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Review of Regional Locomotive Emission Modeling and the Constraints Posed by Activity Data

Gregory Gould and Debbie Niemeier

Diesel–electric locomotives used by U.S. freight railroads are relatively low emitters of criteria air pollutants and greenhouse gases when compared with competing modes. However, the continuous growth in goods movement is cause for concern because locomotive emissions may grow. Railroads account for only a small fraction of all mobile source emissions, but the concentration of emissions along rail facilities raises questions about equity, in particular, environmental justice, and the relative benefits of competing modes of goods movement. This paper provides a synthesis and review of current data and methods used to account for regional locomotive activity. Understanding data limitations and methodological issues at the regional scale provides a starting point for development of more spatially detailed locomotive emission models. Methods developed by the U.S. Environmental Protection Agency and the California Air Resources Board are considered. It is found that each method produces different results and is inadequate for use at the regional (or smaller) spatial scale. Problems arise from activity measures that ignore differences in geography and freight rail services between regions or that depend on detailed operational data that are no longer available. Although detailed activity data do exist, they are not always available because they are owned by private railroads. New methods should minimize the use of detailed or confidential railroad data yet still be sensitive to local factors. Fuel-based methods provide the most hope, but greater cooperation between regulatory agencies and railroads is required.

In 2005, railroads moved more than 38% of goods (on a ton-mile basis) in the United States, the largest share of any transportation mode (*1*). Considering the amount of goods moved by rail, emissions of criteria pollutants are relatively low, accounting for only 15% and 12% of the total oxides of nitrogen (NOx) and particulate matter (PM) mobile source emissions, respectively, generated by goods movement (*2*). However, recent growth in the transport of goods by rail has outpaced all other modes of goods movement (*1*) and forecasts predict continued growth through 2035 (*2*). Despite railroads being one of the most energy efficient and lowest-emitting land transportation modes (*3–5*), both recent and projected growth in rail activity raises concerns about potential impacts of increased criteria emissions, especially diesel PM from locomotives, which has been linked to elevated cancer risk (*6*).

Relatively little is known about the quantity and quality of regional and local locomotive emissions estimates. Two modeling approaches exist to produce county-level locomotive emission inventories: a travel-time-based method used by the California Air Resources Board (CARB) and a fuel-based method used by the U.S. Environmental Protection Agency (EPA). A comparison of the inventories produced by each agency for 2000 (the latest comparable data) shows large statewide differences (*7, 8*):

	EPA (ton/year)	*CARB (ton/year)*	*% Difference from EPA*
NOx	90,780	72,967	–19.6
Carbon monoxide (CO)	8,994	10,946	21.7
PM less than 10 micrometers in diameter	2,258	1,668	–26.1

A more detailed look at county-level emission inventories finds that the magnitude and direction of the differences vary widely across the state (Figure 1). In some cases, CARB's estimates show emissions in counties in which EPA found no emissions (shaded with dots in Figure 1). This finding alone suggests that a large amount of uncertainty exists in current locomotive emission models used at a regional scale, which calls into question what is assumed to be known about localized emissions.

With current modeling methods appearing to provide a somewhat large variance in results, there is a need for more spatially resolved locomotive emission estimates. This need is driven by questions of not only environmental justice and equity, but also climate change issues related to trade-offs between modes of goods movement and a need to account for regional greenhouse gas (GHG) emissions. Public funding is now being recommended and used to encourage freight rail as an alternative or supplement to trucking (*9, 10*). Promoting freight rail, through incentives and increased capacity, may in fact reduce highway congestion, GHG emissions, and regional criteria emission levels. (Alternatively, these policies could induce greater freight rail and trucking demand.) But rail traffic would also increase, raising emission levels along railroad facilities, which would raise equity and environmental justice concerns. Additionally, many states and regions have begun to track GHG emissions in an effort to develop effective solutions to mitigate them. The impacts of increasing rail traffic (as well as current levels) are commonly evaluated based on health risk analysis (*11, 12*), modal comparisons (*5, 13, 14*), and life cycle assessment studies (*4*), which require disaggregate or spatially detailed locomotive emission esti-

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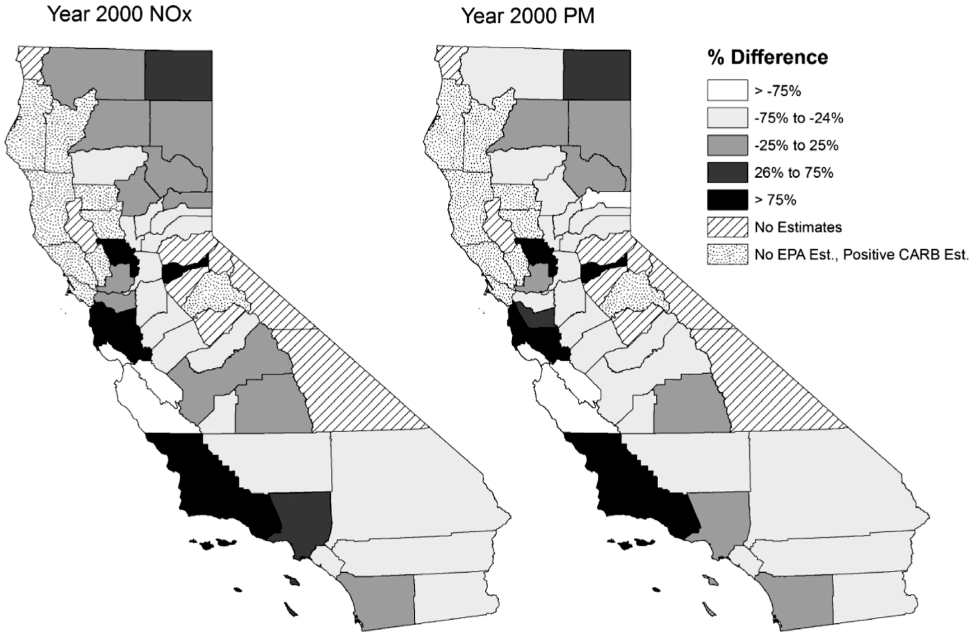


FIGURE 1 Percent difference in CARB's locomotive NOx and PM emission estimates over EPA's estimates for 2000.

mates or activity data. Thus, more accurate and spatially detailed locomotive emission models will provide a clearer picture on which policy regarding rail transportation can be formed.

Part of the problem encountered with current modeling efforts stems from the heavy reliance on past findings, including those that may no longer hold true or do not hold at greater levels of disaggregation. Disaggregation is problematic because important local factors—geography (hills and curves), train types, congestion, and wind—are typically not considered. This paper provides a synthesis and critique of how rail activity data are currently used and modeled. The paper begins with a brief discussion of railroad and locomotive operations that play an important role in emissions modeling. The remainder of the paper reviews the modeling methods used by CARB and EPA and concludes with a suggested method to improve upon current methods. This review focuses on the United States and on California in particular; however, the methods and challenges described are similar in most places where diesel locomotives are used.

BACKGROUND: LOCOMOTIVES AND RAILROADS

All mobile source emission models share a basic framework: a measure of activity is multiplied by an emission factor producing an estimate of the quantity of emissions produced in a given time. Emission factors are typically developed from engine exhaust tests. Because engine emission rates typically vary with engine speed and load, exhaust emissions are weighted by a representative duty cycle. The general modeling framework for locomotives is similar to that for other mobile sources; however, locomotives and railroads have unique attributes that must be considered when evaluating a particular emission model.

Locomotives

Almost all locomotives in the United States are either diesel–electric or electric, with diesel–electric locomotives making up the majority of the locomotive fleet (*15*). Emissions from electric locomotives, commonly used for passenger transportation in urban areas, are not considered here because they occur upstream at the electric power source.

Unlike most vehicles, the engines of diesel–electric locomotives are not mechanically linked to its wheels (*16*). Locomotive engines provide mechanical energy to an electric generator (alternator) that powers electric traction motors connected to the wheels. The mechanical decoupling of the engine and the wheels allows the locomotive engine to operate at discrete throttle positions known as notches. There are typically eight notches for movement of the locomotive in addition to two idle settings and dynamic braking. Dynamic braking uses the locomotives traction motors to slow the locomotive by transforming the kinetic energy from the wheels to electrical power which is then dissipated in a resistance grid.

The discrete engine throttle positions result in steady state engine operation (*16*), producing a relatively constant fuel consumption rate in each notch (*17*). The steady state engine conditions also simplify emission testing, producing stable emission rates in each notch. By comparison, the operation of engines in on-road vehicles is transient; fuel consumption and emission rates vary continuously under changing loads and throttle. Locomotive emission rates are determined by sampling the engine exhaust at each notch. The notch-specific emission rates are then weighted by a representative duty cycle—the relative amount of time that the locomotive operates in each notch—producing a composite locomotive emission factor.

The duty cycle, along with the particular make and model of the locomotive, determines the locomotive emission rate. Different railroad services and operations determine the duty cycle. A number of additional factors also affect the duty cycle: desired train speed, number of locomotives being used, weight of the train, geography (grades and hills), weather, and operator skill (*16–18*).

Operations

Trains can be classified in three categories: intermodal, unit, and manifest. Each type of service makes different trade-offs among speed, reliability, and cost; some of these trade-offs affect emission rates. Intermodal trains carry either truck trailers on flatcars (TOFC) or shipping containers on flatcars (COFC), allowing for quick interchange of freight among shipping, trucking, and rail. Intermodal trains also compete with trucking, tending to offer quicker service than typical trains (*3*). However, intermodal trains have higher costs than other types of trains because of reduced fuel efficiency caused by poor aerodynamics and higher speeds (*16*). Unit trains provide low-cost transportation for bulky, low-value commodities such as coal, grains, and chemicals. Low costs are achieved by requiring large shipments of single commodities, scheduled service, and improved fuel efficiency through the use of identical rail cars (*3*). A manifest train moves a variety of goods using various rail cars that are picked up and dropped off along the train's route. Manifest trains may also require time-consuming rearrangement of cars between trains at rail yards. Dropping off, picking up, and rearrangement of rail cars results in slow travel times and reduced fuel efficiency for manifest trains. Unit and manifest trains may also achieve greater fuel savings by operating with lower power densities (ratio of power to train weight) given the lower priority on speed.

The type of train operation also influences emission rates. Locomotives perform three general categories of work: line-haul transportation of freight, line-haul transportation of passengers, and switching. Line-haul operations move freight trains between rail yards or passenger trains between stations. Switching operations move rail cars around rail yards and sidings, adding and removing rail cars from trains. Locomotives used in line-haul operations spend relatively more time in high-power notches, while switching locomotives spend more time in lower-power and idle notches (*19*). Because of the differing power requirements between line-haul and switching operations, the most powerful locomotives are used for line-haul operations and lower-power, often older, locomotives are used for switching (*15*).

Regulation

Regulations also affect locomotive emissions. Locomotive emissions were unregulated until 2000 when the first of three tiers of federal standards took effect. The first tier of standards (Tier 0) applies to remanufactured locomotives that were originally manufactured from 1973 to 2001, stricter Tier 1 and Tier 2 standards subsequently took effect for new locomotives manufactured from 2002 to 2004, and 2005 and later, respectively (*20*). In 2008 EPA established two additional tiers of standards for new locomotives to be phased in during 2009 and 2014, respectively (*21*). The combination of locomotive lifetimes in excess of 40 years (*15*) and lack of historical regulation has resulted in a large stock of unregulated locomotives. Additionally, recent federal standards preempt states and other local governments from regulating locomotive emissions (40 CFR 85.1603).

Regulations also affect locomotive modeling by setting different data reporting requirements for different types of railroad companies. There are three categories of freight railroads classified by the Surface Transportation Board (STB) on the amount of annual revenue they generate: Class I, Class II, and Class III. Class I railroads generate the most revenue; there are seven Class I railroads in the United States, and they accounted for 84% of all freight rail traffic in 2000 (*3*). Class II and III railroads generate less revenue and account for less freight rail traffic, although there are several hundred of them in the United States. STB requires Class I railroads to submit a detailed report of annual operation and business data, which include fuel consumption, locomotive purchases, and the quantity of freight moved (49 CFR 124.11). Class II and III railroads do not have these reporting requirements.

MEASURES OF ACTIVITY

In estimating emissions of any type, it is critical that there be a robust measure of activity that is strongly correlated with emissions. If emission factors are unknown or unreliable, the relative amount of activity will still indicate the relative amount of emissions. The cumulative amount of time each locomotive spends in each notch would provide the most accurate measure of activity because emission rates are stable at each notch. However, such detailed operational data are typically held as proprietary information or is unknown. An exception: few studies, such as that completed by Barth and Tadi (*13*), compared emissions from trucks and locomotives along a 140-mi Interstate highway corridor; in this case the railroad was willing to provide detailed time-in-notch data.

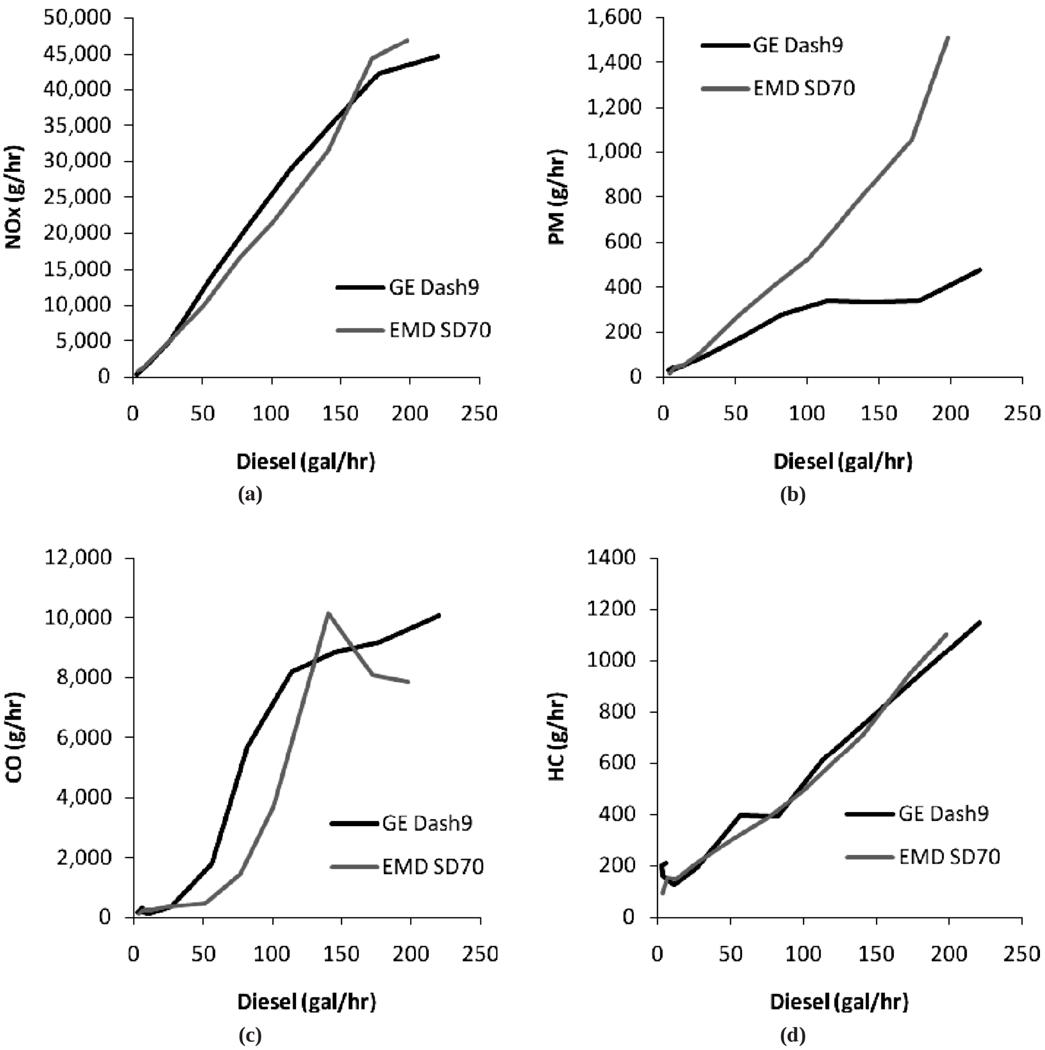
Fuel consumption is a more convenient measure of activity because it is typically observable and is highly correlated with pollutant emissions (Figure 2). However, emission rates can vary across throttle notches, most notably in the idle and braking notches (Figure 3) and for PM and carbon monoxide (CO) (Figure 3*b* and 3*d*), so fuel-based emission factors must be weighted by a representative duty cycle. On the national level, fuel consumption is the preferred measure because data on national fuel consumption are available from surveys (*23*) and railroads (*1, 24–26*). Disaggregate fuel consumption data are not generally publicly available. Locomotives have large fuel tanks and can travel long distances before refueling, making it difficult to track regional fuel consumption based on regional fuel sales data. Railroads do not collect or are unwilling to provide disaggregate fuel consumption data.

The lack of regional fuel consumption data requires that any spatially disaggregate model use alternative methods, typically either an estimate of fuel consumption derived from other factors or operating hours. Fuel consumption can also be estimated by simulation models based on train–rail dynamics. The Train Energy Model (TEM) developed by the railroad industry is the most popular simulation model for estimating energy use; however, a license must be provided by the railroad industry and it requires detailed train, locomotive, and route data, making it impractical as a source of activity data (*17*). In the absence of the availability of the obvious sources of robust disaggregate activity data, EPA and CARB have developed methods for estimating regional emissions inventories from alternative approximations of activity. These methods differ by each agency and by rail classes.

Class I Line-Haul

EPA Guidance

EPA has two methods to estimate regional locomotive emission inventories: the National Emissions Inventory (NEI) method (*27*) and its guidance for regional inventory preparation (*28*).



(a)
(b)
(c)
(d)

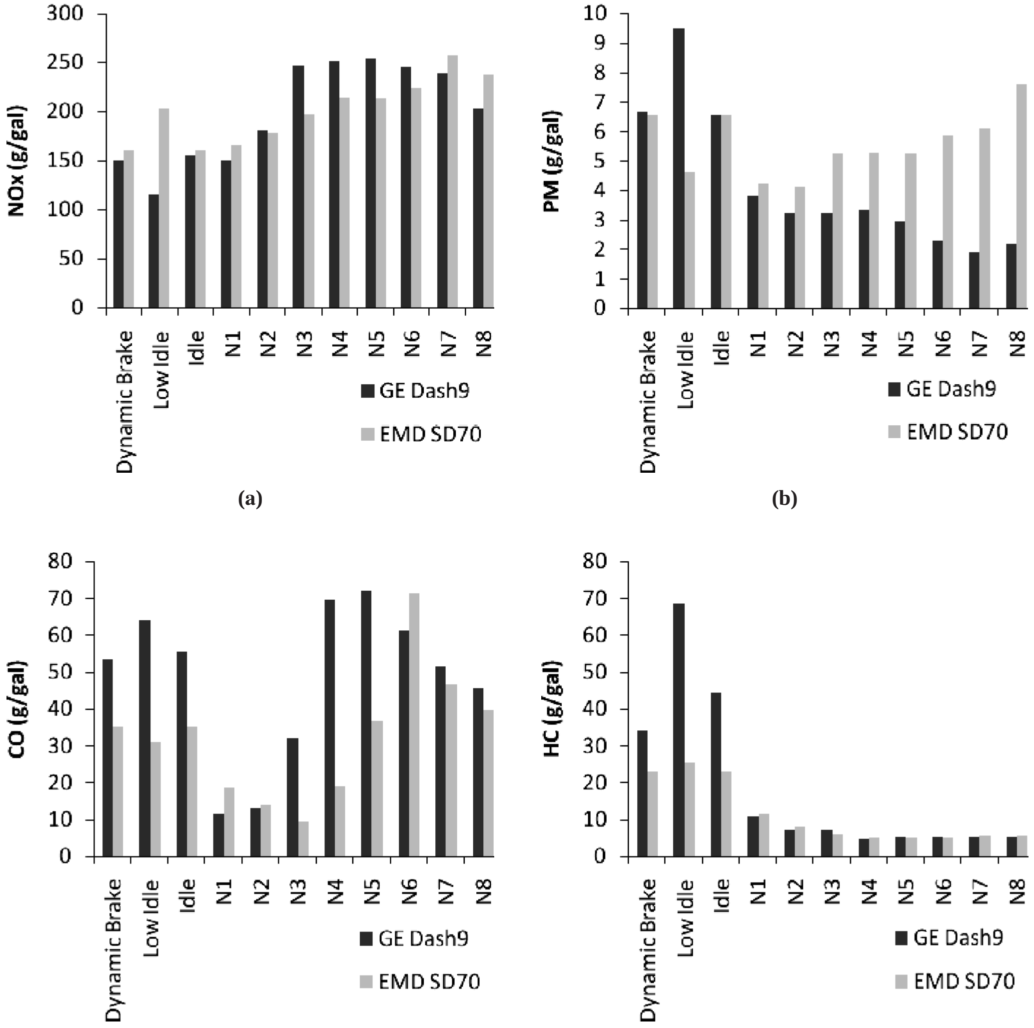
FIGURE 2 Hourly emission rates of (*a*) NOx, (*b*) PM, (*c*) CO, and (*d*) hydrocarbons (HC) versus the fuel consumption rate of two common in-use diesel–electric locomotives (*22*).

The NEI method is simply a disaggregation of EPA's national locomotive emission inventory by county (*27*). The national locomotive emission inventory is estimated by multiplying EPA's national locomotive emission factors (*29*) by the Energy Information Administration's estimate of national railroad fuel consumption (*22*). The NEI is then proportioned to individual counties based on their share of national traffic density (gross ton-miles). County traffic density is obtained from the National Transportation Atlas Database (NTAD) of the Bureau of Transportation Statistics, which contains traffic density data for each track in the United States (*30*). NTAD does not contain actual traffic density, but six ranges of traffic density in order to maintain the confidentiality of railroad company data; the medians of the traffic density ranges are used.

EPA's guidance for regional inventory preparation provides a more detailed approach (*28*) in which the annual fuel consumption for each track segment in a region is estimated by dividing the traffic density of each track by the systemwide fuel consumption index. A systemwide fuel consumption index (gross ton-miles per gallon of fuel burned) is calculated for each railroad operating in the region. Each railroad's annual traffic density is then divided by its fuel consumption index, providing an estimate of annual fuel consumption. Annual traffic density data must be obtained from each railroad, and annual gross ton-mile and fuel consumption data are obtained from each railroad's annual report to STB. The detailed traffic density data are typically considered confidential business information; this method is therefore limited by the willingness of each railroad to provide the data.

Both of these methods would be insufficient for most regional and local emission modeling applications. The NEI approach assumes a constant mass per gross ton-mile emission rate, and the guidance for regional inventory preparation assumes a constant systemwide fuel consumption rate. Each method ignores important local factors: geography and train type, and potentially congestion.

The geography, grades, curves, and wind associated with track alignment can cause a large increase in the amount of work required to move a train. Because locomotive work is directly correlated with fuel use (Figure 4), grades, curves and wind result in greater fuel consumption per gross ton-mile. Currently, no data exist that quantify the effects of these factors. However, because the work required to move a train is proportional to the amount of resistance caused by



(a) (b)

(c) (d)

FIGURE 3 Emission rates of (*a*) NOx, (*b*) PM, (*c*) CO, and (*d*) HC by throttle notch of two common in-use diesel–electric locomotives (*22*).

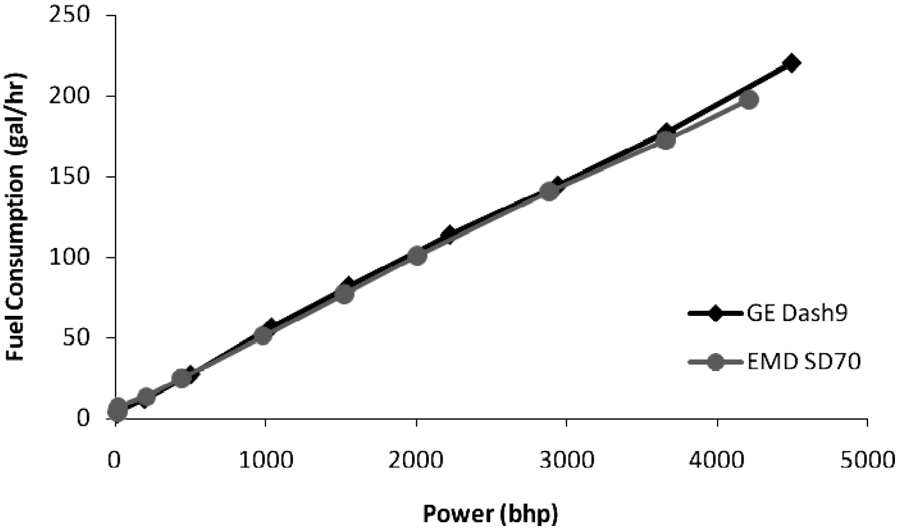


FIGURE 4 Correlation between the fuel consumption rate and power of two common in-use diesel–electric locomotives (bhp = brake horsepower) (*22*).

friction and gravity, it is possible to estimate the effect that grades and curves have on fuel consumption.

In 1926 Davis (*31*) published a paper containing an equation to estimate the unit (lb/ton) resistance acting on a moving train; it became known as the Davis equation. The Davis equation is the basis of the TEM (*17*), which has been shown to produce accurate fuel consumption estimates (*32*). Hay (*16*) provides a "modified" (updated) version of the Davis equation:

$$R_u = 0.6 + \frac{20}{w} + .01V + \frac{KV^2}{wn} \tag{1}$$

where

w = weight per rail car axle (tons),
V = speed (mph),
K = train drag coefficient, and
n = number of axles.

With Equation 1, the total unit force of resistance for a typical 60-ton rail car is 4.7 lb/ton, assuming a drag coefficient of .07 and speed of 45 mph. Hay also shows that the increased resistance caused by a grade is the force needed to balance the downward pull of gravity, and is 20 lb/ton per percent grade. Therefore, a 1% grade adds 20 lb/ton of resistance to move the 60-ton rail car, an increase in resistance of 425% over a level track. Curves cause additional resistance because the wheel flanges rub against the sides of the rail, preventing derailment. Based on a series of tests described by Hay, unit resistance caused by curves is estimated at 0.8 lb/ton/degree, or an increase in unit resistance of 17% over straight tracks. These factors result in large increases in resistance (and thus fuel consumption) and should not be ignored. Hay also reports that wind can cause significant amounts of resistance.

The different types of train service (intermodal, unit, and manifest) represent trade-offs among speed, reliability, and cost. Greater speed requires more work, and thus more fuel, to overcome greater air resistance. Additionally, different train configurations affect air resistance. Substituting the drag coefficient from Hay (*16*) for a COFC into Equation 1 results in a 17% increase in resistance over a typical rail car and a 64% increase for a TOFC. The prevalence of different train types can vary widely by region, affecting fuel consumption per gross ton-mile. For example, intermodal trains serve ports and international trade corridors, whereas unit trains service coal mines and agricultural regions.

California provides a good example of the problems associated with using systemwide fuel consumption indexes and disaggregating national inventories based on traffic density. There are two Class I railroads in California, the Union Pacific (UP) and Burlington Northern Santa Fe (BNSF), and they both primarily provide intermodal train service to the major sea ports. However, nationally, coal accounts for nearly half the tons moved by UP and BNSF, whereas intermodal trains account for less than 10% (*33*). California is also relatively hilly; all Class I railroads must cross the Sierra Nevada Mountains to leave the state or travel between the northern and southern regions. Therefore, the systemwide fuel consumption indexes of UP and BNSF are heavily influenced by the fuel efficient transport of coal over relatively level terrain, while rail traffic in California is typified by fuel intensive intermodal service over mountain passes.

Given the shortcomings of EPA's guidance, a revised inventory method was developed (*34, 35*). Correction factors that adjust the systemwide fuel consumption rate in EPA's guidance for the amount and steepness of grade and the proportion of bulk train traffic were developed. However, development of the revised method was limited by data availability and relied on few outdated data from a previous study (*36*). Corrections for amount of travel across unusually flat terrain or by other train types were not developed.

California's Model

Possibly as a result of the problems related to EPA's methods, the presence of several large ports, and severe air quality problems, California developed its own locomotive emission model. Booz Allen Hamilton was hired to develop the model and worked closely with the railroads operating in the state at the time of the study, the late 1980s.

For line-haul service, the activity measure is the total annual operating hours in each notch for each type of train (intermodal, unit, and manifest) traveling each route (*36*). The detailed travel times were calculated for each route and train type with data provided by Class I railroads operating in the state when the study was conducted. The railroads obtained the data from two sources: locomotive event recorders (devices that record time spent in each throttle notch) and train performance modeling software. These data did not include idle time. An average idling time was developed from an analysis of data provided by a single railroad, which showed that 8 h of idle time was experienced by a locomotive between arriving and departing at a rail yard.

The Booz Allen inventory was conducted only for air basins with large air quality problems and excluded many regions of the state. In a follow up report, CARB's consultant forecasted activity to the remainder of the state and for future time periods (*37*). To forecast activity to the remainder of the state, gram per mile emission rates were calculated for each train in the original study. Route information from the original study was also used to estimate the number and type of trains that traveled routes in the remainder of the state. The number of trains, gram per mile emission rates, and distances of the additional routes were multiplied to produce emission estimates for the additional routes.

The highly detailed approach taken by CARB fully addresses the shortcomings of EPA's methods by considering the differences in activity caused by train type and geography. As previously noted, accounting for the time spent in each notch would provide the most accurate emission estimate. However, the approach is dependent on highly detailed route data, which were made available to CARB only during the initial study. Since that time, CARB has had to rely on updating its emission inventories with growth factors. The methods and data used to estimate growth factors have changed over time, but generally rely on assumptions related to technological change and economic growth (*37–39*). The reliance on growth factors, which are applied equally to all routes in the state, diminishes the spatial detail of CARB's estimates. For example, some of the growth factors, which are based on U.S. economic growth or the national average net ton-miles per locomotive, are not specific to California railroads or individual routes within California. Additionally, the use of growth factors that are not directly correlated to emission rates leads to questionable estimates. Growth factors are unlikely to reflect changes in train length and locomotive power, which both affect locomotive duty cycles and the time spent in each notch. Unlike traffic density or national fuel consumption, which are directly tied to locomotive activity, growth factors based on international trade or economic growth are only partially correlated to locomotive activity. No data exist by which to validate the use of CARB's growth factors.

An additional shortcoming of this method is the assumption that all line-haul locomotives idle for 8 h between arriving at and exiting rail yards. This assumption was based on data collected from a single railroad at a single point in time. Although no data are available to estimate actual idle times in yards, it is known that locomotives idle outside of yards at sidings and throughout the lines because of congestion.

Class II and III Railroads

EPA Guidance

EPA recommends using a different approach for Class II and III railroads because they are exempt from submitting annual reports to the STB. EPA's guidance suggests that regional authorities ask each Class II and III railroad to report its fuel consumption, possibly through a survey. The guidance notes that many Class II and III railroads operate locally, so further disaggregation of fuel consumption data provided by the railroads may not be necessary; however, some Class II railroads do cover a relatively large region. To further disaggregate the Class II and III railroad fuel consumption, EPA guidance suggests proportioning fuel use by route traffic density, provided the data are available from the railroad. If not, the guidance recommends proportioning the fuel use by track length.

Provided that fuel consumption data can be obtained from the railroads, EPA's method should provide a reasonable estimate of emissions from Class II and III railroads. A large number of these railroads operate only a single route or over a relatively small geographic area, so geographic considerations are less important. For railroads that operate over larger regions, the approach recommended for Class I railroads would be sufficient, provided that traffic density data are available; the limitations of this approach noted for the Class I railroads will be reduced because of the comparatively small geographic coverage of even the largest Class II and III railroads. Additionally, small railroads are likely to only offer one type of train service. The largest challenge to this methodology is likely to be obtaining the fuel consumption data. At least one documented attempt by Southeastern State Air Resources Managers Inc. to obtain these data failed. It was found that the railroads did not necessarily collect or archive the required data or did not have personnel available to retrieve the data (*35*).

California's Model

The California model also distinguishes between line-haul and "local" service; local service is described as line-haul service provided by smaller railroads (*36*). For local service, the annual numbers of train trips are counted as the activity measure. Instead of determining the amount of travel time on each local route, an average travel time is developed for all local service. Event recorder and train performance modeling software data were used to estimate that a local train trip is 10 h and that there is 10 h of idling per day per locomotive.

This method is likely to produce large errors because it ignores almost all regional and local factors. Analysis of the NTAD shows that Class II and III routes vary considerably in length; therefore, the time require to travel each route should also vary (*30*). Additionally, this method ignores all geographic and train type differences. The relative amount of error that can be expected is unknown because no distributional data were provided with the average values presented in the original inventory report (*36*).

Rail Yard Activity

To estimate activity at individual rail yards, both EPA and CARB use an extremely simplified approach. EPA's method measures activity by multiplying the number of switching locomotives in each yard by an estimate of annual switching locomotive fuel consumption provided by EPA. The EPA guidance recommends asking each rail yard for the number of switching locomotives used. If the rail yard will not provide the data, the guidance suggests going to the yard and counting the number of switching locomotives in use. The California model uses a similar method: the number of locomotives in each yard is multiplied by 24 h to obtain total operating hours. An average yard duty cycle is then applied to the total operating hours to estimate the total time spent in each notch (*36*).

The above methods assume that there is no variation in the operation of switching locomotives between different rail yards. However, a series of recent toxic air contaminant inventories of major California rail yards completed by the state's Class I railroads to support CARB's rail yard health risk assessments shows large differences in operating hours and fuel consumption per locomotive (Table 1). Fuel consumption estimates (computed by the authors) are based on the fuel consumption rate of an EMD GP39 locomotive (*19*) and average yard duty cycles described in each yard's emission inventory (inventories available at www.arb.ca.gov/railyard/

TABLE 1 Difference Between Activity Estimates Based on Rail Yard Inventories and EPA and CARB Methods

Rail Yard	HRA[a] (gal of diesel)	EPA[b] (gal of diesel)	EPA Δ[c] (%)	HRA (h)	CARB[d] (h)	CARB Δ[e] (%)
BNSF Wilmington–Watson	68,963	83,220	20.7	4,200	8,760	108.6
BNSF Stockton	254,004	249,660	–1.7	19,612	26,280	34.0
BNSF Richmond	118,188	166,440	40.8	17,520	17,520	0.0
BNSF Commerce–Hobart	358,371	416,100	16.1	30,112	43,800	45.5
UP Commerce	244,150	249,660	2.3	17,520	26,280	50.0
UP LATC	569,683	499,320	–12.4	40,880	52,560	28.6
UP Mira Loma	223,804	166,440	–25.6	16,060	17,520	9.1
UP Oakland	488,300	332,880	–31.8	35,040	35,040	0.0
UP Stockton	773,142	665,760	–13.9	55,480	70,080	26.3

[a] Estimates from rail yard health risk assessment (HRA) inventories.
[b] Estimates from *EPA Procedures for Emission Inventory Preparation* (*28*).
[c] Percent difference from HRA estimates [(EPA – HRA)/HRA ∗ 100].
[d] Estimates from CARB–Booz Allen method (*36*).
[e] Percent difference from HRA estimates [(CARB – HRA)/HRA ∗ 100].

hra/hra.htm). The California rail yard inventories show the importance of considering how yard operations differ. For California, the rail yard inventories also provide a detailed source of activity data that could be used to update CARB's emission inventory and study methods to more accurately estimate rail yard activity should such detailed data not be available in the future.

CONCLUSIONS

The current methods of estimating regional locomotive emissions either rely on aggregate data that do not account for important local factors (geography, train types, congestion, and wind) or on detailed data that do account for local factors but are not routinely available. An improved approach that considers these factors is necessary for both regional emission inventories and more spatially detailed emission models.

For line-haul operations, traffic density data appear to be the best source of activity data. All railroads measure traffic density, although public availability of the data may be limited. One way of improving the estimation of emissions is to link traffic density to fuel consumption, but this will be challenging because local factors must be embedded in the relationship, and the required data are scarce. Disaggregate fuel consumption data are needed, but only the railroads can collect and provide this information. There do not appear to be any logistical or technological barriers preventing railroads from measuring fuel consumption, although it may not be current practice to do so. A detailed locomotive fuel consumption study performed in cooperation with the railroads could quantify the impact that local factors have on fuel consumption and therefore emission rates.

Rail yards pose a larger challenge for modeling because fuel consumption can vary widely across individual yards. Single fuel consumption or operating hour estimates per locomotive are unlikely to produce satisfactory results because they include very little local information. Linking line-haul traffic density and the type of train traffic to switching locomotive fuel consumption could be a potential solution. An additional possibility would be collecting fuel consumption data directly from each rail yard. Again, only the railroads can collect and provide this information.

Public agencies and private railroads will have to engage in meaningful cooperation to develop improved locomotive emission models and access to activity data. The objective should be to develop methodologies that minimize the need for regular access to sensitive business data and that reflect important local factors. Mutual cooperation should produce mutual benefits. The public will benefit from better knowledge about local emission concentrations, which can help craft improved public policy. Railroads will benefit from increasing public support for freight rail to mitigate congestion and emissions caused by trucking if public concerns about local emissions are addressed by improved emission estimates.

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