Conceptual Framework and Trucking Application to Estimate the Impact of Congestion on Freight

by

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ABSTRACT

The motivation for the research described in this paper is that there are limited analytical techniques that fully incorporate freight aspects into transportation system monitoring, system evaluation, and project selection. All too often, transportation decisions are made based upon typical performance measures of travel time and delay for passenger travel; and a limited, if any, attempt is made at incorporating goods movement into such analysis.

To better understand freight mobility and reliability issues, this paper describes research performed by the Texas Transportation Institute (TTI), which has developed:

1. An overview of a conceptual framework to help transportation professionals communicate, visualize, and understand factors that affect freight mobility and reliability.
2. A methodology to estimate congestion estimates for the conceptual framework.
3. Two applications of the methodology on truck freight (one in Austin, Texas and one in Denver, Colorado).

The conceptual framework ("freight box concept") visually incorporates the affects of geographic area, commodity type, and time period on freight mobility and reliability. The freight box concept is "scalable" to address any near-term limitations in data completeness, yet provides a method to communicate congestion mobility and reliability as data availability improves. It can be expanded to include all freight modes (e.g., truck, rail, maritime, air, and pipeline). After a discussion of a methodology using the Freight Analysis Framework (FAF) to assist in computing congestion estimates for the freight box, researchers present two applications.

The conceptual framework and methodology provided here can assist transportation professionals better communicate, visualize, understand, compute, and make planning-level decisions based upon the factors that affect freight mobility and reliability.

INTRODUCTION

For over 25 years, the Texas Transportation Institute (TTI) has developed methodologies and appropriate performance measures to estimate and communicate congestion performance to technical and non-technical audiences. TTI's *Urban Mobility Report* (UMR) is highly-cited for congestion trends and to facilitate policy decisions (*1*). Historically, the UMR has focused on passenger-car congestion (i.e., the average commuter). However, there are increasingly more questions about the economic impact of congestion on freight.

To better understand the freight mobility and reliability issues, this paper describes research performed by TTI, which has developed:

1. An overview of a conceptual framework to help transportation professionals communicate, visualize, and understand factors that affect freight mobility and reliability.
2. A methodology to estimate congestion estimates for the conceptual framework.
3. Two applications of the methodology on truck freight (one in Austin, Texas, and one in Denver, Colorado).

The motivation for the research described in this paper is that there are limited analytical techniques that fully incorporate freight aspects into transportation system monitoring, system evaluation, and project selection. There is a need for an analytical framework that allows the mobility and reliability of freight travel to be placed on equal footing with passenger travel. All too often, transportation decisions are made based upon typical performance measures of travel time and delay for passenger travel; and a limited, if any, attempt is made at incorporating goods movement into such analysis. Certainly, there are numerous challenges to providing such an analysis, including institutional issues and data limitations, among others. The conceptual framework provided in this paper is meant to provide a vision for how such analysis can be considered and performed given today's challenges, and provides an adaptable framework as conditions change (i.e., data improve).

Distinguishing between freight and passenger car travel for system monitoring, system evaluation and project selection is important because freight and passenger car travel characteristics differ especially as it relates to the value of time. For example, previous research in Houston, Texas indicated that commercial vehicle travel times were nearly eight percent higher than vehicles instrumented with toll tags (i.e., the general traffic stream) under free-flow conditions, and six percent higher during congested conditions (*2*). The study was along an approximately two-mile corridor, and over longer distances, such differences could become even more significant.

To provide a complete picture of the congestion impacts, the framework and associated measures must incorporate a dollar value on delayed freight and passenger car travel. As evidenced by the work in Houston, the extent of the delay is not the same for urban trucks and passenger cars. To provide dollar values for urban trucks, commodity movement information is desirable. As an example, ultimately such an analysis could provide transportation professionals a method to identify bottleneck locations in a region, and allow them to also know the dollar value of goods impacted along particular routes.

The application in this paper focuses on the urban truck component of the larger freight issue. Theoretically, all modes of freight transportation can be included within the conceptual framework presented here, but the initial focus is trucking.

FREIGHT ISSUES AND CONCERNS

A recent document from the American Association of State Highway and Transportation Officials (AASHTO) outlines the growing demands being placed upon the surface transportation system in the United States (*3*). AASHTO indicates that freight tonnage is expected to increase 114 percent between 2004 and 2035 with trucks carrying 79 percent of the total tonnage (*3*). There is a need for strong investment in freight infrastructure to keep pace with this growing demand. The conceptual framework documented in this paper assists in understanding, identifying, and communicating freight congestion and infrastructure needs.

Survey Results

Many state departments of transportation (DOTs) and metropolitan planning organizations (MPOs) are interested in better understanding freight concerns and congestion impacts on freight movement. As part of this research, TTI performed a survey of selected state DOTs and MPOs about freight issues and concerns. The results provide insight into key areas related to freight mobility and reliability. The following are the highlights:

- The freight mobility and reliability objectives primarily revolve around providing the safe movement of people and goods.
- Methods for capturing freight impacts include a variety of modeling techniques as well as using real-time data.
- A multitude of performance measures are used, several provided from work sponsored by the Federal Highway Administration (FHWA) (*4*). Measures are selected based on user needs. The list of measures is thorough and goes beyond a mobility analysis.
- Available data sources include roadway inventories, aggregate commodity flow information, and selected local studies.
- A variety of needs were identified for moving forward with freight mobility and reliability, and they relate to, 1) data/measures needs, 2) institutional needs, and 3) communication/marketing needs.

Full details of the survey are documented elsewhere (*5*) for the interested reader. To the decision-maker reviewing these needs, it can be daunting. There is a need for a visual framework to organize and facilitate understanding of the myriad issues identified, as well as their interactions.

MOBILITY AND RELIABILITY MEASURES FOR FREIGHT

The travel time index (TTI) and buffer index (BI) are proven for measuring mobility and reliability, respectively, for passenger car travel. These measures have been used by the Texas Transportation Institute for numerous mobility analyses, most notably the FHWA-sponsored Mobility Monitoring Program (*6*) and the *Urban Mobility Report* (*1*).

The travel time index is defined as shown in Equation 1 as the peak-period travel time divided by the free-flow speed or posted speed travel time. Therefore, a TTI of 1.20 indicates that it takes, on average, 20 percent longer to travel in the peak than it does in the off-peak period.

$$\underset{(passenger\ cars)}{Travel\ Time\ Index} = \frac{Peak\text{-}period\ travel\ time}{Free\text{-}flow\ or\ posted\ speed\ travel\ time} \quad \text{(Equation 1)}$$

Obviously, truck travel is influenced by additional factors that do not affect passenger travel. Observed truck speeds are affected by not only congestion levels and time-of-day patterns, but also the urgency of the driver (i.e., an owner/operator's incentive is productivity, and he may likewise be driven to deliver more shipments, while a private company driver may be paid hourly), commodity type, weight, and truck type (size). Grade also has a larger effect than with passenger vehicles, and there may be speed restrictions that limit truck speeds.

Similarly, the free-flow travel time for trucks is limited by some of these same conditions. The urgency, commodity, weight, truck/roadway characteristics, grade, and speed restrictions will all affect, and potentially be limits on, the "free-flow" speed for trucks.
Equation 2 is a proposed travel time index for trucks that can reflect these subtle differences in contrast to Equation 1 for passenger cars.

$$\underset{(trucks)}{Travel\ Time\ Index} = \frac{Observed\ truck\ travel\ time}{Truck\ free\text{-}flow\ or\ posted\ speed\ travel\ time} \quad \text{(Equation 2)}$$

Equation 3 shows the BI equation, which estimates the extra time (buffer) needed to ensure on-time arrival for most trips. For example, a value of 40% means that a traveler should budget an additional 8 minutes for a 20-minute average peak trip time to ensure 95% on-time arrival (i.e., late one day in 20 work days per month). The BI can apply to passenger cars or trucks, and presumably all modes of freight where there is an interest in quantifying reliability. The calculation of the BI requires a continuous data source to obtain reliability over time (e.g., day-to-day, seasonal).

$$\begin{matrix} Buffer\ Index\ (\%) \\ \left(\begin{matrix} passenger\ cars \\ and\ trucks \end{matrix}\right) \end{matrix} = \left(\frac{95th\ percentile\ travel\ time\ \text{-}\ Average\ travel\ time}{Average\ travel\ time} \right) \times 100 \quad \text{(Equation 3)}$$

The Evolution of Data Sources

While the measures for mobility and reliability are proven for passenger cars, there are limited adequate data for quantifying these measures for freight operations. Figure 1 illustrates the current practice, and with improving datasets, where the profession is headed. Figure 1 illustrates the existing data/inputs, measures, and characteristics as well as the future data/inputs, measures, and characteristics that are anticipated with improved datasets. It illustrates that the current practice typically includes link-based data at the roadway inventory level of detail, and how the profession will be evolving to make use of more sophisticated freight models and probe travel time truck data. Such advances will provide more accurate temporal and spatial analysis of trucking operations.

Where profession is headed

Future
Data / Inputs
- Statewide freight model outputs
    - Urban (regional) and statewide
    - O-D for modal shift potential
    - Vehicle class
- AVO (persons) at corridor level
- CFS / FAF / FSC / FPM (with improvements)
- Truck travel times
- Others to come

Future
Measures
- Travel time index
- Mobility (hours of delay) by:
    - Trip
    - Freight/passenger (vehicle type)
    - Link
    - O-D
    - Commodity type
- Reliability (buffer index)
- Economic value of delay by commodity
- Cost of extra operating hours by vehicle type
- Benefit of prioritizing projects
    - Bottleneck removal
    - Include estimate of delay by vehicle type

Future
Characteristics
- Temporal aspects
    - Peak periods
- Spatial aspects
    - Regional coverage
    - Link-by-link
- Trip based
- Truck load factors considered

Improving Datasets (Note: Measures currently ahead of the data).

Current practice

Existing
Data / Inputs
- Roadway inventory
- HPMS
- % Trucks
- HERS-ST
- FAF (coarse data / numerous assumptions)
- CFS
- Assumed AVO (regional)
- Passenger car equivalents

Existing
Measures
- Mobility (hours of delay)
- Vehicle-miles of travel
- Ton-mile
    - Doesn't tell about the trip mobility
- Volume-to-capacity ratio
- Level-of-service

Existing
Characteristics
- Roadway inventory level of detail
- Daily / yearly
- Link-based
    - Per current data collection

CFS = Commodity Flow Survey (Bureau of Transportation Statistics)
FAF = Freight Analysis Framework
FPM = Freight Performance Measures (FHWA)
FSC = Freight Significant Corridors (FHWA)
AVO = Average Vehicle Occupancy
O-D = Origin-Destination
HERS-ST = Highway Economic Requirements System – State Version
HPMS = Highway Performance Monitoring System

FIGURE 1 Evolution of Freight Mobility and Reliability Monitoring (Adapted from Reference *5*).

THE CONCEPTUAL FRAMEWORK

With the prior sections provided as background of current practice and where the profession is headed, the conceptual framework is now presented. The framework proposed here is applicable to all modes of freight (e.g., truck, rail, maritime, air, pipeline). The trucking mode is used in the example described here, and then the discussion briefly illustrates the applicability of the framework to all modes.

Figure 2 shows TTI's "freight box" illustration. As a box in three-dimensions, the three axes of the relationship for trucks are 1) geographic area, 2) commodity type and 3) time period. These axes directly relate to, and visually illustrate, the three critical issues under consideration; specifically, where is the area under study? (geographic area axis), what are the time periods of interest? (time periods axis), and what type of trucks are of interest? (commodity types axis).

Below are brief discussions of each axis, followed by a description of what is in the freight box.

Geographic Area

The first axis along the left-side of Figure 2 is the geographic area. Geographic area is certainly a key consideration of truck mobility and reliability. The transportation system naturally has bottlenecks and corridors where freight mobility and reliability are critical for economic vitality. The geographic level of the analysis could be more aggregate as well—regional or even a portion of a state.

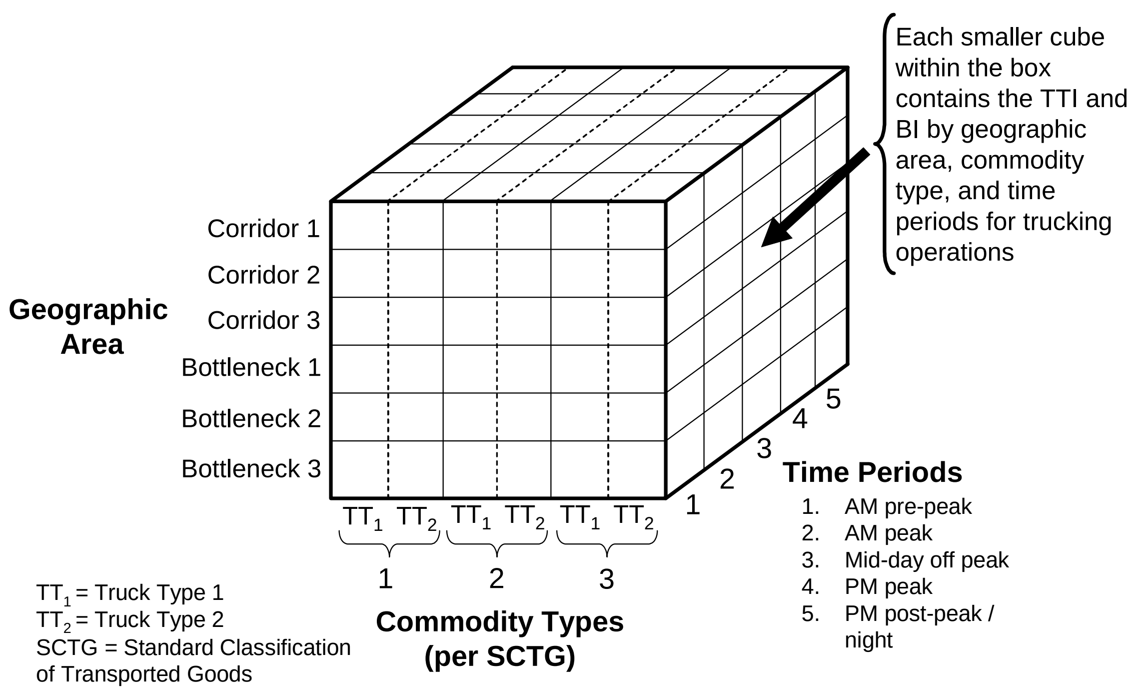

FIGURE 2 Freight Box Conceptual Framework Applied to Trucks (Adapted from Reference *5*).

Commodity Type

The type of commodity being transported, and delayed in congestion, has economic implications. The axis along the bottom of the freight box is commodity type. Commodity types are identified per the Standard Classification of Transported Goods (SCTG). Three commodity types and two truck types (size) are illustrated in Figure 2 though more can be tracked in application.

Time Periods

Trucking operations, and freight movements in general, are sensitive to congestion levels that change over time. The third axis incorporates the temporal aspects of goods movement by truck. As an illustration, five time periods are included. These include the typical morning and afternoon peak periods as well as the off-peak periods between the peak periods.

Freight Box Contents

Now that there is an understanding of the axes, what is in the box itself? As illustrated in Figure 2, each smaller cube within the box contains mobility information (travel time index) and reliability information (buffer index) by geographic area, commodity type, and time period for trucking operations. For each geographic area of interest, there would be a box populated with "target" cubes that incorporate local goals and establish targets for mobility and reliability. In concept, there would also be a freight box of "observed" cubes for each geographic area of interest. This cube would include field observation of trucking mobility and reliability. The two boxes (target and observed) could then be compared to identify where operation is satisfactory or unsatisfactory.

The framework also has geographic scalability. A freight box can be developed for key bottleneck locations or corridors. Theoretically, portions of a state or region could have their own freight box containing cubes with freight mobility and reliability targets.

The framework provides flexibility in analysis. For example, analyses could be categorized by industry, large region (e.g., Midwest), or population. The framework is also flexible in that it incorporates improved datasets and broader analysis in the future. For example, if commodity information is not readily available, the "commodity types" axis might simply be "trucks" and "passenger cars" in the most basic sense. All trucks could be aggregated, and future adaptations of the methodology could include commodity types and truck size as more data become available. Similarly, there might only be interest in one or two of the time periods, and a shorter time scale can be used.

Considering All Freight Modes and Intermodal Facilities

While the discussion above has focused on urban trucks, Figure 3 shows the expansion of the freight box concept to all freight modes. This includes truck, rail, maritime, air, and pipeline. The geographic scope and time period axes remain as before. The third axis is changed to include all freight modes along the bottom of Figure 3. While in Figure 2, truck type was used to represent the size of the truck, Figure 3 uses "transport type" to represent the "size" of the freight component used (e.g., double-stacking of rail, container ship size, cargo airplane size, pipe size).

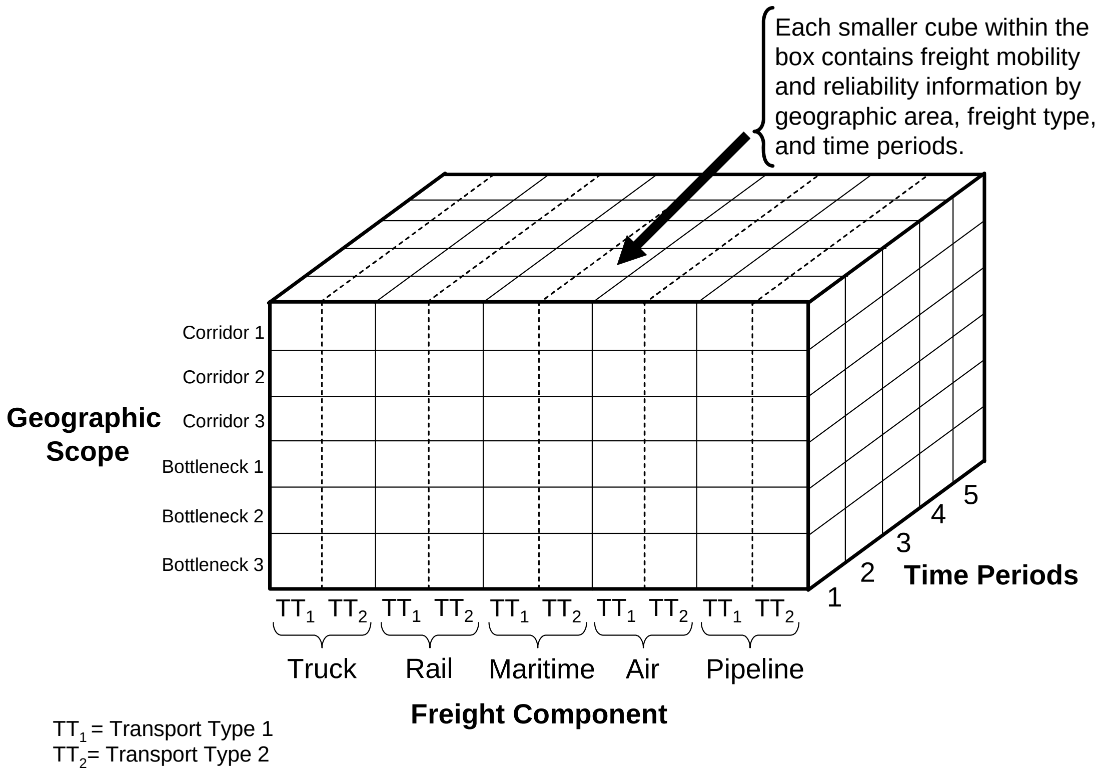

FIGURE 3 Expanded Freight Box for All Freight Modes (Adapted from Reference *5*).

In concept, the framework would apply in a similar manner as illustrated previously for trucks. Each cube within the box contains freight mobility and reliability information by geographic area, freight component, and time period. As before, the information in each cell can be a measured value or a target value based upon goals and objectives of the region(s) and community or communities. These can then be compared to observed conditions to identify needs.

The framework could also be expanded to intermodal facilities, distribution centers, borders, or ports. For example, the analysis could be disaggregated to the container level to assess mobility and reliability through intermodal facilities.

Certainly each freight mode or logistical structure would require a unique analysis and associated models. The different freight modes have unique operations and capacity constraints that may or may not affect roadway congestion directly. This distinction is made to further note that the initial focus will be on urban trucks, but the framework certainly could be expanded. For example, freight modes could be aggregated together by commodity value or tonnage or other appropriate value to obtain an aggregate travel time index value for all freight in the area of interest.

Analytical Approaches for Implementing the Freight Box Concept

The freight box concept is a visual tool. It provides a visual context to describe the whole freight picture. The concept is transferable to different areas, and the applications at the end of this paper demonstrate how components of the box can be estimated.

Data for transportation analyses typically originate from three sources:

1. *Real-time*: Including speed, volume and occupancy data from traditional point sources (e.g., inductance loops). Also includes probe data sources such as toll tags or cellular telephones.
2. *Planning models:* Include the output of typical travel demand models. Typically include vehicle-miles of travel (VMT) and delay estimates by roadway functional class and area type.
3. *Link-based:* Include roadway inventory level of data (e.g., average annual daily traffic, capacity, number of lanes, percent trucks). The Highway Performance Monitoring System (HPMS) is an example of such a dataset.

Data coming from these different data sources are subjected to quality control and quality assurance checks prior to use in analysis. This is performed by ensuring the analyst performs "reasonableness" checks on the available data (i.e., do congestion measures identify congested locations on the roadway system?; are the number of trucks on a given roadway inordinately high or low?) The application at the end of this paper incorporates link-based data inputs from Austin, Texas and Denver, Colorado.

A METHODOLOGY TO APPLY THE FREIGHT BOX CONCEPT TO TRUCK FREIGHT

Figure 3 previously showed that the freight box concept can be expanded to include, and visually illustrate, all elements of freight travel. The methodology provided in this section focuses on truck freight. The objective of this proposed methodology for trucking is to identify the estimated economic impact of congestion on freight (trucking) by investigating available data. Understanding this economic impact can facilitate placing the mobility and reliability of freight travel on equal footing with passenger travel to analyze, 1) system monitoring, 2) system evaluation, and 3) project selection. The economic impact of congestion on truck freight, is a function of:

- What's in the trucks?
- How are the trucks distributed on the network (temporally and spatially)?
- What is the origin-destination (O-D) of the trucks?
- What are delivery schedule expectations?

This section describes a four-step methodology for using existing data sources to estimate the impact of congestion on freight, with an initial emphasis on trucking. Two example applications of the methodology (one in Austin and one in Denver) follow the methodology. The methodology proposed here will allow analysts a method to evaluate the economic impacts of congestion on trucking in metropolitan areas. It allows the analyst to estimate portions of the freight box shown in Figure 2.

The four steps of the proposed methodology are as follows:

1. Estimate tonnage and dollar amount of each commodity traveling <u>through</u> a metropolitan area.
2. Estimate tonnage and dollar amount of each commodity type that <u>originates in</u> or is <u>destined to</u> a metropolitan area.
3. Estimate tonnage and dollar amount for each commodity type that travels <u>within</u> a metropolitan area.
4. Estimate delay and cost to trucks by commodity.

Defining Typical Truck Movements in a Metropolitan Area

There are four typical truck movements addressed in the proposed methodology and each of these movements is handled in an individual step in the methodology. For the purposes of this methodology, these truck movements are defined as follows:

1. "Through metro" — Trucks that travel through the metro area and have neither origin nor destination in the area.
2. "From metro" — Trucks that originate in the metro area of interest.
3. "To metro" — Trucks that have a final destination to the metro area of interest.
4. "Within metro" — Trucks that originate in, and are destined for, the metro area of interest. They are sometimes referred to as "local" trucks.

Step 1. Estimate Tonnage and Dollar Amount of Each Commodity Traveling Through a Metropolitan Area

The objective of the first step of the methodology is to identify the truck volume that passes through the metropolitan area ("through metro" trucks). The methodology uses data from the Federal Highway Administration (FHWA) Freight Analysis Framework (FAF, version 2.2). There are 114 geographic areas for FAF, which correspond to the regions used for the 2002 Commodity Flow Survey (CFS) however FAF includes projections for other years in 5-year increments. FAF allows an analyst to estimate the volume of freight moving between and within the FAF regions by mode and commodity. FAF provides tonnage and dollars of commodities moving between each of the 114 geographic areas based on the Commodity Flow Survey. The value (or tonnage) of commodities is identified in FAF using the Standard Classification of Transported Goods (SCTG) system.

Researchers developed a two-step process to estimate the through commodity movements through the region of interest. First, a "proximity" matrix was created for each origin-destination pair with factors for how close a given trip could be expected to go through the metropolitan area of interest. The factors were based on quartiles (i.e., 0, 0.25, 0.50, 0.75, and 1.00). The proximity matrix provides a way to rationally expedite an approximation of through trips.

Secondly, a "likelihood" matrix was created for each origin-destination pair with factors based on the likelihood that a trip would pass through the area of interest (Austin or Denver) based on the roadway network existing in the region. Again, the factors were based upon quartiles. By applying the "likelihood" matrix, the roadway network in the area of interest is considered, along with the possibility that a trip from a given origin-destination might pass through the area of interest.

After applying the percentages from the "proximity" and "likelihood" matrices, the tonnage and dollars of commodities are summed across all origin-destination pairs for the metropolitan area of interest to obtain the total tonnage and dollar amount of each commodity traveling through the metropolitan area of interest for the through truck trips.

Step 2. Estimate Tonnage and Dollar Amount of Each Commodity Type that Originates in or is Destined to a Metropolitan Area

Building from Step 1, Step 2 uses a similar summation method to estimate the tonnage and dollar amount by commodity type that originate in or are destined to a given metropolitan area. Those commodities that have an origin of the metropolitan area of interest are considered “from metro” truck trips. Those commodities that have a destination of the metropolitan area of interest are considered “to metro” truck trips. The tonnage and dollars of commodities are summed across all origin-destination pairs for the metropolitan area of interest to obtain the total tonnage and dollar amount of each commodity for the trips that either begins or ends in the metropolitan area of interest.

Step 3. Estimate Tonnage and Dollar Amount for Each Commodity Type that Travels within a Metropolitan Area

This step estimates the “within metro” tonnage and dollar amount by commodity type. The “within metro” trucks are often referred to as “local” trucks. FAF provides an estimate of the “within metro” FAF tonnage and dollar amount by SCTG code. “Within metro” truck trips in FAF are those that begin and end in the same metropolitan area of interest. For the FAF database, these trips are 50 miles or longer. The “within metro” trips less than 50 miles in length are obtained as the difference between the number of trucks identified from the state roadway inventory data and the sum of the “through metro,” “to metro,” and “from metro” trips. As in Steps 1 through 3, the tonnage and dollar amount by commodity type can be summed for the final estimate of the “within metro” truck trips.

Step 4. Estimate Delay and Cost to Trucks by Commodity

This step begins with the output from Steps 1 through 3. Specifically, this is the total annual tonnage and dollar amount by commodity code (SCTG) for trucks designated as “through metro” (Step 1 result), “from metro” (Step 2 result), “to metro” (Step 2 result), and “within metro” (Step 3 result). Figure 4 illustrates the process for this step. The first step in the process is to transfer the CFS region to the metropolitan area of interest. Tonnage and dollars of each commodity movement were converted to a number of trucks by using average payload weights from the FHWA report *Development of Truck Payload Equivalent* Factor (*7*). The result will be daily truck estimates by commodity for each metropolitan area.

The Highway Performance Monitoring System (HPMS) dataset and most state roadway inventory databases include percent trucks (“panel trucks” and “tractor trailers”—both peak period and daily) and average daily traffic (ADT) by link. For each metropolitan area of interest, the percent of trucks operating in the peak period, and the off-peak period, will be estimated. Users can then estimate these percentages by truck movement type (“through metro,” “to metro,” “from metro,” or “within metro”) and link.

Given these percentage estimates by truck movement, and the daily truck volume estimates by commodity for a metropolitan area, the user can distribute the FAF commodity data by proportion to the HPMS link data. The commodity data can be “overlaid” on the HPMS link data, allowing for an accounting of the associated congestion ranges where the trucks are assigned. After the commodity assignment to the HPMS data, speeds, and subsequently delays, can be estimated using ADT/lane-speed relationships of the roadways where trucks are assigned. The ADT/lane-speed relationships are those used for TTI’s *Urban Mobility Report* (*1*). The analyst can then sum delay across all roadways and commodities to obtain a total delay estimate for areawide planning-level applications.

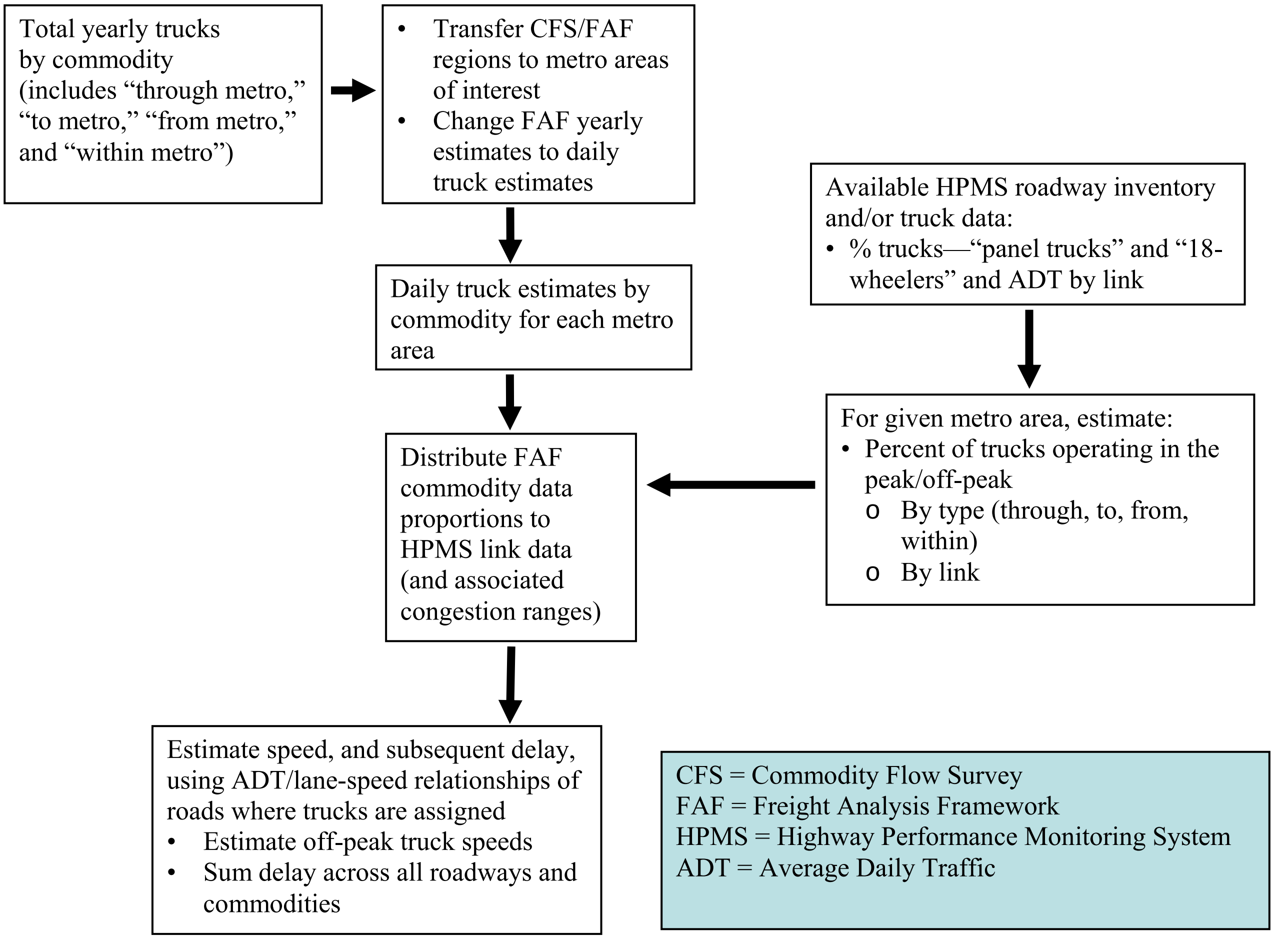

FIGURE 4 Procedure to Estimate Delay by Commodity (Adapted from Reference *5*).

METHODOLOGY APPLICATION IN AUSTIN, TEXAS AND DENVER, COLORADO

After developing the conceptual framework (freight box), and the methodology to estimate values within the freight box, researchers applied the four-step methodology to the Austin, Texas and Denver, Colorado metropolitan areas to show how delay information could be estimated to complete the freight box. According to the Austin Chamber of Commerce, the estimated population of the Austin metropolitan area in 2008 is 1.65 million (*8*). Austin is located along I-35 in central Texas. I-35 is the primary north-south route in Austin, and it links the U.S. to Mexico via Laredo which is a major port of entry. US 290 (east to west), US 183 (southeast to northwest), and SH 71 (from the east) are also major highways serving the Austin metropolitan area. The Austin metropolitan area includes three urban counties and two rapidly developing counties.

The Denver metropolitan area is comprised of six urban counties and in 2008 had a population of about 2.4 million (*9*). Denver is located at the crossroads of I-25 and I-70 along the eastern side of the Rocky Mountains. I-76, I-255, and I270 are all critical links that also serve the Denver metropolitan area.

Researchers downloaded the data files for the Freight Analysis Framework (FAF) from the FHWA Office of Freight Management and Operations Internet site (http://ops.fhwa.dot.gov/freight/freight_analysis/faf/). The FAF (version 2.2) data contains 2002 origin-destination freight data for domestic truck, sea, and border. For purposes of this paper, the 2010 FAF projections were used since they are more current than the 2002 data. All domestic trips begin and end within the 50 United States. Border freight begins or ends a trip crossing a land border into or out of the United States. Sea freight begins or ends a trip at a sea port to enter or leave the United States. Researchers assigned the border and sea trip end locations to one of the existing 114 domestic regions because they were often different than the previously defined regions in FAF. For example, in Texas, Laredo was defined as a border point of entry/exit. However, it was not one of the five regions listed for Texas. Therefore, any border freight moving through Laredo was assigned the “rest of Texas” label. In most cases, these border and sea trip ends are assigned to the “rest of state” category. After making these changes, researchers re-summed the tons and dollars of each commodity moving by truck for each of the 114 x 114 region pairs to include the truck traffic that had border or sea origins or destinations.

Step 1. Estimate Tonnage and Dollar Amount of Each Commodity Traveling Through Austin and Denver

Researchers applied the “proximity” matrix as previously described. The proximity matrix provides a way to rationally expedite an approximation of through trips. For example, in the Austin application, it is very unlikely that a trip from Maine to Oregon will go through Texas, so it was given a very low “proximity” value while a trip from Florida to Arizona would receive a high value.

Secondly, researchers applied the “likelihood” matrix as previously explained and defined. By applying the “likelihood” matrix, the roadway network in the area of interest (Austin or Denver) is considered, along with the possibility that a trip from a given origin-destination might pass through the area of interest (Austin or Denver). For example, a trip from Louisiana to New Mexico has a high “proximity” value for going through Austin but would receive a lower “likelihood” value because of the lack of a major east/west roadway through the Austin area. This trip would likely use an interstate highway through San Antonio or the Dallas/Fort Worth region.

The quartile percentages obtained from the “proximity” and “likelihood” matrices were multiplied by the tons and dollars of cargo for each commodity in every origin-destination pair. Because there are 114 unique origins and destinations, the use of the “proximity” and “likelihood” matrix provided a rational approach to obtaining these estimates for all 12,996 (114 x 114) origin-destination pairs. Finally, researchers summed all of the tons and dollars of cargo for each commodity to estimate the commodity movements through the area of interest (Austin or Denver areas).

Step 2. Estimate Tonnage and Dollar Amount of Each Commodity Type that Originates in or is Destined to Austin and Denver

“From metro” and “to metro” trips were defined by whether the area of interest (Austin or Denver) was a beginning or ending point in the FAF dataset. Truck movements that had a beginning point in the area of interest (Austin or Denver) were considered the “from metro” trips. Truck movements that had an ending point in the area of interest (Austin or Denver) were considered the “to metro” trips. Because both of these trip types would affect the area of interest

(Austin or Denver), researchers included them in the summation of tons and dollars by commodity.

Step 3. Estimate Tonnage and Dollar Amount for Each Commodity Type that Travels within Austin and Denver

All trips that had both a beginning and ending point in the area of interest (Austin or Denver) were considered "within metro" trips. Because these "within metro" truck trips would affect the area of interest (Austin or Denver), researchers included them in the summation of tons and dollars by commodity. These trips are defined in FAF as being at least 50 miles in length but remaining within the region. The discussion at the end of the next step discusses how the truck trips less than 50 miles in length are obtained in the methodology.

Step 4. Estimate Delay and Cost to Trucks by Commodity for Austin and Denver

Assigning Truck Traffic to Austin's Roadway Network and Denver's Roadway Network

Researchers obtained 2007 existing truck and passenger car average daily traffic (ADT) estimates from the Texas Department of Transportation (TxDOT) roadway inventory for the five counties that comprised the FAF region represented by the Austin area. Researchers obtained similar 2008 data from the Colorado Department of Transportation (CDOT) from CDOT's traffic data Internet site (*10*). Researchers analyzed the regional roadway system to determine where through trips might occur and where other special truck generators exist that could account for any type of significant truck movements (e.g., "to metro," "from metro," or "within metro" trips).

For this research, the 2010 estimates from FAF were used which most closely matched the TxDOT and CDOT traffic information. Tons and dollars of each commodity movement were converted to a number of trucks by using average payload weights from the FHWA report *Development of Truck Payload Equivalent Factor* (*7*). The number of trucks for each commodity type was calculated for each of the four trip types (through, origins, destinations, and local trips).

The through movements were assigned to roads that served through movements (typically interstates and other major highways through the region). Some through movements were assigned to all roadways leaving the metropolitan region but over 70 percent were assigned to I-35 in Austin and split between I-70 and I-25 in Denver.

Origin ("from metro") and destination ("to metro") truck trips that traveled from inside or outside of the FAF area for Austin or Denver were assigned to roadways that carried traffic beyond the area (e.g., Interstates and U.S. highways).

The "within metro" (local) trips were then assigned to fill the remaining truck volumes on Austin's major roadways based on the existing truck ADTs from TxDOT's roadway inventory. For all roadways, researchers found that the number of assigned trucks was lower than the truck ADT values obtained from the TxDOT and CDOT roadway inventory. In these situations, researchers added more "within metro" (local) trips to make up the difference. These additional "within metro" trucks were assigned commodities based on those percentages of the already assigned FAF "within metro" commodities. The reason these local trips are needed is because the FAF database only reports local trips that are over 50 miles. Many local trips are not long enough to satisfy this requirement.

Delay and Cost Findings

Researchers analyzed segments of a minimum distance of approximately 5 to 10 miles in length. Segments were divided based upon major interchanges, changes in geometric characteristics, or geographic boundaries. Because this analysis is meant to provide planning-level areawide results, analyses were not performed at the link level.

Researchers supplemented the commodity movements and truck movements obtained through this process with congestion (delay) information calculated using the methodology from TTI's *Urban Mobility Report* (*1*). Researchers used the methodology to calculate delay in the UMR to calculate the passenger car and truck delay on the freeways and highways in the Austin region. Each roadway segment contains a total ADT, truck ADT, and the peak-period hours of delay and wasted fuel associated with trucks and cars. The value associated with the wasted delay and fuel was reported as the congestion cost for both the passenger cars and truck as well.

Table 1 shows the results for a few selected segments from the highways in the Austin and Denver regions. The value of the freight moving in each roadway segment is shown as well. The value of the commodities moving in each roadway segment is far greater than the price tag for the congestion in that segment, even on I-35 which has the highest ADTs.

The following example will help to put the comparison of cargo and delay into perspective. If a single car on I-35 with one occupant is delayed for 15 minutes on a given day, the cost of that delay would be under $4.00. If a single truck was delayed for the same 15 minutes, the cost of the delay would be about $26. However, the average value of the commodities in Austin is approximately $12,000. This value may be even higher if a just-in-time shipment is delayed, which could lead to an assembly line shutdown. This suggests that project selection and prioritization processes should value truck delay much higher than car delay, which might shift investments towards ports, intermodal terminals, and significant freight corridors. From an economic sense, it is important to note the cars and trucks are impacted differently by congestion.

The interested reader can review reference *5* for delay and commodity values aggregated to the corridor level from the segment data shown in Table 1. The corridor delay can be summed from all of the segment delays. Annual commodity values are weighted by truck travel to obtain the corridor commodity values. Many of the trucks will travel multiple segments along each corridor so their commodity value should not be counted more than once.

An example of the commodity level information is shown in Table 2 for two individual segments from the Denver region. This is the level of detail that is available from the FAF dataset, and it is the most basic level of data behind the information shown in Table 1. The value of each truckload becomes apparent from this table. For example, the average value for a truckload of alcoholic beverages is about $12,000 while the value for a chemical products truck is almost $22,000. These individual commodity values would populate the individual cubes within the freight box mentioned in Figures 2 and 3.

It should be noted, many assumptions were made to apply the FAF-based commodities to individual roadways. As data are improved, and as more knowledge is gained regarding freight mobility, these assumptions may be replaced with actual measurements.

TABLE 1 Congestion Costs and Commodity Values for Selected Roadway <u>Segments</u> in the Austin and Denver Regions (Adapted from Reference *5*)

Roadway	Segment Length (miles)	Daily Traffic Volume	Daily Truck Volume	Annual Congestion Cost ($million)[1]		Annual Commodity Value ($mil)[2]
				Passenger	Commercial	
Austin						
I-35	9.2	200,000	24,000	106.50	29.60	95,938
US 290 E	9.6	42,000	3,360	0.56	0.16	13,175
US 209 W	3.5	45,000	2,250	0.22	0.05	7,949
US 183	8.3	120,000	2,400	22.60	1.21	8,849
US 79	4.8	28,000	5,320	0.16	0.10	17,838
Loop 1	4.7	130,000	2,600	21.37	1.14	8,613
SH 71	4.3	60,000	5,400	0.35	0.12	18,568
Denver						
I-70	4.8	105,000	9,450	6.35	1.76	45,969
I-25	5.7	190,000	11,400	49.44	10.88	56,399
I-76	4.2	75,000	7,500	5.00	1.68	27,325
I-225	5.0	115,000	8,050	44.80	9.86	27,102
I-270	6.0	80,000	10,400	9.31	3.70	33,783
C-36	6.0	80,000	3,200	9.77	1.60	10,411
US-6	5.4	120,000	4,800	11.78	1.92	14,776
C-470	9.2	90,000	5,400	26.73	5.88	17,197
C-121	5.0	50,000	1,500	11.33	1.22	5,091
US-285	8.9	60,000	2,400	28.76	4.69	7,730
C-2	3.9	56,000	1,680	7.68	0.83	5,619

[1]Annual congestion costs are for 250 days (weekdays).
[2]Annual commodity values are for 365 per year.
See reference *5* for assumptions and detailed discussion of estimation procedures.

TABLE 2 Daily Commodity Level Breakdown for Selected Denver Roadway Segments (Adapted from Reference *5*)

Commodity	I-70		C-2	
	Trucks	Value ($000)	Trucks	Value ($)
Alcoholic beverages	293	3,517	52	631
Animal feed	129	583	14	50
Articles-base metal	370	4,627	42	637
Base metals	171	2,774	20	315
Basic chemicals	147	1,116	24	137
Building stone	12	38	3	7
Cereal grains	384	308	42	32
Chemical products	158	3,437	8	265
Coal	285	120	0	0
Coal-n.e.c.	185	601	29	110
Crude petroleum	8	12	3	5
Electronics	100	9,496	7	523
Fertilizers	101	133	10	13
Fuel oils	259	815	54	165
Furniture	96	2,051	12	243
Gasoline	89	684	16	130
Gravel	913	135	167	26
Live animals/fish	52	742	13	183
Logs	26	463	3	61
Machinery	227	22,430	45	3,774
Meat/seafood	103	4,489	6	296
Metallic ores	3	69	0	12
Milled grain products	319	2,052	46	197
Misc. mfg. products	171	7,288	17	547
Mixed freight	287	14,362	44	1,853
Motorized vehicles	125	6,050	10	484
Natural sands	248	17	54	3
Newsprint/paper	19	357	0	10
Nonmetallic mineral products	1309	2,368	334	374
Nonmetallic minerals	105	170	8	19
Other agricultural products	163	1,614	25	160
Other foodstuffs	399	5,847	58	675
Paper articles	42	975	3	72
Pharmaceuticals	21	1,454	4	207
Plastics/rubber	199	5,334	13	557
Precision equipment	368	2,489	117	243
Printed products	165	3,427	12	277
Textiles/leather	34	4,607	3	291
Tobacco products	1	112	0	48
Transport equipment	81	3,149	5	407
Unknown	358	3,388	98	923
Waste/scrap	595	510	211	159
Wood products	330	1,729	46	270
Total-Daily	9,450	125,943	1,680	15,395

See reference *5* for assumptions and discussion of estimation procedures.

CONCLUSIONS

As with most complex transportation issues, the "freight mobility and reliability problem" is obfuscated by limited data and largely untested analytical methods. It is also clouded because there is often no clear conceptual vision for what is needed, and how it might be obtained. The research presented in this paper provides tools to better understand freight mobility and reliability issues as well as assisting transportation professionals and the research community with communicating, visualizing, and computing freight mobility estimates. Several conclusions can be drawn from the research to better understand freight mobility and reliability issues, including the following:

1. The conceptual framework ("freight box") presented in this paper provides an understandable visual tool for understanding the factors that affect freight mobility and reliability. It is flexible and scalable for various geographic regions, time periods, and commodities. The freight box shows promise for other modes (see Figure 3) and this is a promising area for future work.
2. Mobility data sources are improving, and the freight box concept presented in this paper is flexible and can use data inputs from several sources for illustrating freight mobility and reliability. The applications presented in this paper use link-based data as an example. As data-sources improve, freight mobility estimates can be improved, and decision-making for freight infrastructure improvements can be improved.
3. The Freight Analysis Framework (FAF) database can be used to provide mobility estimates with the four-step methodology presented in this paper for planning-level analysis at the areawide level.
4. For all roadways in Austin and Denver, researchers found that the number of assigned trucks from FAF was lower than the truck ADT values obtained from the state DOT roadway inventory. In these situations, researchers added more "within metro" (local) trips to make up the difference. The reason these local trips are needed is because the FAF database only reports local trips that are over 50 miles. Many local trips are not long enough to satisfy this requirement.
5. The "proximity" matrix and "likelihood" matrix provide a rational and expedited way to estimate through travel between origin-destination pairs in the FAF dataset. The matrix of 12,996 cells (114 FAF regions to/from 114 FAF regions) with probability quartiles of truck movement between each pair is expected to be valuable for future projects estimating through travel in a metropolitan region using the FAF data.
6. The "freight box" framework provides additional information (e.g., commodities) beyond existing traffic congestion data that can be used in the decision-making process for the prioritization and programming of projects. The applications described in this paper show computations of commodity values on an annual basis.
7. The findings of the Austin and Colorado applications presented in this paper suggest that project selection and prioritization processes should value truck delay much higher than car delay, which might shift investments toward corridors which serve large volumes and/or high value of freight and/or lead to ports, intermodal terminals, and significant freight corridors.

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