Comprehensive Truck Size and Weight (TS&W) Study

Phase 1-Synthesis

Environment

and

Truck Size and Weight Regulations

Working Paper 11

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1.0 Technical Relationships of Truck Size and Weight Policy Consequence Concerning the Environment

In general, very little work has been done relating the impact of changing truck size and weight (TS&W) regulations to impacts on the environment. Some work was done by the American Trucking Associations (ATA) in the late 1970s and early 1980s. Other work by the Society of Automotive Engineers (SAE), the Environmental Protection Agency (EPA) and several European sources has focused a great deal on characterizing the heavy duty engine. This includes emission requirements and standards, noise levels, performance standards, noise abatement, and fuel economy. While this is all useful information and a great deal of it was used for the development of this paper, most of the work related directly to truck size and weight issues has focused on the physical and structural impacts to bridges, pavements, etc. The majority of sources for this paper regarding environmental impacts focus on heavy duty engine emissions, noise levels, and other topical areas, not specifically the environmental impact associated with changes in truck size and weight regulations.

Significant regulatory incentives for raising air quality have been put into place with implementation of the 1990 Clean Air Act Amendments (CAAA), the Energy Policy Act of 1992, and the proposed Federal Implementation Plan (FIP)* of 1994 (for the Los Angeles Basin in California) that focus on air quality. These regulations force both manufacturers and users of heavy duty vehicles to evaluate their products not only by how they "perform," but also their impacts on the environment. By establishing urban areas of "non-attainment" throughout the country, these regulations force State and local governments to consider legislative mechanisms to improve their ambient air quality. Depending on the timing, form, and scope of these regulations, they may have significant impact on future proposed changes in truck operations and usage, with corresponding impacts on size and weight regulations.

By moving to heavier, longer trucks, studies have shown the trucking industry can increase its productivity and reduce emissions by transporting more freight per vehicle mile of travel (VMT). Taken by itself, this would seem to support the idea of allowing longer, heavier

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*The United States Environmental Protection Agency (EPA) has proposed the FIP for the Los Angeles, Ventura, and Sacramento areas to bring these areas into attainment of the National Ambient Air Quality Standards (NAAQS) for ozone and to also bring the Los Angeles area into compliance with the NAAQS for carbon monoxide.

vehicles. However, additional considerations such as the amount of modal shift between trucking, rail, air, and water must be addressed, as well as operational restrictions, when considering any changes in truck size and weight regulations.

1.1 Alternative Fuel Use

Fuel use is an increasingly important topic in addressing environmental concerns. The type and amount of emissions from truck engines are greatly dependent on the type of fuel used. While all fuels result in some form of emissions when burned, certain fuels have more favorable characteristics when it comes to their effect on the environment. However, since the majority of scenarios under consideration for changing truck size and weight regulations focus on the heaviest and longest of heavy duty vehicles, the environmental impact from alternative fuel use resulting from these changes is not likely to be significant.

The predominant fuel used by heavy duty vehicles, both now and in the foreseeable future, is diesel. However, alternative fuels are gaining in popularity. With major legislation such as the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, the CAAA of 1990, the Energy Policy Act, and the Proposed FIP all requiring reduced emissions from mobile sources, alternative fuels that reduce or remove harmful tailpipe emissions will become increasingly more popular.

As mandated by the CAAA and implemented on October 1, 1993, (except Alaska and Hawaii), the sulfur content of diesel fuel for use in motor vehicles cannot contain a concentration of sulfur that exceeds 0.05 percent by weight, or fail to meet the cetane rating of at least 40. "Low sulfur diesel fuel contributes significantly to the lowering of nitrogen oxide exhaust emissions from heavy duty diesel trucks" (Thompson, 1991, pp. 4-8).

Until recently, the trucking and diesel engine manufacturing industries were very confident that with the federal mandate of low-sulfur diesel fuel availability throughout the continental United States, diesel engines would run clean enough to meet emission laws at least until 1998 (Winsor, 1993, pp. 59-60). However, because the FIP proposes a standard of 1.5 g/bhp-hr (grams per brake-horsepower-hour) of nitrous oxide (NOx) emissions effective in 1999, industry opinion is that it will not be technologically feasible to reach that standard by model year 1998 (EPA Docket No. A-94-09, 1994, pp. 25). In a report prepared for the California Air Resources Board by Accurex Corporation, heavy-duty diesel engine technology was projected to be able to achieve a 2.0 NOx (g/bhp-hr) standard no sooner than 2002 -- a level one-third greater (and three years later) than what EPA has proposed in the FIP for 1999.

Operationally, another concern with the use of alternative fuels is the infrastructure associated with refueling and maintaining alternatively fueled vehicles. Truck size and weight regulations cannot be put in place that encourages the use of alternatively fueled vehicles without the proper infrastructure for maintaining and refueling these vehicles.

In a study of the feasibility of using alternative fuels in the trucking industry, it was determined that applications most suited for the use of alternative fuels were light and medium duty vehicles (up to 26,000 lb. gvw) operating in a limited radius from the base of operation, and which returned to the base each night (Ritchey, 1990). In ATA's comments to the EPA on the proposed FIP, they indicated that the penalties in lower performance, increased vehicle weight and reduced payload from extra fuel tanks and lower operating range are reasons that alternative fuels will not make sense for the largest heavy-duty trucks (EPA Docket No. A-94-09, 1994, pp. 27). Alternative fuels also suffer from the lack of an established infrastructure for the storage and delivery of these fuels on more than a local level. "With so many different alternatives -- natural gas, CNG, propane, methane -- it's difficult for manufacturers to determine where to put their development dollars, and nobody's going to invest in an infrastructure until they know what the fuel of choice will be" (McCullough, 1994, pp. 38).

The increase (or decrease) in truck size and weight regulations will impact the use of alternative fuels, though this is not likely to be a significant impact. If the regulations steer the shipping industry to use rail (linehaul) and drayage for final delivery, then the use of alternative fuels such as CNG, LNG, etc. will likely gain favor due to fuel availability at the localized area, centralized refueling, and reduced emission levels in an urban area. One scenario could be to continue the use of diesel fuel for long-haul, over-the-road shipments but shift local pick-up and delivery to alternative fuels. With the lack of an established infrastructure for refueling, alternative fuel use will be restricted to local short-haul uses where vehicles can be refueled at a local refueling station (centralized fueling). However, if the regulations steer the shipping industry to use trucks for linehaul shipments as well as delivery, there will likely be very little increased alternative fuel use due to the localized refueling requirements of alternatively fueled vehicles.

1.2 Vehicle Weight

Changing the gross vehicle weights (GVW) of heavy duty trucks impacts not only the size of engine required to pull the truck but also the emissions associated with that truck. Allowing heavier trucks means more freight can be carried per trip thus reducing the number of truck-trips necessary to carry a given amount of freight. In addition, as the weight of the trucks increases the emissions per truck mile traveled tend to increase but as the total number of trips decreases, the total emissions of pollutants (carbon monoxide (CO), NOx, particulates, etc) into the environment decreases.

The ATA evaluated the environmental impacts of increasing truck sizes and weights (Barr, 1981). In this analysis, increases in the GVW of heavy duty trucks was linked to increased productivity, reduced number of truck trips, and a reduction in emissions. The report estimated that interstate emissions of HC, CO, NOx, and particulates could be reduced by 66,100 tons if national standards of 80,000 lb. GVW and twin-trailer lengths of 65 feet were established. While ATA's report is directly relevant to this paper, there are several problems with this analysis. First, it was of very limited scope. The paper only dealt with the impacts associated with requiring the "barrier states" in the Mississippi River Valley to bring their maximum GVW limits up to the 80,000 lb. GVW. This is no longer the situation with barrier states. In addition, it looked at the impacts of mandating states to allow 65-foot twin-trailer combinations. The second major problem with this report is that it is dated. The report was published in 1981 and was based on data as late as 1975. A third shortfall is that it does not account for any anticipated modal diversion from rail to trucks as a result of the new limits. While some general conclusions are possible and the methodology has some merit in evaluating the environmental impact of truck size and weight regulations, the absolute numbers contained within this report are of little use.

With increased weight also comes increased emissions on a per trip basis. The emission rate for heavy duty diesel engines tends to follow more directly the horsepower requirements of the engine as opposed to the load being pulled. The Society of Automotive Engineers estimated that a 50 percent increase in the gross vehicle weight results in an increase in fuel consumption of only 10 percent (Barr, 1981, p. 6). This makes sense since the horsepower requirements to pull the 50 percent additional weight would not necessarily be increased a similar amount. This indicates that there is a positive relationship between fuel consumption/emissions and weight pulled, but not a one-to-one relationship. Considering that gaseous and particulate emissions in terms of pollutant per pound of fuel consumed are a function of truck weight, the larger the vehicle, the more fuel burned, and consequently, the greater the quantity of pollutants per mile of operation. While increasing the GVW of heavy duty vehicles does result in increased emissions from the engine on a per-vehicle basis, the increased productivity resulting from the vehicles ability to carry more payload per trip will reduce the number of trips and VMT necessary to carry a given amount of freight. The fuel and air pollutant savings from higher productivity associated with carrying heavier loads more than offset the higher emissions and consumption of individual vehicles (Barr, 1981, p. 6).

Considering the impact on the environment from changes in truck weights is potentially incomplete if done in isolation. Simply looking at the amount of freight carried today and how that would be handled under different truck size and weight scenarios, ignores potential increases (or decreases) in freight traffic from modal shifts. Typically, rail transport is considered more fuel efficient and emits less pollutants on a per ton-mile traveled basis than truck travel. This is discussed in more detail in Section 1.4.

1.3 Vehicle Configuration

For the trailer configurations, you might expect that as the number and/or size of trailers pulled by a single vehicle increases, the GVW would increase, thus increasing fuel consumption and emissions. As the number of trailers increases, the aerodynamic drag from the additional trailer will increase the load on the engine, thereby increasing fuel consumption and emissions. In the Transportation Research Board's (TRB's) analysis of Twin-Trailer Trucks (TRB SR211), they indicated that twin-trailer combinations encounter more air resistance than tractor-semitrailers and are less able to sustain high speeds. One factor that can enhance the aerodynamic properties of the truck-trailer configuration is the cab design. "Because of their better aerodynamic shape, cab-behind-engine tractors encounter less air resistance than do cab-over-engine tractors" (TRB, 1986, pp. 286). While it seems intuitive that as the number of trailers and aerodynamic drag increase, the engine load, and therefore emissions, would also increase, to date no studies have been found that directly quantify this relationship. From the limited data available, vehicle configuration per se would have a relatively minor impact on emissions and the environment as a result of changes in allowable truck sizes and weights. The major impact would come from the change in the GVW associated with the different configurations. Weight impacts on the environment were discussed in Section 1.2.

The number of axles and/or tires follows a similar logic. As the number of axles and perhaps, GVW increases, tire friction with the road would increase causing an increase in fuel consumption and emissions.

In a 1981 study for the United States Department of Transportation (DOT), multiple scenarios were evaluated with regards to truck size and weight regulations (U.S. DOT, 1981). This report found that by increasing the Federal TS&W limits on the interstate and primary systems, emission levels would be reduced by 2.3 percent to 3.1 percent, which result from decreased VMT as well as more utilization of twin-trailer combinations (U.S. DOT, 1981, pp V-22 to V-79). The scenarios considered in the report were: 1) elimination of the "Grandfather Clause"; 2) elimination of the "barrier limits" which existed in six Mississippi Valley States; 3) establishment of uniform national TS&W limits by eliminating both the grandfather and barrier limits; 4) reduction of Federal limits to those which existed prior to the increases enacted in 1974; and 5) increases in Federal TS&W limits, along with the elimination of barrier limits. All these scenarios were analyzed relative to a base case that represented projections of truck activity for the year 1985 in the absence of any changes in TS&W limits.

The major inputs for this analysis included the following:

- 1985 forecast of medium and heavy duty vehicle VMT by Interstate and Primary routes by region of the country.

- Vehicle operating speeds by Interstate and Primary routes by region of the country.

- HC, NOx, CO, and particulate emission factors for medium and heavy duty vehicles.

- Changes in rail fuel consumption and locomotive emission factors (HC, NOx, CO, and particulates) (U.S. DOT 1981, pp. IV-23).

Vehicle operating speeds were from the 1975 National Highway Inventory and Performance Summary. The emissions factors were developed using EPA's MOBILE 1 computer program (described later), and the particulate emission factors used were derived from the paper "Heavy Duty Diesel Particulate Emission Factors," published in the Journal of the Air Pollution Control Association (June 1979).

For the scenarios involving the elimination of the grandfather clauses, there were minimal impacts on emissions of HC, NOx, CO and particulates (increases of less than 0.6 percent) resulting from the increase in truck miles. By eliminating the barrier limits on both the interstate and primary systems, emissions were estimated to decrease slightly (1.1 to 1.2 percent) resulting from the use of heavier trucks and a slight decrease in VMT. Establishing a uniform national TS&W limit would result in minimal reductions of emissions (0.6 percent or less) resulting from the improved utilization of trucks. If the Federal limits were reduced to those which existed prior to the increases enacted in 1974, emissions of all types would increase by more than 1.3 percent primarily as a result of the increases in VMT for heavy duty vehicles.

1.4 Intermodalism

As truck size and weight regulations are modified, the allocation of freight between various modes of transportation will be affected. For example, a scenario which would increase axle and gross vehicle weight limits will increase the allowable tonnage (per trip) which can be carried in certain truck configurations. Under these circumstances, fewer trips and VMT will be required to carry the same amount of freight. This, in turn, would result in a lower truck operating costs which, it is assumed, would be passed through as a rate reduction to customers. These rate reductions could attract some traffic from rail. The opposite is also true, as truck size and weight limits are reduced, freight traffic will tend to shift somewhat from truck to rail.

Throughout the trucking industry, the use of intermodal freight transport is increasing. Current estimates are that between 5 and 15 percent of motor carrier's long-haul traffic currently moves on rail at some point. This is happening despite the fact that current fuel prices are at a 15-year low (Schulz, 1994, pp. 41-42)

The shift of freight movement between rail and truck is a tradeoff between the better fuel efficiency (ton miles/gallon) and emissions (pounds of pollutant per ton mile) of rail operations and the better flexibility of trucking operations. In an analysis titled Environmental Impacts of a Modal Shift, the Minnesota DOT used the following fuel consumption and emission figures for comparison between rail and trucking:

	Fuel Use Ton Miles/Gallon	Emissions Pounds/Gallon
Truck	60	0.31 (.00517)
Rail	204	0.69 (.00338)

Source: (MnDOT, 1991, p. 2)

Care must be exercised when using these or any numbers for comparison between rail and truck fuel economy and emissions levels. These numbers were based on fuel efficiency data from 1980 and emission results from the EPA's Mobile Four model, both of which are now out of date. While the data presented in the table above appears to show rail fuel consumption as "dirtier" than truck (more pounds of emissions per gallon of fuel), this is misleading. By converting these figures to pounds of emissions per ton-mile, it shows truck emissions at .00517 pounds per ton-mile while rail is .00338 pounds per ton-mile. As discussed later in this paper, the emission numbers generated from the Mobile model also are of questionable accuracy for the purpose of analyzing the impacts of changes in truck size and weight regulations. However, these numbers do serve to provide a relative ranking and rough order of magnitude comparison between the two modes.

Another problem with intermodal comparisons of fuel economy and emission rates is that quite often when analyzing rail transportation data, only the fuel used and pollution emitted from the locomotive are analyzed. The drayage portion of this freight shipment is often ignored. If the pick-up and delivery of freight between points A and B can be done by both truck and rail, then there is not usually a problem with these numbers. However, freight moved via rail is typically moved using the hub-and-spoke system. Quite often freight must be transported to and from the rail yards (drayage) prior to and after being transported via rail. In the comparison numbers mentioned above, it is not known whether they included fuel consumed and pollutants emitted from the drayage process in the rail numbers or not. If not, this would certainly impact the overall environmental comparison between truck and rail transport.

In general, as truck size and weight regulations are modified, the environmental impact from intermodal freight movement will mirror the shift in freight movement between the modes. As the size and weight of trucks is increased, there will be a shift in the amount of freight carried from rail onto trucks. Since trucks are typically less fuel efficient (ton miles/gallon) and emit more pollutants (pounds/ton-mile) than rail shipments, this shift will tend to have a negative impact on the environment. Conversely, as size and weight limits are reduced, freight would shift from trucks onto rail having a positive environmental impact.

1.5 Truck Usage (i.e., Federal Implementation Plan)

The EPA, under the authority of the Clean Air Act, has promulgated the proposed FIP (an air quality plan) for three areas in California: the South Coast Area, Ventura, and Sacramento. The FIP was issued as a Notice of Proposed Rulemaking on May 5, 1994, and contains several significant proposals which could impact the trucking industry. As changes in truck size and weight regulations are addressed, potential implications and interactions with the FIP must be considered.

As stated earlier, the FIP proposes a standard of 1.5 g/bhp-hr NOx emissions for 1999. Given the state of technology with regards to diesel emissions, it is projected that the most advanced engine could only achieve a level of 2.0 g/bhp-hr NOx by the year 2002 (EPA Docket No. A-94-09, 1994, p. 25) If the FIP requirements are imposed and diesel engines in fact cannot meet these emission limits, the impact of changes in truck size and weight regulations would be very different in the FIP areas than in other areas.

The FIP proposes other operational restrictions that could impact truck size and weight regulations. Based on the FIP, in year 2000, out of state truckers in California who don't comply with the fleet averaging program (for emissions) would be limited to one stop per California trip in the FIP areas and two stops in the state. In Sacramento, on-road vehicles would be prohibited from driving one of every five workdays (FHWA, 1993, p. 38). Regardless of how this type of regulation would be enforced, it could pose significant operational difficulties for trucking companies.

1.6 Engine Emissions

Little data is available that would facilitate the analysis of engine requirements from changes in truck size and weight regulations. From the sources reviewed, some general observations are possible. In general:

- As the weight of a vehicle increases, it's engine size must increase to maintain the same level of performance (weight-to-horsepower ratio).

- As engine size increases, fuel consumption and emission levels also increase, though not on a one-to-one relationship.

- As the number of trailers, tires, and articulation points increases, the engine load associated with aerodynamic drag will increase thus requiring a larger engine to pull the increased load.

Increases in truck size and weight limits might influence carriers to shift their vehicles to newer, bigger, and potentially more technologically advanced (less polluting) engines. As a given engine is required to pull bigger, heavier loads, its useful life will be reduced and therefore require either earlier/more rebuilds or premature retirement of the engine. While this may have a detrimental economic impact, the potential for upgrading the overall heavy duty vehicle fleet may help in reducing the total emissions from this source. As engines are retired or rebuilt to new standards, the overall emission levels will decrease and improve the air quality. Based on previous studies though, carriers are generally not expected to increase tractor horsepower as they switch to more heavily loaded tractor-trailer combinations (TRB, 1986, p. 176). As a result, the biggest environmental impact associated with changes in truck size and weight regulations from an engine emission viewpoint would be from the increased fuel consumption and emissions necessary for existing engines to pull bigger, heavier loads.

How heavy duty trucks are measured and certified for emission characteristics at the present time deserves discussion. For automobile emission certification, the entire automobile is tested and certified for compliance to emission standards. This is not the case for heavy duty vehicles. The EPA requires the engines of heavy duty vehicles be tested and certified separately for compliance with emissions standards and characteristics. Once the engine is tested and certified, it can be placed in a variety of final vehicle body configurations based on vehicle size, chassis type, intended use, etc.

A heavy duty engine is tested using the Engine Dynamometer Test (40 CFR Part 86, Appendix 1, Part F) commonly referred to as the "transient test". This test runs the engine through a pre-determined horsepower curve to simulate the various forms of actual usage and measures the emissions over time as the test is conducted. While this test cycle attempts to mimic the actual duty cycle the engine will be run through in its normal use, it falls short. Since only the engine (not the entire tractor configuration) is tested, how a particular engine will be used in a specific truck-trailer configuration cannot be known. The material reviewed for this analysis all relied on analyses of testing engine performance separate from vehicle configuration. This is an important limitation because the actual usage and emission characteristics of the engine will depend on the final configuration of the tractor it is placed in and the operational requirements placed on that tractor. An engine placed in a tractor used primarily for urban situations will typically have many more short trips with more stops and starts. Since start-ups (cold and hot) and the initial few miles of a trip generate a significant portion of the emissions for the whole trip, those engines placed in short-haul, pick-up and delivery operations will likely emit more pollutants than similar engines placed in long-haul operations. Also, since these vehicles will likely travel only within a specific geographic location (typically a more urbanized location), all their emissions would be released in this area compounding potential ambient air quality problems. In contrast, engines placed in tractors intended for line-haul usage will typically have much longer trips, and fewer starts and stops. In addition, their emission would be spread over a larger geographic area, where they are less likely to add to a specific area's ambient air quality problems.

In an effort to better understand and model the emissions of the heavy-duty vehicle, West Virginia University, working with the U.S. Department of Energy, has developed a Transportable Vehicle Emissions Testing Laboratory. This laboratory consists of a box trailer containing equipment for emissions measurement, data acquisition, and control, and a flatbed carrying the chassis dynamometer unit. At the present time, this laboratory has the ability to perform transient and steady state chassis dynamometer emissions tests on vehicles, simulate a range of urban and highway driving cycles, and measure the emissions from heavy duty vehicles operating on conventional and alternative fuels. This has the potential to solve some of the problems mentioned earlier regarding emissions testing of only the engine and not the entire vehicle configuration. However, the mobile lab currently can only simulate GVW from 20,000 to 60,000 pounds, which does not help when looking at GVW limits above 60,000 pounds.

As part of the Clean Air Act Amendments, the EPA is required to set new emissions standards for emissions of HC, CO, NOx, and particulate matter. Achieving the NOx limits contained in the CAAA by model year 1998 is not likely to cause a large problem with the trucking industry. (This is not the case for the limits in the proposed FIP discussed earlier.) Navistar International Transportation Corporation has already road tested a new heavy duty truck using low sulfur fuel, which meets 89 percent of the 1998 model year requirements. The remaining 11 percent reduction is likely to be achievable through continuing research and development over the next couple of years. In addition, the increased use of low sulfur fuel, which "... contributes significantly to the lowering of nitrogen oxide exhaust emissions from heavy duty diesel trucks", will make the attainment of these standards easier (CRS Report, 1991, p. 8).

1.7 Environmental Modeling Capabilities

There are several air quality models currently being used that incorporate engine emissions into their analysis. The two models that appear to be most commonly used are the EPA's MOBILE model and California Air Quality Management District's EMFAC (EMissions FACtors) model.

The MOBILE and EMFAC emissions models calculate the in-use emissions of Volatile Organic Compounds (VOCs), NOx, CO and particulates of mobile sources as functions of calendar year, ambient temperature and driving situation in units of grams per mile (g/mi) for class specific vehicles. These emissions factors, in conjunction with the estimated VMT are used to estimate the total emissions of the regulated pollutants within a geographical region. These emissions inventories may then be used as inputs to urban air shed models to determine if the urban air will be in compliance with regulations.

The EMFAC and MOBILE models use effectively the same algorithms to estimate the emission factors for mobile sources. The primary difference between the models is that the emissions factors data are different due to different emissions regulations in California. As a result, for truck size and weight issues, there is no appreciable difference between the two models and the remainder of the discussion regarding the applicability of these models to truck size and weight regulations will focus around the MOBILE model.

The MOBILE model generates in-use emissions factors for the eight vehicle classes listed below:

LDVG	Light duty gasoline powered automobiles
LDGT1	Light duty gasoline powered trucks, less than 6,000 lb. (GVW)
LDGT2	Light duty gasoline powered trucks greater than 6,000 lb. and less than 8,500 lb. (GVW)
HDGV	Heavy duty gasoline powered trucks, greater than 8,500 lb. (GVW)
LDDV	Light duty diesel powered automobiles
LDDT	Light duty diesel powered trucks, less than 8,500 lb. (GVW)
HDDV	Heavy duty diesel powered trucks, greater than 8,500 lb. (GVW)
MC	On road motorcycles

Recently the MOBILE model has been modified to generate emissions factors for particulate matter only using an expanded vehicle classification system for HDDV. These expanded classes include:

LHDDT	Light heavy duty diesel trucks (10,000 < > 19,500)
MHDDT	Medium Heavy duty diesel trucks (19,500 lb. < >33,000 lb.)

HHDDV Heavy duty diesel powered trucks, greater than 33,000 lb. (GVW)

The emission factor for each vehicle class is derived from the relationship:

$$\frac{\text{mass of emissions (g)}}{\text{miles traveled (mi)}} = \frac{\text{mass of emissions (g)}}{\text{energy delivered (BHPhr)}} \times \frac{p\text{(lb/gal)}}{\text{BSFC (lb/BHPhr)} \times \text{FE (mi/gal)}}$$

where the energy unit, bhp-hr is a brake horsepower hour, BSFC (break specific fuel consumption) is a measure of the pounds of fuel consumed per unit energy delivered, FE (fuel economy) is a measure of the miles traveled per gallon of fuel consumed, and p is the density of the fuel used. The four terms in this calculation are provided by either the vehicle manufacturers or are obtained in laboratory tests. A weighted fleet average is then obtained using vehicle sales and/or registration records.

The MOBILE and EMFAC models are comprehensive in that they have been designed to estimate the emissions factors for a wide range of scenarios and are based on sound methodology. But, these models were not intended to be used as tools to investigate the impact of truck size and weight regulations on the emission rates of regulated pollutants. Rather, these models were developed to monitor emissions inventories within various urban areas and to investigate the level of compliance within these urban areas with air quality standards. Both models treat all diesel powered trucks greater than 8,500 pounds as heavy duty trucks. By not distinguishing among trucks heavier than 8,500 pounds, these models cannot be used to effectively evaluate the environmental impacts of changes in truck size and weight regulations. Even the more precise numbers used to estimate particulate emissions group all trucks with GVW greater than 33,000 pounds into one category. To use these models for evaluating the environmental impact of truck size and weight regulations, modifications must be made in order to produce reasonable estimates of the impact on net emissions due to truck size and weight policies. Alternatively, an independent model could be developed with specific application to the trucking industry.

Another problem with the existing environmental emission models is their reliance on VMT. The models estimate emissions by using an emission factor (grams per mile) and VMT. Therefore, if a scenario reduces VMT by 10 percent, then it would also reduce emissions by 10 percent. There is a danger in using VMT as the underpinning of environmental evaluations. While it is true that the farther and longer a vehicle travels, the more emissions it will release, a significant portion of a vehicles emissions are released during the "cold start" phase or beginning of a trip. By pinning emissions directly to VMT, these models are effectively ignoring the cold-start/hot-start problem with vehicle emissions.

1.8 Vehicle Related Noise Considerations*

(a) Background

The major contributor of noise pollution from trucks are the tires and engines. Additional sources of truck noise come from auxiliary systems such as compression brakes and refrigeration units. Typically, the engine sound level is associated with its revolutions per minute. As the engine revolutions increase, the sound level increases. Engine noise is related more to load (grade and acceleration) than it is to truck speed and consists of the block vibration, cooling system (fan noise), exhaust system, combustion-air inlet system, engine-driven air-brake compressor, and transmission and driveline. Although a function of load more than speed, engine and drivetrain noise dominates overall truck noise generation below 30 mph. Truck size and weight does play a part in the engine noise generated at speeds below 30 mph. Assuming similar truck designs and configurations, the difference in sound levels between say, an 80,000 pound truck and a 105,000 pound truck, will vary with engine speed while accelerating through the gear ranges. Therefore, given similar engines in both trucks, the heavier truck will have greater engine loads during operations and generate greater noise levels than the smaller truck. Actual truck noise characteristics are dependent on engine, transmission, and vehicle design characteristics. At speeds above 30 mph, tire noise dominates truck noise generation. While tires are not the only noise source at speeds above 30 mph, tire noise increases with speed at a greater rate than do engine and driveline noise sources.

In the vicinity of roads on which trucks make up more than 2 or 3 percent of the traffic volume, truck noise usually dominates the noise from all other vehicles. An increase in total truck traffic brought about by improved efficiency of operations and a resulting diversion from rail to truck could increase these deleterious effects even if improvements are made in noise and exhaust emissions. As a result of the effectiveness of federally mandated noise control, the range of noise levels attributable to gross weight difference is small at full-load engine conditions below 30 mph. However, because tire noise increases with truck speed at a greater rate than engine and driveline noise, it begins to dominate the total noise at about 30 mph. At higher speeds, tire

* Unless referenced otherwise, the discussions on noise impacts associated with changes in truck size and weight are from charles Rodman, Battelle. Mr. Rodman is a professional engineer (Ohio) with over 23 years experience in research relating to environmental noise analysis, monitoring and control of machinery noise, vibration, and dynamic stress.

noise becomes the major contributor to the overall truck noise level.* Engine and driveline noise, although a less significant contributor to the noise level in areas adjacent to the highway, is important from the standpoint of penetration of truck noise into the communities through which the highways pass. This seemingly paradoxical behavior of sound occurs because the higher frequency tire sound is attenuated more than the lower frequency engine sound.

According to the U.S. DOT, changes in truck size and weight regulations would change community exposure to noise in three ways:

- Changes in the distribution of weights and axle configuration types would change the noise levels generated by a given number of trucks on the road.

- Larger loads might increase the time trucks spend in the acceleration mode if new and larger engines are not used.

- Diversion of freight traffic from rail to truck (or vice versa), together with changes in the average load per truck, would change the number of trucks generating noise (U.S. DOT, 1981, pp. IV-24).

The type of driving (urban vs. rural) can influence the noise associated with truck operations. While urban vehicles, for the majority of operating conditions, will not achieve highway speeds, a longer and heavier vehicle under these conditions will produce the same noise level as a shorter, lighter combination due to the fact that the truck noise level is dominated by engine and exhaust noise (Barr, 1981, p. 15). As scenarios are considered to modify the truck size and weight limits, care must be taken as to the effects on the percentage of urban and rural traffic affected. If the majority of the changes will occur on interstate highways and rural settings, the dominant noise source will be the tires. However, if changes are made that impact the number and/or size of trucks operating in urban settings, then the engine noise will tend to dominate the noise issue.

*As measured according to the procedures specified by applicable federal standards. (SAE J366b).

(b) Technical Relationships with Specific Issues

Truck size and weight regulations can impact noise emissions in four basic areas:

- Effects of increased horsepower
- Effects of increased load (other than increased horsepower)
- Effects of increased trailer size
- Effects of reducing/increasing the number of trucks operating as a percentage of overall traffic.

Effects of Increased Horsepower. One can expect an increase in engine horsepower if truck size increases. Increases in weight, aerodynamic drag, and rolling resistance (from more tires), combined with the desire to maintain truck operating performance standards are the factors that will dictate the horsepower increase.

Assuming that the same vehicle technology would apply, the increase in low-speed (below 30-50 mph) engine and drive train noise can be expected to increase as a function (10 times the Log_{10} of the ratio representing the increase in horsepower) of the increase in horsepower requirements (Rodman, 1994). For example, the maximum low speed engine sound level would increase by 1.8 decibel (dB) if the engine horsepower were increased by 50 percent.

Effects of Increased Load (Other than Increased Horsepower). One source would be the increase in tire noise. As the number and/or size of tires per truck increases, the overall truck noise increases. Assuming the increase in tire-generated noise followed a similar relationship as the engine noise, the estimated increase in sound level is 10 times the $Log_{(Base\ 10)}$ of the ratio of the number of wheels or 1 dB for an increase from 16 wheels to 20. While this increase is theoretically not noticeable to a listener, the increase for two trucks in close proximity would be 4 dB. This unexpected increase is the result of the manner in which sound levels combine.

The increased horsepower requirements of auxiliary equipment on the truck/trailer would also contribute to the overall truck noise. For example, the increased horsepower of refrigeration equipment is required to meet the demands of larger refrigerated trucks. The expected increase in sound level would be approximately the same order of magnitude as for truck engine noise. Another example would be the increased noise from an engine compression brake (if used). This would be the result of having to dissipate the increased energy resulting from the increased mass of the vehicle.

<u>Effects of Increased Trailer Size</u>. Increased reflection of adjacent-lane noise is another factor that would increase the noise associated with increased trailer sizes. The flat sides of a trailer act as a reflector to noise from vehicles in adjacent lanes. The larger the area of the reflector, the more sound energy there is reflected. One of the effects would be a reduction in the effectiveness of road-side noise barriers because more noise would be directed over the top of the barrier. This would tend to increase the quantity of people "highly annoyed."

As the size of the trailer increases, it enhances the line-source effect. For a point noise source (relatively small, single source, like a single automobile or truck), the dispersion of sound energy with distance is approximately 6 dB for each doubling of distance. For a line source (longer source or multiple vehicles, like a truck convoy), the dissipation drops to 3 dB for each doubling of distance. As a consequence, noise from longer trucks, especially when in convoys, will propagate further into a roadside community before it undergoes a specific amount of attenuation.

<u>Effects of Reducing/Increasing the Number of Trucks Operating as a Percentage of Overall Traffic</u>. At 55 mph, reducing the percentage of traffic made up of trucks produces the following changes in traffic related sound level.

Changes Truck Factor	Reduction in Sound Level
20% to 15%	1 dB
15% to 10%	1.5 dB
10% to 5%	2.5 db

That is (from the above table), to produce a noticeable change in sound level (5 dB) it would be necessary to reduce the mix of trucks on the road from 20 percent of total traffic to 5 percent of total traffic (Harris, 1979).

1.9 Truck Induced Vibrations

In addition to being a source of noise pollution, heavy truck transport has another potentially adverse environmental impact: vibration, both earthborne and airborne. For example, it has been postulated that earthborne and airborne vibration from the engines and tires of heavy trucks is responsible for structural damage to buildings (specifically windows, walls, and floors) residing adjacent to or near roadways with moderate traffic volumes and vehicular speeds. Additionally, vibration can adversely affect those living in houses close to highway infrastructure (i.e., sleep disruption and general quality of life). People are more frequently disturbed by airborne vibration (in the frequency range of 50-100 Hz affecting windows and suspended floors), but earthborne vibration (in the 8-20 Hz range affecting walls and solid floors) has the greater potential for causing damage to buildings. Obviously, heavy truck (and in fact, all vehicular) vibration is essentially an urban problem because it exclusively affects those individuals and structures residing within 400 feet of a highway. The major determinants of vibration are vehicle weight and speed, but pavement surface roughness is also a contributing factor. While both vibration and noise are potential problems for structures and individuals residing near highways with moderate heavy truck transport, vibration effects decrease more rapidly with distance than do noise levels. Although current research on the magnitude of traffic-induced vibration is limited, there is no evidence that traffic vibration damages buildings.(Watts, 1990) In fact, one report states that in-house activities often create greater building vibrations than those caused by earthborne vibration, such as vehicular traffic, construction equipment, and train passbys (Hatano and Hendricks, 1985).

2.0 Knowledge Gaps and Research Needs

2.1 Existing Studies

Although there have been a few environmental studies examining the impacts from modifying truck size and weight regulations, these are now out of date and of limited scope. The study conducted by the ATA in 1981 is now 13 years old and only addressed the "barrier states" which, at the time, did not have the same GVW and length maximums as the remainder of the states. Finally, all the analyses within this report were based on VMT. While VMT has been the standard used for this type of analysis in the past, it does not fully address the problem at hand. The easiest way to describe the problem is with a simple example.

If you had two 50,000 lb. GVW heavy duty trucks each traveling a distance of 10 miles, there would be a total of 20 VMT (10*2). If you were able to combine those two vehicles into one, 100,000 lb. GVW heavy duty truck, traveling the same 10 miles, you would then only have 10 VMT. Using a strict tie to the VMT, you would expect emissions to be cut in half with the larger truck because there are half as many VMT. However, as discussed earlier in this paper, this is not the case. While you would expect the emissions from the one larger truck to be less than the combined emissions of the two smaller trucks, it would not likely be half as much. Therefore, tying environmental analysis to VMT when analyzing the effects of truck size and weight regulations is likely to lead to erroneous results that do not accurately portray the real world.

Another area lacking in research is the comparison of vehicle engine condition with emission levels. While it is generally believed that newer vehicles are less polluting than older vehicles, no significant research was found documenting vehicle emission levels as the vehicle ages.

2.2 Modeling

To estimate the impact of truck size and weight regulations on the emissions of pollutants the vehicle classifications for heavy duty vehicles must be expanded. The expanded vehicle classification system must be capable of resolving different emissions factors for heavy duty vehicles differing in GVW by 10,000 pounds or less and also must be able to resolve different emission factors for heavy duty vehicles with different trailer configurations.

Systematic expansion of the data base will depend on what the expected operating conditions for the additional vehicle classes and on what aspects of vehicle size and configuration have a significant impact on vehicle emissions. Because the heavier truck classes would most likely be involved in long-haul trucking, the operating conditions may be a simplifying factor in this case. A determination would still need to be made as to whether or not the small amount of urban driving still contributes significantly to the total vehicle emissions.

The effect of different vehicle size and configuration on emissions could be much more complicated. If vehicle emissions are sensitive to only a few factors and are strongly correlated, then extending the data base should be straightforward. However, if emissions are strongly dependent on a large number of separate variables with little correlation, then a much larger program of testing and modeling will be required in order to incorporate the characteristics of the additional heavy-duty classes. Preliminary investigations along these lines are being carried out by Accurex. A panel to discuss this issue is being planned for the next SAE congress in Detroit in February, 1995.

Because of the relatively large number of engine types and chassis, it is not feasible to directly measure directly measure the performance of all possible engine-chassis combinations. Some combination of modeling and direct measurement will be required in order to generate emission and performance numbers for the engine-chassis combinations in actual use.

Emission numbers for each individual engine type are provided by the manufacturer as part of the certification program. These numbers are obtained as averages over an engine test stand measurement using a transient test cycle designed to reflect driving in urban conditions. Information from the individual parts of the test cycle is obtained by the manufacturers but is usually treated as proprietary. The California Air Resources Board is currently conducting experiments using a heavy-duty chassis dynamometer to investigate how well transient test stand data correlates with emission from actual engine chassis combinations. West Virginia University has developed a portable heavy-duty vehicle emission testing laboratory that is currently being used to look at emissions from different types of fuels. This apparatus could be used to generate in-use correlations for heavy-duty vehicles, although it is not currently being used for this purpose.

The current methods for estimating truck emissions could be significantly improved. The transient engine test stand data on which current estimates are based is designed to reflect urban use and is likely to be a poor indicator of emission from vehicles engaged primarily in long-haul trucking. Measurements for engine emissions that reflect long-haul use need to be collected. More work needs to be done to develop conversion factors that accurately translate between engine test stand data and vehicle emissions, these conversion factors also need to be validated against measurements for actual engine-chassis combinations. Alternatively, the engine emissions-conversion factor model could be discarded entirely, and a different model developed. This would then need to be parameterized and validated against experimental data. There is also a need for field tests of emissions to verify that the models and correlations developed in the lab are accurate predictors of emissions in real life.

2.3 Fuels

The MOBILE model assumes all heavy duty vehicles are diesel fueled. To estimate the impact of gasoline or other alternative fuels on the emissions of pollutants, this model must be expanded to include additional classes of vehicles. Since these models are based on data obtained in laboratory tests, additional laboratory tests on engines using alternative fuels would be needed. Alternatively, theoretical simulations could be used to estimate this data.

Experiments are currently under way at West Virginia University to determine the effects of different fuel use on heavy-duty engine emissions.

2.4 Vehicle Weight

The broad classification of vehicles used by the MOBILE model lumps all heavy duty vehicles greater than 8,500 lb. into one category. An expanded classification system is needed that is capable of differentiating vehicle weight with a higher resolution and incorporates the characteristics of the vehicles when loaded to different weights and trailer configurations. The extension of this model to address the impact of vehicle weight regulations on emissions requires the extension of these models and the collection of the necessary data.

2.5 Vehicle Configuration

The MOBILE and EMFAC emissions models differentiate the emissions of vehicles based on the GVW and therefore cannot be used to estimate the impact of the vehicle configuration on the emissions of pollutants except to the extent that these vehicles may require different engines. Therefore, if the effect of truck size and configuration on engine output is known for the extended vehicle classifications, then the MOBILE model can be used to estimate the impact on emissions.

2.6 Truck Usage

The emissions factors for gasoline powered vehicles are calculated based on emission measurements obtained using the Federal test procedure (FTP). The FTP measurements are obtained for three modes of operation: cold start, hot stabilization, and hot start. MOBILE then provides various correction factors to account for the effects of age, speed, fuel composition, etc. The proportion of VMT accumulated in the different modes must be specified based on the driving conditions of the vehicles considered. No such level of detail is available for heavy-duty diesel vehicles. The starting point for the emission factors is test stand data for the engine. Conversion factors are then applied to this data to generate the emission factors. The effects of truck size and configuration are accounted for through the conversion factor. To estimate the impact of truck size and weight regulations requires, at a minimum, that the conversion factors for the expanded truck classes be generated along with the VMT estimates for the new categories. Beyond this, improved emission factors could probably be generated using models based on direct measurements of engine-chassis combinations. Breaking down the emissions numbers so that they reflect different driving conditions (cold start, acceleration, cruise, etc.) would also make possible more detailed modeling.

2.7 Engine Size

The MOBILE and EMFAC models use engine efficiency data obtained from laboratory experiments or the manufacturer on most engines used by heavy duty vehicles. Therefore, if the effect of truck size and weight regulations on the engines sizes is known and if the vehicle classification system is extended, these models can be used to estimate the impact of engine size on emission levels.

2.8 Time of Day Operating Regulations (i.e., L.A. City/County)

Determining the effect of time of day operating regulations on smog requires an atmospheric model that combines the effects of photochemistry with the local meteorology. Emissions from trucks and other motor vehicles will act as a time-dependent source term for this model. If the effect of the regulations on the time dependence of emissions can be resolved, then this can be used as input to atmospheric models to determine the effect on smog levels. Atmospheric codes capable of these predictions for a given emissions source term are available from several sources. The MOBILE model can be used to evaluate the effect of regulations on the source term.

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