



Modeling Real People in Real Buses: Implications Concerning Tire, Axle and Vehicle Weights

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Abstract

The current certification requirements under CFR 49, Part 567 state that GVWR of a motor vehicle shall not be less than the sum of the unloaded vehicle weight, rated cargo weight and 150 pounds times the number of designated seating positions. Actual occupant weight distributions versus certified weight per occupant seat causes a potential conflict between a vehicle's in-use weights versus its certified GVWR. Population weight distributions were developed based upon The Center for Disease Control's (CDC) publication of 2007 - 2010 anthropometric reference data and publically available weights of a special population from high school football teams. For five buses from small (18-seat) to large (55-seat), key parameters were measured. The weight distributions and bus parametric data were combined in a probabilistic analysis to explore the probability that passengers and rated cargo would result in weight distributions that exceeded tire load capability, Gross Axle Weight Rating (GAWR), or Gross vehicle Weight Rating (GVWR). The scope of the paper does not investigate whether increasing the required weight per seat would produce net benefit, but, given historical usage and understandings and recent requirements for objective test criteria, an objectively derived and, if judged necessary, updated occupant weight per seat requirement is suggested. Results demonstrated that load conditions and usage restrictions are identifiable that decrease the probability of operating in a condition that exceeds a tire or vehicle weight rating. The analysis of this paper supports that a median unclothed adult weight of at least 79.3 kg (175 pounds) which would represent an equal male and female population of all race and ethnicity in the United States of America should be considered.

Introduction

The current Certification requirements under Code of Federal Regulations Title 49, Part 567 (49CFR567) state that Gross Vehicle Weight Rating (GVWR) of a motor vehicle shall not be less than the sum of the unloaded vehicle weight, rated cargo

weight and 150 pounds times the number of designated seating positions [1]. In describing its understanding of the genesis of the 150 pound standard the Federal Transit Administration (FTA) stated: "Although NHTSA [National Highway Traffic Safety Administration (NHTSA)] did not provide an explanation for this figure [150 pounds] in its 1971 rulemaking documents, NHTSA staff believes their average was based on data derived from the National Health Examination Survey for 1960 - 1962" [2]. Code of Federal Regulations Title 49, Part 567 allows school buses to use a minimum occupant weight allowance of 120 pounds per passenger and 150 pounds for the driver [1].

The average reported weight from the National Health Survey for 1960 - 1962 for men and women from 18 to 79 years old was 168 pounds and 142 pounds, respectively. The survey reported cumulative percentile for men and women. Certainly, data from the National Health Survey for 1960 - 1962 would support an average around 150 pounds - though the calculated average for all adults (assuming equal men and women) from the survey was 155 pounds and the calculated median was 153 pounds [14].

The 150 pound convention for passenger load may also have been derived from longstanding industry practice as demonstrated in the 1934 SAE paper titled, "Weight Distribution of Motor Vehicles," in which two examples of motor coach weight analysis use exactly 150 pounds per passenger [4]. The current FMVSS 110, which specifies tire selection to prevent overload, defines normal occupant weight as 68 kg (150 pounds) and uses 68 kg per designated seat position in the definition of Vehicle Carrying Weight [5].

The Federal Aviation Administration upgraded its Advisory Circular (AC), AC-120-27D, Aircraft Weight and Balance Control in August of 2004 [6]. The AC includes a section on Standard Average Passenger Weights that, according to the AC, was based on data from the 1999 and 2000 National Health and Nutrition Examination Survey (NHANES) conducted

by the Center for Disease Control (CDC). NHANES data are the primary source of body measurement and related health and nutrition data for the civilian, noninstitutionalized U.S. population [7]. The Standard Average Adult passenger weight was 190 pounds. Average Adult Male and Female Passenger weight was 200 pounds and 179 pounds, respectively. Child weight (2 years to less than 13 years of age) was 82 pounds. According to the Advisory Circular, "the standard average passenger weights include 5 pounds for summer clothing, 10 pounds for winter clothing, and a 16-pound allowance for personal items and carry-on bags." Where no gender is given, the standard average passenger weights are based on the assumption that 50 percent of passengers are male and 50 percent of passengers are female. The AC also requires checked baggage average weight of at least 30 pounds.

By stripping away included weights, the average weights of FAA AC-120-27D, later duplicated in AC-120-27E (6/10/05) [8], revealed an assumed average adult passenger weight of 169 pounds and average male and female adult passenger weights of 179 pounds and 158 pounds, respectively. Youth above 12 years of age are treated as adults and children 2 years to 12 years of age have a unique average weight of 82 pounds and 87 pounds in summer and winter, respectively.

In December 2010 the United States Coast Guard amended its regulations governing the Assumed Average Weight per Person (AAWPP) to 185 pounds (83.9 kg). Under Title 46 of the CFR the prior AAWPP was 160 pounds (72.6 kg), except vessels operating exclusively on protected waters and carrying a mix of men, women, and children could use an AAWPP of 140 pounds (63.5 kg) per person. A weight of 75 kilograms (165 pounds) per person was required for damage stability calculations. According to the Coast Guard the prior weights were established in the 1960s and had not been updated since. The Coast Guard noted, "Updating regulations to more accurately reflect today's average weight per person will maintain intended safety levels by accounting for this weight increase" [9].

In March 2011 The Federal Transit Administration (FTA) proposed to amend its bus testing regulation to more accurately reflect average passenger weights and actual transit vehicle loads. Specifically, FTA proposed to change the average passenger weight from 150 pounds (68 kg) to 175 pounds (79.3 kg). In addition, because greater passenger weight was associated with greater passenger space requirements, the FTA proposed to change the floor space occupied per standing passenger from 1.5 to 1.75 square feet (.14 m² to .16 m²). The FTA noted that the establishment of a more accurate average passenger weight was of Department-wide [USDOT] interest, and initiated a new average passenger weight only after consultations within the Department. To avoid conflicts with NHTSA's definition of Gross Vehicle Weight FTA proposed a new definition, "fully loaded weight," which incorporated the heavier and wider dimensions of the average transit bus rider [10]. In July of 2006 the US Congress passed the Moving Ahead for Progress in the 21st Century Act (MAP-21) requiring FTA to establish new pass/fail standards for its bus testing program which must include new safety

performance standards [11]. Because MAP-21 required a more comprehensive review of its overall bus testing program, FTA withdrew its proposal that addressed increased passenger weight and size in December of 2012 [12].

A remaining issue in bus evaluation is determining the appropriate occupant weight per seat. For buses that are overweight when fully loaded, a corollary issue is how can they be used and fall within weight ratings. The current study uses modern US population weight distributions to calculate the probability that a loaded bus will weigh more than its certified Gross Vehicle Rating (GVWR) and Front and Rear Gross Axle Weight Ratings (FGAWR, RGAWR). The paper first presents and compares modern weight distributions of the US adult population and presents the weight distribution from all Arizona Division I high school football roster for 2012-2013. Five different buses from small (18-seat) to large (55-seat) are identified and carefully measured for inclusion in the analysis. Results for each bus are presented listing the relative probability that a certification weight will be exceeded for an adult population of equal men to women assuming a weight distribution reported for a current US population. Finally, a discussion is provide, including comments on loading restrictions that may prevent exceeding the certification weight ratings and ending with concluding remarks.

Method

Prediction of the bus weight distribution from occupant load used a Monte Carlo analysis in a Microsoft Excel spreadsheet. The use of Excel spreadsheets in performing Monte Carlo analysis was described by Bartlett in his 2003 SAE Paper [13]. Weight distribution was calculated in two modules. The first module used the spreadsheet to randomly simulate, utilizing a uniform distribution, the position of empty passenger seats. If all seats were occupied, the first module was not employed. The second module assigned occupant weight for occupied seats using the discrete weight distribution of the passenger population. The method was described in more detail in the SAE Paper, "Predicting Weight Distribution from Occupant Load Using a Monte Carlo Method [14]."

Several models for occupant weight were developed. The principal source for occupant weight was the October of 2012 National Health Statistics Report, Anthropometric Reference Data for Children and Adults: United States, 2007-2010. The National Health Statistics Report was based upon the NHANES and reported the average weight for men and women of all racial and ethnic groups 20 years and over as 88.7 kg (195.5 pounds) and 75.4 kg (166.2 pounds), respectively [15]. The survey reported cumulative percentile for men and women and children as shown in Appendix A. An additional model of occupant weight was developed from the reported roster weight of 2012-2013 Arizona Division I varsity football players. The Division I includes the 29 most populous high schools from across the state of Arizona and totaling 1682 mostly junior and senior players (14-freshman, 169-sophomore, 727-junior, 723-senior and 48-no reported weight) [16].

Table 1. Description of buses

Description	Seat Capacity	Overhead Cargo	Cargo Area	GVWR (kg)
2005 Mid-Sized Bus	18	no	inside right front	5,216
2003 Mid-Sized Bus	21	no	none	6,372
2005 Mid-Sized Bus	33	yes	none	8,845
2007 Mid-Sized Bus	41	yes	rear	11,793
1998 Motor Coach	55	yes	under floor	21,722

Because the Excel spreadsheet required a discrete distribution as a lookup table for making weight distribution calculations and since NHANES anthropometric weight statistics were reported separately for men and women, a separate polynomial curve fit for men and women of all racial and ethnic groups 20 years and over from each population's reported weight cumulative percentile was made. From the equation describing each curve fit, a combined model of an equal male to female population was statistically analyzed to generate a discrete distribution. Analysis of the Arizona Division I football population was performed after compilation of the data into a format similar to the National Health Statistics Report format.

Five separate buses across a range of sizes from 19 passenger to 55 passenger were weighed, measured and analyzed. The largest bus was a full size motor coach whereas the four others were in the mid-sized bus class. According to the Mid-Sized Bus Manufacturing Association (MSBMA) a mid-sized bus "means a motor vehicle designed to carry passengers built on a cutaway or rail chassis or on monocoque construction, under 40 feet (12.2 m) in length and having a gross vehicle weight rating class of VII (26,001 - 33,000 lb) (11,794 - 14,969 kg) or less" [17]. Table 1 lists the buses and their configurations.

In addition to the weight of occupant load, the weight of cargo load was simulated consistent with the weight rating requirements of the MSBMA Recommended Practice, Weight Distribution and Payload [17]. The Recommended Practice required 11.3 kg (25 pounds) per occupant if a cargo compartment was present and 2.3 kg (5 pounds) s per occupant when an overhead cargo rack was present. For the motor coach 13.6 kg (30 pounds) per passenger was modeled in the cargo compartment and 2.3 kg (5 pounds) per occupant was added because of overhead storage. The cargo load in the cargo compartment was simulated at the center of the cargo area floor. Overhead cargo was simulated with the occupant in each occupied seat.

For reference, additional industry standards that describe appropriate allowance for baggage include the Tire and Rim Association Standard, for the Selection of Tires for Trucks, Busses and Trailers and Definition of Terms, which defined driver and occupant weight as 150 pounds and, for buses involved in intercity transportation, required 185 lbs. per occupant (to include luggage) and 100% full-seating rating [18].

And, the FAA AC-120-27E, Aircraft Weight and Balance Control, required checked baggage average weight of at least 30 pounds, included 5 pounds for summer clothing, 10 pounds for winter clothing, and a 16-pound allowance for personal items and carry-on bags [8].

From the cargo and occupant load a calculation based upon Newtonian physics was performed to yield the weight per axle and weight per tire. For the dual rear wheel axle the weight per tire was calculated at the center of the inner and outer track width and divided by two (2). The calculations for load distribution were described by Sparks in his 1990 SAE Paper, Utility Vehicle Weight Problems and Design Considerations [19] and are embodied in publically available spreadsheet-based software sold by the National Truck Equipment Association (NTEA) [20]. For the 55 passenger bus with trailing tag axle the effective wheel base and rear/tag axle weight distribution were calculated assuming that the tag axle carried 50 percent of the weight of the rear dual tire axle; in other words, the tag axle carried 1/3 of the combined effective rear weight at the effective wheel base.

Comparisons of calculated weight to GVWR, GAWR and tire load ratings were made. Tire load ratings are based upon the tire and tire pressure specified on the bus certification placard and are the load limits listed in the 2006 Yearbook of The Tire and Rim Association, Inc. [18]. Comparisons were made using the certification load requirements of 68 kg (150 pounds) per seat plus rated cargo load and probabilistic analysis load with every seat occupied and cargo consistent with available cargo space and industry standards.

Results

The model of the combined population for men and women of all racial and ethnic groups 20 years and over (2007-2010) is shown in Figure 1 as the combined adult. Figure 1 also show the separate distributions of the male and female populations. Figure 2 compares the 1960-1962 CDC anthropometric statistics combined distribution to the 2007-2010 combined distribution from the National Health Statistics Report. Figure 3 shows the male population distribution for the various racial and ethnic groups distinguished by the National Health Statistics Report. Figure 4 shows the distribution of Arizona Division I football player for the 2012-2013 season and the distribution 18 year old male and female children reported in the National Health Statistics Report.

Table 2 reports the results from analysis using the 68 kg (150 pounds) per designated seat position and rated cargo load. Results that exceed a weight rating or tire load limit are indicated by numbers in parentheses and highlighted with a grey background. Table 3, Table 4, Table 5, Table 6, Table 7 report results of the probabilistic analysis for each bus and show results in rows by percentiles. Because the size of the right front cargo area in the 2005 mid-sized 18 seat bus was small, cargo weight was limited to the rated cargo capacity for the results shown in Table 3. Table 7 does not report weight relative to tire limit because the margin was not exceeded and large. Results that exceed a weight rating or tire load limit are indicated by numbers in parenthesis and highlighted with a grey background.

Discussion - Weight Distributions

The NHANES anthropometric weight data is obtained with subjects wearing a standard examination gown, which consists of a disposable shirt, pants, and slippers. Only underpants are worn beneath the gown [21]. The reported NHANES anthropometric weights appear to be effectively unclothed weights. Assuming equal men and women, the calculated average for all adults from the 2007-2010 survey was 82 kg (181 pounds). The FAA average adult passenger weight, adjusted for clothing and carry-on baggage, was 77 kg (169 pounds). Without adjustment for clothing or baggage, the Coast Guard required 84 kg (185 pounds), and the FTA proposed 79 kg (175 pounds) for its required testing. It is possible that the population modeled by each government agency differs from the general population represented by the NHANES data. The use of 68 kg (150 pounds) for occupant weight, except for its long standing inclusion in Federal Vehicle Certification requirements, was not supported by modern surveys of the U.S. population.

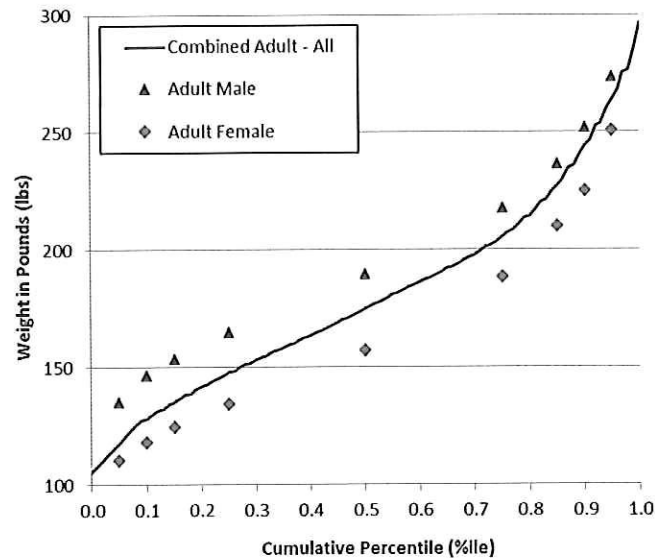


Figure 1. Distribution of 2007-2010 combined adults of all race and ethnicity with distribution for male and female.

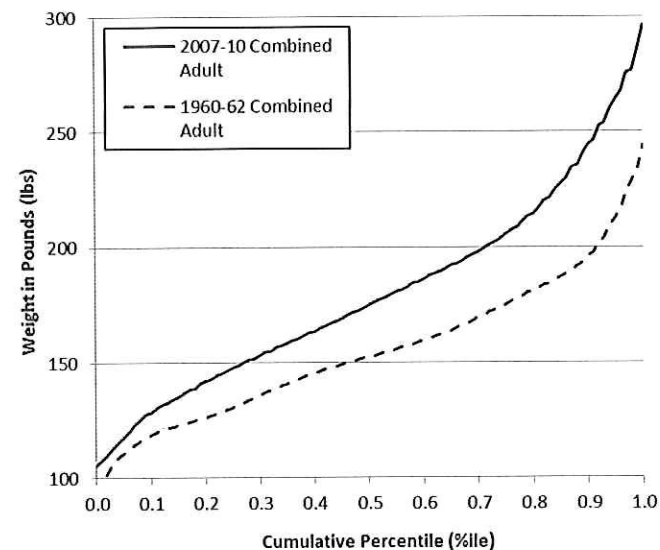


Figure 2. Distribution of 1960-1962 combined adult and 2007-2010 combined adult weight.

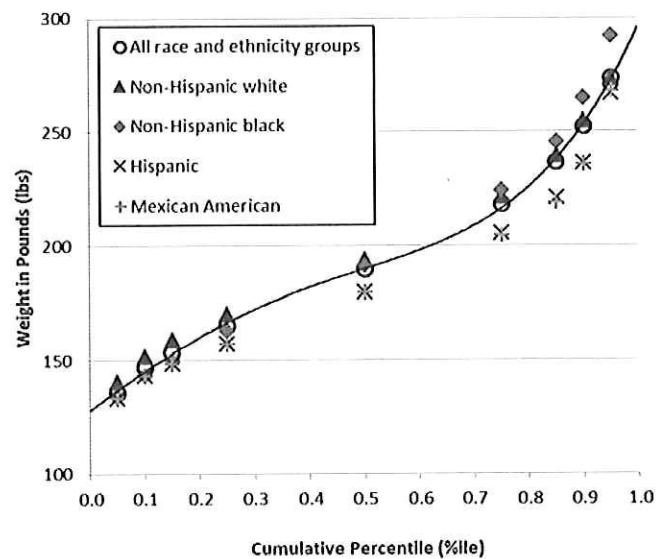


Figure 3. Distribution of 2007-2010 male weight comparing the breakout of race and ethnicity

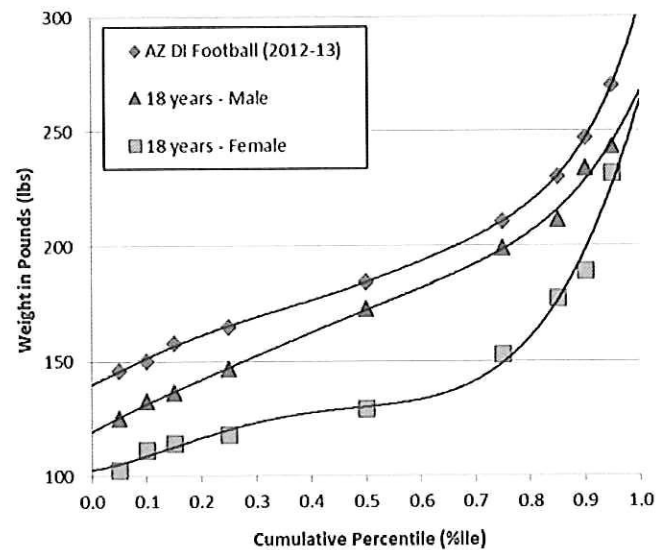


Figure 4. Distribution of Arizona Division I football roster for 2012-2013 and 18 year old male and female children.

Table 2. Summary of bus weight analysis at 150 pounds per seat plus rated cargo

Description	Margin to Rating (kg)			Margin to Tire Limit (kg)			
	Gross	Front Axle	Rear Axle	Left Front	Right Front	Left Rear	Right Rear
2005 Mid-Sized Bus	27	566	(130)	307	291	(4)	(21)
2003 Mid-Sized Bus	830	125	705	65	91	215	235
2005 Mid-Sized Bus	(349)	(231)	336	(100)	(5)	58	147
2007 Mid-Sized Bus	(277)	552	148	338	401	106	36
1998 Motor Coach	1186	304	1381	404	381	N/A	

Table 3. 2005 mid-sized bus with 18 passenger seats and right front cargo area

Description	Margin to Rating (kg)			Margin to Tire Limit (kg)			
	Gross	Front Axle	Rear Axle	Left Front	Right Front	Left Rear	Right Rear
5th %ile	(98)	611	(251)	332	321	(34)	(43)
10th %ile	(126)	602	(281)	326	316	(42)	(52)
15th %ile	(146)	596	(302)	321	312	(48)	(57)
25th %ile	(175)	587	(333)	316	306	(57)	(65)
50th %ile	(232)	569	(393)	304	297	(73)	(82)
75th %ile	(288)	552	(452)	293	288	(91)	(98)
85th %ile	(319)	543	(486)	286	283	(100)	(107)
90th %ile	(341)	537	(510)	282	280	(107)	(113)
95th %ile	(374)	527	(542)	275	274	(117)	(123)

Table 4. 2003 mid-sized bus with 21 seats

Description	Margin to Rating (kg)			Margin to Tire Limit (kg)			
	Gross	Front Axle	Rear Axle	Left Front	Right Front	Left Rear	Right Rear
5th %ile	675	85	606	52	79	193	217
10th %ile	646	74	584	44	72	187	210
15th %ile	624	65	569	39	67	183	206
25th %ile	593	53	546	31	59	176	199
50th %ile	534	30	504	16	46	163	186
75th %ile	468	5	458	0	31	149	173
85th %ile	435	(8)	434	(8)	23	142	166
90th %ile	412	(18)	417	(15)	17	137	161
95th %ile	380	(30)	393	(23)	9	129	154

Table 5. 2005 mid-sized bus with 33 seats

Description	Margin to Rating (kg)			Margin to Tire Limit (kg)			
	Gross	Front Axle	Rear Axle	Left Front	Right Front	Left Rear	Right Rear
5th %ile	(707)	(327)	105	(141)	(45)	6	97
10th %ile	(744)	(344)	75	(151)	(55)	(3)	89
15th %ile	(772)	(355)	57	(158)	(61)	(9)	83
25th %ile	(811)	(372)	27	(168)	(71)	(18)	74
50th %ile	(888)	(405)	(29)	(187)	(90)	(35)	57
75th %ile	(968)	(439)	(87)	(209)	(109)	(52)	39
85th %ile	(1011)	(457)	(117)	(219)	(120)	(62)	30
90th %ile	(1040)	(469)	(139)	(227)	(128)	(69)	23
95th %ile	(1082)	(488)	(169)	(238)	(138)	(80)	14

Table 6. 2007 mid-sized bus with 41 seats and rear cargo area

Description	Margin to Rating (kg)			Margin to Tire Limit (kg)			
	Gross	Front Axle	Rear Axle	Left Front	Right Front	Left Rear	Right Rear
5th %ile	(1217)	712	(1198)	439	491	(348)	(273)
10th %ile	(1260)	696	(1234)	427	480	(362)	(288)
15th %ile	(1288)	684	(1261)	419	473	(371)	(298)
25th %ile	(1333)	668	(1300)	407	461	(386)	(313)
50th %ile	(1419)	637	(1374)	384	439	(414)	(341)
75th %ile	(1507)	605	(1452)	361	417	(442)	(370)
85th %ile	(1553)	588	(1493)	348	405	(457)	(387)
90th %ile	(1586)	577	(1522)	340	397	(469)	(397)
95th %ile	(1632)	558	(1565)	327	385	(484)	(413)

Table 7. 1998 Motor Coach with 55 seats with under floor cargo area

Description	Margin to Rating (kg)			Margin to Tire Limit (kg)			
	Gross	Front Axle	Rear Axle	Left Front	Right Front	Left Rear	Right Rear
5th %ile	530	81	1011	291	280		
10th %ile	478	51	976	275	264		
15th %ile	443	33	952	266	254		
25th %ile	391	4	915	251	238		
50th %ile	297	(50)	847	222	208		
75th %ile	201	(104)	778	193	179		
85th %ile	148	(133)	739	179	163		
90th %ile	111	(153)	713	168	152		
95th %ile	60	(184)	674	151	136		

The distribution of weight was not symmetrical about the median. A demonstration of this phenomenon was the observation that the median weight of the NHANES adult men population was 2.6 kg (6 pounds) lighter than the average weight, and the median weight of the NHANES adult women population was 4.1 kg (9 pounds) lighter than the average weight.

The method for describing and simulating occupant weight distribution could be applied to unique populations. For example, a unique distribution was developed for Arizona Division I football player for the 2012-2013 season. The weight distribution for high school varsity football players would be different from a church's preschool population; both would be different from a general population of youth. [Table 8](#) and [figure 5](#) demonstrates that Arizona Division I football player for the 2012-2013 season were on average slightly lighter than the adult male population, but as a population of youth are heavier than the population of male 18 year olds.

Discussion - Bus Weight Calculations

All simulations described in this paper assume independent random selection of occupied seats and occupant weights. One should consider that these variables may be dependent. For example, a passenger population that draws from a

common community might be more likely to sit next to each other and, in instances of related passengers, body size may be more likely similar.

Table 2 documents a potential problem with the mid-sized bus fleet in that even under certification weight requirements gross weight ratings and tire load limits are exceeded. Under certification weight requirements the 55-seat motor coach appeared to be well within weight ratings and tire load limits. Table 3, Table 4, Table 5, Table 6, Table 7 document that when the combined discrete distribution of adult weight, in combination with standardized centrally distributed cargo, was randomly applied in every seat of all five analyzed buses some probability of overload was predicted. Table 4 illustrates that the 2003 midsized bus when simulated with every seat occupied and standardized per occupant cargo has a less than 25 percent probability of exceeding its front axle weight rating and left front tire load limit.

Based upon Table 7, the motor coach front axle weight rating had a slightly greater than 50 percent probability of being exceeded. Further simulation revealed that to reduce the probability that the front axle weight rating was exceeded to below 50 percent required randomly vacating 7 seats or effectively reducing the weight distribution by 3 percent (median weight from 79.3 kg (175 pounds) to 77.0 kg) or limiting a centrally located cargo load to 12.25 kg (27 pounds) per passenger. Passenger cargo could also be positioned further rearward in the three cargo compartments. The simulation suggested that a 0.61 meter (2 ft) net rearward shift of cargo would produce the same reduced probability of exceeding the front axle weight rating.

Table 8. Comparison of youth and adult male population weights.

	Average Weight (kg)	Median Weight (kg)
Adult Male	88.7	86.1
AZ DI Football	87.1	83.7
18 Years Male	81.3	78.3

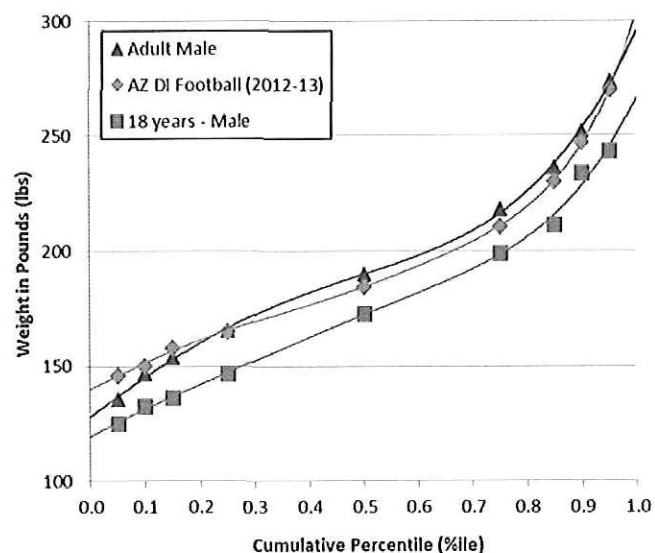


Figure 5. Comparison of youth and adult male population weights.

Table 9. Parameters required to reduce the probability of exceeding a weight rating or tire load limit to less than 50 percent.

Description	number of empty seats	Percent reduction of weight	Reduce median weight from 79.3 kg (175 pounds) to:
2005 Mid-Sized Bus (18 seat)	5	27%	57.9 kg (127.7 lb)
2005 Mid-Sized Bus (33 seat)	16	42%	46.0 kg (101.6 lb)
2007 Mid-Sized Bus (41 seat)	16	49%	40.5 kg (89.2 lb)

Expanding on baggage weight and location, the use of a distribution for per-occupant cargo would be an improvement to simulations of possible load distributions. The FAA's CA-120-27E included 7.3 kg (16 pounds) per average occupant weight for in-cabin personal items and 13.6 kg (30 pounds) per checked baggage stored in the luggage compartment. Data from the FAA, based upon its analysis of several surveys conducted on 10 to 19 seat airplanes, reported personal items on average weighed 6.85 kg (15.1 pounds) with a standard deviation of 3.72 kg (8.2 pounds); checked bags on average weighed 13.11 kg (28.9 pounds) with a standard deviation of 4.90 kg (10.8 pounds) and; heavy checked bags on average weighed 26.62 kg (58.7 pounds) with a standard deviation of 3.27 kg (7.2 pounds). Further, since it is unlikely that a cargo load's center of gravity location is always positioned at the center of a cargo area, a distribution of cargo CG location should be considered.

Three mid-sized buses exceed a weight rating at the certification occupant weight and cargo requirement so usage limitations suggested by simulations using 2007-2010 adult weight statistics were determined. Table 9 presents occupant loading required to reduce the probability of exceeding a weight rating or tire load limit to less than 50 percent. The 2007 41-passenger mid-sized bus was noted to have an incorrect rear tire listed on the certification label and was presented in table 9 using load limits of the correct rear tire. With the incorrect rear tire the 41-passenger bus would be limited to at least 20 empty seats because of the left to right weight imbalance.

Table 9's presentation of occupant and cargo conditions that mitigated overload used median simulated weight as the evaluation criteria. Meaning, for a given condition or assumption, roughly half of the simulated loads resulted in overload and half did not result in overload. Median simulated weight was used consistent with regulatory requirements that sanction use of average weight, but the paper does not provide analysis that substantiates the adequacy or inadequacy of the use of median or average weight or a median or average weight criteria. The simulation method allows for the computation of statistical percentiles of predicted weight for given vehicle occupancies. For example, it is possible to

determine the occupancy and loading characteristics that would produce vehicle weights within one standard deviation, or at approximately the 85 percentile, of the median weight.

The 1998 motor coach and the 2003 21-passenger mid-sized bus appear to be compatible with a median occupant weight of 79.3 kg (175 pounds). One-hundred seventy five pound (79.3 kg) was proposed by the FTA in March 2011 [10] for use in its bus testing program (though withdrawn in December 2012 [12] because of preemptive congressional action). Further, 79.3 kg (175 pounds) is the unclothed median weight for all adults, including male and female and all race and ethnicity, as calculated from the 2007-2010 anthropometric statistics reported by the CDC.

Exceeding weight ratings was not in compliance with requirements of 49CFR567, FMVSS120 and Federal Motor Vehicle Safety Standards (FMVSS) that reference Gross Weight Ratings. FMVSS were promulgated by the National Highway Traffic Safety Administration (NHTSA) under authority of the National Traffic and Motor Vehicle Safety Act and, by definition, are minimum standards for motor vehicle or motor vehicle equipment performance [22]. Not meeting the requirements of these Federal requirements means the vehicle was not legally sold and not certifiably free of unreasonable dangers that the FMVSSs were promulgated to prevent. The MSBMA noted that, "NHTSA has indicated that the Agency considers it to be a safety defect for a manufacturer to produce a vehicle that would be overloaded by design in carrying it's (sp) intended payload" [23]. Overweight conditions have been noted previously in other buses as indicated by the article, "Exceeding the Gross Vehicle Weight on a Bus," in which the author stated, "I do not know of a state where you can operate a bus fully loaded with passengers, fuel, bags, ADA equipment, when that bus is heavier than its chassis manufacturer rating" [24].

Summary/Conclusions

A method was described for combining reported U.S. population weight distributions into a statistically derived model. The model was based upon combining polynomial curve fits of male and female weight data and generating a table with one percentile increments for use in simulations of bus weight. The weight distribution of Arizona Division I football players for the 2012-2013 season was also presented.

Simulations of five bus weights were conducted. The simulations assumed a bus full of occupants using a 2007-2010 occupant weight model and standardized cargo. In instances when the bus was not full of occupants the model randomly selected occupied seats. The simulations randomly assigned occupant weights according to the statistically derived combined weight distribution. Examples illustrated how for a vehicle certified in accordance with 49CFR567 - in other words, certified under requirements of 150 pounds per designated seat position - a real population weight distribution could be evaluated and legal usage can be determined.

This paper addresses the modeling of occupant weight distributions and simulation of vehicle weights in comparison to maximum weight ratings and tire load limits. The paper does not attempt to address the legal or safety implications of exceeding or complying with maximum weight ratings or the effectiveness of current standards that used average weight as a constitute. Given historical usage and understandings and recent requirements for objective test criteria, an objectively derived and, if judged necessary, updated occupant weight per seat requirement is suggested. The analysis of this paper supports that a median unclothed adult weight of at least 79.3 kg (175 pounds) which would represent an equal male and female population of all race and ethnicity in the United States of America should be considered.

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AC - Advisory Circular

NHANES - National Health and Nutrition Examination Survey

CDC - Center for Disease Control

NHTSA - National Highway Traffic Safety Administration

NTEA - National Truck Equipment Association

MSBMA - Mid-Sized Bus Manufacturing Association

AAWPP - Assumed Average Weight per Person

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Definitions/Abbreviations

GVWR - Gross Vehicle Weight Rating

FTA - Federal Transit Administration

NHTSA - National Highway Traffic Safety Administration

APPENDIX

Appendix A

Table A1. Copy of page 5 from the Anthropometric Reference Data for Children and Adults: United States, 2007-2010 [15].

Table 1. Weight in kilograms for children and adolescents from birth through age 19 years and number of examined persons, mean, standard error of the mean, and selected percentiles, by sex and age: United States, 2007-2010

Sex and age ¹	Number of examined persons	Mean	Standard error of the mean	Percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
Male				Kilograms								
Birth to 2 months	82	5.2	0.09	3.5	3.8	4.0	4.5	5.4	5.8	6.0	6.1	6.3
3-5 months	111	7.1	0.11	5.6	5.8	6.0	6.2	7.0	7.5	8.1	8.4	8.6
6-8 months	103	8.7	0.13	7.2	7.5	7.7	8.1	8.7	9.2	9.5	10.0	10.6
9-11 months	108	9.6	0.15	†	8.1	8.2	8.7	9.3	10.5	11.1	11.2	11.7
1 year	318	11.3	0.09	8.9	9.4	9.7	10.2	11.4	12.2	12.8	13.0	13.8
2 years	325	14.0	0.14	11.3	11.8	12.2	12.6	13.9	15.0	15.7	16.4	17.3
3 years	203	16.2	0.21	13.1	13.6	14.0	14.7	15.9	17.2	17.8	18.3	20.2
4 years	244	18.5	0.22	14.9	15.2	15.6	16.2	17.7	19.5	21.5	23.0	25.5
5 years	205	21.2	0.32	16.3	17.1	17.8	18.9	20.2	22.1	24.4	27.1	31.0
6 years	193	24.3	0.47	16.8	18.1	19.1	20.3	23.1	25.6	29.1	35.0	36.5
7 years	216	26.7	0.43	19.7	20.3	21.1	22.2	24.9	29.6	33.5	34.8	39.5
8 years	211	31.3	0.70	21.6	22.7	23.8	25.8	29.8	35.3	39.4	42.1	46.5
9 years	191	36.6	1.17	22.8	24.6	26.6	28.3	33.0	42.8	49.2	52.6	†
10 years	197	40.0	0.93	25.8	28.6	30.2	32.1	38.0	46.1	52.2	54.0	59.7
11 years	211	46.6	1.13	31.5	33.7	34.5	35.9	42.4	54.4	60.8	66.8	73.5
12 years	159	51.5	1.27	31.3	34.5	36.6	39.9	49.2	60.7	68.0	69.7	75.1
13 years	146	59.2	1.45	38.0	42.7	44.6	48.5	56.6	63.6	71.4	81.0	95.8
14 years	177	63.9	1.92	40.2	42.3	47.0	52.2	60.4	71.2	81.2	88.9	†
15 years	160	70.1	1.95	48.4	50.6	53.9	56.2	66.0	76.4	86.9	94.2	115.3
16 years	175	75.1	1.52	52.0	56.2	57.7	62.3	70.7	84.4	92.9	99.8	108.9
17 years	188	77.4	2.41	52.3	58.1	60.9	64.4	71.0	85.4	95.3	104.8	128.5
18 years	142	81.3	2.00	56.7	60.1	61.9	66.5	78.3	90.3	95.8	106.1	†
19 years	179	79.5	1.39	57.6	62.3	63.6	66.9	78.6	85.6	95.8	98.8	119.1
Female												
Birth to 2 months	82	5.0	0.11	3.0	3.6	4.2	4.5	5.1	5.4	5.6	5.8	6.0
3-5 months	104	6.7	0.07	5.2	5.4	5.7	6.1	6.8	7.2	7.4	7.7	7.9
6-8 months	103	8.1	0.07	6.7	7.0	7.2	7.4	8.0	8.7	8.9	9.3	9.6
9-11 months	119	9.0	0.12	7.3	7.6	7.8	8.4	8.9	9.7	10.0	10.2	10.7
1 year	297	10.9	0.10	8.7	8.9	9.2	9.7	10.7	11.7	12.2	12.7	13.1
2 years	282	13.4	0.15	10.9	11.2	11.7	12.1	13.2	14.4	14.9	15.6	16.5
3 years	191	15.7	0.24	12.3	12.8	13.1	13.8	15.4	16.9	18.1	18.9	19.7
4 years	200	17.7	0.21	14.2	14.9	15.1	15.8	17.1	18.9	20.4	22.0	23.1
5 years	177	21.1	0.54	15.9	16.6	17.4	18.1	19.7	22.4	24.2	26.4	†
6 years	177	23.6	0.47	18.3	18.7	19.2	20.4	22.5	25.2	27.6	30.3	33.5
7 years	207	26.8	0.53	19.4	20.6	21.0	22.1	25.2	28.9	32.8	35.4	39.6
8 years	203	31.9	1.01	21.8	23.1	23.7	25.0	29.2	37.8	42.4	43.6	48.0
9 years	205	35.5	0.98	23.3	26.1	26.5	28.0	31.9	40.1	46.1	49.3	55.7
10 years	183	41.1	0.74	27.3	29.1	30.1	33.6	39.0	45.3	52.3	55.0	61.3
11 years	219	47.5	1.28	30.0	31.5	33.0	36.1	43.3	56.5	63.0	66.8	79.6
12 years	166	52.3	1.26	30.6	34.8	38.0	43.1	51.4	60.3	65.7	72.1	75.7
13 years	140	58.8	1.41	38.8	41.4	44.6	46.1	52.3	64.8	72.4	75.7	83.2
14 years	168	61.6	1.13	42.7	44.8	47.7	51.1	59.0	67.1	73.5	76.4	†
15 years	137	63.3	1.32	44.2	46.5	48.2	54.5	59.5	70.6	77.1	85.8	92.3
16 years	156	62.4	1.11	45.5	48.4	50.0	51.3	58.7	69.5	77.9	84.8	92.0
17 years	143	63.7	1.58	45.4	47.9	49.1	51.8	60.8	68.4	80.0	83.8	92.0
18 years	137	65.4	1.67	46.6	50.6	51.8	53.5	58.6	69.5	80.4	85.8	105.0
19 years	118	68.0	2.00	44.4	47.1	51.0	55.1	62.8	76.8	88.2	94.9	106.7

† Standard error not calculated by SUDAAN

¹Refers to age at time of examination

NOTE: Pregnant females were excluded

SOURCE: CDC/NCHS, National Health and Nutrition Examination Survey

Table A2. Copy of page 7 from the Anthropometric Reference Data for Children and Adults: United States, 2007-2010 [15].

Table 3. Weight in kilograms for females aged 20 and over and number of examined persons, mean, standard error of the mean, and selected percentiles, by race and ethnicity and age: United States, 2007-2010

Race and ethnicity and age	Number of examined persons	Mean	Standard error of the mean	Percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
<i>All racial and ethnic groups¹</i>				Kilograms								
20 years and over	5,844	75.4	0.35	50.2	53.6	56.6	61.1	71.3	85.5	95.4	102.2	113.8
20-29 years	906	73.4	1.13	48.6	52.1	53.8	57.3	67.7	82.2	94.8	103.1	120.0
30-39 years	962	76.7	0.94	50.9	53.9	57.4	62.2	72.5	88.1	97.6	102.2	115.2
40-49 years	1,056	76.2	0.74	50.8	54.8	57.4	61.2	71.8	85.7	96.2	103.7	114.9
50-59 years	873	77.1	0.83	51.1	55.9	58.4	62.8	73.2	87.9	96.8	104.4	115.8
60-69 years	951	77.4	0.65	52.8	57.2	60.0	63.7	75.2	87.3	95.7	102.7	109.5
70-79 years	679	74.8	0.69	49.9	53.5	57.0	62.1	72.3	84.9	91.5	99.1	109.2
80 years and over	397	64.9	0.73	45.4	49.8	51.8	55.8	63.5	71.9	78.4	82.9	87.4
<i>Non-Hispanic white</i>												
20 years and over	2,730	75.0	0.51	50.6	53.8	56.7	61.2	71.0	85.0	95.0	101.5	112.0
20-29 years	792	74.7	1.16	50.1	53.4	55.8	59.9	69.9	84.6	96.3	102.2	116.8
40-59 years	861	76.1	0.66	50.9	55.0	57.5	61.8	71.9	86.1	96.2	103.0	115.5
60 years and over	1,077	73.9	0.44	50.4	53.5	57.1	61.3	71.4	84.1	91.7	98.5	106.8
<i>Non-Hispanic black</i>												
20 years and over	1,128	85.2	0.78	53.9	58.7	61.9	68.5	80.5	97.7	107.7	115.7	130.5
20-29 years	372	84.4	1.16	51.6	57.0	60.9	65.8	79.9	98.3	109.7	117.4	133.6
40-59 years	383	88.3	1.22	56.9	60.7	65.4	71.0	83.2	100.5	110.4	116.7	131.7
60 years and over	373	80.7	1.04	52.8	57.1	61.2	67.6	77.7	90.9	100.3	106.1	114.8
<i>Hispanic²</i>												
20 years and over	1,708	72.9	0.46	49.7	53.1	56.0	60.5	70.2	82.3	89.9	95.6	103.5
20-29 years	619	72.3	0.60	48.8	52.1	54.1	58.8	68.7	83.3	91.1	96.5	105.1
40-59 years	579	74.6	0.83	52.0	57.0	59.4	63.9	72.1	82.7	89.5	95.3	103.7
60 years and over	510	70.7	0.47	48.0	51.8	55.6	60.5	69.4	79.1	85.5	90.2	96.9
<i>Mexican American</i>												
20 years and over	1,032	73.2	0.40	50.3	53.6	56.5	61.0	70.8	83.0	90.0	94.3	104.0
20-29 years	386	72.7	0.66	50.1	52.8	55.0	59.9	69.0	84.0	91.6	96.6	105.9
40-59 years	347	75.2	0.97	53.3	57.7	60.5	64.8	73.4	83.0	89.4	93.4	102.5
60 years and over	299	70.6	0.56	47.1	51.5	55.5	60.4	69.5	79.3	85.1	89.5	94.1

¹Persons of other races and ethnicities are included.²Mexican American persons are included in the Hispanic group.

NOTE: Pregnant females were excluded.

SOURCE: CDC/NCHS, National Health and Nutrition Examination Survey

Table A3. Copy of page 9 from the Anthropometric Reference Data for Children and Adults: United States, 2007-2010 [15].

Table 5. Weight in kilograms for males aged 20 and over and number of examined persons, mean, standard error of the mean, and selected percentiles, by race and ethnicity and age: United States, 2007-2010

Race and ethnicity and age	Number of examined persons	Mean	Standard error of the mean	Percentile								
				5th	10th	15th	25th	50th	75th	85th	90th	95th
All racial and ethnic groups¹				Kilograms								
20 years and over	5,651	88.7	0.45	61.5	66.5	69.7	75.0	86.1	98.9	107.2	114.4	124.1
20-29 years	894	83.4	0.85	58.4	62.6	65.3	69.5	80.1	93.7	101.6	109.0	116.8
30-39 years	948	90.5	0.75	63.3	67.8	70.8	75.4	86.7	101.1	110.1	117.8	128.0
40-49 years	933	91.0	0.96	64.4	69.5	73.5	78.5	87.9	100.6	108.6	116.2	126.3
50-59 years	934	91.3	1.10	63.8	69.0	72.9	78.2	88.6	102.9	109.8	117.6	126.6
60-69 years	933	90.5	0.76	61.7	67.9	70.9	76.4	88.5	101.2	108.3	115.1	127.4
70-79 years	649	86.5	0.88	62.6	68.8	70.4	75.1	84.7	95.1	102.9	109.4	117.9
80 years and over	360	79.3	0.81	57.6	61.5	64.1	69.0	77.9	88.2	94.3	97.3	104.5
Non-Hispanic white												
20 years and over	2,738	90.4	0.42	63.7	68.9	72.2	77.3	88.0	100.6	108.7	115.6	124.1
20-29 years	796	88.3	0.77	61.5	65.9	69.4	73.8	85.3	98.5	107.9	113.5	122.7
40-59 years	832	92.9	0.71	66.4	72.1	75.0	80.4	90.0	103.1	111.9	117.7	128.7
60 years and over	1,110	89.0	0.55	63.5	69.0	72.2	76.6	87.0	98.5	105.6	112.6	121.0
Non-Hispanic black												
20 years and over	1,094	90.4	0.74	60.9	65.1	67.9	74.0	86.8	101.8	111.4	120.1	132.5
20-29 years	356	89.9	1.43	61.3	64.2	66.6	72.1	85.6	101.4	111.7	120.0	134.3
40-59 years	372	92.1	1.26	60.5	66.2	71.2	76.9	89.1	103.3	113.3	120.8	132.4
60 years and over	366	87.8	1.15	58.0	63.8	67.1	72.0	85.3	98.0	106.5	116.4	128.8
Hispanic²												
20 years and over	1,541	84.4	0.88	60.4	65.0	67.3	71.4	81.6	93.2	100.2	107.3	121.0
20-29 years	573	84.0	1.21	58.6	63.7	66.3	70.3	79.9	92.8	100.4	109.4	123.2
40-59 years	577	85.9	0.80	64.2	68.2	70.3	74.9	83.6	94.2	101.3	105.4	117.0
60 years and over	391	82.0	1.13	58.6	63.0	66.5	70.2	80.4	90.9	96.6	101.5	109.4
Mexican American												
20 years and over	991	84.1	1.04	60.4	65.0	67.3	71.3	81.4	92.8	99.2	106.9	121.4
20-29 years	386	84.0	1.48	59.4	63.5	66.2	70.3	80.1	92.9	100.1	109.5	125.3
40-59 years	371	85.0	0.90	64.0	68.0	70.1	73.9	82.9	93.7	99.7	104.0	115.8
60 years and over	234	81.9	1.44	59.3	63.0	67.1	70.6	80.4	90.4	94.8	97.6	109.1

¹Persons of other races and ethnicities are included.²Mexican American persons are included in the Hispanic group.

SOURCE: CDC/NCHS, National Health and Nutrition Examination Survey

The Engineering Meetings Board has approved this paper for publication. It has successfully completed SAE's peer review process under the supervision of the session organizer. The process requires a minimum of three (3) reviews by industry experts.

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