Assessment of Freight System Efficiency Measure: GDP/GHG

Final Report

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Abstract

This report presents an assessment of the Freight System Efficiency metric (FSE) which is being used to measure progress towards the California Sustainable Freight Action Plan (CSFAP) 2030 target of a 25% increase in freight system efficiency. We describe the data and methods used to generate FSE, and consider the extent to which the components of FSE are comparable. We then discuss the potential biases of the metric, and how these biases may affect measurement of progress toward the 2030 target. We find that the components are not fully comparable and are subject to biases that can affect measurement over time. We suggest that consideration be given to an alternative metric. At a minimum, computation of the current metric should be modified to reduce biases.

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Introduction

The purpose of this report is to assess the effectiveness of the freight system efficiency metric (FSEM) in terms of its consistency in quantifying economic output per greenhouse gas emissions as well as tracing its trends over time. In this report, we first review key efficiency metrics that have been used to measure freight transportation system efficiency. We then assess the FSEM and suggest supportive metrics.

The State of California is committed to improving the efficiency and economic productivity of the freight industry as well as to reducing Greenhouse Gas (GHG) emissions. With the Governor's Executive Order B-32-15, the California Sustainable Freight Action Plan (CSFAP, 2016) became the long-term guide to achieve these goals. This plan integrates various State agencies' programs, policies, and investments and sets up a high-level vision for such programs, policies, and investments. The plan has three targets: freight efficiency, number of zero emission trucks, and economic efficiency. This report addresses the freight efficiency target. The CSFAP defines the freight system efficiency metric (FSEM), which is intended to assess the impact and progress of the recommended actions. The stipulated system efficiency target is a twenty-five percent increase by 2030 in the value of goods and services the freight sector produces (GDP in million dollars, numerator), compared to the of GHG emissions that the freight sector emits (GHG in metric tons, denominator).

We found that the freight sector activity captured in the numerator and denominator does not perfectly match. The numerator omits part of freight activity conducted by non-freight transportation sectors, whereas the denominator omits light and medium duty truck activity which accounts for a large portion of the freight sector activity.

Due to lack of data, we could not examine whether the extent of disparity is large and whether disparity increases or decreases over time. We suggest three main factors that might bring about inconsistency in the metric: changes in industry mix, economic expansion or contraction, and changes in freight practices.

Finally, we suggest a more accurate measure: freight ton-miles per GHG emissions. This measure has a consistent unit of analysis (freight vehicle) and more consistent numerator and denominator. It can also be broken down by mode.

This report is organized as follows. In Part 1, we review key freight transportation performance metrics frequently used in the transportation sector. In Part 2, we assess the freight system efficiency metric and evaluate whether it consistently measures system efficiency over time. In Part 3, we suggest a more accurate measure, as well as some possibilities for reducing the bias of the current measure.

Part 1. Literature Review

In this section, we review key efficiency metrics that have been used to gauge freight transportation system efficiency. The literature on transportation performance measures is extensive. Thus, we primarily focus on those for freight transportation. The goal of the freight transportation system is to connect goods production lines, supply chains, and consumer markets by transporting intermediate/final goods between locations of production and locations of consumption. Transportation system efficiency is important because it influences economic productivity at the local, regional, and national level. Also, the transportation sector, as a whole, which constituted approximately 3% of U.S. GDP in 2015, produced 27% of greenhouse gas emissions (CO_2 equivalent by weight). Both transportation providers and the public sector understand the sector's economic and environmental significance. Hence, public and private sectors have developed multiple metrics and have continuously monitored system efficiency. Such monitoring is particularly important when transportation issues are to be understood and when system improvements are made.

The public and private sectors have different perspectives on what an efficient freight transportation system is. For example, freight service providers are interested in reducing travel times, improving travel reliability, and decreasing travel costs. The public sector not only seeks system efficiency, but also seeks to reduce negative externalities.

The freight transportation system includes multiple modes of transportation -- truck, water, air, rail, and pipeline. It is both inter-modal and multi-modal. Also, each mode has its own infrastructure and operating practices. Hence, separate efficiency metrics for each mode have been developed. We review metrics proposed by public and private sectors separately, metrics for the freight transportation system as a whole, and mode specific metrics.

1.1 Public Sector Perspective

The Transportation Research Board (TRB) has been the main platform for establishing performance measures to evaluate national transportation systems. Conferences on measuring system performance were held in 2000, 2005, 2007, 2011, and 2015. In 2011, TRB published the National Cooperative Freight Research Program (NCFRP) Report 10 "Performance Measures for Freight Transportation" (Proctor, 2011). This report covers freight issues, performance measures, and potential data sources related to efficiency, capacity, congestion and delay, safety, security, infrastructure condition, energy use, and the environment. It proposes a "balanced scorecard" as a complete measure of the freight system in six categories: freight demand, freight efficiency, freight system condition, freight environmental impacts, freight safety, and freight system investment adequacy. In Table 1, we list all categories and relevant performance measures. The scorecard includes trend lines for past and future trends of leading indicators. Within the freight efficiency category, leading indicators are urban and rural NHS travel speeds, trend lines of top 10 highway freight bottlenecks, composite class I railroad speeds, rail freight market share, and cost of logistics as % GDP. This report also conducted surveys and interviews of private sector freight companies and state transportation agencies. Results showed significant differences in perceptions of performance metrics. Operational measures, such as costs, reliability, and timeliness, were the primary metrics of interest for private firms, whereas planning and investment measures for local/regional highway performance and externalities were of main interest for state transportation officials.

Table 1 Suggested freight transportation performance measures in NCFRP Report 10

Category	Measures
Freight demand measures	• Freight volumes, all modes • Truck freight volumes • Rail freight volumes • Inland water freight • Containerized imports/exports
Freight efficiency measures	• **Interstate highway speeds** • **Interstate highway reliability measure** • **Trendline of top interstate bottlenecks** • **Composite Class I RR operating speed** • **Rail freight market share of ton-miles** • **Logistics as a percentage of GDP**
Freight system condition indicators	• NHS bridge structural deficiencies • NHS pavement conditions
Freight environmental measures	• Truck emissions • Greenhouse emissions • Rail-produced greenhouse emissions • Water-produced greenhouse emissions • Particulates • Volatile organic components (VOCs) • Truck NOx • Rail VOCs and NOx • Ship NOx
Freight safety measures	• Truck injury and fatal crash rates • Highway-rail at-grade incidents
Freight investment measures	• Investment to sustain national highway system • Rail industry cost of capital • Estimated capital to sustain rail market share • Investment to sustain inland waterway system

State transportation agencies have continued TRB's effort to assess and manage freight transportation systems using performance measurement. One example is a study in 2010 commissioned by the Oregon DOT (McMullen and Monsere, 2010). It surveyed performance measures adopted by 50 state transportation agencies and identified key transportation policy goals: safety, environmental stewardship, maintenance of transportation investment, mobility of goods, accessibility, system efficiency, system connectivity, security, and economic vitality. In Table 2, we provide a summary of suggested freight performance measures related to system efficiency (mobility, reliability, accessibility, and connectivity). We only present those measures for which data is available or can be obtained by data manipulation/analysis, as per the authors. The authors pointed out that no aggregate index for the entire freight transportation system is available, but data envelope analysis (DEA) is one possible methodology, which uses measures of infrastructure and vehicles as inputs and ton-miles as output for each mode (highway, water, rail, and air). It can be seen that there is substantial variation in the performance measures.

Table 2 Suggested freight transportation performance measures by ODOT

Mode	Performance Measures
Highway	• Hours of congested conditions per day • Average hours of delay per day for freight vehicles on freight-significant links • Travel time index (TTI) on freight-significant links • Buffer index on freight-significant links • Triple trailer VMT as a percentage of total freight VMT
Railway	• Tons or ton-miles of freight over relevant period • Percent of shippers within 50 miles of intermodal trailer-on-freight-car (TOFC) facility • Number or capacity of intermodal facilities
Water	• Tons of traffic arriving at port • TEUs passing through port (port throughput) • Gate reliability or truck turn time • Average delay per barge tow
Air	• Flight frequency by airlines with cargo capacity (number per day) • Average time between flights by airlines with cargo capacity • Percent of on-time departures and arrivals at freight-significant airports • Average travel time delay for on airport access roads • Number of docks or acres of cargo-handling facilities

1.2 Private Sector Perspective

The literature on private sector freight transportation performance and optimization is extensive (Boisjoly, 1979; Miller, 1990; Mentzer and Konrad, 1991; Ferreira and Sugut, 1992; Stewart, 1995; Lawrence, et al., 1997; Stainer, 1997; Duma, 1999; Morash, 2000;

Gunasekeran, et al., 2001; Lai, et al., 2002 and 2004; Jones and Sedor, 2006; and Cottrell, 2008). Cottrell (2008) compared the performance metrics used by the private sector with those used by the public sector. Cottrell finds that freight performance measures considered important by the public sector are not commonly utilized by freight service providers. The author argues that because of the profit-driven nature of the private sector, many measures are customer and financially driven. For example, several customer service measures frequently mentioned in the literature are percent on-time pickup, percent on-time delivery, loss/damage rate, and percent claims paid. Financial measures include costs for logistics management and return processing, inventory duration of supply, asset turns, value-added productivity, costs or revenue per mile or ton-mile per vehicle, proportion of miles traveled empty, proportion of actual load per capacity, and various fuel usage measures (BIE, 1992; Lawrence, et al., 1997; Lai, et al., 2002).

Six measures commonly used in all freight modes (truck, air, rail, water, and pipeline) are: average length of haul, operating ratio (total expenses per total revenue), revenue per ton-mile, tonnage (total, all loads), ton-miles, and terminal dwell time. The average length of haul is related to load consolidation, fleet usage, and route optimization (Belman and White, 2005). Ton-mile does not carry with it the information on the vehicle characteristics (Levine, 1985; Duma, 1999). For example, one ton-mile is quantitatively identical whether transported by truck or air, despite differences in cost and travel time. The ton-mile measure is most commonly used across all modes at various levels of geography. It is also one measure that can be utilized to calculate and compare goods movement among multiple modes of transportation. Terminal dwell time – a measure of non-productivity – measures the duration of freight residing in a specific terminal.

In Table 3, we list sector-specific freight performance measures commonly used by the private sector. These measures are based on multiple firm surveys of transport service providers and trade groups (e.g. American Association of Railroads, American Transportation Research Institute) (Cottrell, 2008). The first row lists the six common measures across all modes, and the following rows list only those that are more sector-specific. We also present the primary sources of the measures for each item. For the trucking industry, three key measures are length of haul, percent empty miles, and operating ratio. The empty miles percentage is the percentage of the miles traveled empty between loads divided by the total miles traveled. For the Class I railroads, railcars on line (daily inventory), terminal dwell time, and train speed are important performance measures. Other sector-specific measures include average length of haul, train speed (linehaul velocity), and delays due to interferences, such as signals, right-of-way interferences, and detours. Air and water modes include performance measures for seaport and airport terminals as well as measures for carriers. Key measures for seaports are vessel turnaround time and daily average tonnage handled. Ocean carriers care for delayed days, revenue per ton-mile and towboat usage. For pipelines, operation and system integrity measures are important, such as inspected pipeline miles and number of leaks and incidents.

Table 3 Sector-specific freight performance measures (private sector)

Mode	Performance Measures
Measures commonly used in all modes	• Average length of haul • Operating ratio (margin, expenses per revenue) • Revenue per ton-mile • Tonnage (total, all loads) • Ton-miles or barrel-miles • Terminal dwell time or empty miles factor
	Below are sector-specific measures only
Truck	• Percent empty miles between loads • Freight volume • Loaded miles per load • Revenue per shipment, business day, or loaded mile • Trailers in service; Trailer operating life; Equipment utilization rate • Number of customers; percent returning customers; customer duration *Measures used by USA Truck, US Xpress, and Frozen Food Express (FTL/LTL carriers)*
Rail	• Average tons per carload and per train • Average length of haul • Carloads originated • Containers transported • Freight cars/locomotives in service • Railcars on line (daily inventory of railcars on-line) • Train speed (linehaul velocity = train miles / (total operating time – terminal time)) • Time a railcar resides at a terminal • Freight access fees • Safety: fatalities, injuries, movement of hazmat • Delays due to freight interferences, slow orders, signals, commuter/passenger rail interferences, maintenance, routing, detours • Other inconvenience: debris strike, weather, trespassers, customs and regulations *Measures used by Class I railroads (Union Pacific, BNSF, CN, CSX, Kansas City Southern, Norfolk Southern)*
Air	Air cargo terminals (ACI-NA analysis) • Total allied services (trucking, ground handling) • Ratio of fulfilled shipment • Customer service promptness Air cargo carriers • Percent scheduled transit time accomplishment • Ratio of fulfilled promises or contractual obligations *Measures used by Air Cargo World excellence survey*
Water	Port terminals (from Chung, 1993) • Vessel turnaround time (length of stay between arrival and departure) • Dwell time (number of days a ton of cargo stays in port) • Tonnage handled per ship day in port • Vessel calls and capacity Marine vessel operators (from Holcomb, 2004) • Delay measured in days • Towboats operated • Revenue per ton-mile *Measures used by Crowley Maritime, Horizon Lines, Matson Navigation Company, Seaboard Marine*

Mode	Performance Measures
Pipeline	• Accuracy of scheduled volumes • Number of scheduled and immediate repairs, • Miles inspected • Number of pipeline incidents, leaks, spills, and failures Incidents caused by corrosion and excavation damage • Average barrels per day • Average haul and barrel-miles • Revenue per barrel shipped *Measures used by Magellan and Enbridge Energy to report to US Securities and Exchange Commission*

In summary, we draw the following observations. First, there exists an extensive list of performance measures that have been used to measure freight transportation performance by public and private sectors. Second, public and private sectors pursue different performance/efficiency goals: public agencies focus on capacity, throughput, and reliability, whereas private operators focus on cost, reliability, and customer service. Third, the areas of focus for performance management vary widely across transportation modes due to the significant variation in infrastructure and operational characteristics. Fourth, there are several measures commonly important for both public and private sectors and across modes, such as tons and ton-miles. These measures count freight throughput and are used as a basis for enumerating per-throughput cost efficiency in almost all modes (e.g. revenue per ton-mile). Particularly, the ton-mile measure is most useful because it carries with it both freight volume and distance information. The extent of GHG emissions is correlated with the freight volume and distance-traveled as well as other operational (e.g. routing, load consolidation) and technological (e.g. bio-diesel, clean-diesel, ZEV) factors. Hence, a metric that consists of ton-mile and GHG emissions (or fuel consumption) would be able to effectively capture system efficiency gains of various transport modes and over time.

Part 2. Assessment of the Freight System Efficiency Metric

California seeks to reduce Greenhouse Gas (GHG) emissions within the freight industry – one of the largest contributors. The Governor's Executive Order B-32-15 requires State agencies to establish a freight system efficiency metric to be used to measure progress toward the GHG reduction target. The system efficiency target is to "*improve freight system efficiency 25 percent by increasing the value of goods and services produced from the freight sector, related to the amount of carbon that it produces by 2030*" (CSFAP, 2016, pp. 10).

The California Department of Transportation (Caltrans) was tasked with developing a metric for freight system efficiency. In collaboration with CARB, Caltrans defined the freight system efficiency metric as the ratio between the value of freight sector goods and service production and the amount of carbon dioxide equivalent emissions that the freight sector generates. This measurement has been widely used in other industry sectors, as well as to quantify the rate of greenhouse gas emissions per economic output. It is often referred to as economic emission intensity (EEI) or greenhouse gas intensity of the economy. This measure is intended to be used to track trends over time and to obtain a general indication of progress toward the stated 25% improvement goal. The mathematical formula is as follows:

(Equation 1)

$$Freight\ System\ Efficiency\ (FSE) = \frac{GDP\ (NAICS\ 48-49, minus\ passenger\ components)}{CO2e\ (freight\ movement)}$$

2.1 Numerator – Freight Sector GDP

The US Bureau of Economic Analysis publishes gross domestic product (GDP; million dollars) of the freight sector – the numerator. The expenditure method is used, which considers consumption (measured at market prices for final users), investment, government spending, and net exports (BEA, 2015). GDP in both the current and chained dollars (inflation adjusted) are published: the chained dollar figures are suitable for time-series analysis. GDP statistics are published on a quarterly and annual basis by state based on three-digit industry sector classification (North American Industry Classification System Code, NAICS). The NAICS defines grouping of economic activity, namely an industry sector, based on *production processes* or *producing units* rather than produced goods or services (NAICS Manual; Office of Management and Budget, 2017). The unit of analysis is an establishment – "*a single physical location where business is conducted or where services or industrial operations are performed*" (NAICS Manual, 2017, pp. 19). Thus, the primary economic activity of a single physical location – establishment – is assigned an industry sector. One or multiple establishments may comprise an enterprise. When multiple distinct economic activities (e.g. retail shops in a hotel) are performed in a single location, which are commonly documented in the economy, every activity is "*classified, to the extent feasible, according to the NAICS code related to their own activity*" (NAICS Manual, 2017, pp. 20). According to the NAICS manual, "*each activity is treated as a separate establishment provided: (1) no one industry description in the classification includes such combined activities; (2) separate reports can be prepared on the number of employees, their wares and salaries, sales or receipts, and expenses; and (3) employment and output are significant for both activities*" (NAICS Manual 2017, pp. 19). Hence, some economic activity within a location provided by in-house units as a support (captive) activity would not be identified as a separate establishment.

For the FSE, the freight sector is defined as NAICS 48-49, transportation and warehousing, minus NAICS 485 Transit and ground passenger transportation (CSFAP, 2016, pp. B-1). Specifically, the freight sector consists of "*establishments primarily engaged in: air transportation, rail transportation, water transportation, truck transportation, pipeline transportation, other transportation and support activities, and warehousing and storage*" (CSFAP, 2016, B-2). There are two potential sources of error where the true portion of freight activity might not be accurately enumerated. First, at the three-digit level, there are portions of some sectors that are not freight. These are highlighted in Table 4. For example, 481 Air and 483 Water include both passenger and freight transportation. 487 Scenic and sightseeing is passenger transport, with land transport taking place in buses. The GDP measure does not include 491 Postal service (USPS) because it is a federal government enterprise. Thus, the GDP measure is not a "pure" measure of freight activity.

It is important to note the following. First, it is not possible to delete the non-freight subsectors, because the GDP data are provided only at the three-digit level. Second, GDP measures all the economic activity of the sectors, whether associated with freight movement or not (e.g. management and administrative costs). If for example navigational services or packing and crating prices increase, all else equal, freight sector GDP would increase, even though there is no increase in transport services. Third, there are also portions of freight activity that are performed in non-freight sectors, and thus excluded from the freight sector's GDP accounting. If goods distribution or warehousing capacity are provided by in-house units as a support (captive) activity of a non-freight transportation business and do not meet the 3 NAICS conditions for separate accounting, it is highly likely that outputs of such freight activity are recorded as the sector of the primary activity. This could happen with a manufacturing firm that ships products within the same establishment, or a retailer that uses part of its on-site storage as an online shopping fulfillment center.[1] According to the NAICS manual, receipts or sales records are often not available for transactions within an establishment.

[1] Available at: https://www.usatoday.com/story/tech/2013/09/28/retailers-ship-from-store/2862405/

Table 4 Definition of the freight sector within NAICS 48-49 transportation and warehousing

Sectors	Six-digit Subsectors	Included in GDP (BEA) as freight sectors
481 Air transportation	4811 Scheduled air transportation 481111 Scheduled passenger air transportation 481112 Scheduled freight air transportation 4812 Nonscheduled air transportation 481211 Nonscheduled charter passenger air transportation 481212 Nonscheduled charter freight air transportation	Included **+ passenger transport portions**
482 Rail transportation	4821 Rail transportation 482111 Line-haul railroads 482112 Short-line railroads	Included
483 Water transportation	4831 Deep sea, coastal, and Great Lakes water transportation 483111 Deep sea freight transportation 483112 Deep sea passenger transportation 483113 Coastal and great lakes freight transportation 483114 Coastal and great lakes passenger transportation 4832 Inland water transportation 483211 Inland water freight transportation 483212 Inland water passenger transportation	Included **+ passenger transport portions**
484 Truck transportation	4841 General freight trucking 4842 Specialized freight trucking	Included
485 Transit and ground passenger transportation	4851 Urban transit system 4852 Interurban and rural bus transportation 4853 Taxi and limousine service 4854 School and employee bus transportation 4855 Charter bus industry 4859 Other transit and ground passenger transportation	Excluded
486 Pipeline transportation	4861 Pipeline transportation of crude oil 4862 Pipeline transportation of natural gas 4869 Other pipeline transportation	Excluded
487 Scenic and sightseeing transportation	4871 Scenic and sightseeing transportation, land 4872 Scenic and sightseeing transportation, water 4879 Scenic and sightseeing transportation, other	Excluded
488 Support activities for transportation	4881 Support activities for air transportation 4882 Support activities for rail transportation 4883 Support activities for water transportation 4884 Support activities for road transportation 4885 Freight transportation arrangement 4889 Other support activities for transportation	Included
491 Postal service	4911 Postal service	Excluded (Federal government enterprise)
492 Courier and messengers	4921 Couriers and express delivery services 4922 Local messengers and local delivery	Included
493 Warehousing and storage	4931 Warehousing and Storage	Excluded

2.2 Denominator – Freight Sector CO2e Emissions

The denominator is Carbon Dioxide Equivalent emissions (CO2e, consisting of CO_2, CH_4, and N_2O; million metric tons) from freight movement. The California Air Resources Board (CARB) publishes annual statistics of this emissions metric. In this section, we summarize how the emissions metric is quantified, referring to the methodology and data sources detailed in the 2016 technical support document of California's 2000-2014 Greenhouse Gas Emission Inventory (CARB, 2016).[2]

The CARB CO2e emissions are calculated and reported according to the 2006 Intergovernmental Panel on Climate Change (IPCC) GHG Inventory Guidelines.[3] Like the NAICS codes, IPCC has levels of subcategories. We identify all subcategories relevant to the freight industry and present levels 3, 4 and 5 to show how the levels are nested. Level 3 "1A3 Transport" is under Level 1 "1 Energy" and Level 2 "1A Fuel Combustion Activities." We list the activity of each Level 5 category and show which are included in the state level GHG calculation for all vehicles (passenger and freight). International and interstate portions of aviation and water-borne transportation are excluded, as suggested by the IPCC guidelines. The last column of Table 5 identifies which subcategories are relevant to freight activity.[4] These categories are similar to the subsectors of the NAICS 48-49 transportation and warehousing listed in Section 1.1. However, the two classification systems are not perfectly comparable, because the unit of analysis is different: GDP is classified by industry sectors of business firms, and GHG is categorized by the mode of transportation. One

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[2] Available at: https://www.arb.ca.gov/cc/inventory/data/data.htm
[3] Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/
[4] This description is based on a telephone interview with Anny Huang, Manager of Greenhouse Gas Inventory Analysis, CARB, on 4/7/17.

potential source of error is any freight activity associated with light and medium duty trucks (e.g. online shopping fulfillment; last mile goods movement).

Table 5 IPCC categories and relationship to freight sector activity

IPCC Level 3	IPCC Level 4	IPCC Level 5	Sector Activity Details	In CA GHG calculation?	Related to freight activity?
1A3 Transportation	1A3a Civil Aviation	1A3ai – International aviation	International civil aviation	No	Yes
		1A3aii – Domestic aviation	Domestic air transport - interstate	No	Yes
			Domestic air transport - intrastate	Yes	Yes
			Domestic air transport - aviation	Yes	Yes
		non-specified		Yes	-
	1A3b Road Transportation	1A3bi – Cars	Passenger cars	Yes	No
		1A3bii – Light-duty trucks	Light- and medium-duty trucks and SUVs	Yes	No
		1A3biii – Heavy-duty Trucks and Buses	Heavy-duty trucks (8,500 < GVW lbs.)	Yes	Yes
			Buses	Yes	No
			Motorhomes	Yes	No
		1A3biv – Motorcycles	Motorcycles	Yes	No
		non-specified		Yes	-
	1A3c - Railways	Rail		Yes	Yes
	1A3d Water-borne Navigation	1A3di – International water-borne navigation	International navigation	No	Yes
			Port activities	Yes	Yes
			Transit (CA waters)	Yes	No
		1A3dii – Domestic water-borne navigation	Inter/intrastate: port activities	Yes	Yes
			Inter/intrastate: transit (CA waters)	Yes	No
			Intrastate: harbor craft	Yes	Yes
			Non-specified	Yes	-
	1A3e Other Transportation	1A3eii – Off-road	Airport ground support equipment	Yes	Yes
			Construction and mining equipment	Yes	No
			Industrial equipment	Yes	Yes
			Oil drilling equipment	Yes	No
	Non-specified transportation			Yes	-
1A4 Other sectors	1A4a - Commercial/ Institutional		Retail and Wholesale: Warehousing Retail and Wholesale: Refrigerated warehousing	Yes	No
	1A4a - Commercial/ Institutional		Transport services	Yes	No

The IPCC Guidelines specify inventory categories by transport mode, but do not require separation of the freight portion from general passenger and public transit transportation activities. Therefore, CARB's annual GHG inventory does not disaggregate freight emissions. In developing the CSFAP, CARB compiled a custom inventory for freight activities. Table 6 shows how the freight portions were calculated for the CSFAP (2016). We further describe the detailed methodologies to estimate fuel consumption by subcategory in the following sections. The fuel sales volume in California is the benchmark when fuel consumption is estimated across all the subcategories. The CARB calculations come very close to the actual fuel sales figure; in 2016 the estimate was within 2%.

Table 6 Calculation of freight portions by IPCC subcategory

IPCC Categories	Freight portion
1A3a Civil aviation	Fixed rate (12%)
1A3b Road transportation	Heavy-duty truck only (≥14,000 lbs. GVW) in 1A3biii Heavy-duty trucks and buses
1A3c Railways	Actual fuel consumption data of freight trains
1A3d Water-borne navigation	Shipment data from CARB (2011) with sub categories that separate the passenger portion from the rest
1A3e Other transportation	Cargo handling equipment, transport refrigeration units, ground support equipment, and industrial equipment
1A4a Commercial, Institutional – Retail and wholesale: warehousing and refrigerated warehousing; and Transportation services	Not included

2.2.1 Estimation of GHG Emissions – On-road heavy-duty truck portions

The estimation of the fuel consumption of heavy-duty trucks is based on the EMFAC (emissions factor) model, which uses 1) vehicle population and age by fuel type, make, model, and year-specific vehicle population data, 2) vehicle miles traveled data from local and regional transportation surveys, and 3) tailpipe emissions test data.[5] This model uses a bottom-up approach – the estimation of aggregated fuel consumption of detailed vehicle subcategories that is then matched to the total fuel sales figure. Thus, the EMFAC model allows apportioning of fuel sales figures among detailed vehicle subcategories. The emissions volume is based on the fuel consumption by vehicle type by fuel type in a given year multiplied by heat content and emissions factor by fuel type – Equation (2). The CO_2 accounted for only considers the pure volume of each type of fossil fuel consumed (U) in the fuel blend. The emission of CH_4 and N_2O is quantified by multiplying different factors to each fuel-type consumed, including biofuels. The volume of fuel sales is the benchmark for emissions calculation. Hence, the modeled volume is adjusted by the ratio of sale volumes to modeled volumes.

(Equation 2)

$$E_{type,fuel,year} = U_{type,fuel,year} \times HC_{fuel} \times EF_{CO_2,fuel}$$

Where,

E = CO_2 emissions by vehicle type by fuel blend in a given year;
U = pure fuel quantity by vehicle type which uses the given fuel in a given year;
HC = heat content by fuel type (BTU/unit);
EF = CO_2 emissions factor by fuel type (g CO_2/BTU)

There are multiple sources to enumerate the entire population of heavy-duty trucks (Table 7). The primary source is the California Department of Motor Vehicles (DMV), from which a list of vehicles by class, body type, weight, and other parameters are drawn in April

[5] Items 1 and 3 are updated annually; since item 2 comes from other agencies, the data may or may not be updated annually.

and October in the year prior to each EMFAC release. Second, a portion of vehicles in the International Registration Plan (IRP) is included in the DMV database; these data are used to capture the portion of interstate or international travel that takes place in California. Third, the International Fuel Tax Agreement (IFTA, administered by the Motor Carrier Section of the Board of Equalization) is used to quantify truck travel miles by fleet by registered jurisdiction. Fourth, the Vehicle Inventory and Use Survey (VIUS) provides data on the physical and operational characteristics of private and commercial trucks at the national level. From the VIUS database, the accrual rates of truck mileages are calculated from the cumulative odometer counts by vehicle type by model year. The VIUS program was terminated in 2002. Fifth, the ARB vehicle survey is an online survey conducted in 2008 that collected truck age, body type, travel miles, and other factors. Lastly, the UC Davis Out-of-State truck travel survey, conducted in 2006, collected data on physical characteristics, operational characteristics, travel miles, fuel consumption, and fueling location data on 433 out-of-state (registered, domiciled, and/or refueled outside California) trucks. Based on these databases, the total populations of heavy-duty trucks operating in California but registered elsewhere are estimated. Table 7 shows data sources for each vehicle subcategory.

Table 7 Data sources for heavy duty diesel trucks and power take-offs

Category 1	Category 2	Vehicle population	Source and rate of average annual mileage calculation
Heavy-heavy	Out of state	DMV+IRP+IFTA	VIUS Neighboring states: 40% of annual miles in CA Non-NS: 10% of annual miles in CA
	CA interstate	DMV+IRP Trucks; construction trucks	VIUS CA IRP: 55% of annual miles in CA
	In-state tractor	DMV+IRP Trucks; construction trucks	VIUS
	In-state single	DMV+IRP Trucks; construction trucks	VIUS
	Drayage tractors	DMV, gate count and license plate info survey South Coast; Bay Area; Other facilities	Drayage truck rule staff report (ARB, 2007)
	Agriculture trucks	Surveys administered by Agricultural Trade Association	Surveys administered by Agricultural Trade Association
	Utility trucks	DMV	TIAX report (2003)
Medium-heavy	In-state trucks	DMV+IRP Trucks; construction trucks	VIUS
	Interstate trucks	DMV+IRP CA IRP trucks; out-of-state trucks	VIUS CA IRP: 63% of annual miles in CA Out-of-state IRP: 8% of annual miles in CA
	Agriculture trucks	Surveys administered by Agricultural Trade Association	Surveys administered by Agricultural Trade Association
	Utility trucks	DMV	TIAX report (2003)
Other	Power take-off (PTO) (e.g. crane lifting, cement mixer)	Use fuel consumption data for PTO in CA (2005) reported by CA Board of Equalization (BOE)	Age distribution assumed the same as HHDDT single unit trucks

*TIAX LLC., a consulting firm, prepared the 2003 Final Report of "California Public Fleet Heavy-Duty Vehicle and Equipment Inventory."

2.2.2 Estimation of GHG Emissions – Air transportation

The volume of commercial airline's jet fuel consumption in California is calculated as the total jet fuel consumption, available from the US Energy Information Administration (USEIA), excluding the portions of general aviation and military aviation. The USDOT's air carrier statistics database is the data source. Fuel consumption is subdivided into international, interstate and intrastate segments by type of aircraft, length of flights, and other parameters. As advised in the IPCC guidelines, fuel consumption for flights that have both origin and destination within the boundary of California only is accounted for in the state portion. Referring to the European Environment Agency's Air Pollution Emissions Inventory Guidebook (2007), the rates of fuel consumption per flight miles in association with that of fuel consumption while landing/takeoff are estimated using linear least-square formulae by type of aircraft. These formulae are used to disaggregate fuel usage by flight segment and by type of aircraft. Twelve percent of the fuel consumption is set as the freight portion. That is based on approximations of freight-specific weights or cargo-specific flights over a number of years.

2.2.3 Estimation of GHG Emissions – Rail transportation

The volume of fuel consumption of rail transportation is based exclusively on fuel purchased in CA. Staff used those numbers without any modification. Sales of rail distillate fuel (in gallons) in California were reported by the US Energy Information Administration EIA (2015).

2.2.4 Estimation of GHG Emissions – Water-borne Transportation

Water-borne transportation accounts only for the activity that occurred in CA or within 24 nautical miles of the coast. The disaggregation of shipments across intrastate, interstate, and international activities within the 24 nautical-mile limit is based on the shipment data from the emissions estimation by CARB (2011). Because this estimate uses only the 24 nautical-mile portion of travel, the matching between the refueled volume in California (statistics from California Board of Equalization) and fuel consumption quantified as a function of travel miles and vehicle types may be quite different and subject to error.[6]

2.3 Evaluation of Consistency and Reliability of the Metric

Given that the FSE is intended to track progress toward the 2030 target, it is important to validate its consistency over time. In this section, we evaluate the comparability of the numerator and denominator.

2.3.1 Differences in numerator and denominator

The basic question is whether the numerator and denominator are measuring the same thing. The contents of freight sector GDP and freight vehicle GHG are clearly not perfectly matched. As discussed earlier, the former quantifies the economic output of the freight transportation *sector*, whereas the latter quantifies GHG emissions from freight *vehicles*. From the perspective of GDP, the freight sector is measured as the market value of its outputs, which includes the labor, rent, and other inputs used to produce it. Although GDP is related to the quantity and value of outputs, and hence to the movement of vehicles, it is clearly not perfectly related to freight vehicle GHG. For example, one otherwise identical shipment transported for express delivery will generate more GDP than one regular delivery, yet the shipment distance (and VMT) may be the same. From the perspective of GHG emissions, the movement of vehicles is the critical factor. GHG calculations ignore industry sectors, but pay a lot of attention to VMT and vehicle characteristics. Using the

[6] Per Anny Huang, 4/7/17.

example above, whether the two deliveries take place with the same or different vehicles would determine generation of GHGs.

Does it matter whether there are differences between the GDP and GHG calculations? If the differences were constant, FSE would be biased, but likely still a reliable measure of progress in freight efficiency. For example, if the share of "non-VMT" GDP in the transportation sector GDP were constant, we would consistently over-estimate GDP relative to what is included in GHG, but in using the metric to compare relative progress, it would not have any effect. However, if the differences are not constant, the measure would not be reliable. Again, using the simple example of express and standard deliveries, we expect that express deliveries, assuming identical vehicles, routes, and VMT, occur more frequently in growing economies. All else equal, more express deliveries increase GDP, which increases FSE. In a declining economy, we would have the reverse effect, and FSE would decline. FSE would indicate progress toward the target in the first case, but regression from the target in the second, even though GHGs and physical output (delivery of the shipment) don't change.

Even if FSE is biased in a way that affects results over time, it may still be an acceptable metric, as long as the biases are small. For example, we would not expect variations in the share of express deliveries to have much of an effect. There are many sources of error in a calculation as complex as that for CO2e, and there are many sources of error in the reporting of GDP.[7] The errors are likely larger than the effect of something like variation in express deliveries.

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[7] The potential for error can be incorporated by using probability distributions of the GDP and CO2e values, rather than point values. This approach would show that small changes in FSE are not statistically significant.

Differences matter when the potential effect of bias is large. We therefore explore whether FSE is subject to large differences in comparability of GDP and CO2e calculations. Table 8 shows the subcomponents included and excluded in GDP and GHG. GDP information is given in the columns, and GHG information is given in the rows. If the measures were fully compatible, all entries would be in the right diagonal (boxes 1 and 4). It is evident that this is not the case. Starting with GDP, the entire freight transport sector (NAICS 48-49 minus transit, scenic, pipeline, postal service, and warehousing) is included. This means not only the HDTs and vehicle portions of air, rail, water, and transport services in the GHG calculation (box 1, as represented in market values), but light and medium duty trucks as well (box 3). As discussed above, the unit of GDP calculation is establishment rather than enterprise, hence auxiliary establishments that provide freight transportation and warehousing services to non-transportation sector firms (i.e. the addresses must be different) are included in box 1 (Kort and Morgan, 2005). For example, the GDP of private warehouses (a separate establishment) under a manufacturing enterprise is captured as warehousing activity (NAICS 493). In addition, the GDP of self-employed truck drivers are included from the SBO (survey of business owners) in the various truck transportation subsectors. However, the GDP calculation omits all sources of freight activity (non-primary) occurring within a non-freight transportation establishment (box 2). Thus, part of the freight movement associated with manufacturing, construction, retail, etc. may be excluded. The GHG calculation is based on all HD movements, so includes these freight movements. Finally, box 4 represents activities excluded in both, mainly transit and general passenger vehicle activity. To sum up, FSE is actually calculated as:

(Equation 3)

$$FSE_{real} = GDP([1] + [3])/GHG([1] + [2])$$

Table 8 Freight activities included and excluded from the GDP and GHG calculations

Metric		GDP	
		Included *NAICS 481 Air, 482 Rail, 483 Water, 484 Truck, 488 Support activities, 492 Courier*	**Excluded** *NAICS 485 Transit, 486 Pipeline, 487 Scenic, and 491 Postal, 493 Warehousing, and freight activity in all other sectors*
GHG	**Included** *Freight vehicles*	***[1] Freight transport*** Air, Rail, Water, Truck (heavy-duty only), Courier	***[2] All other sectors' freight activity not captured as separate establishment*** Agriculture, utility, manufacturing, wholesaling, retail, administration, accommodation, public, and other services
	Excluded *Transit/ground transport, LDT, MDT, Pipeline, scenic, postal & warehousing and non-transport sectors*	***[3] Part of freight transport*** Light and medium duty trucks operated for freight transport, support activities	***[4] Non-freight transport*** Transit and ground transport, general passenger vehicle, pipeline, scenic, postal, and warehousing as well as two non-transportation sectors (mining and construction)

The difference between FSE as calculated and a fully comparable FSE is mostly a function of the size of boxes [2] and [3]. With regard to box 2, it is possible that much of the freight movement is captured via establishment data. However, according to the VIUS 2002 dataset, vehicles utilized in agriculture, mining, construction, manufacturing, wholesale and retail trade, utilities and all other service sectors account for about 60% of the number (61.6%) and the truck miles (61.7%) of all trucks, excluding pickups, minivans, other light vans, and sport utility vehicles. Because the VIUS program was terminated in

2002, we do not know whether this proportion is still the case. Unfortunately, we have no way to know how much of the freight activity represented in these sectors is captured in the establishment data. We can examine changes in industry mix with GDP data, but not changes in the contribution of transportation within sectors. With regard to box 3, GHG emissions of light duty trucks accounted for 33.9% of the total emissions of the 1A3 Transportation category in 2000, reached its peak in 2009 (38.2%), and then decreased to 36.5% in 2014. We have no way to separate out the box 3 subcomponents from the GDP calculation. The share of freight activities of box 3 is not quantifiable, but certainly not small.[8] We therefore must address the question of how these differences could affect FSE measurement over time.

2.3.2 How differences may affect FSE measurement over time

Changes in industry mix

We first examine the effect of a change in industry mix. Transportation and warehousing makes up a very small proportion of state GDP: about 2.8% in 2015.[9] Roughly 60 percent of HDTs are in the other 98% of GDP (per the VIUS data). What happens as industry mix changes? Using freight trip generation data from the SCAG region, we categorize one digit sectors into high, medium and low freight intensity.[10] We use national real GDP (chained 2009 dollars) data from BEA to generate Table 9, a rough estimate of changes in freight intensity relative to changes in industry mix. Transportation and warehousing is in the

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[8] We were not able to access to DMV records to be able to estimate vehicle type shares for the transport sector. With DMV records, we would have linked vehicles to firms, and hence to NAICS codes.
[9] Source: https://www.statista.com/statistics/304869/california-real-gdp-by-industry/, accessed 4/21/17.
[10] Source: Southern California Association of Governments 2012 model data.

high freight intensity category. Over the past 2 decades, both high and medium freight intensity shares have dropped, while the low freight intensity share increased. Thus, the total amount of freight activity *relative to GDP* is declining.

Table 9 US Industry mix 1996 – 2016 by real GDP (2009 chained) by freight intensity category

Freight intensity categories	1997	2006	2016
High (transport, warehouse, utilities)	5.6%	4.8%	4.5%
Medium (wholesale, retail, manufacturing, construction)	30.1%	30.7%	27.8%
Low (public admin, all services, health)	62.9%	62.2%	64.6%

*This table excludes agriculture and mining sectors. Freight intensity is measured as the trip generation rate, truck trips per employee.

The change in industry mix and associated freight intensity (declining), all else equal, would reduce GHG (box 2, freight activity in non-transportation sectors, declines), which would increase FSE. The change would likely not affect GDP very much, because the high freight intensity sectors are likely using few medium and light duty vehicles (box 3). Thus, the overall effect would be an increase in FSE, independent of any change in technology or GHG/mile.

Economic expansion or contraction

A second consideration is economic growth. Over a 1-2 decade period, we must consider the effects of the business cycle. In a period of expansion, there are short-term shortages that generate price increases (e.g. increased wages, higher prices for raw materials, higher rents, etc.). GDP increases, but at the same time freight gets more efficient (more opportunities for full loads and backhaul business). All else equal, GDP would grow faster than GHG, independent of GHG/mile. Again, FSE would increase. The opposite would take place during a recession. Prices drop and excess capacity increases. GDP would go down faster than GHG, and FSE would decrease, all else equal.

Changes in freight practices

Finally, we consider changes in freight practices. One example is in-house or out-sourced shipping. If a retail firm uses its own on-site trucks for shipment, it would not be captured as a separate establishment, and the associated GDP would fall outside the transport sector (NAICS 48-49), but not outside the GHG calculations. If a retail firm purchases shipping services, these services are included in both GDP and GHG calculations. If business practices change, and more retail firms out-source for shipping services, GDP will rise, GHG will not change (all else equal), and FSE would increase. If the trend were reversed, with more retailers taking shipping in house, GDP would fall, GHG would remain the same, and FSE would decline.

Another example is the shift in freight transport mode choice, in conjunction with changes in logistics structure. Over the last decade, advances in information management technologies have enabled goods production and distribution firms to respond to consumer demand more quickly. At the same time, online shopping has expanded significantly, and demand for instant delivery has increased. Sales in online shopping are expected to grow rapidly in the coming years. All these changes have resulted in increased demand to transport goods more quickly and reliably. On the one hand, more volume should lead to more efficiency (both economic and with respect to GHG emissions) through more full truck loads and efficiencies in routing. These types of efficiencies would be reflected in the FSE (again assuming all else equal, including prices). On the other hand, the expected increase in the proportion of instant deliveries is likely to influence the last mile delivery mode, likely towards smaller trucks (light- or medium-duty). Light and medium duty trucks are not included in the FSE. To the extent that large trucks are substituted for smaller trucks, the GHG calculation would decrease, even though GHG emissions may have in fact increased. Similarly, if these changes in supply chains increase demand for air cargo carried in the belly of commercial passenger service, the added volume would not be captured in the GHG calculation, because a fixed factor is used for this type of air cargo.

2.4 Discussion

Because of the fundamental differences in what is counted by GDP and GHG in the FSE metric, there are many possibilities for changes in the metric that would not reflect actual per mile (or per value) emissions reductions, which is the goal for the CSFAP. In order to improve the reliability of the FSE metric, we should focus on shrinking the contents of box 2 (freight activity associated with non-freight sectors) and box 3 (light- and medium-duty trucks' GHG emissions) in Table 8.

First, we could include light- and medium-duty trucks as well as light-heavy duty trucks in the GHG calculations so that most of the contents of box 3 is shifted into box 1. However, this will simultaneously introduce a substantial amount of error and noise into the calculation. As more light-duty trucks are accounted for, it will become more likely that vehicles not explicitly utilized for freight activity are included. Specifically, according to the 2002 Vehicle Inventory and Use Survey (VIUS), pickups, minivans, and sport utilities, all included in the light-duty truck category, accounted for 94.6% of all California truck stocks. The use of these vehicles is so extensive (e.g. usage in agriculture, utility, construction, manufacturing, transportation, and accommodation sectors) that their inclusion might introduce an entirely different comparability problem. One potential remedy is to filter out any vehicle without a commercial license plate. Box 2 is more difficult. The main question is the extent to which separate establishments capture freight activity associated with non-freight sectors. It may be necessary to conduct a survey of firms and review how freight activity is reported.

All in all, we conclude that FSEM is likely not a reliable metric to measure success in reducing GHG emissions in the freight sector. Linking GHGs to GDP is the major problem, because there is no way to generate a GDP measure that is fully consistent with the GHG measure.[11] At this point we do not know whether these potential biases are large or small. It may be possible to establish upper and lower bounds via numerical simulation. This is beyond the scope of this project, but should be considered as a useful next step in evaluating the reliability of the metric.

[11] Note this is not the case when the metric is used to measure the GHG emissions efficiency of an entire economy.

Part 3. Development of Supportive Measures

Based on our assessment above, we conclude that the FSEM may not reliably measure progress in freight system efficiency because (1) the units of measurement are different between the numerator and denominator (economic output of businesses vs. GHG emissions of freight vehicles) and (2) portions of GDP and GHG calculations are inconsistent with each other (portions in box 2 and box 3 in Table 8). Use of a numerator less prone to these measurement biases could improve the accuracy and reliability of a freight efficiency metric. Furthermore, the FSEM, as an aggregate metric of the entire freight transport sector, cannot capture a given transport mode's efficiency improvement. Every transportation sector utilizes distinctive infrastructure and operational practices. In that sense, the metric should be capable of measuring the freight system efficiency consistently across different modes.

3.1 New metric: ton-miles/GHG

The ratio of ton-miles to GHGs, with both calculated on the same set of vehicles, would be a much stronger metric. This measure compares the weight-distance of transported goods, as a proxy for freight outputs, to freight vehicle GHG emissions, as a proxy for energy inputs as well as freight externalities. A mathematical formula is as follows:

(Equation 4-1)

$$Supportive\ FSEM\ (1) = \frac{\sum_i Freight\ ton\ miles\ by\ mode\ i}{\sum_i GHG\ emissions\ by\ mode\ i}$$

(Equation 4-2)

$$Supportive\ FSEM\ by\ sector\ j\ (1) = \frac{Freight\ ton\ miles\ by\ mode\ i}{GHG\ emissions\ by\ mode\ i}$$

Where (i) indicates mode of freight transportation.

Compared to the GDP/GHG metric, T-M/GHG has several advantages in capturing freight efficiencies in a consistent manner. First, ton-miles per GHG measures the "freight work" produced by expended energy. The freight work is expressed by shipment distance and weight and is directly related to vehicle-level freight activity. Second, our literature review indicates that ton-miles is one of the most commonly used metrics that quantify operational efficiency across all modes at various levels of geography. Third, it can be used as an aggregate measure for all sectors as well as a disaggregate measure by each mode of transportation. In either case, it produces consistent results across modes over time, because the numerator is mode neutral. That is, ton-miles is not sensitive to the variation in mode/type of freight vehicle, but only to changes in the amount of the freight work. Specifically, one ton-mile shipment by truck is equivalent to one ton-mile shipment by rail. In terms of the freight work, the two cases are identical. However, the two are different in terms of operational practices and energy efficiency. The denominator captures efficiency differences between the two modes. Therefore T-M/GHG would effectively capture efficiency gains or losses from operational adjustments or technological advancements.

To illustrate how T-M/GHG would work, consider the case of alternative fuel trucks. Drayage of a 40,000 lb. (20 tons) container 50 miles with empty backhaul would result in 100 ton-miles and 200 vehicle miles. The trip could be made by conventional diesel truck, hybrid electric, CNG, or battery electric truck. Each trip would generate different amounts of GHG. The ratio would clearly show differences in the GHG efficiency of the various fuels. However, performance of alternative fuel vehicles also varies. If we consider a series of repeated trips, trucks with shorter ranges than conventional diesel will add more miles due to more frequent refueling, and refueling locations are more limited for alternative fuels. Since GHG estimation is based on vehicle miles, these added miles would also be captured in the GHG denominator. A GDP estimate would obscure these effects because of the non-transport related expenditures in the sector GDP calculation.

3.1.1 Data problems

The main disadvantage of a ton-mile measure is the lack of data. There is no source for annual state level data on ton-miles. Every five years, the Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA) produce the freight analysis framework (FAF) dataset, which includes ton-mile freight flow estimates by value and weight by mode and by SCTG commodity type.[12] Seven classes of transportation modes are available: truck, rail, water, air, multiple modes and mail, pipeline, other and unknown. Truck includes private and for-hire trucks and excludes personal use vehicles, utilized by retail establishments. Oftentimes, goods purchased at a retail store are delivered by the store using its fleet of vehicles. The choice of vehicle, either truck or pickup/SUV, largely depends on the type and volume of goods. The FAF applies a fixed rate, which varies with respect to commodity types (e.g., 1% of clothing or 70% of furniture purchases are delivered by trucks), to calculate the ratio of vehicle utilization. Air includes shipments

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[12] Available at: https://ops.fhwa.dot.gov/freight/freight_analysis/faf/
SCTG: Standard Classification of Transported Goods

over 100 pounds transported by "air" or "air-and-truck" combinations in commercial/private aircraft. Shipments below 100 pounds are included in "multiple modes and mail" which include parcel delivery, USPS, and couriers. This classification is compatible with the IPCC categories, except for the USPS portion. FAF provides flows in tons, ton-miles, and by value.

The FAF-based estimate of ton-miles by mode has some disadvantages. First, the commodity part of FAF is based on the Commodity Flow Survey, which is conducted every five years (the current most recent CFS is 2012). Thus, the most recent FAF data is based on 2012, and a metric based on FAF could only be updated every five years. Second, the FAF estimation is based on different data than that used by CARB to estimate vehicle miles, hence it is unlikely that FAF ton-miles would be adequately comparable to CARB vehicle miles. These problems argue for a state level data collection effort, if a ton-mile metric is to be used.

3.2 Alternative metric: freight VMT/GHG

Given the difficulties of establishing a state level ton-mile database, we considered a second-best option. One possibility is freight vehicle miles per GHG emissions. It would compare the mileage of freight vehicles to the GHG emissions that freight vehicles generate.

As discussed earlier, CARB must estimate freight VMT by mode and vehicle attributes in order to estimate emissions via the EMFAC models. Thus, freight VMT is or can be available annually. The CARB VMT estimate must be highly correlated with emissions estimates, given that VMT is a key input into the emissions estimates. The risk is that numerator and denominator measure the same thing, as VMT is a reasonable proxy for emissions. Absent modal shifts or changes in fuel efficiency, the ratio would be basically constant from year to year. Unlike the ton-miles measure, the VMT based ratio will only capture changes in mode or vehicle technology. Operational changes that increase efficiency (e.g. reduce empty miles) would be mixed with changes in VMT from sector growth, shifts within subsectors, or other factors. Table 10 summarizes the advantages and disadvantages of T-M/GHG and VMT/GHG.

There are several advantages of using these measures. First, both numerator and denominator have a common unit of analysis – a freight vehicle. As discussed previously, the disparate unit of analysis of the original FSEM is one of the fundamental problems that make its numerator and denominator not directly comparable. Vehicle based measures compare transportation outcomes (ton-miles, miles) directly to GHG emissions generated by the activity. Second, both T-M/GHG and VMT/GHG directly quantify efficiency gains in vehicle-level technological advancement. T-M/GHG also captures operational efficiencies. Both are more robust to changes such as the increase in e-commerce. Increased e-commerce will add to VMT; T-M/GHG would capture the reduced efficiency inherent in moving more goods in smaller units. Finally, technology and business practices are changing rapidly. A system efficiency metric capable of monitoring such changes in a consistent manner is appropriate. Table 10 summarizes the advantages and disadvantages of the two alternative measures.

Table 10 Advantages and disadvantages of using supportive FSE metrics

Measure	Advantages	Disadvantages
Ton-mile per GHGs	• Has a consistent unit (vehicle) of analysis • Measures the "freight work" produced by the expended energy • Can be disaggregated by mode • Captures efficiencies in operations and in fuel consumption • Captures changes in efficiency over time	• Does not reflect value of work produced • FAF data only available every five years and may not be comparable to state VMT estimates • State level data would require new data collection effort
VMT per vehicle per GHGs	• Has a consistent unit (vehicle) of analysis • Can be disaggregated by mode • Captures efficiencies from modal or fuel shifts • Annual VMT estimates available from CARB emissions models	• Does not measure freight work produced or its value • Captures only fuel and mode shift efficiencies, not operational efficiencies • Not applicable to pipeline transportation • CARB estimates for VMT and GHGs, which are a fixed function of VMT, are highly correlated.

Conclusions

The CSFAP was developed in a short period of time. Given the many constraints on delivering a single metric to measure freight efficiency, the FSEM was selected. The intent of the FSEM is to link value produced by the freight industry to GHGs produced by the industry. As the freight sector becomes more operationally efficient, more value should be created with fewer miles, and hence less GHG emissions. As the freight sector adopts more alternative fuel vehicles, the same virtual process should occur.

While metrics similar to FSEM have been used effectively at the national level, there are problems when applying to specific sectors. Economic value is measured by industry sector, while GHGs are measured by vehicles. It is not possible to fully map between sectors and vehicles, and therefore FSEM has comparability problems. For GDP, potential sources of error are 1) inclusion of non-freight transport sector activity in air, water and scenic transportation sectors, 2) inclusion of activity not necessarily associated with freight movement, and 3) exclusion of freight activity conducted by non-freight transportation sectors. For VMT, potential sources of error are 1) exclusion of light and medium duty trucks, and 2) ambiguity in calculating freight transportation shares within the air and water transportation categories.

We conclude that the numerator and denominator of FSEM are not fully compatible. We explored how this might affect measurement over time. In considering examples of changes in industry mix, operational practices, and economic growth or decline, we find that FSEM could lead to significant bias in trends over time.

Recommendations

We provide the following recommendations and suggestions for future research.

- **Improve FSEM measure to the extent feasible**: The fundamental problem with FSEM is the mismatch of what is counted in the GDP calculation and what is counted in the GHG calculation. Vehicles included in the GDP calculation but excluded in the GHG calculation should be included in the GHG calculation to the extent possible. This is mainly an issue of light duty trucks. It may be possible to identify the share of LDTs in commercial service by vehicle registration. For activities included in GHG but not included in GDP, it may be possible to capture some activities by including 3-digit codes outside of 48-49. For example, sector 23 (construction) includes many activities that involve freight movement (home construction). By using other sources of data (say employment by sector) it may be possible to estimate the share of GDP from the sector that should be included.
- **Test VMT/GHG:** Although VMT/GHG is a limited measure, only reflecting efficiencies due to mode shifts or alternative fuels, it merits testing. The CSFAP is committed to an ambitious AFV target; VMT/GHG will show how much more GHG efficient the entire freight sector becomes as a result of moving towards this target. The measure would also allow for comparisons in progress across modes.
- **Explore feasibility of using FAF to estimate T-M/GHG:** T-M/GHG is conceptually a much better measure than VMT/GHG. The problem is lack of data. Although we have concerns that the FAF data may present another mismatch problem, we recommend that the FAF data be further explored to determine the potential extent of mismatch. Five-year intervals are certainly not preferred, but it is quite likely

that changes associated with fleet turnover will take years to be evident in a statewide measure.

- **Establish method and funding to obtain needed data to effectively monitor the freight sector:** The lack of freight data is pervasive. We have no statewide database of freight flows or VMT that is collected regularly and consistently. The Los Angeles and San Francisco regions have invested in developing metropolitan freight flow models, but the data come from one-time surveys and other sources. Less freight data is available outside of these two metro areas. Cities have little to no data on truck volumes on their streets, or on the goods they carry. With expectations to dramatically reduce GHG emissions from the freight sector, it is imperative to have the data needed to effectively monitor the sector. We therefore recommend that the state initiate a freight data collection program to establish a freight database sufficient for both monitoring and understanding trends in VMT, ton-miles, origins and destinations, and vehicle attributes at a minimum. The data collection program should include existing freight data from sources such as HPMS, NPMRDS, WIM stations, and Inrix. New, passive data collection methods (e.g. GPS tracking) should be considered to the extent possible in order to minimize costs.

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