

Vehicle Handling Parameter Trends: 1980 - 2010

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ABSTRACT

Handling and tire performance continue to evolve due to significant improvements in vehicle, electronics, and tire technology over the years. This paper examines the trends in handling and tire performance metrics for production cars and trucks since the 1980's. This paper is based on a significant number of directional response and tire tests conducted during that period. It describes ranges of these parameters and shows how they have changed over the past thirty years.

INTRODUCTION

This paper can be considered an extension of work that was done describing handling performance parameters in the 1970's [1] and 1980's [2]. Implementing standard test procedures [3] and standardized test processing to obtain vehicle and subsystem performance metrics over a sustained period of time allows a significant volume of comparative results to be collected. The use of relational databases of test results and test object attributes enable mining of the databases to provide learning opportunities such as trend analysis over a period of three decades.

The following vehicle attributes will be examined:

- Wheelbase (mm)
- Mass (kg)
- Mass Distribution (% front)
- Center of Gravity Height (mm)
- Geometric Stability Ratio

The following handling performance characteristics will be examined:

- Steering Sensitivity (g/100 deg SWA)

- Roll Gradient (deg/g)
- Understeer Gradient(deg/g)
- Lateral Acceleration Rise Time from Bandwidth (s)

The following tire attributes and tire performance characteristics will be examined:

- Rim Width
- Rim Diameter Code
- Section Width
- Aspect Ratio
- Normalized Lateral Force at 1 Degree Slip
- Normalized Aligning Moment at 1 Degree Slip (mm)
- Normalized Lateral Force at 4 Degree Slip
- Rolling Resistance Coefficient

Suspension attributes and suspension performance characteristics that were historically discussed in [References 1](#) and [2](#) were collected, but the number of summary tables required to adequately describe the trends were too large to include in this paper.

Sample statistics for each attribute or characteristic such as sample size, minimum, mean, median, maximum, standard deviation and range are shown for each decade. The decades are defined for vehicles having model years from 1981 to 1990, 1991 to 2000 and 2001 to 2010, and for tires tested during the aforementioned range of years.

VEHICLE SAMPLE

This vehicle collective does not represent actual market or sales distributions. The test results sample chosen for this

study are for production vehicles manufactured by General Motors, or global competitive vehicles that have been tested by General Motors during the course of normal vehicle testing activities between the calendar years 1980 to 2010. Each vehicle was subjected to different tests depending on the purpose of testing; so the sample size for any given attribute or performance characteristic will vary.

Vehicle Attributes Sample

The vehicle attributes sample included 4659 vehicles.

As vehicles have evolved, it has become more difficult to characterize vehicle types. In the 1980s, cars and trucks were the major vehicle types. Today there are a large number of vehicle types as manufacturers strive to satisfy smaller and smaller market niches.

For this paper, the vehicle attributes sample is either viewed as a whole, or is broken into two types: cars, and non-cars (trucks, crossovers, and vans). Cars and crossover vehicles are primarily body-frame-integral vehicles; although a number of body-on-frame cars from the 1980s and 1990s are included in the car sample. The truck population consists of all body-on-frame vehicles. Vans can be of either body-frame-integral or body-on-frame construction.

The vehicle attributes sample can be viewed in many ways. Select comparisons are shown in [Figures 1, 2, and 3](#). The categories shown in each figure are listed in decreasing order of size.

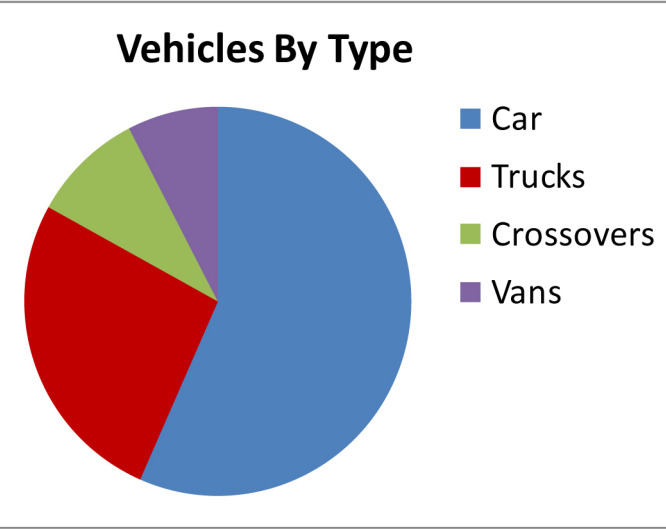


Figure 1.

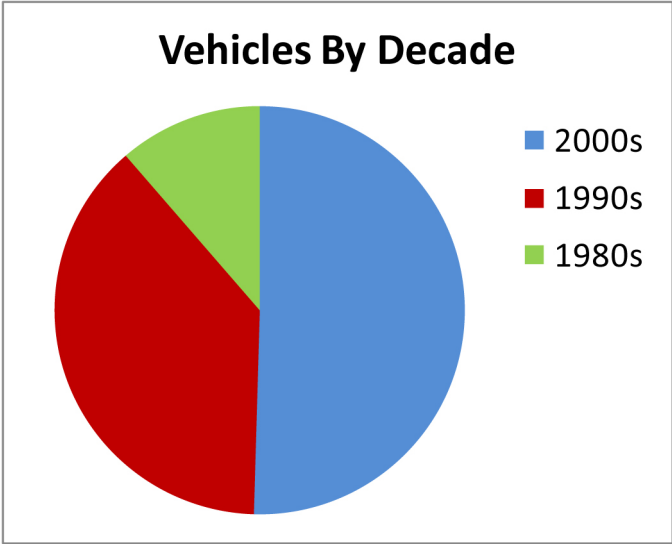


Figure 2.

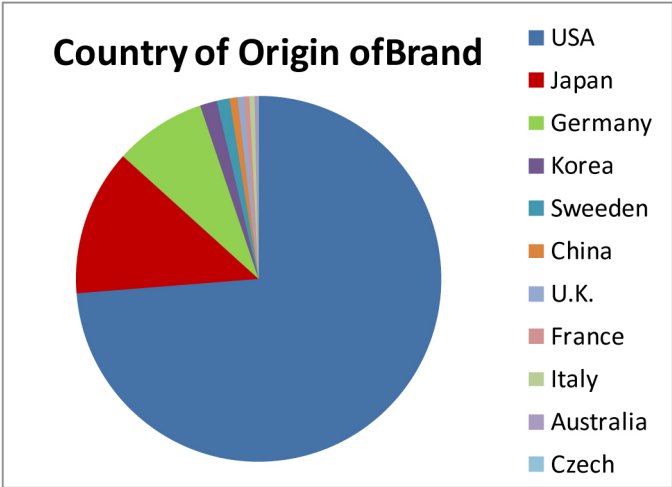


Figure 3.

Vehicle Performance Characteristics Sample

The vehicle performance characteristics sample included 1455 vehicles. This sample is significantly smaller than the vehicle attributes sample because it is limited to the subset of vehicles subjected to the tests providing the performance characteristics examined in this paper.

For this paper, the vehicle performance characteristics sample is either viewed as a whole, or is broken into two types: cars and crossover vehicles, and trucks and vans. The definitions of cars, crossovers, trucks, and vans are the same as used in the vehicle attributes sample.

The vehicle performance characteristics test sample can be viewed in many ways. Select comparisons are shown in [Figures 4, 5, and 6](#). The categories shown in each figure are listed in decreasing order of size.

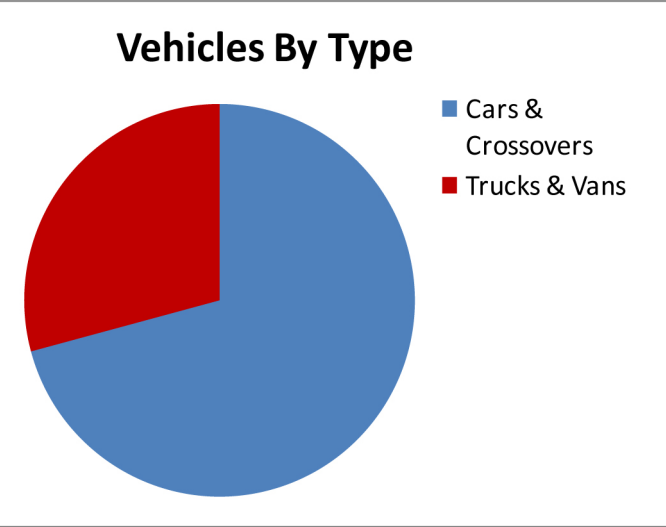


Figure 4.

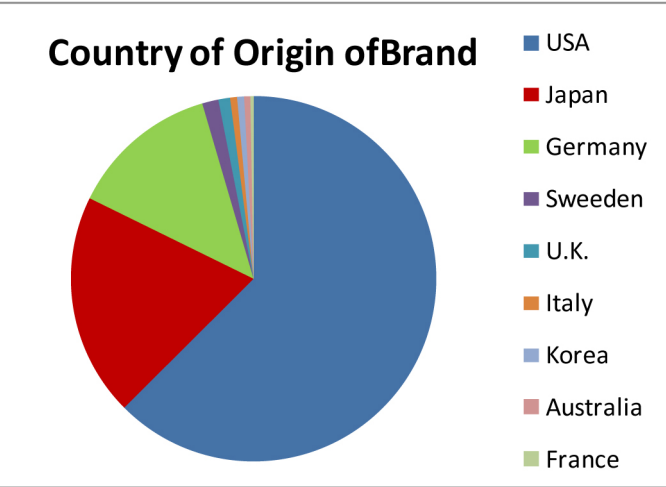


Figure 5.

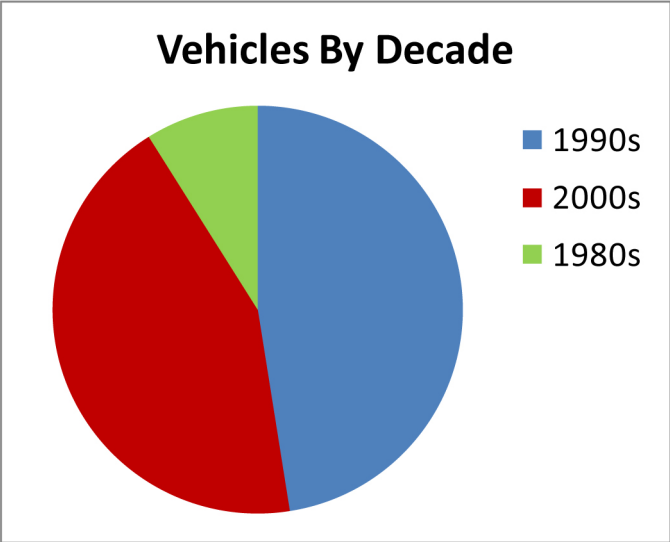


Figure 6.

VEHICLE ATTRIBUTES

Vehicle and subsystem descriptive attributes such as mass, suspension type, tire information, etc. are typically recorded during the testing process. Some are determined by inspection and others require measurement. The following vehicle attributes will be compared and contrasted.

- Wheelbase (mm)
- Mass (kg)
- Mass Distribution (% front)
- Center of Gravity Height (mm)
- Geometric Stability Ratio

The definitions of these attributes can be found in [Reference 4](#).

Wheelbase (mm)

Wheelbase statistics are shown in [Table 1](#). The histogram and fitted normal distributions are shown in [Figure 7](#) and a comparison of the normal distributions is shown in [Figure 8](#). It can be seen that standard deviations of wheelbase characteristics for the 1990 and the 2000 decades are similar, and there is an increase in the mean, median, and range values over time.

TABLE 1. WHEELBASE (mm) STATISTICS

Period	Sample	Min	Mean	Med	Max	St Dev	Range
1985-1990	529	2149	2682	2660	4058	243	1909
1991-2000	1779	2062	2849	2740	4510	363	2448
2001-2010	2354	1802	2899	2850	4506	333	2704
All	4662	1802	2857	2806	4510	342	2708

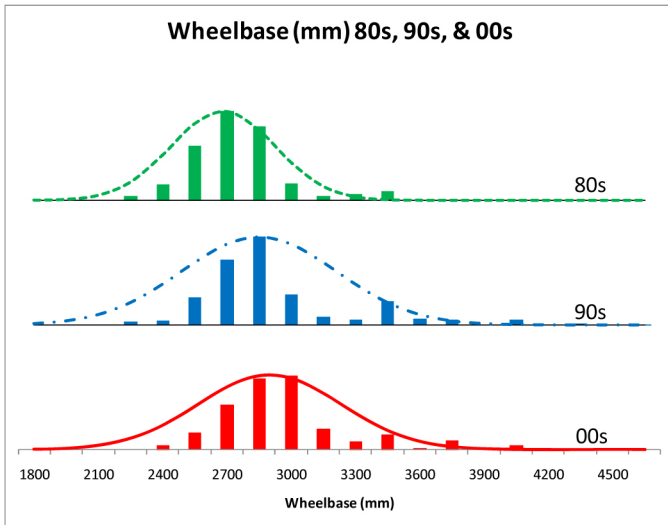


Figure 7.

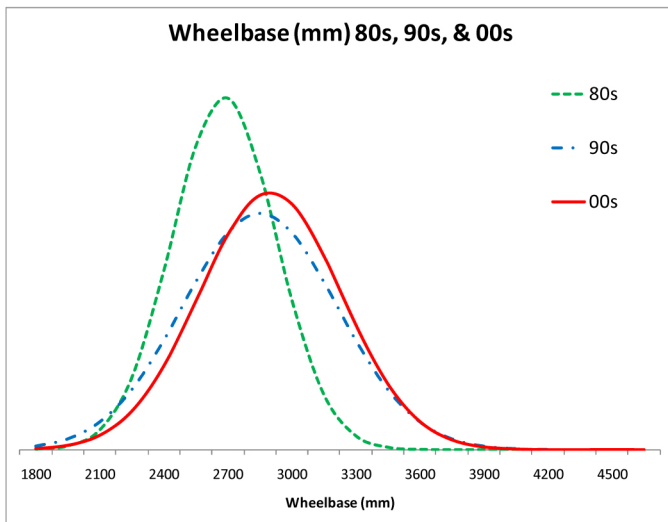


Figure 8.

Mass (kg)

Mass (kg) statistics are shown in [Table 2](#). The histogram and fitted normal distributions are shown in [Figure 9](#) and a comparison of the normal distributions is shown in [Figure 10](#). The central tendencies of mass and the ranges and standard deviations of mass of the test population have increased over time. This may indicate an increase in vehicle types to meet market needs.

It should also be noted that the mean and median values of the test populations were not similar. This would suggest that the mass values of this population are not normally distributed about the mean.

Table 2. MASS (kg) STATISTICS

Period	Samples	Min	Mean	Median	Max	St Dev	Range
1985-1990	529	688	1494	1477	2733	314	2045
1991-2000	1779	567	1723	1613	3914	466	3347
2001-2010	2354	492	1886	1811	4123	490	3631
All	4662	492	1779	1691	4123	481	3631

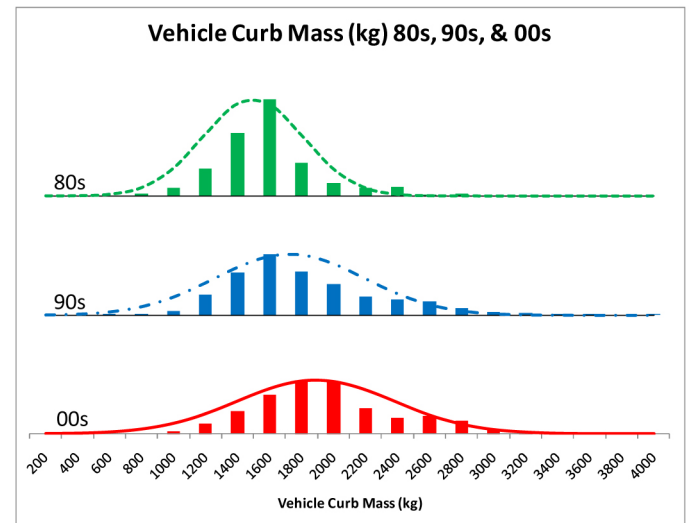


Figure 9.

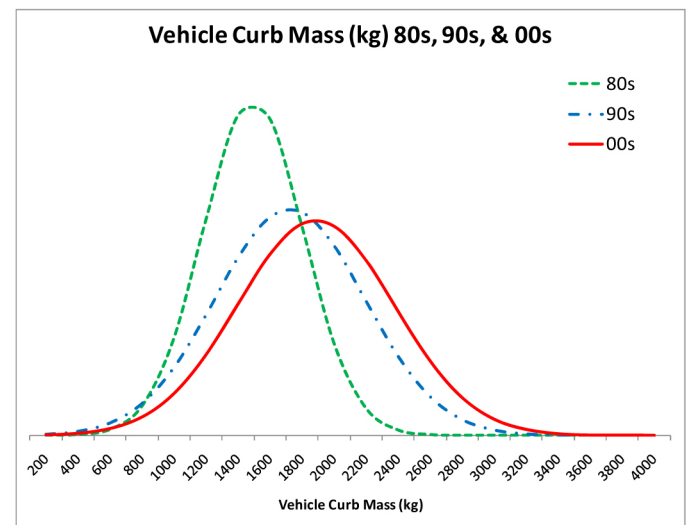


Figure 10.

Mass Distribution (% front)

Mass Distribution (% front) statistics are shown in [Table 3](#). The histogram and fitted normal distributions are shown in [Figure 11](#) and a comparison of the normal distributions is shown in [Figure 12](#). It can be seen that the mean and median mass distribution of the test population has become less front biased over time. The central tendencies of these distributions

are similar, but inspection of the histograms shows a more bimodal effect. There is a concentration around 53% front and also a concentration around 65% front. The concentration around 65% has since migrated towards 60% front over time. Examination of the data samples indicates the group of vehicles with a mass distribution in the vicinity of 53% front consists of sport utility vehicles (SUVs) and sports cars, while the vehicle grouping with a front mass distribution in the 63% consists of front wheel drive vehicles.

Table 3. MASS DISTRIBUTION (% front) STATISTICS

Period	Samples	Min	Mean	Median	Max	Range
1985-1990	529	40.5	59.0	60.5	68.0	27.5
1991-2000	1779	37.8	58.0	58.7	67.7	29.9
2001-2010	2352	38.0	56.2	56.4	68.5	30.6
All	4660	37.8	57.2	57.5	68.5	30.7

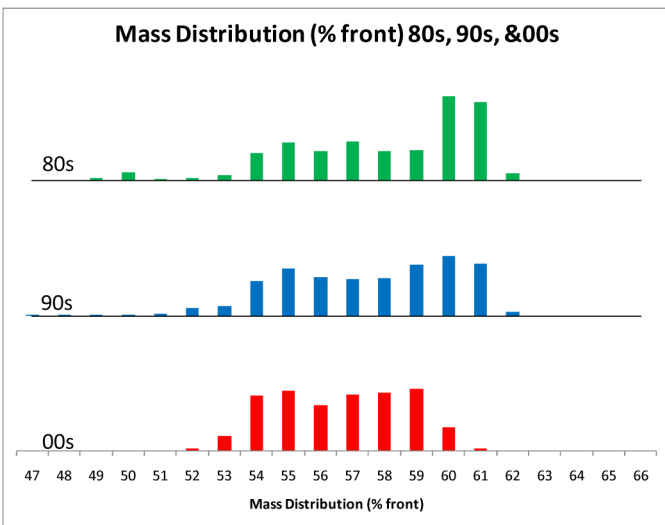


Figure 11.

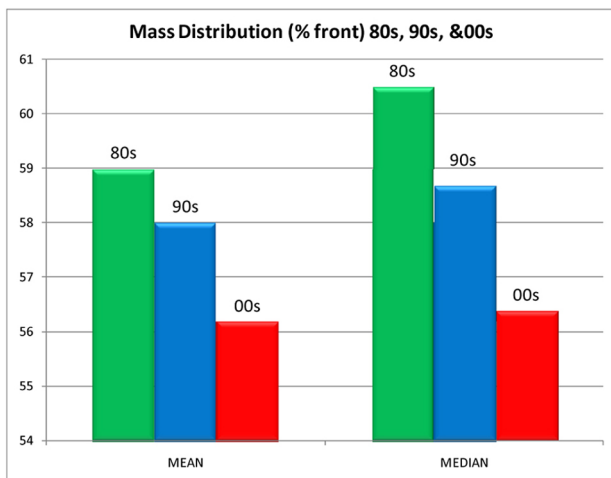


Figure 12.

Center of Gravity Height (mm)

Center of Gravity (CG) Height test results up to April, 2001 were generated by a General Motors built roll angle tilt table[5]. After April, 2001, a Vehicle Inertia Measurement Facility (VIMF) pitch angle based tilt table[6] was used. The Curb loading condition was chosen for CG test results because the majority of vehicles were tested at this load.

When separated into cars and crossovers, and trucks and vans, the distribution of the total population showed a distinctly bimodal tendency. The distributions were more normally distributed when the population was broken into two groups: cars and non-cars (trucks, vans, and crossover vehicles).

CG Height (mm) statistics are shown for each group in [Tables 4 and 5](#) respectively. The histogram and fitted normal distributions for each group are shown in [Figures 13 and 15](#) respectively. A comparison of the normal distributions for each group are shown in [Figures 14 and 16](#) respectively.

The mean and median of both test population groups is increasing over time. The standard deviation of both groups exhibited a large increase from the 1980s to the 1990s. The reason for the larger standard deviations is most likely the increased penetration of front drive vehicles in both car and non-car populations. The car population was still making a transition from predominantly rear drive vehicles to predominantly front drive vehicles during the 1980s. The truck, van, and crossover population also saw the introduction of the front wheel drive minivan in the mid 1980s, which became increasingly popular.

Table 4. CENTER OF GRAVITY HEIGHT (mm) STATISTICS CARS

Period	Samples	Min	Mean	Median	Max	St Dev	Range
1985-1990	112	454	522	521	589	28	135
1991-2000	97	415	527	530	600	33	185
2001-2010	217	431	534	540	603	34	172
All	426	415	529	533	603	33	188

Table 5. CENTER OF GRAVITY HEIGHT (mm) STATISTICS TRUCKS, VANS, and CROSSOVERS

Period	Samples	Min	Mean	Median	Max	St Dev	Range
1985-1990	48	571	667	661	838	49	267
1991-2000	155	535	686	675	989	65	454
2001-2010	442	534	697	691	945	63	411
All	645	534	692	683	989	63	455

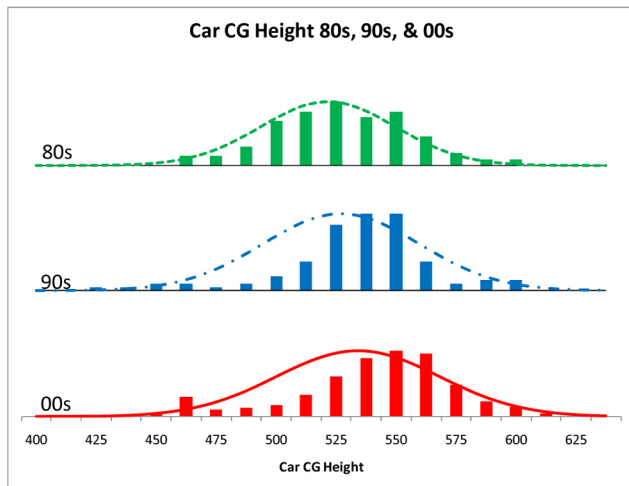


Figure 13.

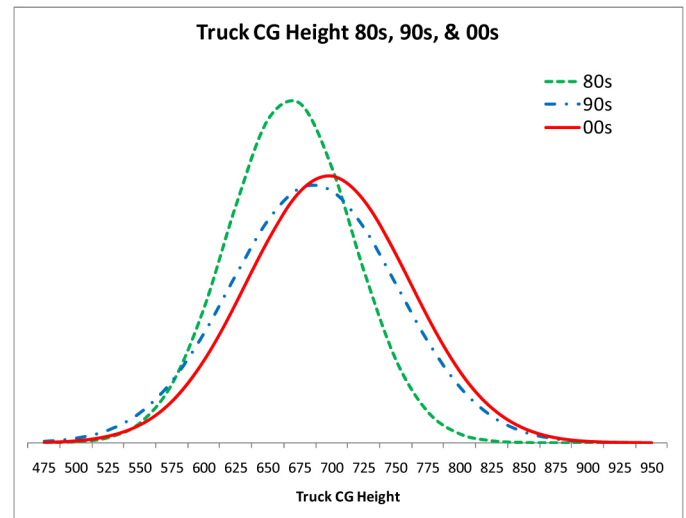


Figure 16.

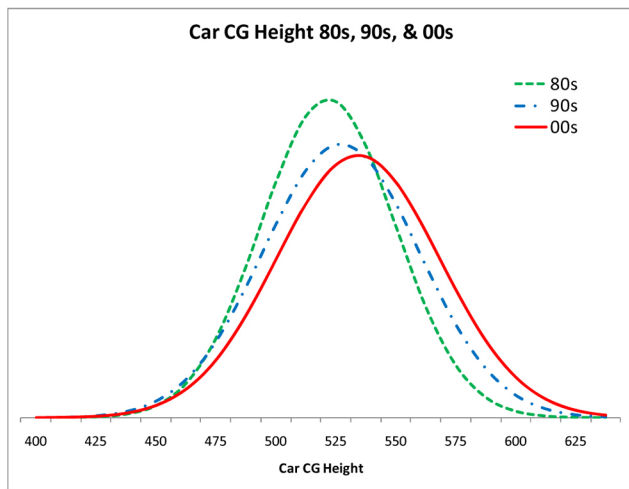


Figure 14.

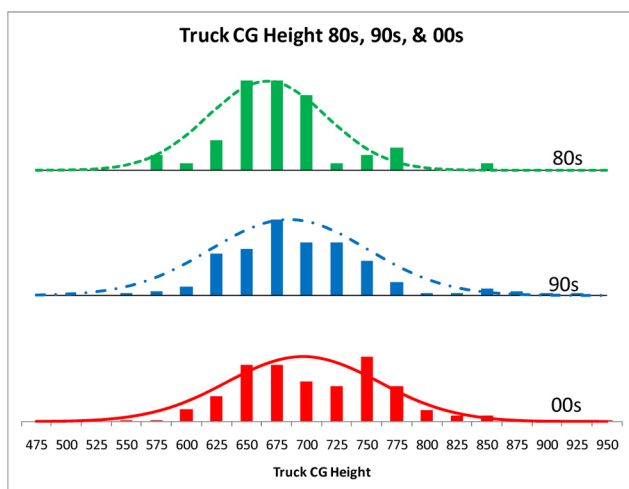


Figure 15.

Geometric Stability Ratio

Geometric Stability Ratio is defined as the CG Height divided by twice the track width. The Curb loading condition was chosen for these results because the majority of vehicles were tested at this load.

As with Center of Gravity, the distribution of the total population of Geometric Stability Ratio was bimodal when crossovers were grouped with cars. This initial distribution also had a decreasing central tendency over time. The distributions were more normally distributed when the population was broken into two groups: cars and non-cars (trucks, vans, and crossover vehicles).

Geometric Stability Ratio statistics are shown in [Tables 6](#) and [7](#) respectively. The histogram and fitted normal distributions for each group are shown in [Figures 17](#) and [19](#) respectively, and a comparison of the normal distributions for each group are shown in [Figures 18](#) and [20](#) respectively.

These statistics are in general agreement with the trend results of a Static Stability Factor study conducted by NHTSA in 2005 [7]. Static Stability Factor is the Geometric Stability Ratio evaluated at One Passenger loading (vs. Curb loading in this study). The sample sizes in the NHTSA study were significantly larger than the sample sizes seen in this study and the load condition of this.

The central tendency values of the car test population are significantly greater than those of the truck, van, and crossover test population. The central tendency values of both test populations are seen to be increasing over time while the variation in both populations has remained nearly constant.