minimized. This is an iterative process that involves comparing assigned

demand truck traffic flow with baseline flows. The output of this task is a calibrated 24-hour baseline O-D truck trip matrix for the entire freight analysis network.

The challenge in calibrating network assignment stems from the fact that the truck freight flow volumes and the facility traffic counts derive from different sources. They each combine primary data with processing and interpretative steps, as this document and its sister report have described. They can be subject to definitional differences in what is regarded as a truck: the flow data is oriented to commercial movement of goods, and the facility counts to vehicle activity, whose inclusiveness can change according to the needs and practices of recording jurisdictions. Reconciling these flows and minimizing their differences is a major challenge.

The calibration effort involves adjusting the link cost or capacity of the network or both so that the assigned link flows are as close as possible to the baseline flows. The size of the network makes it impossible to balance the flows link by link. However, efforts were made to balance the assigned flows to the baseline flows as closely as possible for the major route (mostly interstate). Table 4-5 summarizes the results of the calibration effort. The table shows a breakdown of the percent differences between the baseline (i.e., data from the state counts) and assigned traffic volumes. Overall, 15% of the total FAF highway network mileage shows assigned traffic volumes greater than the traffic volumes from the baseline traffic.

Table 4-5. Results of Calibration.

% Change from Baseline	Under	Over	Total
>= 0, < 25%	8.7%	5.2%	13.9%
>= 25%, < 50%	14.6%	3.1%	17.8%
>= 50%, < 75%	21.7%	2.0%	23.7%
>= 75%, < 100%	31.6%	1.2%	32.8%
>= 100%	8.2%	3.7%	11.9%
Total	85%	15%	100%

Once the network has been calibrated, the forecast truck trip matrices for 2010 and 2020 were assigned to the network. Figures 4-4 through 4-6 show the assigned freight truck flows on the network in 1998, 2010, and 2020 for the base case. The next major step is to determine the highway capacity-related performance measures resulting from the assigned freight traffic.

The summary sheet of the input and output parameters for the TransCAD assignment process is shown in Figure 4-7. The outputs of the assignment process are used in the capacity analysis presented in Chapter 5 of this report.

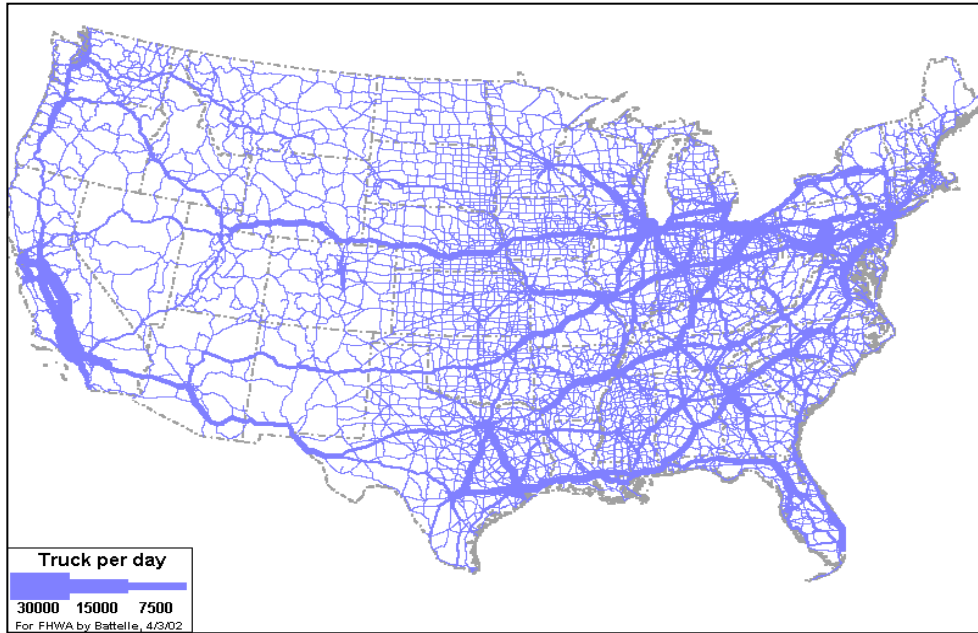


Figure 4-4. Assigned Truck Flows – 1998.

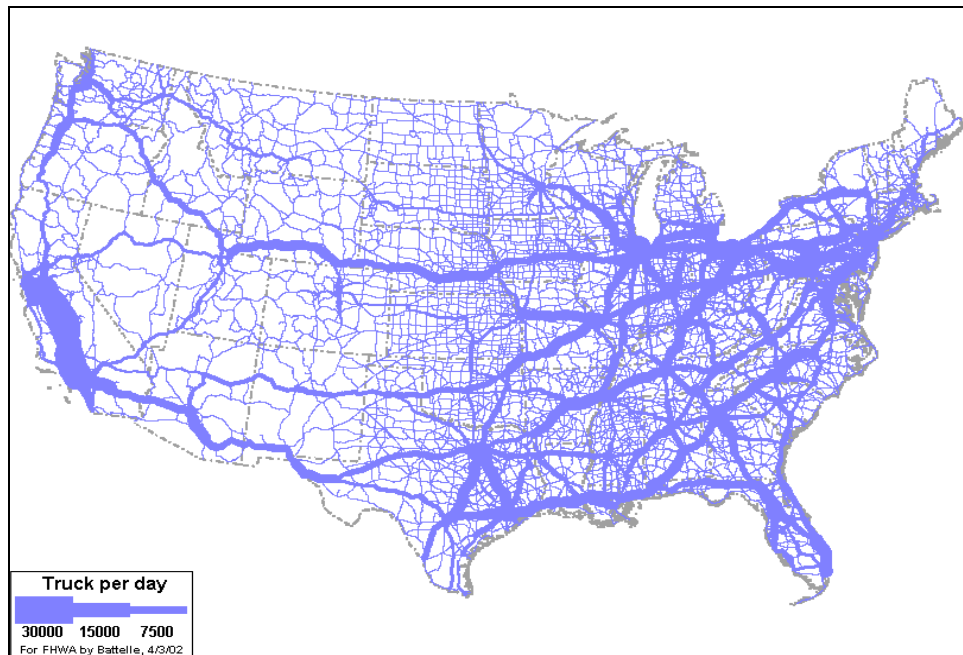


Figure 4-5. Assigned Truck Flows – 2010.

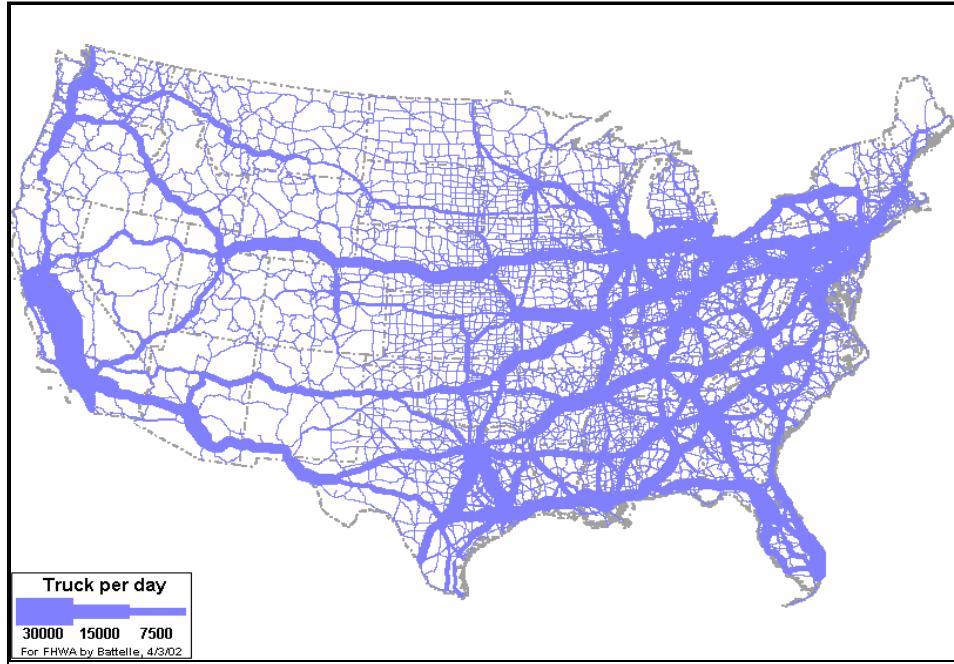


Figure 4-6. Assigned Truck Flows – 2020.

Starting Procedure Traffic Assignment on April 10, 2002 (01:53 PM)		
Iteration	Relative Gap	Max. Flow Change
1	0.006893	14801.256854
<u>INPUT FILES</u>		
Network	: F:\FAFCapacity\GISdata\Network\FAFNET.net	
Demand Table	: F:\FAFCapacity\1998OD\TCMATRIX\BASE10_OD.mtx	
<u>OUTPUT FILES</u>		
Flow Table	: F:\FAFCapacity\analysis\Assignment_April10\B10.bin	
<u>LINK FIELDS</u>		
Cost	: Cost_TT	
Capacity	: Capacity_Dir	
Preload Flow	: Preload10	
Probability Function	: Normal	
<u>OD DEMAND</u>		
OD Pairs	:	12190572
Non zero OD Pairs	:	4173333
Demand	:	1434852.82
Intranodal Demand	:	83339.63
Skip Values Below	:	0.010000
Cells Skipped	:	2514464
Flow not Assigned	:	5052.27
<u>PARAMETERS</u>		
Method	: Stochastic User Equilibrium (with Preload)	
Maximum Iterations	:	20
Iterations	:	2
Conv. Criteria	:	0.01
<u>Running Results</u>		
Relative Gap	:	0.00689313728
Max Flow Change	:	14801.2569
Equilibrium reached	:	Yes
Total V-Time-T	:	5.5032698e+009
Total V-Dist-T	:	5.19098621e+009
Total Running Time 00:12:55.595.		

Figure 4-7. Summary Output Sheet Form TransCAD Assignment Process.

5 CAPACITY

5.1 INTRODUCTION

The purpose of this building block is to determine the capacity deficiencies of the freight transportation highway network based on the supply and demand of freight (truck traffic) flows. Given that truck travel patterns are different from commuter travel patterns, it is necessary to determine the effects of truck traffic on capacity requirements of the network for truck peak hour flows. However, in order to estimate the critical performance measures, a time of day (TOD) analysis is required. Outputs from the TOD analysis are then used to identify the congested segments of the highway network based on the certain performance measures.

5.2 CAPACITY ANALYSIS

The highway capacity analysis is intended to provide information on a set of performance measures for each highway link. Highway capacity-related performance measures include traffic volume, travel time, link delay, average speed, and service to flow ratio. These performance measures are estimated for the present (base year) as well as forecast years 2010 and 2020. Differences in these performance measures between the base year and the forecast years are indications of changes in congestion and the ability of the highway system capacity to support freight transportation system demand in the future.

The outputs from the post-processor can be used to generate thematic maps that show highway links with capacity problems. The performance measures can also be aggregated to identify those congested highway links connecting border crossings, seaports, airports, and other gateways including intermodal transfer points. The performance measures resulting from the analysis can also be organized and aggregated to serve as inputs into the Highway Economic Requirements System (HERS) model and other policy-related analysis.

This section explains the calculation of the performance measures for capacity analysis including

- Traffic Volume
- Design Hour Volume
- Capacity
- v/c (volume:capacity) ratios
- Travel times
- Delay.

5.2.1 Traffic Volume

The traffic volume on any link on the network, for a particular forecast year x , is the sum of passenger vehicles, freight trucks, and non-freight trucks as expressed in equation 5-1.

$$V_x = N_x + FAF_x + P_x \quad (5-1)$$

where

- V_x = The total AADT volume in a segment of the network
- N_x = The total non-FAF trucks on the segment
- FAF_x = The total freight trucks on the segment
- P_x = The passenger cars on the segment.

The freight truck volumes on each highway link for 1998, 2010, and 2020 are outputs of the assignment process. This relationship holds true for all the forecast years (1998, 2010, 2020). However, the calculation of non-freight and passenger volumes varies from 1998 to 2020. The non-FAF truck volume in 1998 is calculated as follows:

$$N_{98} = \begin{cases} AADTT - FAF_{98} & \text{if } AADTT \geq FAF_{98} \\ 0 & \text{otherwise} \end{cases} \quad (5-2)$$

where $AADTT$ = baseline truck volume for 1998.

The passenger car volume is the difference between the AADT and the AADTTs available for each segment.

$$P_{98} = AADT_{98} - AADTT_{98} \quad (5-3)$$

where $AADT$ = baseline total volumes for 1998.

In order to obtain the corresponding passenger and non-FAF truck traffic volumes for 2010 and 2020, growth factors are applied. The growth factors were derived as part of freight forecasts by WEFA. The volumes of passenger cars and non-freight trucks for 2010 and 2020 are given by equations 5-4 and 5-5 as follows.

$$P_{2010} = P_{98} (1 + G_p)^{12} \quad (5-4)$$

$$P_{2020} = P_{98} (1 + G_p)^{22}$$

$$N_{2010} = N_{98} (1 + G_t)^{12} \quad (5-5)$$

$$N_{2020} = N_{98} (1 + G_t)^{22}$$

where

- G_p = growth rate for passenger cars per year (0.0227 for 2010 and 0.019 for 2020)
- G_t = growth rate for trucks per year (0.0315 for 2010 and 0.0293 for 2020)
- P_{98} = passenger car traffic volume for 1998
- P_{2010} = passenger car traffic volume for 2010
- P_{2020} = passenger car traffic volume for 2020
- N_{98} = non-FAF truck traffic volume for 1998

N_{2010} = non-FAF truck traffic volume for 2010
 N_{2020} = non-FAF truck traffic volume for 2020.

5.2.2 Design Hour Volume

While daily volumes are useful for planning purposes, they cannot be used alone for design or operational analysis. Volume varies considerably during the course of the day and direction. The peak hour volumes are often used as the basis for highway design and for many types of operational analysis. One way of estimating peak hourly volumes is to use the daily volume projections and the K-Factor, using the following relationship.

$$DHV_x = V_x \times \text{K-Factor} \quad (5-6)$$

where

DHV_x = Design hour volume on the link for forecast year x (*vph*)
 V_x = Daily volume on the link for forecast year x (*vpd*)
 K-Factor = Proportion of daily traffic occurring during the peak hour, expressed as a decimal. For design purposes, this represents the proportion of AADT occurring during the 30th highest peak hour of the year.

The AADT volumes for 1998, 2010, and 2020 are converted using the above relationships to obtain design hour volumes.

5.2.3 Capacity

The capacity of a segment is assumed as the service volume at level of service (LOS) E. These values are from the Highway Capacity Manual 2000 (HCM) [25], which relates the service volumes to the terrain, the number of lanes, and the free flow speeds.

Of these assumptions, the critical one to the study is the percentage of trucks. In order to remove the effect of the assumption, the service volumes are translated to passenger car volumes by using a passenger car equivalent as follows:

$$C_{PC} = C_{HCM} (1 + 0.05(P.C.E - 1)) \quad (5-7)$$

where

C_{PC} = Capacity in terms of passenger cars only
 C_{HCM} = Capacity from HCM 2000 [25]
 $P.C.E$ = Passenger car equivalent for trucks [25].

This value of passenger car capacity can then be modified to include the truck percentage existing on the segment from the assignment process for the final FAF capacity. The existing truck percentage is the total of non-freight and freight volumes divided by the total volume.

$$C_{FAF} = \frac{C_{PC}}{(1 + T_{\%}(P.C.E - 1))} \quad (5-8)$$

where

- C_{FAF} = The final capacity of the segment
 $T_{\%}$ = Truck percentage on the segment. Sum of non-freight and freight volumes divided by the total volume.

5.2.4 V/C Ratios

A critical factor in any capacity analysis is the proportion of the facility's capacity being utilized by current or projected traffic. This ratio is often used as a measure of sufficiency of existing or proposed capacity. In forecasting situations, a volume:capacity (v/c) ratio above 1.00 predicts that the facility will fail, i.e., be unable to discharge the demand arriving at the section, leading to excessive delays and queues. The v/c ratios for each segment are calculated by dividing the design hour volume by the capacity calculated in the previous section. These ratios are then classified into three groups: <0.8, 0.8 to 1.0, and >1 for different groupings like functional classes, rural/urban, etc. The v/c ratios can also be combined with the network and be plotted thematically, allowing visual inspection of congested segments of the roadway.

5.2.5 Travel Time/ Speed/Delay

The Bureau of Public Road (BPR) function was used to calculate the travel times on the segment. The BPR function relates the link travel times as a function of the v/c ratio as:

$$t = t_f \left(1 + \alpha \left(\frac{v}{C} \right)^{\beta} \right) \quad (5-9)$$

where:

- t = Congested link travel time
 t_f = Free Flow link travel time (Length of the link divided by Free Flow Speed)
 v = Link Volume
 c = Link Capacity
 α, β = Calibration parameters (usually taken as 4.0 and 0.15 respectively).

The delay traveling the link is assumed as the difference between the congested link travel time and the free flow link travel time. The speed on the link is assumed to be the length divided by the congested travel time.

6 CONCLUDING REMARKS

The primary objective of the highway freight capacity analysis is to develop a policy tool for analyzing potential freight related policy and examining the sufficiency of capacity of the transportation system in meeting forecast freight demand. Developing a framework for policy analysis relating to the highway capacity for freight transportation is multi-dimensional and challenging. The U.S. freight system is complex and diverse in terms of the spatial and temporal distribution of freight generation activities and movement.

The critical elements of the national level freight transportation modeling process include the establishment of the network and freight data preparation. Procedures for converting commodity flows into truck trips are not well developed. Inconsistencies in traffic data collection and reporting formats among states pose challenges in developing a comprehensive baseline truck traffic data for national level freight analysis.

It is important to take into account the specific characteristics of truck traffic in adapting and applying existing transport demand modeling techniques. The use of GIS-Transportation application software for the analyses is not only efficient but also facilitates communication of outputs of the analysis to policy makers. The truck flow maps and other thematic maps for example, provide visual presentations of the volume and spatial variation of freight traffic. The outputs of the analyses can be expected to assist policy makers in evaluating improvement and policy options that affect freight transportation.

Potential areas for future research include the following:

- Update of the FAF network based on the updated NHPN. The FAF network for this study was developed from NHPN version 3.0 with about 70 percent HPMS coverage. Over 90 percent HPMS coverage can be achieved once this version is updated.
- Development of linkage between VTRIS and other modal databases such as the highway-railway grade crossing inventory and FAF network.
- Development of a method for converting tonnage data to truck trips.
- Development of an interface for the FAF highway capacity analysis database in order to facilitate its use in examining potential freight transportation policy initiatives.

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