INFLUENCE OF REGULATIONS AND TECHNOLOGIES ON THE WEIGHT OF TRANSIT BUSES IN THE UNITED STATES

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ABSTRACT

The introduction of federal regulations such as the Clean Air Act (1990) and the Americans with Disabilities Act (1990) forced radical changes in the design of transit buses. Mandated reductions in the level of tailpipe emissions and required improvements in passenger accessibility resulted in new bus designs and the installation of additional equipment. As a result, modern, heavy-duty transit buses contribute some of the heaviest single-axle loads regularly encountered over urban transit routes. This paper examines the influence of regulation and technology on the weight of heavy-duty transit buses in the United States and discusses efforts to mitigate the trend toward increased bus weight through the introduction of advanced materials and light-weighting techniques.

INTRODUCTION

The Pennsylvania Transportation Institute (PTI) of The Pennsylvania State University operates the Bus Testing Program for the U.S. Department of Transportation's Federal Transit Administration (FTA). Federal regulation requires the testing of all new model transit buses purchased using FTA funds (STURAA, 1988). Buses are tested for structural integrity, reliability, maintainability, safety, performance, fuel economy, and noise [Klinikowski et al., 1997]. Braking and emissions tests will be added to the program in the near future. More than 240 vehicles, ranging from modified minivans to full size, heavy-duty transit buses, have been tested since the program was initiated in 1989.

The inception of the Bus Testing Program immediately preceded the introduction of legislation that would prove to have a dramatic impact on transit bus design; specifically, the Clean Air Act, administered by the U.S. Department of Environmental Protection; and the Americans with Disabilities Act, administered by the U.S. Department of Transportation. In an effort to comply with the requirements of the new regulations, transit bus manufacturers and suppliers were compelled to innovate. New bus designs incorporated advanced materials and design practices, lower floors, larger door openings, alternative fuels, electric and hybrid-electric propulsion, and exhaust after-treatment. Design changes and the introduction of new components and equipment have a direct effect on factors such as structural integrity, reliability, and performance, and often result in increased bus weight. Data obtained while testing new bus models during this period of design evolution provide insight into the regulatory influence on these factors. The testing program, and the resulting design improvements implemented by bus manufacturers, continue to address many of the problems associated with the introduction of new designs and technologies. However, the problem of maintaining bus weight within legal axle limits continues to challenge transit bus manufacturers. This paper discusses the impact of the Clean Air Act and the Americans with Disabilities Act on transit bus weight and design and includes a summary of the advanced materials and light-weighting techniques being introduced in an effort to mitigate the trend toward increased transit bus weights.

EFFECT OF THE CLEAN AIR ACT ON BUS WEIGHT

The Clean Air Act requires that the U.S. Environmental Protection Agency set national health-based air quality standards to protect against common pollutants including ozone (smog), carbon monoxide, sulfur dioxide, nitrogen dioxide, lead, and particulate soot. Congress passed the core provisions of the Clean Air Act in 1970. The law was amended in 1977 and again in 1990. The 1990 amendment mandates increasingly stringent vehicle emissions standards for transit buses [42 USC Part 7554]. Heavy-duty transit buses are an easy target for emissions reductions because they primarily operate in congested urban areas and are largely supported with public funds.

In an effort to comply with the 1992 emissions reduction requirements, manufacturers of diesel-powered buses initially used turbo-charging and retarded fuel injection timing along with diesel particulate traps. Use of electronic controls started in 1991 and was adopted by nearly all engine manufacturers by 1998. Oxidation catalysts and improvements to combustion chamber design were introduced in 1994. Standards will continue to tighten and by 2007, engine manufacturers will be forced to switch to low-sulfur diesel fuel and install catalyzed particulate traps, NO_x absorbers, and other emissions control technology. Initially, the addition of particulate traps increased the weight of diesel buses; however, advances in diesel engine design have reduced engine weight and effectively offset the weight of additional emission reduction components.

Although the cleaner technologies introduced above resulted in dramatic reductions in diesel bus emissions, many manufacturers developed buses that meet the emissions requirements by using engines powered by alternative fuels such as natural gas, methanol, ethanol, and propane. After much debate and several fleet demonstration projects, natural gas has emerged as the alternative fuel of choice and may be stored on-board the vehicle in compressed or liquid form. In 1993, less than 1% of the transit bus fleet was fueled with natural gas; by 2003, this number increased to 10.7 % [APTA, 2003]. For compressed natural gas (CNG) vehicles, the gas is stored at a pressure of 200-300 bar in an array of high-pressure cylinders. The cylinders are usually mounted under the floor or on the roof of the bus. Early natural gas cylinders were constructed using thick-walled steel or aluminum tanks, wrapped with fiberglass. Recent composite designs are substantially lighter in weight. Buses fueled using liquefied natural gas (LNG) store the fuel as a cryogenic liquid and are less common than CNG buses. The cryogenic tanks consist of vacuum-insulated stainless steel tanks that are usually mounted under the vehicle. Both CNG and LNG fueled buses are significantly heavier than their diesel-fueled counterparts. Figure 1 provides a comparison of bus weights for several heavy-duty bus models equipped with both diesel and natural gas fueled engines. The natural gas buses tested by PTI are on average 11.3 kN heavier than the corresponding diesel model. This represents an 11% increase in weight. One study concludes that current CNG systems raise the weight of transit buses and impose additional stresses on route pavements [Harrison et al., 1995].

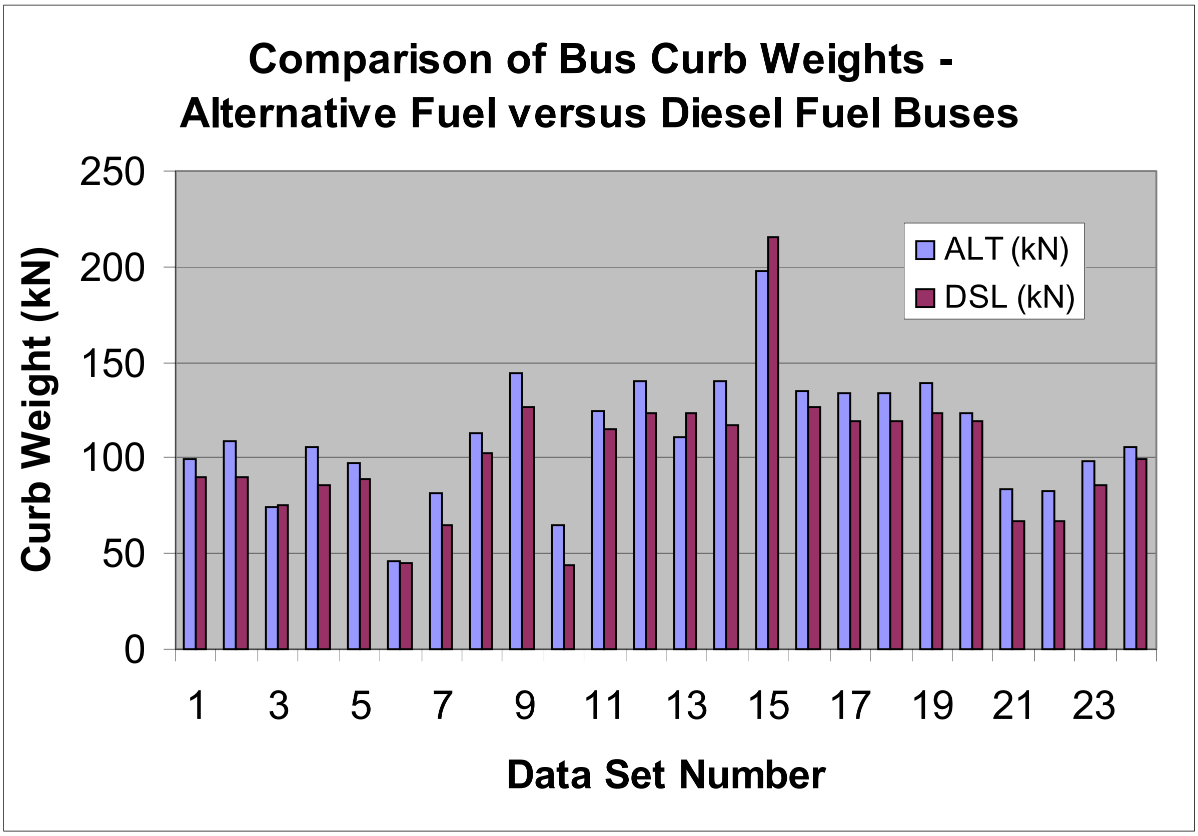

Figure 1. Comparison of bus curb weights - Alternative fuel versus diesel fuel buses.

Bus manufacturers and transit agencies have become increasingly interested in advanced technology, low-emission, hybrid-electric propulsion systems. These systems offer the advantage of using the existing fuel infrastructure while realizing the benefits of efficient, clean hybrid-electric propulsion. Hybrid-electric buses are available in a variety of drive configurations and fuel types. Although these designs are able to use a smaller fuel tank and a lighter internal combustion engine, they must also be equipped with an electric drive motor, generator, power controller, and energy storage system. The energy storage is usually provided by batteries, which can add significant weight. Figure 2 provides a comparison of bus weights for several bus models equipped with both hybrid-electric and conventional diesel drives. The hybrid-electric buses tested by PTI are on average 10.8 kN heavier than the corresponding diesel models. This represents a 9.5 percent increase in average weight.

Hybrid-electric buses are an enabling technology for ultra-low or zero emission fuel cell buses. The promise of a practical fuel cell-powered transit bus is the primary focus of almost all advanced bus propulsion research. While there are many obstacles to overcome, such as the development of a hydrogen infrastructure, etc., the solution to the problem of sufficient on-board hydrogen storage will be a major hurdle to the introduction of a practical fuel cell bus. Proposed solutions include storing hydrogen at high pressure (600 bar) in steel cylinders, as a cryogenic liquid in insulated tanks, and other more exotic methods. Each of these storage methods requires the installation of heavy components. The added equipment required for on-board reforming of conventional fuels would also tend to significantly increase bus weight [Battelle, 2002].

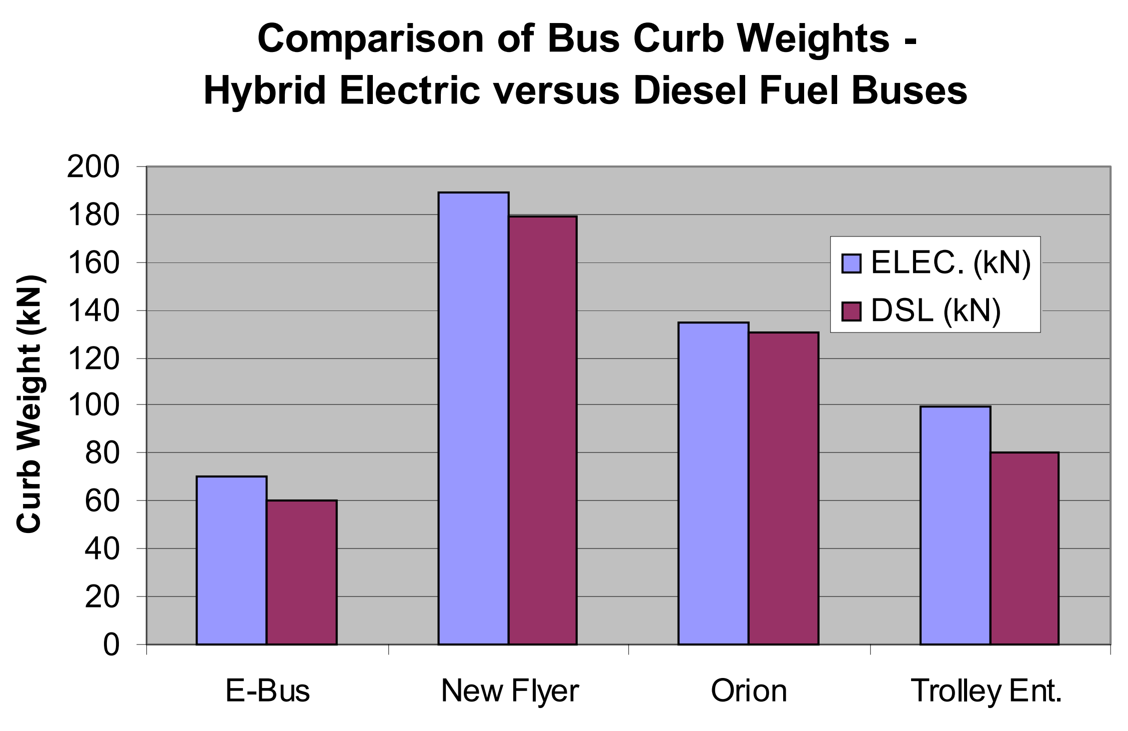

Figure 2. Comparison of bus curb weights – Hybrid-electric versus diesel buses.

EFFECT OF THE AMERICANS WITH DISABILITIES ACT ON BUS WEIGHT

The Americans with Disabilities Act (ADA), signed into law in 1990, consists of wide-ranging legislation intended to make all aspects of society more accessible to people with disabilities. The act’s various titles prescribe a comprehensive program that affects every aspect of transportation and places considerable responsibility on the Federal Transit Administration. Public transit is used by millions of Americans every day. ADA requires that all current and future fixed-rail and bus systems across the country be fully accessible and requires that the FTA periodically review transit agencies to ensure compliance. The accessibility requirements for transit buses have had a dramatic impact on vehicle design. All public transit buses must now comply with regulations defining items such as wheelchair lifts and mobility aids, door openings, step heights, seating, lighting, information and fare-box systems, etc. [49 CFR Part 38, Subpart B].

Although European bus fleets adopted low-floor bus technology in the 1980s, the typical North American transit bus prior to 1990 consisted of a high-floor vehicle that did not easily accommodate passengers using wheelchairs. Passengers were usually required to climb several steps after entering through a narrow door opening. Existing high-floor designs were difficult and often impossible to modify. Bus manufacturers initially modified adaptable designs by increasing the size of door openings and installing complicated and heavy step or platform-style wheelchair lifts. These systems were often unreliable and could add several hundred kilo-Newtons to the vehicle [King, 1994].

By the mid 1990s, American manufacturers started introducing low-floor buses. Low-floor buses required a radical departure from traditional bus design. The lower floor virtually eliminates under-floor space and displaces equipment that would otherwise be located beneath the vehicle. This equipment must be relocated to unconventional, less accessible spaces above the ceiling panels, on the roof, or in the engine compartment. In general, a conventional low-floor design has fewer passenger seating positions than a standard high-floor bus. The interior floor space of a low-floor bus is often decreased by the intrusion of the wheel housings and engine compartment. In some cases, this results in a 16% reduction in passenger capacity. While the gross vehicle weight of a low-floor bus is potentially less than that of a conventional bus, the reduced passenger capacity may require the operation of additional buses to service a given route [NABI, 1997].

EFFORTS TO MITIGATE THE TREND TOWARD INCREASING BUS WEIGHT

Improvement in vehicle fuel economy and a reduced dependence on fossil fuels have been vigorously pursued by the automobile industry for the past few decades. Some technologies that help meet this end have been identified as better engine and transmission technologies, improved aerodynamics, tires with lower rolling resistance, and increased use of lightweight materials. While many of these measures have already been used in production vehicles, the only area that promises significant improvement in fuel economy in the future (aside from the development of totally new power plants and perhaps hybrid-electric vehicles) is the use of lightweight materials for body and chassis components [Argonne Natl. Lab., 1995].

Apart from an increase in fuel economy, reduced vehicle weight is especially beneficial to buses as it provides for additional seating, reduces axle loads and resultant tire wear, and allows for the use of a smaller power plant/engine [IVECO, 1994]. The vehicle industry has pursued two different methodologies toward this end. The first one is based on continuing with the present mainstay material, namely steel, and focusing the research on structural optimization techniques like finite element analysis while simultaneously looking for high-strength steel alloys. The second method proposes the extensive use of alternative materials like aluminum, wrought magnesium alloys, and high-performance, polymer-matrix composites (PMCs) along with different forms of fiberglass, carbon fiber reinforcement and lightweight structural foams. As expected, there are strong proponents of both methodologies.

Breakthrough material technologies and improved manufacturing processes for steel have demonstrated and validated that unneeded mass strategically removed from steel results in lighter steel components [SAE 2000-01-3424, 2000]. The UltraLight Steel Auto Body (ULSAB) study conducted by the International Steel Institute suggests that the weight of automotive structural bodies can be reduced by 24% to 37% while keeping the content in low-cost steel. This would, however, require advanced steel alloys and manufacturing technologies that have only recently come to market. An interesting finding of the Improved Materials & Powertrain Architecture for 21st Century Trucks (IMPACT) program indicates that cost savings are achievable for weight reductions up to 25 %. At these lower weight reductions, costs associated with higher grade steels are outpaced by the amount of weight reduction. The IMPACT study, as reported in the SAE paper, also claims that it is only in the buckling region that aluminum has clear advantages over steel. This is because the material modulus and density are not subject to wide variation and cannot be manipulated through the manufacturing process. Auto and truck bodies seldom have buckling problems, so the rationale for using aluminum in aircraft fails to carry over to automobiles and trucks [SAE 2000-01-3424, 2000].

As per Argonne National Laboratory findings, Aluminum Intensive Vehicles (AIVs) are between 20% and 30% lighter than conventional steel vehicles and are equally safe. Research suggests that for structural applications in automobiles and passenger-oriented trucks, limited use of aluminum can provide up to 19% weight reduction, while vehicles with maximum use of aluminum provide for up to 31% weight savings. Auto manufacturers have also developed Prototype AIVs based on mass-produced versions. In the passenger car segment, Ford has developed the aluminum-body Mercury Sable and the aluminum concept car Ford Synthesis 2010. The stamped-aluminum body of the Mercury Sable weighs 47% less than the equivalent steel body. The Ford Synthesis concept car has a 27% lower curb weight than the comparable steel vehicle [Stodolsky et al., 1995]. Apart from better fuel economy and handling because of reduced weight, AIVs also offer a body that is less susceptible to corrosion. However, for significant market penetration of aluminum-intensive vehicles, manufacturing costs would have to be reduced. Researchers also feel that significant additional weight reductions could be achieved by greater use of low-density magnesium (Mg) and its alloys. Magnesium sheet could be used in non-structural body and semi-structural applications, while extrusions could be used in structural applications as spaceframes. Magnesium is 36% lighter per unit volume than aluminum and 78% lighter than iron. When alloyed, Mg has the highest strength to weight ratio of all structural metals [Gaines et al., 1996]. A magnesium-intensive vehicle is thought to be capable of achieving weight reductions as high as 40%. The main point in favor of magnesium is that it is abundant, being present in seawater. However, it also has some severe drawbacks, including high reactivity and susceptibility to corrosion.

Extensive test data available from the Bus Testing Program at PTI indicate that buses that employ alternative materials like aluminum, fiberglass, and composites show a substantial weight reduction as shown in Figure 3. Figure 3 compares four buses that use conventional steel technology with four similar buses that use alternative materials.

The CompoBus by North American Bus Industries (NABI) is said to be about 31.1 kN lighter than a conventional bus. The body of CompoBus is made from glass-fiber reinforced resin [NABI web-site]. Northrop Grumman's Advanced Technology Transit Bus (ATTB), which employs a composite body fabricated from fiberglass and foam and uses a hybrid propulsion system, weighs approximately 44.5 kN less than an equivalently configured conventional transit bus [BMP website].

In summary, actual data suggest that advanced materials have the potential to achieve considerable weight savings. However, advanced steel alloys together with manufacturing technologies provide another viable option that could be explored for optimizing weight reduction.

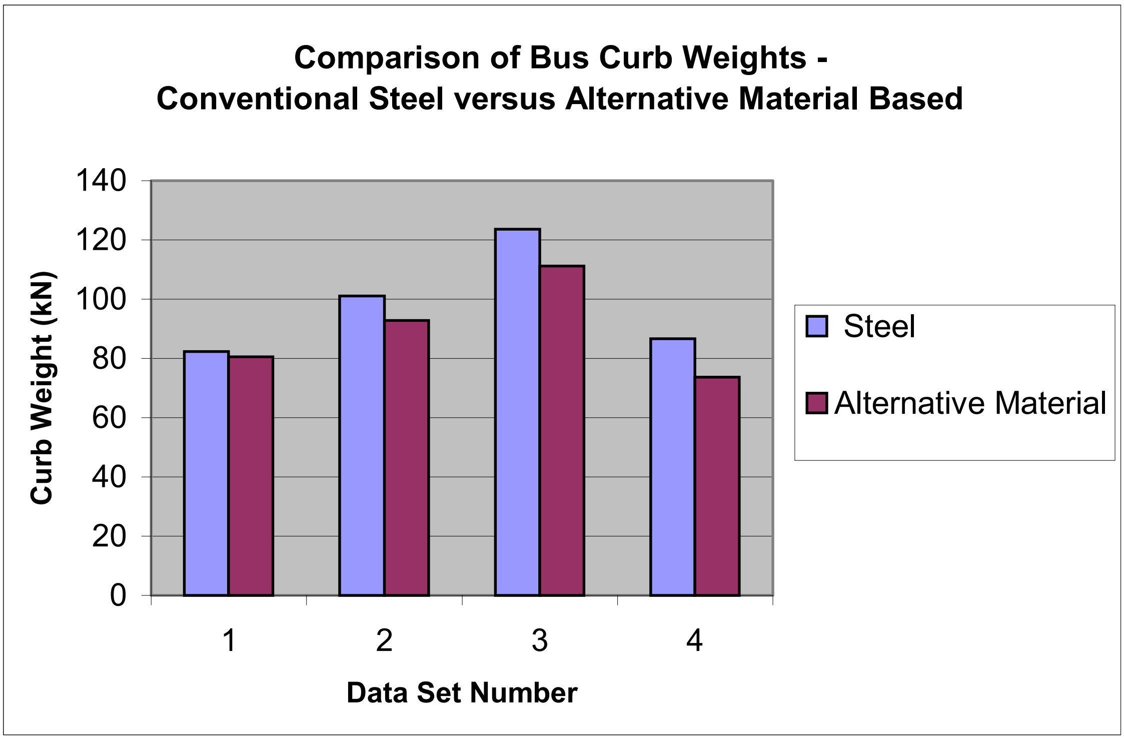

Figure 3. Comparison of curb weights of similar buses – Conventional steel based versus alternative material based.

CONCLUSIONS

Federal legislation will continue to impact the design of transit buses in the United States as a part of an on-going effort to improve accessibility, efficiency and emissions. New vehicle technologies and equipment are necessary to meet the requirements of increasingly stringent regulations. Legislators must carefully weigh the impact of added cost versus the expected benefit when mandating new regulations. They must also recognize the need for regulatory flexibility to encourage innovation intended to enhance vehicle design and performance. Manufacturers of transit buses will continue to comply with regulatory changes by developing innovative transit bus designs that do not exceed existing axle-weight limits. Meeting this challenge will require the continued development and implementation of advanced systems, materials and design methods.

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