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Building Innovation through Research

Safe and Sustainable Parking Garage Live Loads in the Age of the Electric Vehicle

RGA #05-24

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Supporters included: Simpson Gumpertz & Heger (SGH), HGA Architects, Desimone Engineering, National Council of Structural Engineers Associations (NCSEA), Rimkus, Walter P Moore, Martin / Martin, DCI Engineering, Parking Consultants Council (PCC), and the Precast/Prestressed Concrete Institute (PCI).



Abstract: Parking garages, loaded primarily by sets of vehicles sampled from the prevailing vehicle fleet, are subject to changes in loads and demand as vehicle purchasing preferences of the market shift over time. As electric vehicles (EVs) continue to become more popular in the US and globally, some have questioned whether a shift to EVs, with their significant battery weight, necessitates a change in the prescribed design live load in the ASCE 7 specification. This study implements the stochastic live load method that was used to establish the existing 40 psf garage live load value in ASCE 7, but using data reflective of the current state of the US vehicle fleet. Additionally, an approach is introduced to account for future increased adoption of EVs and the presence of EV charging stations grouped together. Corresponding equivalent uniform design loads (EUDLs) are calculated for a wide variety of cases, considering geographic and temporal variation as well as a variety of EV adoption scenarios. In all but the most extreme cases of EV adoption and EV weight, calculated EUDLs are equal to or lower than 40 psf. In the cases where the EUDL exceeds 40 psf it is prudent to consider the additional safety margin provided by the presence of a load factor greater than 1.0 in the specification of load combinations. Using direct simulation of loading and column axial forces on multiple levels of a parking garage, it is found that a 10% reduction in live load is supported for columns supporting multiple levels.

0.0 Setting and Perspective

The recent and impending market penetration of electric vehicles has created a situation in which current design live loads for parking garages may not adequately reflect true, real world, loadings.

As electric vehicles (EVs) are gaining popularity through private and public support, their impact on the built environment is being reviewed by building officials throughout the United States and internationally. The weights of electric vehicles are trending higher than petroleum-powered internal combustion engine (ICE) vehicles over the past 10 years. This report is the result of research assessing whether the existing parking garage live load of 40 psf is acceptable for future parking garages, as well as determining if existing parking garages can sustain the weights of EV.

While parking garage live loads have been the subject of limited research over the past 50 years¹, there is currently a paradigm shift with the introduction and potential eventual domination of electric vehicles. The additional weight of these vehicles in comparison to internal combustion engine cars and the selective alignment with charging aisles called for a thorough probabilistic and data-driven analysis of the safety of current standards. Specifically, it was unclear whether the existing parking garage live load of 40 psf is acceptable for current and future parking garages.

This project consisted of three major components:

1. Acquisition and analysis of data regarding vehicle registrations and curb weights (and it should be noted that all vehicle data throughout the report refers to the United States only);
2. Development and implementation of a stochastic live load model for parking garages that takes the data from (1) as input;
3. Assessment of the adequacy of the 40 psf live load value for past and current vehicle fleet compositions as well as assessment of live load adequacy for a range of future scenarios for the continued growth of the EV sector.

Before getting into the details of the report, a few limitations and cautions are important to mention.

One is that various agencies use different definitions for vehicles, for instance some including SUV's as cars, and others include pickup trucks. Often the data lack these distinctions.

Secondly, the national data used in this research excludes commercial registrations. The non-commercial registration policies vary by states, with some, for instance, excluding pickup trucks, others including those under a certain weight threshold, and others requiring the owner to declare the intended use. A correction for the undercount of pickup truck has been made.

A third limitation is that examination of a few states showed that distribution of vehicle types vary from state to state, and that analysis in this research is based on national statistics. As with some

other design load requirements, individual states or authorities having jurisdiction can adjust national statistics if they see fit. We did not attempt to determine guidelines differing by state.

A fourth limitation is the projection of the effect of weight conversion from internal combustion engine (ICE) power to electric vehicles (EV). We found a number of sources, but each is limited to particular models and assumptions, and most of the time these are not otherwise identical models. We were able to determine an approximate number from a source that compares the actual weight difference between the internal combustion engine and its associated equipment with those of a fully electric vehicle. This information does not incorporate projected consumer preferences for future vehicles.

There is some evidence that the population in parking garages differs from the overall population of vehicles on the road. Whether this economics-based bias is significant was not studied in this research.

Finally, our data show that the average weight of vehicles (both ICE and to the limited status of EV history) has been increasing steadily over the past few decades (while the standard deviation has varied much less). We have no idea whether this trend will continue, and it could be significant. Without reliable sources of data for predicting the future of this trend, we have not incorporated it into our analysis, and we have limited the future projections to penetration of EV's versus ICE's. Standard-writing bodies will want to decide whether they should include some projections of this trend into the future, especially taking into consideration that current ASCE SEI 7 philosophy for live loads is to use the 50-year maximum load expected. Under steady state conditions, one can relate the annual rate of exceedance to lifetime reliability. The question of anticipating and incorporating future trends and considering the changing reliability over future years is an important one for the standard-writing bodies.

1.0 Introduction

Starting around 1990, interest in SUV's grew in the United States, with market share growing from 6% to 26% by 2005 (The Economist 2024). That same article states that this caused the average weight of new cars to increase from 3400 pounds to nearly 4100 pounds. Another source (EPA 2025) indicates that the average vehicle weight has increased from about 3800 pounds (1724 kg) in the year 2000 to about 4400 pounds (1996 kg) in 2023. Another source (Hedges & Co 2025a) estimates that the percentage of SUV's and light trucks exceeded 60% by 2023. The average weight of an SUV is about 4000 pounds, and of a pickup truck about 4600 pounds (as opposed to the average weight of sedans and station wagons of about 3700 pounds (EPA 2025). It should be noted that these figures are based on gross vehicle weight and not curb weight. Curb weight is the total weight of a vehicle with all standard equipment, fluids (fuel, oil, coolant), and a full fuel tank, but without passengers, cargo, or optional accessories. Vehicle Gross Weight (GVW) is the actual weight of a fully loaded vehicle, including its own empty weight (curb weight) plus passengers, cargo, fuel, and accessories, while the Gross Vehicle Weight Rating (GVWR) is the manufacturer's maximum safe limit for this total weight. It does not appear to be necessary to design parking garages for parked vehicles fully loaded to gross weight, so this study uses the curb weight plus an allowance for passengers and cargo.

Figure 1 shows these trends, and it can be seen that the increased weight of pickup trucks and SUV's, when combined with increased market share, has a strong effect on the average weight of vehicles on the road. This change in consumer preferences could be important for the design of parking garages and is in addition to any effect of the presence of EV's and their higher weights as compared to internal combustion engine (ICE) vehicles. Migration of pickup trucks, for instance, from utility vehicles to luxury vehicles has been a trend over the past few years, and what this means for future weight trends should be taken into consideration.

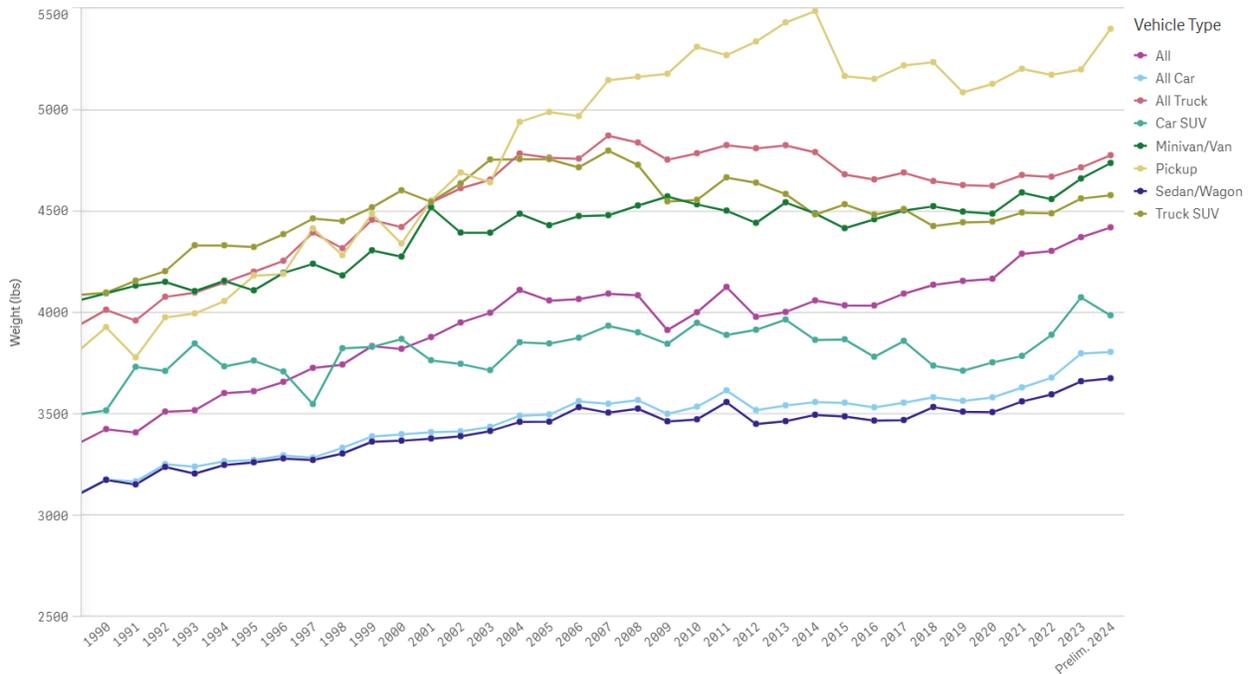


Figure 1: Estimated vehicle weight across the U.S. until 2024 (EPA 2025)

The statistics above are not highly influenced by market penetration of electric vehicles (EV's), since their market share was relatively small during the years in the above paragraph. It is noted, however, that the average gross weight of an electric sedan is 6040 pounds (2740 kilograms), and thus the increasing market share of EV's is of concern (McDonald et al 2024).

The number of vehicles registered in the United States has increased slightly over the past several years, with a total around 280,000,000 – 300,000,000, or even 370,000,000, depending on the source (Hedges & Co. 2025a, Forbes 2025). This represents an increase of about 1-2% a year for the past decade. Of this total, about 60% are commercial vehicles (US DOT 2023). The remaining 40%, or about 100,000,000 are classified as cars (Forbes 2025).

It is estimated that about 60% of vehicles are SUV's and light trucks (Hedges, 2025), and it appears that this calculation does not include commercial registrations. Sources indicated that the ratio of SUV's to pickup trucks is about 1½:1 (US DOT 2023). Therefore, it is reasonable to conclude that of the approximately 100,000,000 “cars”, about 60,000,000 are SUV's and light trucks, and that breaks down to about 35,000,000 SUV's and about 25,000,000 light trucks.

From the source discussed above (US DOT 2023), it is concluded that about 25% of the S&P Global registrations should be light trucks and about 35% should be SUV's, with the remainder being sedans, station wagons, sports models, etc. But registration of pickup trucks varies by state. Some states require they be registered as commercial, some states differentiate by gross weight, some states require declaration of intended use, and some states appear to provide for interpretation by the registration agent. Therefore, it is expected that the S&P Global data (which excludes commercial registration) would under-represent pickup trucks. Indeed, the S&P Global data consists of about 18% pickup trucks (the data do not distinguish SUV's from other cars). Therefore, in the interest of being complete, and not underestimating the distribution of weights due to missing pickup counts, we used the distribution of pickup trucks, which passed the fitness tests for lognormal distribution, to generate additional pickup data to increase the representation from 18% to 25%.

Future scenarios of EV sales and EV penetration of vehicles on the road vary among published articles, but show a fairly consistent underlying Assumption.

McDonald et al. (2024) state that EV sales in the United States in 2023 were 7.2% (they actually state this as a percentage of U.S. auto market", which we assume means sales). They then predict 25% - 35% by the year 2035 and 45% - 50% by 2050. Assuming constant growth, these imply between 1.5% and 2.5% annual growth between now and 2035, about 1% - 1.5% annual growth between now and 2050 (presumably with higher percentages for the first ten years and then lower thereafter).

Hurwitz et al. (2024) predict 40% - 52% EV sales by 2035, and 70% - 95% by 2050. These relate to 7% - 10% annual growth over different time spans.

Hurwitz et al. (2024) also make a prediction of the percentage of EV's on the road, taking into account the average lifetime of vehicles. They predict 14% - 28% by 2035 and 42% - 64% by 2050. These yield annual growth rates around 7%.

Another source (Ahmed et al. 2025), predicts that EV sales will increase at about 2.3% per year (not growth rate). That article also provides a "high" prediction of 10% EV's on the road by 2030 and 25% - 40% by 2040 annual growth around 7%.

For the consideration of design values for structural load standards, we have looked at two different time horizons. The first is for current conditions (2023 for the data purchased), and the second is for 25 years from now (the year 2048) From all of the above references, we have taken two scenarios of annual growth for penetration of EV's into total vehicles on the road. The low scenario is 7% annual growth and the high scenario is 10% growth.

Data for this study were purchased from S&P Global, a private company that, among other things, aggregates vehicle registration records from around the US. All non-commercial registration data were purchased for the US states of California (CA) (2014, 2017, 2020, 2023), Kansas (KS) (2023) and the entire United States (US) (2014, 2017, 2021, 2024). Each record (a location and year combination) includes the vehicle make, model, model year, curb weight, fuel type and the total count of each vehicle specification in the database record. While there was no attempt to determine

whether California and Kansas are extremes, it is clear that they represent very different behaviors in terms of EV penetration and pickup truck usage in broad rural areas. This collection of nationwide data is an important aspect of this study, giving a full picture of vehicle number and types actually registered in the country. The study did not purchase data to study the variation of trends across states. While such statistics have not been used heretofore for live loads, standards-writing bodies may wish in the future to incorporate such variations. Most parking garage designs are controlled by gravity loads, and hence the load combination of 1.6L + 1.2D often controls the design. Standard-writing committees may wish at some point to incorporate both the 50-year expected maximum and the 1.6 load factor into a complete reliability analysis.

2.0 Vehicle weights and EV conversion

2.1 Weights

It is important to follow not just the average weight of vehicles, as discussed in the Introduction, but also the evolution of the full distribution. According to J.D. Power (JD Power 2025), the weight of a typical vehicle in the U.S. can vary significantly depending on its type and size. According to recent data from the Environmental Protection Agency (EPA 2025), the average curb weight across all vehicle types is around 4,419 pounds. For passenger cars specifically, the average weight is lower, averaging around 3,806 pounds. Trucks, (a category often inclusive of SUVs) tend to be heavier, with an average weight of about 4,775 pounds.

Since different sources use their own definitions of vehicle type, often not reported within the articles, the following table, taken from The Hedges Company (Hedges & Co. 2025a), is presented to provide some perspective for vehicles often (although not always) registered as non-commercial. Classes null to 2 and sometimes 3 may be included in non-commercial registrations. This terminology and the definitions are those provided by The Hedges Company, and some of them are for vehicles no longer sold

Table 1: Vehicle weight classes and GVWR classes (Hedges & Co, 2025a)

GVWR Classes 1-8	GVWR Description	GVWR Class Descript.	Examples
Blank or “null”	Light-duty vehicle	Passenger cars	Common passenger cars; no SUV’s or CUVs
GVWR Class 1	Light-duty vehicle	Medium-size pickup trucks, mini vans, SUVs and CUVs under 6000 pounds (2772 kg)	Common “quarter ton” pickups, SUVs and crossover CUVs; GMC Canyon, Chevy Colorado, Ford Maverick
GVWR Class 2	Light-duty vehicle	Mini vans, full-size pickups, step vans or cargo vans 6,001 lbs. to 10,000 lbs. (2,722–4,536 kg)	Common “half ton” pickups including Ram 1500, Ford F-150, Chevy Silverado
GVWR Class 3	Light-duty or medium-duty vehicle	Heavy-duty pickups, box trucks, walk-in commercial vans 10,001 lbs. to 14,000 lbs. (4,536–6,350 kg)	“3/4 ton” pickups including Ram 3500, Ford F-250, Ford F-350, GMC Sierra 3500
GVWR Classes 4-6	Medium-duty vehicles	Walk-in vans, school buses, delivery vans, normally with 2 axles	Ford F-550, GMC 5500, Ram 5500, Thomas Built
GVWR Classes 7-8	Heavy-duty vehicles	Transit buses, semi trucks, moving vans, sleeper cabs	GMC C7500, Freightliner, Mack Anthem

Between 1990 and 2005 the market share of SUV’s in America grew from 6% to 26%, pushing up the weight of an average new car from 3,400lb to nearly 4,100lb (Economist 2024). The United States Environmental Protection Agency website “Explore the Automotive Trends” (EPA 2025) contains data from 1975 to 2023. From 1975 to 1980, the average curb weight of vehicles sold decreased, due to efforts to increase the mileage per gallon efficiency following the oil embargo issues. This decrease was from about 4000 pounds to 3,200 pounds. Since then, there has been an increase to about 3,800 in 2,000 and to about 4,400 in 2023. This represents about a 15% increase from 2000 until today.

Even before significant penetration of EVs, there has been a 10% increase in curb weight from 2000 until 2020. Another source (goodcarbadcar 2025) indicates that in 2022, pickup trucks accounted for 20.5% of new vehicle sales in the US, up from 16.8% in 2016. This increase is documented by the United States Department of Transportation (US DOT 2023), as well as a private corporation source (Hedges 2025a). That source presents the following information:

- Percentage of registered vehicles that are cars in 2018 35%
- Sport Utility Vehicles (SUVs), percentage of total vehicles 12%
- Cars or station wagons, percentage of total vehicles in 2010 53.4%

The following two figures of new vehicle purchases reflect the trend from traditional passenger cars to pickup trucks and SUV's (<https://www.statista.com> > ... > Vehicles & Road Traffic, accessed August 7, 2025). Some sources group SUVs with pickup trucks and some do not, so the data are often confounded.

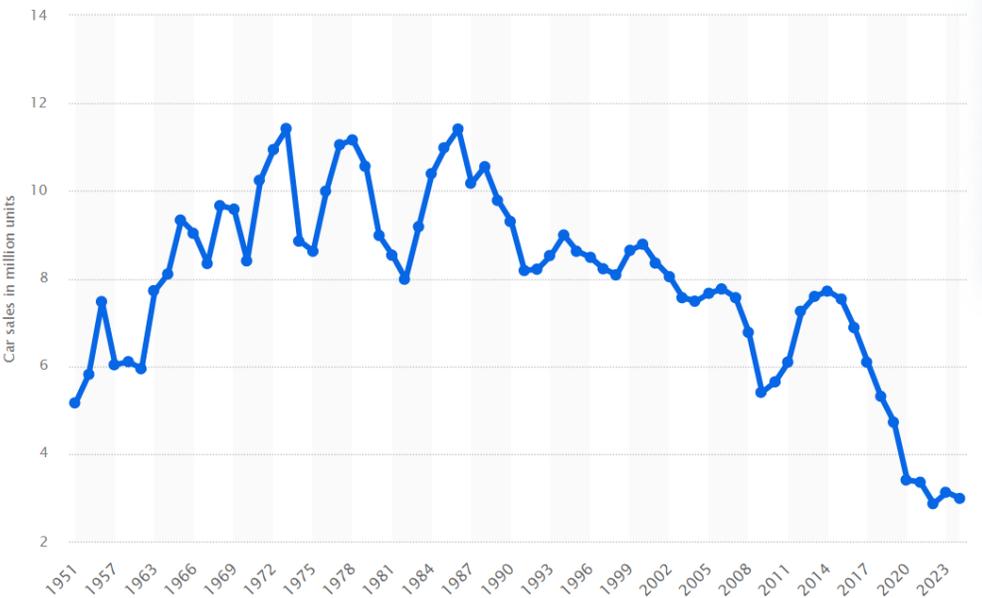


Figure 2: Annual passenger car sales in the U.S. from 1951 to 2024 (Statista, 2025)

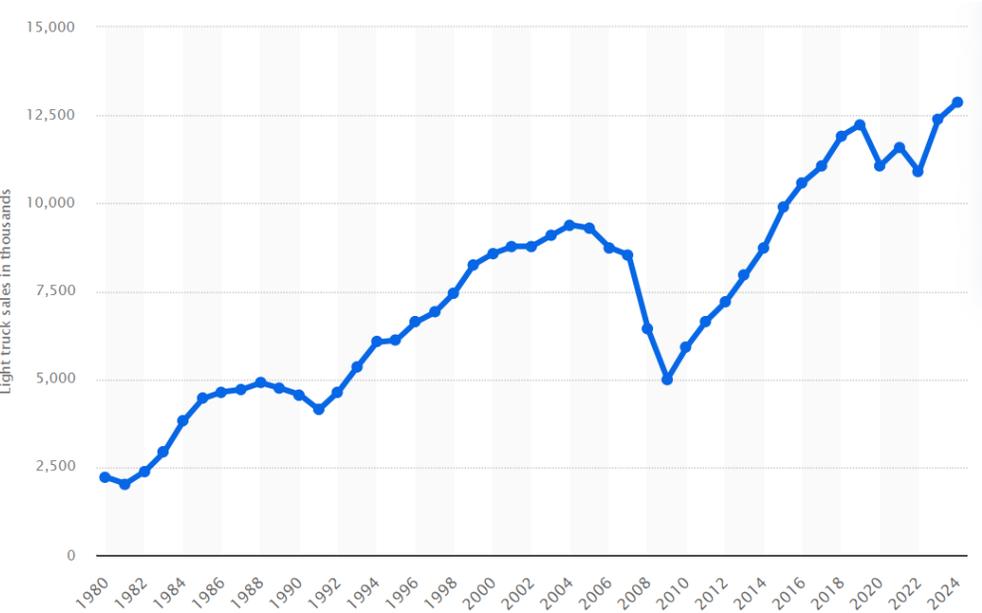


Figure 3: U.S. light truck retail sales from 1980 to 2024 (Statista, 2025)

Another source (Forbes2025), reflects this trend by reporting that car ownership statistics for 2025 shows that there were 170,239,357 registered private and commercial trucks as compared to 98,573,935 registrations for cars. Still another source reports on the increasing popularity of EV's

and pickup trucks (McDonald et al. 2024). The article notes that the average gross weight of an electric sedan is 6040 pounds, as compared to the 4625 pounds of the Toyota Camry, the best-selling ICE in America.

2.2 ICE to EV conversion

How does vehicle weight change when switching from an internal combustion engine (ICE) to an electric vehicle (EV)? Electric vehicles generally weigh more than comparable gasoline-powered vehicles (ICEs), primarily due to the weight of their large, high-voltage battery packs. The average EV battery can weigh around 1,000 pounds. This means that EVs can be up to 30% heavier than their ICE counterparts. Several factors can affect this weight difference, however:

Battery size: Larger battery packs, which offer greater range, will naturally increase the vehicle's weight. For instance, a Tesla Model S battery weighs roughly 1,200 pounds, while a smaller Nissan Leaf battery weighs around 668 pounds.

Vehicle size and class: Comparing an EV truck to an ICE truck, or an EV sedan to an ICE sedan, will yield different weight differentials. EV trucks and SUVs, especially larger models like the GMC Hummer EV, can be significantly heavier than their ICE equivalents (often having differences on the order of 50%)

Lightweighting: Manufacturers are increasingly using lightweight materials like high-strength steel, aluminum alloys, and carbon fiber to offset some of the battery weight and improve overall efficiency.

Battery technology: Advancements in battery technology are leading to improved energy density, allowing for smaller, lighter batteries that still offer comparable range.

The effect of conversion, however, depends on the size of the vehicle. Below are curb weight comparison between various types of ICE passenger cars and corresponding EVs (Encycarpedia.com 2025), also quoted in Liu et al. (2021).

- Small size

Average EV = 1298 kg, 2862 lbs; average ICE = 1101 kg, 2427 lbs

Average weight difference 197 kg, 435 lbs; 18%

- Medium size

Average EV = 1558 kg, 3435 lbs; average ICE = 1326 kg, 2923 lbs

Average weight difference 232 kg, 512 lbs; 17.5%

- Large size

Average EV = 2276 kg, 5018 lbs; average ICE = 1914 kg, 4220 lbs

Average weight difference = 362 kg, 798 lbs; 19%

Thus, for the U.S. average weight vehicle of 4400 lbs referenced above, (EPA 2025) the average weight difference is around 800 lbs. The S&P Global data used in our research for all vehicles

registered in the United States in 2023, including the adjustment for the shortfall in reported pickup trucks, showed an average weight of 4072 pounds, which has been used in this report as the most accurate assessment of the current U.S. fleet. Therefore, this research adopted an adjustment of around 700 pounds. Note that our complete data for ICE vehicles and EV vehicles shows a much lower weight penalty for EV's. This is because manufacturers have generally developed new EV models, and these display weight-saving design features. Therefore, adding 700 pounds to each of our ICE vehicles in the S&P Global data should be considered an upper estimate for our analysis.

Given below are some figures for specific models, generally 2025 models (TheDriven 2025):

Hyundai Kona ICE (AWD) 1450 kg, and increase (FWD) varies 11% to 17% to 1615-1698 kg
 Genesis G80 ICE (2023 kg) and GV70 ICE (2038 kg), and increase of 15% and 13.3%, respectively, to 2325 kg and 2310 kg
 Volvo XC 40 ICE hybrid Recharge with increase of 14% (1760 kg to 2001 kg)

As shown by Table 1, full electric versions for some common vehicles are around 10% to 15% heavier than their direct ICE equivalent.

Another source (JD Power 2025) describes vehicle category slightly differently, as shown below:

Small, Subcompact Cars: ~2,600 pounds
 Midsize Cars: ~3,300 pounds
 SUV's: Range from 3,000 to 6,000 pounds, depending on size and type
 Trucks: Weight between 3,500 to over 6,000 pounds

These categories are not inconsistent with the earlier breakdown but reflect the myriad ways in which vehicle sales and registrations are recorded by various agencies and associations.

Finally, the United States Environmental Protection Agency (EPA 2025) presents data from 1975 to 2023 with a detailed breakdown of the weight of vehicles on the road in the United States. Shown below is a sample comparing 2010 and 2023 of their data from heaviest to lightest as taken from their graphs to illustrate the trend over the past slightly more than decade:

Table 2: Vehicle weight classes and GVWR classes (The Hedges Company, 2025a)

Vehicle type	Average weight in pounds	
	2010	2023
Pickup	5250	5250
All trucks	4750	4750
Minivan/van	4550	4700
Truck SUV	4550	4650
All	4000	4450
Car SUV	3950	4000
All car	3500	3750
Sedan/wagon	3500	3700

These data reflect the increases in most categories of vehicle.

3. Analysis of S&P Global data

3.1 Statistical curb weight of all vehicles

The mean and standard deviation of vehicle curb weight is calculated for all the collected years and locations. Some entries in the provided dataset reported zero curb weight, primarily for RAM and Ford F-150 models. These anomalous records are excluded from the statistical analysis to maintain the integrity of the results (Table 3). Histograms, best fit distributions and statistical summaries of curb weights are prepared for CA, KS and for the US as a whole (Fig. 7). Table 4 and Figures 4 to 7 present the statistical summary of curb weights across the selected years.

Table 3: Percentage of zero curb weights in datasets

Year	Zero curb weight percentage (%)		
	USA	CA	KS
2023	3.6	3.0	4.2
2020	3.0	2.3	
2017	2.8	2.4	
2014	3.2	3.1	

Table 4: Statistical curb weight data of Total Vehicles throughout the years

Year	USA			California			Kansas		
	Total Vehicles	Mean curb weight (lb)	Curb weight Std Dev	Total Vehicles	Mean curb weight (lb)	Curb weight Std Dev	Total Vehicles	Mean curb weight (lb)	Curb weight Std Dev
2023	275,025,894	3,969	975	30,368,092	3,794	915	2,786,455	4,083	1,016
2020	273,200,856	3,895	953	31,078,703	3,726	900	-	-	-
2017	260,572,962	3,820	936	29,199,624	3,670	897	-	-	-
2014	243,211,569	3,753	917	26,837,977	3,623	891	-	-	-

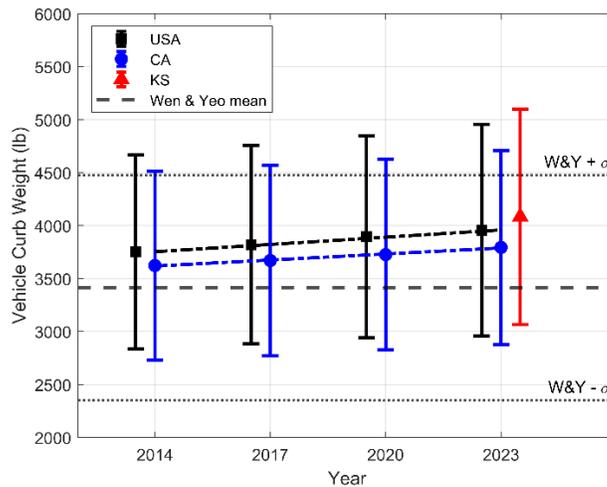


Figure 4: Mean curb weight and standard deviation in each respective area throughout the years

Table 4 and Figure 4 present the curb weight statistics in tabular and graphical form. For the US and CA, the two locations where temporal data are available, mean curb weight increased by 216 lb from 2014 to 2023 and the standard deviation increased by 58 lb over the same period. Vehicles in CA are lighter, on average, than US vehicles by 175 lb and KS vehicles are heavier than US vehicles by 114 lb.

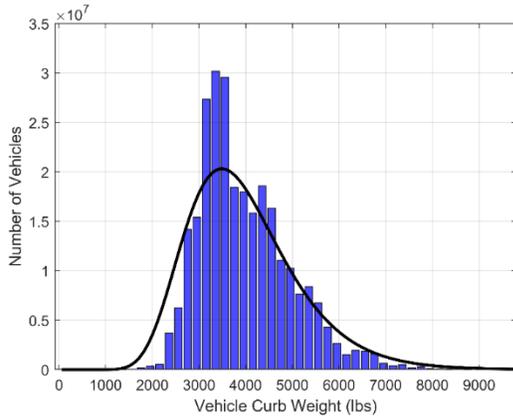


Figure 5: Vehicle curb weight distribution in the US 2023

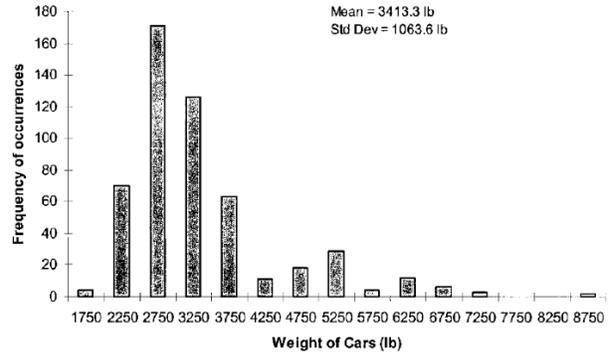


Figure 6: Vehicle curb weight distribution from Wen and Yeo study (2001)

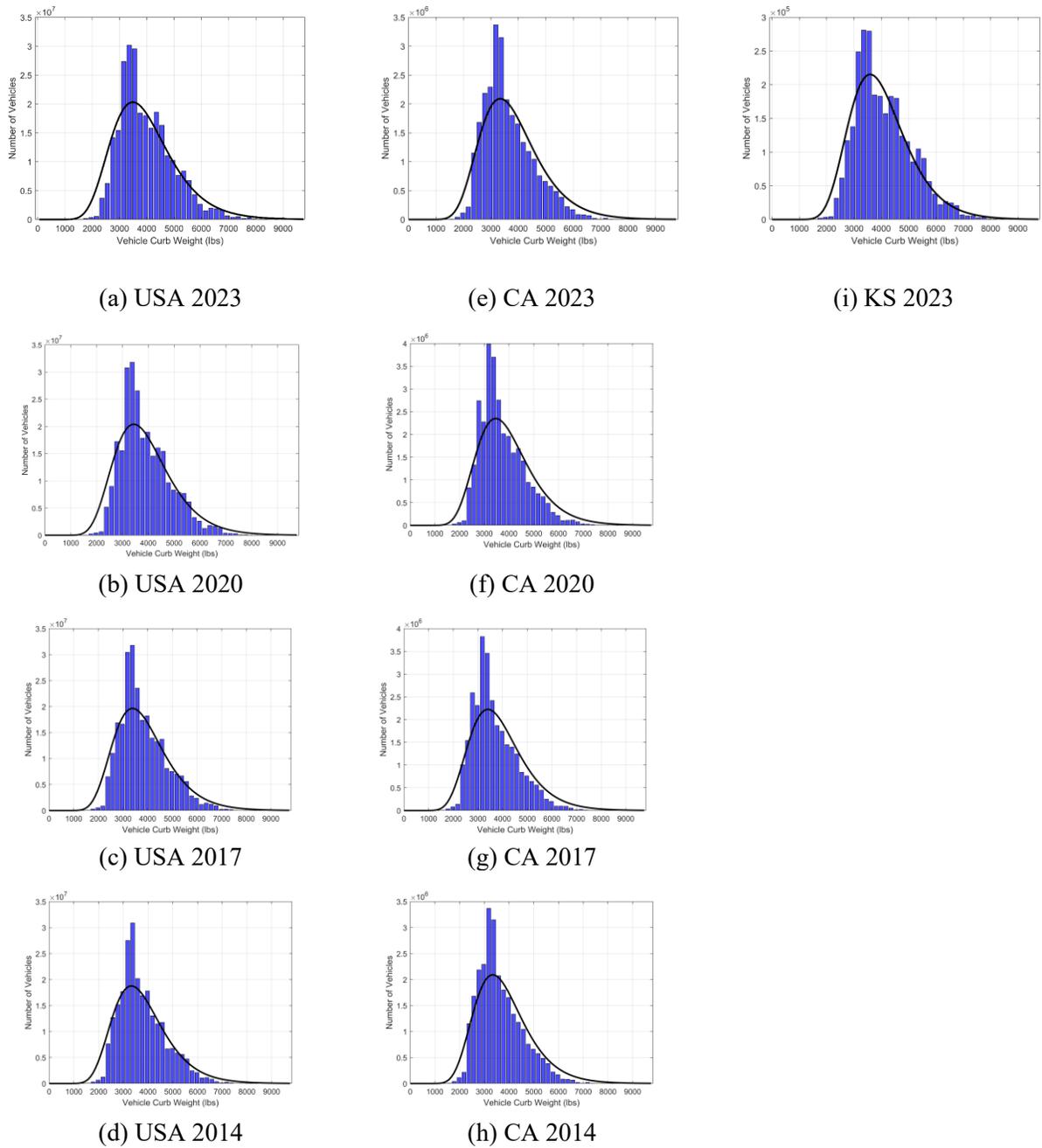


Figure 7: Vehicle curb weight distribution from other datasets

The histograms exhibit asymmetry and a positive skew, suggesting that a lognormal distribution provides a suitable representation of the data, following the approach of Wen and Yeo (2001) (Figure 6). The parameters of the lognormal distribution, ζ and λ , can be derived from the sample mean and standard deviation of vehicle curb weights; the method of moments. For example, with a sample mean of $\mu = 3969$ lb and a sample standard deviation of $\sigma = 975$ lb for US 2023, the values of $\zeta = E(\ln x)$ and $\lambda = \sigma_{\ln x}$ are obtained using the following expressions:

$$\zeta^2 = \ln\left(1 + \frac{\sigma^2}{\mu^2}\right) \rightarrow \zeta = 0.242$$

$$\lambda = \ln\mu - \frac{1}{2}\zeta^2 = 8.257$$

The quality of the lognormal distribution assumption is illustrated in Figures 5 and 7. The fit is reasonably accurate, particularly in the upper tail. Since the primary interest lies in extreme load effects generated by vehicle weights, the upper tail of the curb weight distribution is of particular interest. In practical terms, heavier vehicles are most likely to govern the load effects used in design. The lognormal model provides an appropriate representation of this portion of the distribution. Consideration of these extreme loading effects is presented in Section 8.

Table 5: Lognormal parameters of datasets

Region	Year	Mean	StD	ζ	λ
USA	2023	3,969	975	0.242	8.257
	2020	3,895	953	0.241	8.238
	2017	3,820	936	0.241	8.219
	2014	3,753	917	0.241	8.201
CA	2023	3,794	915	0.238	8.213
	2020	3,726	900	0.238	8.195
	2017	3,670	897	0.241	8.179
	2014	3,623	891	0.242	8.166
KS	2023	4,083	1,016	0.245	8.285

The vehicles can be classified into EVs and ICEs based on the fuel type field in the database. For each category, the total number, means and standard deviations of vehicles are compiled in Tables 6 and 7. Table 6 also includes, in parentheses below the vehicle count, the percentage of the total fleet that is EV.

Table 6: Statistical curb weight data of EVs throughout the years

Year	USA			California			Kansas		
	EVs (% of Total)	Mean curb weight (lb)	Curb weight Std Dev	EVs (% of Total)	Mean curb weight (lb)	Curb weight Std Dev	EVs (% of Total)	Mean curb weight (lb)	Curb weight Std Dev
2023	1,826,387 (0.66%)	4,132	683	681,943 (2.25%)	4,077	672	5,778 (0.21%)	4,166	708
2020	746,380 (0.27%)	3,925	781	332,473 (1.07%)	3,870	760	-	-	-
2017	263,977 (0.10%)	3,638	966	129,536 (0.44%)	3,576	933	-	-	-
2014	75,946 (0.03%)	3,299	1,001	33,871 (0.13%)	3,367	966	-	-	-

Table 7: Statistical curb weight data of ICEs throughout the years

Year	USA			California			Kansas		
	ICEs	Mean curb weight (lb)	Curb weight Std Dev	ICEs	Mean curb weight (lb)	Curb weight Std Dev	ICEs	Mean curb weight (lb)	Curb weight Std Dev
2023	273,199,507	3,968	977	29,686,149	3,787	919	2,780,677	4,083	1,017
2020	272,454,476	3,895	954	30,746,230	3,724	901	-	-	-
2017	260,308,985	3,820	936	29,070,088	3,670	897	-	-	-
2014	243,135,623	3,753	917	26,804,106	3,623	891	-	-	-

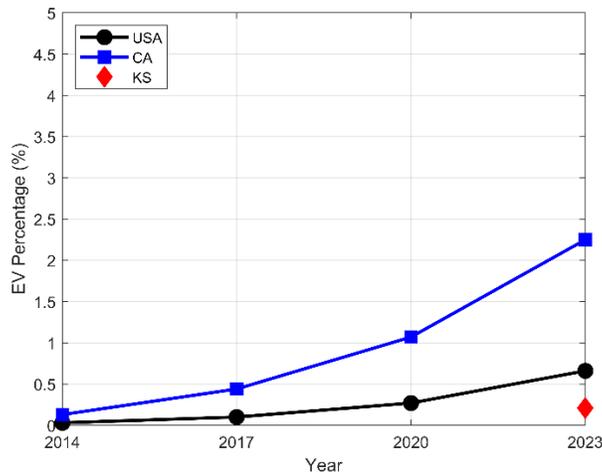


Figure 8: EV percentage in each respective area throughout the years

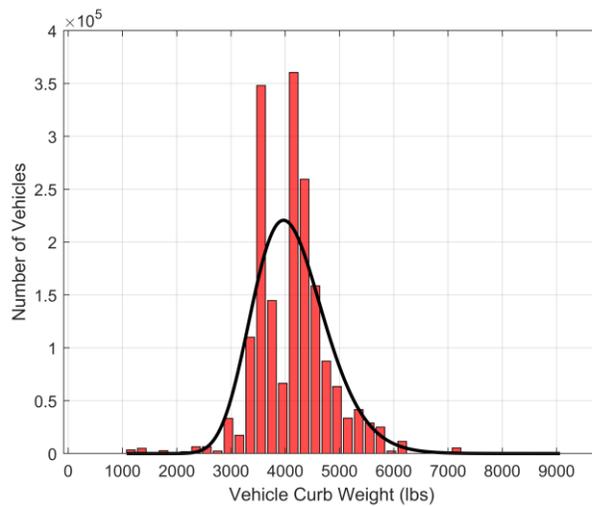


Figure 9: EV curb weight distribution in the US 2023

While the percentage of EVs in the fleet has been increasing in the US (0.03% to 0.66%), CA (0.13% to 2.25%), fleet penetration remains very modest. Various sources claim that CA leads the US in EV adoption and KS trails the US in EV adoption (Figure 8).

The current US EV fleet is, on average, 164 lb heavier than the ICE fleet and has a substantially lower standard deviation of curb weight; 683 lb for EVs compared to 977 for ICEs. EV fleet curb weight standard deviation has been declining whereas ICE fleet curb weight standard deviation has been increasing over time.

The EV fleet comprises many fewer vehicle types (make and model) than the ICE fleet and, therefore, the histogram of curb weights for EVs is less smooth than for ICEs (Figure 9). Nevertheless, the lognormal distribution is chosen as a model fit for EV curb weight to be consistent with models for ICEs, total fleet and that used in Wen & Yeo (2001). In the 2023 U.S. vehicle fleet, we see spikes around 3500 lbs, attributable primarily to the Chevrolet Bolt, Nissan

Leaf and Tesla Model 3, and around 4200-4600 lbs due to the Tesla Model S. Exact weight varies due to battery configuration options.

Figure 10 shows a comparison among the best-fit lognormal distributions for the Wen & Yeo (2001), US 2023 and US 2023 EV datasets. The distributions clearly show the increase in mean from 2001 to 2023 as well as the higher mean, but lower standard deviation of EV curb weights.

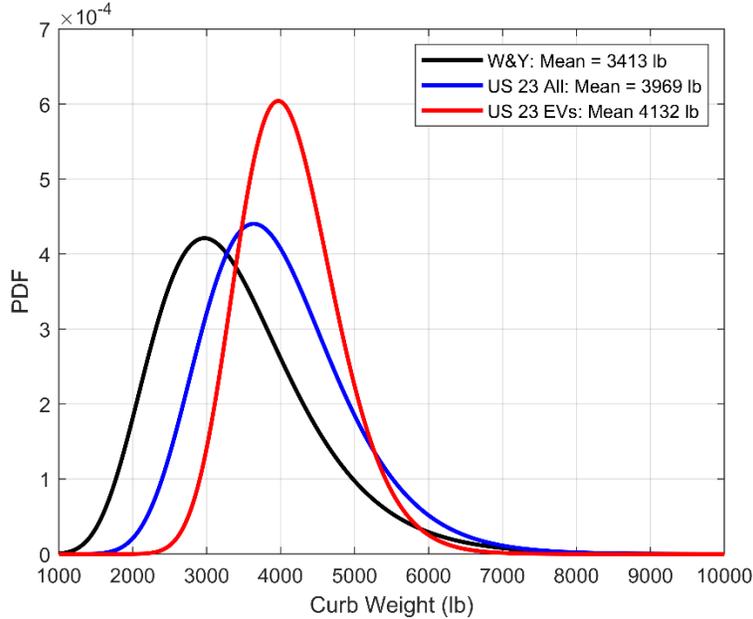


Figure 10: Data distribution comparison between Wen and Yeo, US 23 all vehicles, and US 23 EVs

Table 8: Statistic comparison between datasets

Dataset	Mean curb weight (lb)	Curb weight Std Dev
Wen and Yeo	3413	1064
US 23 All Vehicles	3969	975
US 23 EV Only	4132	683

3.2 Statistical curb weight of pickup trucks

Wen and Yeo (2001) conducted a load survey of various vehicle makes and models from nine garages across the United States. Nevertheless, the vehicle ownership patterns before 2000 differed considerably from those observed today, with the share of SUVs and pickup trucks having increased substantially in recent years, as established in Section 1.

Given that parking garages are designed for a 50-year service life, it is necessary to anticipate future vehicle trends to establish appropriate design loads. Pickup trucks, in particular, contribute significantly to increased live loads within garage bays due to their size and weight. They are common in the vehicle fleet as described by the S&P Global; data, making up 14.0% of the U.S. fleet in 2014, rising to 18.0% in 2023. Regional data for 2023 show similar or higher proportions: 14.2% in California and 22.7% in Kansas. The statistics of pickup truck models in the S&P Global dataset were therefore examined, and the results are summarized in Tables 9 to 12 and Figure 11. EV pickups remain rare, less than 0.2% even in CA 2023, but they weigh substantially (1395 lb)

more, on average, than ICE pickups. They do, to the contrary, have a substantially smaller standard deviation of curb weight (458 lb less) compared to ICE pickups.

Table 9: List of pickup trucks from the S&P Global data based on Hedges & Co. 2025b

No.	Manufacturer	Model	Type
1	Ford	F150; F250; F350; F450	Full-size pickup trucks
2	Chevrolet	Silverado	
3	Ram		
4	GMC	Sierra	
5	Toyota	Tundra	
6	Honda	Ridgeline (not full-size)	
7	Tesla	Cybertruck	
8	Nissan	Titan/Titan HD	Mid-size and compact trucks
9	Toyota	Tacoma	
10	Ford	Maverick	
11	Chevrolet	Colorado	
12	Nissan	Frontier	
13	Ford	Ranger	
14	Jeep	Gladiator	
15	GMC	Canyon	
16	Hyundai	Santa Cruz	
17	Rivian	R1T	

Table 10: Statistical curb weight data of Total Pickup Trucks throughout the years

Year	USA			California			Kansas		
	Total Pickup Trucks	Mean curb weight (lb)	Curb weight Std Dev	Total Pickup Trucks	Mean curb weight (lb)	Curb weight Std Dev	Total Pickup Trucks	Mean curb weight (lb)	Curb weight Std Dev
2023	49,692,454	5,075	969	4,311,715	4,814	989	631,843	5,118	950
2020	44,837,701	4,984	954	4,051,630	4,714	978	-	-	-
2017	38,812,136	4,879	963	3,609,276	4,615	984	-	-	-
2014	33,982,221	4,732	961	3,289,456	4,470	972	-	-	-

Table 11: Statistical curb weight data of EV Pickup Trucks throughout the years

Year	USA			California			Kansas		
	EVs (% of Total)	Mean curb weight (lb)	Curb weight Std Dev	Evs (% of Total)	Mean curb weight (lb)	Curb weight Std Dev	Evs (% of Total)	Mean curb weight (lb)	Curb weight Std Dev
2023	23,787 (0.05%)	6,470	511	5,989 (0.14%)	6,576	528	124 (0.02%)	6,398	478
2020	204 (0.00%)	4,198	668	70 (0.00%)	4,335	648	-	-	-
2017	270 (0.00%)	4,246	660	76 (0.00%)	4,364	609	-	-	-
2014	375 (0.00%)	4,252	658	168 (0.00%)	4,349	613	-	-	-

Table 12: Statistical curb weight data of ICE Pickup Trucks throughout the years

Year	USA			California			Kansas		
	ICEs	Mean curb weight (lb)	Curb weight Std Dev	ICEs	Mean curb weight (lb)	Curb weight Std Dev	ICEs	Mean curb weight (lb)	Curb weight Std Dev
2023	49,668,667	5,074	969	4,305,726	4,812	988	631,719	5,118	950
2020	44,837,497	4,984	954	3,619,513	4,714	978	-	-	-
2017	38,811,866	4,879	963	3,609,200	4,615	984	-	-	-
2014	29,070,092	4,732	961	3,289,288	4,470	972	-	-	-

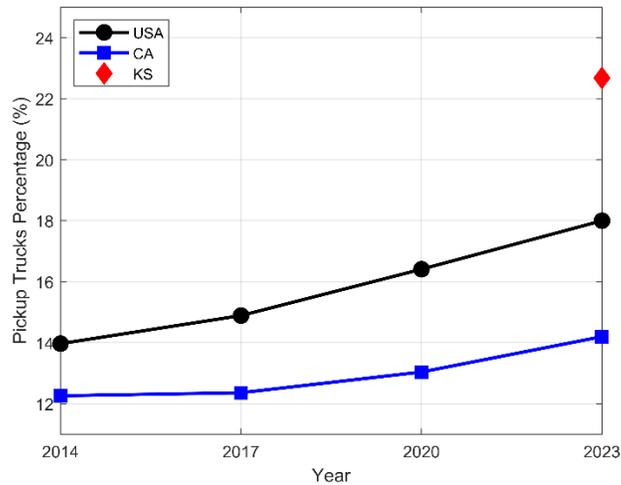


Figure 11: Pickup trucks population percentage in each respective area throughout the years

4. Summary of Wen & Yeo modeling approach and key results

Wen & Yeo (2001) established the approach for estimating the appropriate EUDL for parking garages, following the ASCE 7 practice of selecting design loads that correspond to the expected, or average, lifetime maximum EUDL. This section summarizes the method, which is then applied in this study to evaluate parking garage EUDL for current US fleet conditions and forecast fleet conditions. Wen and Yeo investigated the EUDL for both beam midspan moment and column axial load. They found that the latter was critical in all cases, so we have used that for our computations of EUDL.

The Wen & Yeo procedure (Figure 12) follows this systematic procedure based on modeling the distribution of vehicle fleet weights and the use of extreme value theory:

1. Collect data representative of the fleet of vehicles that will utilize parking garages.
2. Fit a lognormal distribution to the data.
3. Establish a typical layout of a parking bay including parking stalls and possible vehicle positions in the travel lanes.
4. Compute the influence surface for key structural members corresponding to the parking bay layout.
5. Compute the parameters of the lognormal distribution corresponding to member demands (e.g. axial force, bending moment) by treating vehicle weights as random variables that

- map through the influence surface. Include in this calculation an allowance of 7% additional weight for parked vehicles and 17% additional weight for traveling vehicles.
- Using extreme value theory, compute the parameters of the Type II extreme value distribution corresponding to the lifetime maximum member demand, assuming a 30-year lifetime and daily parking turnover.
 - Compute the mean of the resulting extreme value distribution, which represents the expected lifetime maximum member demand.
 - Establish the EUDL as the uniformly distributed load that generates the expected lifetime maximum member demand.

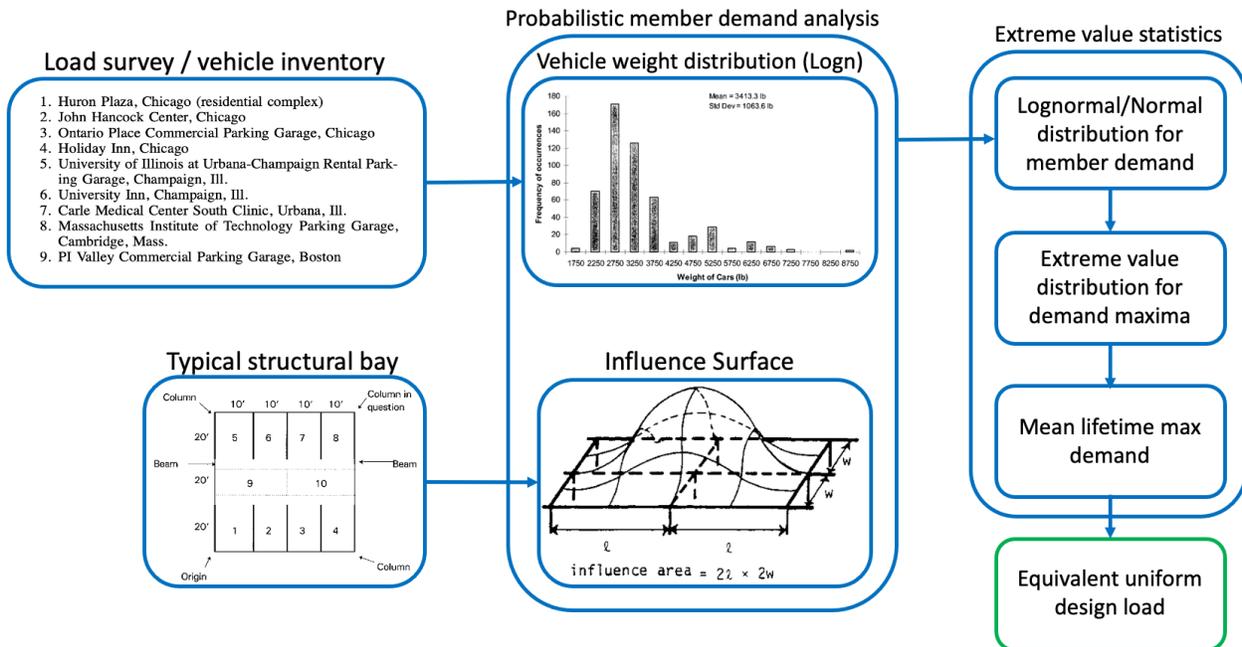


Figure 12: Wen & Yeo (2001) live load estimation method.

As a result of their work, Wen & Yeo calculated an expected lifetime maximum load of 34.8 psf for a 10-stall bay and recommended that the then-current ASCE 7 design live load of 50 psf be reduced to 40 psf. The recommendation to adopt 40 psf instead of, for example, 35 psf, was made to allow for the possibility of vehicle weights increasing due to increased penetration of heavy SUVs into the vehicle fleet.

5. Adjusting for the under-representation of pickup trucks in the S&P Global data

The Bureau of Transportation Statistics (2023) reported the proportion of pickup trucks in the national vehicle fleet to be approximately 25%, compared with 18% in the S&P Global U.S. 2023 dataset (Figure 11) collected from the list of 17 pickup truck models (Table 9). This discrepancy indicates that pickup trucks are under-represented in the S&P Global database. As discussed in the introduction, the most likely explanation for this under-representation is that many pickups are registered as commercial vehicles, which are not included in the S&P Global database. Rules on non-commercial and commercial registrations vary state-by-state. This under-representation introduces a possible bias to the fleet data since pickup trucks are, on average, heavier than the average of the entire US fleet.

To address this under-representation and bias, the dataset is augmented to raise the pickup truck percentage to 25%. An additional number of pickup trucks, P_{new} , is introduced into the 2023 U.S. vehicle dataset. The number of additional vehicles is calculated as:

$$\frac{49,692,454 + P_{new}}{275,025,894 + P_{new}} = 0.25 \rightarrow P_{new} = 25,418,692$$

To remain consistent with the U.S. 2023 EV fleet penetration, 0.66% of these additional trucks are EVs ($\mu = 6470$ lb, $\sigma = 511$ lb), while the rest are ICEs ($\mu = 5074$ lb, $\sigma = 969$ lb). Individual curb weights are assigned to each additional pickup by sampling from the appropriate lognormal distributions. Table 13 presents the statistical summary of each vehicle type (US 2023) after the addition of new pickup trucks. The introduction of the additional pickup trucks raises the fleet average curb weight by 103 lb, from 3969 lb to 4072 lb.

Table 13: Statistical curb weight data of each vehicle types in the adjusted USA 2023 dataset

Type	Number of vehicles	Mean curb weight (lb)	Curb weight Std Dev
Total Vehicles	300,444,586	4,072 (compared to 3,969)	1,011
EV	1,838,555	4,155	719
ICE	298,606,031	4,072	1,013

Figure 13 shows the histogram of the US 2023 fleet curb weights along with the best fit lognormal distribution and Figure 14 compares the US 2023 fleet curb weight distribution before and after the introduction of the additional pickup trucks.

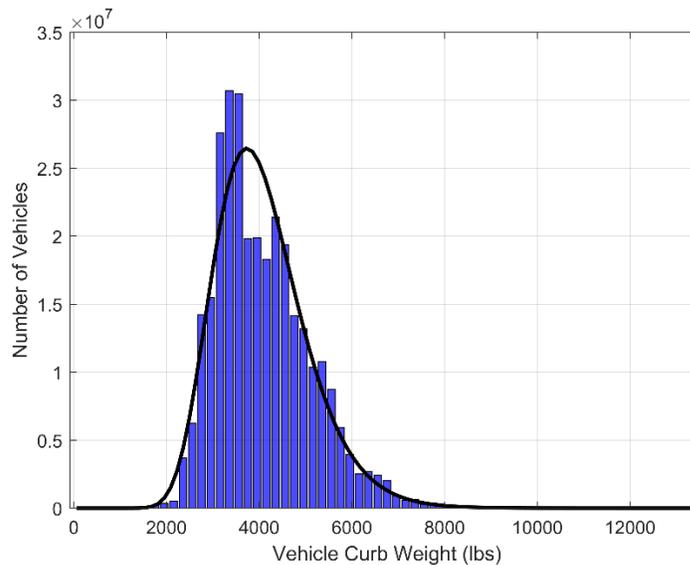


Figure 13: Total vehicle curb weight distribution in the adjusted US 2023 dataset

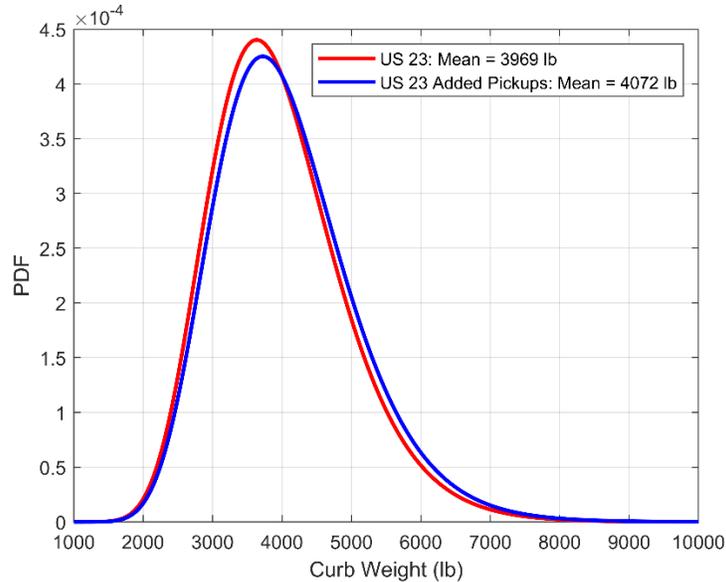


Figure 14: Data distribution comparison between US 23 all vehicles and US 23 added pickups

Table 14: Data distribution comparison between US 23 all vehicles and US 23 added pickups

Dataset	Mean curb weight (lb)	Curb weight Std Dev
US 23	3969	975
US 23 Added Pickups	4072	1011

6. EV conversion and forecasting

This report will present analysis of design loads corresponding to current fleet characteristics, but will also address future conditions with respect to the expected higher fleet penetrations of EVs in the coming decades, during the design lifetime of garages being designed and built today. In the following, a model for forecasting EV fleet penetration is presented that accounts for EV sales penetration and vehicle lifespan.

6.1 Vehicle lifespan

The S&P Global data shows an approximation of 280 million total non-commercial vehicles registered in 2023. According to MarkLines Automotive Sales Volume Report (MarkLines 2024), U.S. new vehicle sales have averaged about 16 million per year, with relatively little variation by year (15.6 million in 2023). These two numbers suggest an average vehicle lifespan of about $280/16 = 17.5$ years.

Other sources indicate a similar estimate. For example, Auto Recycling World cites data from Todd Bialaszewski (Auto Recycling World 2025), founder of Junk Car Medics, who analyzed over 50,000 records from 2023. The study found that vehicles in the United States have an average lifespan of 16.58 years, with an average mileage of 156,470 miles at the time of disposal.

Thus, both the registration-based estimate (17.5 years) and the recycling-based estimate (16.6 years) indicate an average vehicle lifespan of approximately 17 years, which is used in the model presented next.

6.2 EV forecasting

The fraction of new vehicle sales that are EVs will be represented by an exponential growth equation of the form:

$$s_{EV}(t) = s_{EV}(0)(1 + r_{EV})^t$$

Where:

- $s_{EV}(t)$ = EV sales penetration at end of period (%)
- $s_{EV}(0)$ = initial EV penetration at the beginning of the period (%)
- r_{EV} = annual rate of increase in penetration percentage (%)
- t = number of years from beginning to end of period

For this analysis, the initial year was taken as 2025, with an EV sales penetration of 8.7%, based on first-quarter data from Hurwitz et al. (2023). Predicted EV sales penetrations for future years were drawn primarily from the same study, whose high and low scenarios are presented across two different publications. The corresponding annual growth rates were then back-calculated using the above formula.

Hurwitz et al. (2024) project EV sales penetration of 40%–52% by 2035, and 70%–95% by 2050. These figures correspond to an implied annual growth rate of 10.7%–19.6% between 2025 and 2035, and 8.7%–10% between 2035 and 2050.

In addition, Hurwitz et al. also predict the percentage of EVs on the road, accounting for average vehicle lifespan. Their estimates are 14%–28% by 2035 and 42%–64% by 2050, which correspond to implied annual growth rates of 30.2%–39.6% between 2025 and 2035, and 16.1%–18.1% between 2035 and 2050.

Predictions by Hurwitz suggest the following annual sales growth rates scenarios:

- Low value for annual sales: approximately 7%
- Medium to high value: approximately 10% (which would result in nearly 100% sales penetration)

which are illustrated in Figure 15. With 10% sales growth, the sales penetration reaches nearly 100% by 2050. With 100% sales penetration as an upper bound, an asymptotic model would be needed to extend forecasts beyond 2050.

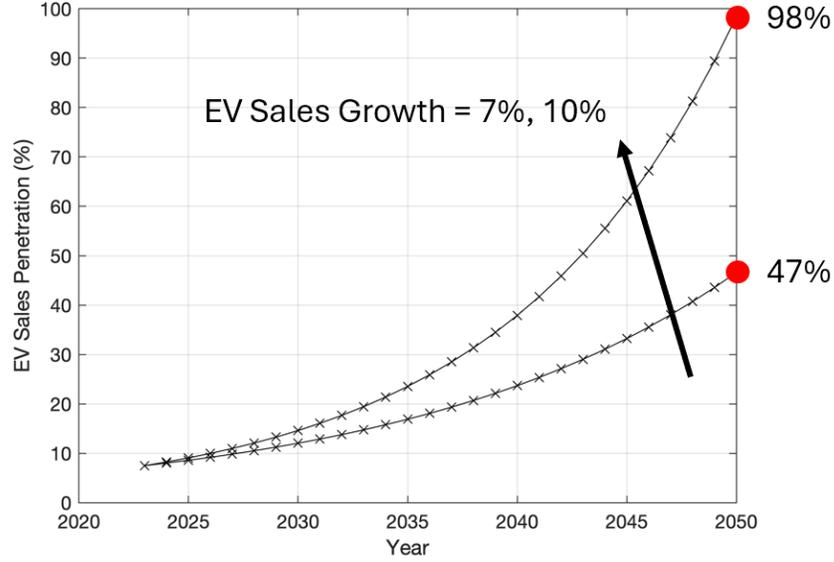


Figure 15: EV sales percentage throughout the year

To convert EV sales penetration into EV fleet percentage, the inflow of new vehicles and the outflow of aging vehicles from the fleet must be considered. With an average vehicle lifespan of $L = 17$ years, the fleet size in each year can be updated recursively as follows:

Let:

- $N_{EV}(t)$ = number of EVs in year t .
- $N_{ICE}(t)$ = number of ICEs in year t
- $N_{tot}(t) = N_{EV}(t) + N_{ICE}(t)$ = total fleet in year t
- $s_{EV}(t)$ = fraction of EVs in new vehicle sales in year t
- n_{in} = annual new vehicle sales ($n_{in} = 16m$ vehicles, stable)
- r_{EV} = annual growth rate in EV sales share
- r_T = annual growth rate in total vehicle sales (assuming stable sales, $r_T = 0$)

The EV sales share is assumed to grow exponentially as:

$$s_{EV}(t) = s_{EV}(0)(1 + r_{EV})^t$$

The inflow of new EVs and ICEs in year t is given by:

$$N_{EV,in}(t) = n_{in}(1 + r_T)^t s_{EV}(t)$$

$$N_{ICE,in}(t) = n_{in}(1 + r_T)^t [1 - s_{EV}(t)]$$

The outflow due to vehicle aging is given by:

$$N_{EV,out}(t) = \frac{N_{EV}(t-1)}{L}, N_{ICE,out}(t) = \frac{N_{ICE}(t-1)}{L}$$

Thus, the fleet size is updated each year according to:

$$N_{EV}(t) = N_{EV}(t - 1) + N_{EV,in}(t) - N_{EV,out}(t)$$

$$N_{ICE}(t) = N_{ICE}(t - 1) + N_{ICE,in}(t) - N_{ICE,out}(t)$$

Finally, the percentage of EVs in the total fleet is:

$$f(t) = \frac{N_{EV}(t)}{N_{tot}(t)} \times 100 (\%)$$

Following this procedure, the EV fleet penetration percentage are calculated corresponding to the EV sales growth of 7% and 10%. Fleet percentages (Figure 16) grow much more slowly than sales percentages and reach values of 21% and 36% for the 7% and 10% sales growth rates in 2050.

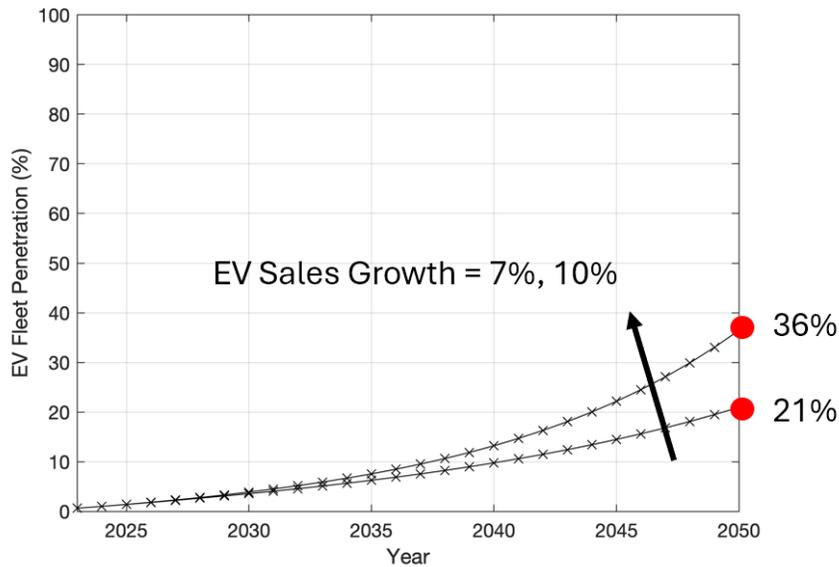


Figure 16: EV fleet penetration percentage throughout the year corresponding to EV Sales growth

6.3 EV fleet curb weight statistical characteristics

The models presented in the prior section provide reasonable forecasts of EV fleet penetrations through 2050. The distribution of EV curb weights in the future is also required for the resulting loads analysis. In the US 2023 data, the small number of EVs have a small standard deviation (683 lb) compared to that for the entire fleet (975 lb). This standard deviation is, likely, artificially low due to the small number of EV makes and models in the fleet—there is no reason to believe that the EV fleet, once grown to a more substantial fraction of the total fleet, should have a significantly different standard deviation from that of ICEs.

As discussed in Section 2, adding 700 pounds to each ICE vehicle in the S&P Global dataset represents a conservative model for EV weight adjustment. The statistics of the modified dataset, reflecting a hypothetical 100% EV conversion, are presented in Table 15 for both the original S&P Global data and the dataset with the added pickup truck adjustment. The corresponding curb weight distributions are shown in Figure 17.

Table 15: Statistical curb weight data in the adjusted 100% EV for USA 2023 dataset

Dataset type	Number of vehicles	Mean curb weight (lb)	Curb weight Std Dev
Total Vehicles	275,025,894	4,668 (compared to 3,969)	976
Added Pickups	308,211,910	4,768 (compared to 4,072)	1,012

Because of the small EV percentage from the initial dataset (less than 1% in the U.S. dataset for 2023), the mean curb weight for the adjusted dataset is approximately 700 lb greater than that of the original dataset. This adjusted dataset scenario will be used in Section 8 for the analysis of the EUDL.

The additional weight of 700 lb for each EV could have been made a function of the vehicle curb weight, but the simpler approach was considered adequate since the structural effect is the summation (weighted by the influence surface coefficients) of the 14 vehicles in the 40' x 62' bay. This renders the result less sensitive to variation in individual vehicles.

It should be noted that the weight of cargo (and cargo plus people for cars in the travel lanes) is added as a random variable with a mean of 7% of the vehicle curb weight for the ten vehicles in the parked stalls and 17% for those four in the travel lanes. Because of this approach of proportionality to the vehicle curb weight, the actual average effect for the ICE to EV conversion is 749 pounds (700 x 1.07) for the parked cars and 819 pounds (700 x 1.17) for those in the travel lanes, or an average of 769 pounds average per bay. When compared to the average curb weight from the adjusted S&P Global data of 4072 pounds, this represents an actual average ICE to EV effect of 18.9%. It should be noted that in general there are few direct comparisons of two vehicles that are identical models except for their propulsion systems. It is believed that the average comparison of 18.9% is reasonably conservative. Some recent conversions of pickup trucks, however, exhibit much higher differences (for instance, the 2023 Ford F150 crew cab ICE has a curb weight of 4400 pounds, whereas the equivalent Lightning weighs about 6000 pounds).

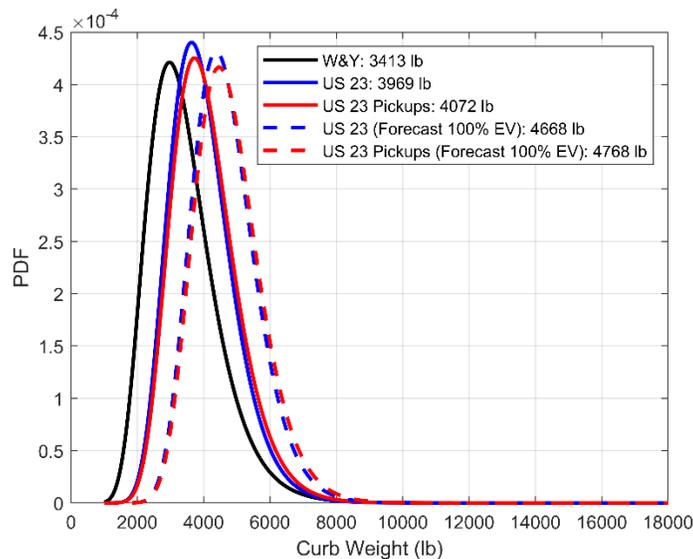


Figure 17: Dataset comparison with EV conversion

6.4 Statistical data with different EV fleet penetration

Using the 700 lb conversion weight, the influence of EV fleet penetration on fleet curb weight statistics can be investigated (Figure 18). The mean curb weight increases linearly with the percentage of EVs, whereas the relationship between standard deviation and EV fleet penetration is nonlinear, with a peak at 50% EV penetration. This peak reflects a balanced mix of EV and ICE vehicles in the dataset. These variations directly influence the EUDL, which will be discussed in detail in Section 8.2.

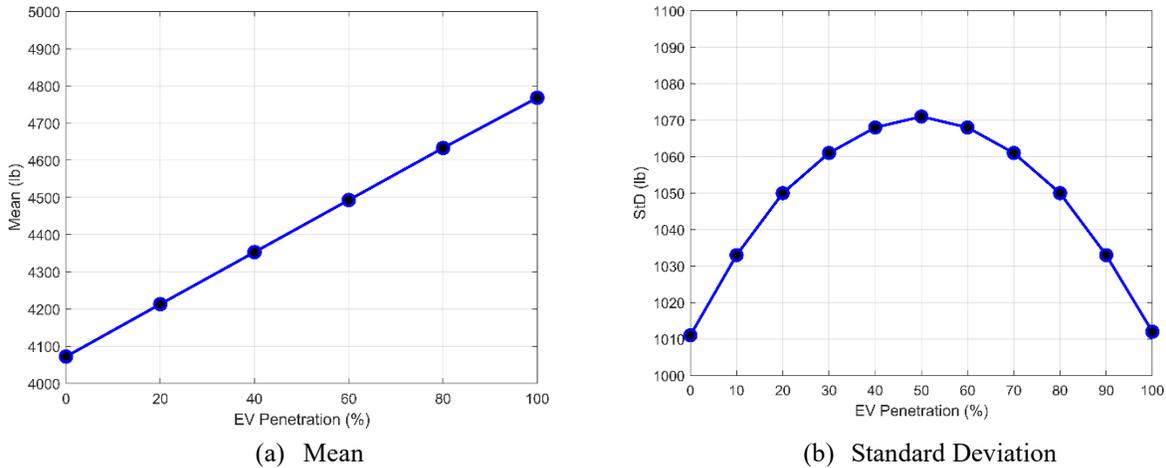


Figure 18: Statistical data with different EV fleet penetration

Table 16: Statistical data with different EV fleet penetration

	EV Penetration (US 23 Added Pickups)					
	1%	20%	40%	60%	80%	100%
Mean	4072	4213	4353	4493	4633	4768
StD	1011	1050	1068	1068	1050	1012

7. Description of analysis cases

This section describes the combinations of fleet characteristics and garage bay sizes for which EUDL values are calculated. Consideration of a broad range of cases provides insight into the adequacy of the current ASCE 7 LL provisions as well as their adequacy for potential future scenarios. Additionally, key modeling assumptions are introduced.

7.1 Bay sizes

According to PCI Parking Structures guidelines (2015), the width between individual stalls in a precast, prestressed concrete bay typically ranges from 8 to 9 ft, with a standard bay length between 60 and 62 ft. Wen and Yeo (2001) adopted a 40' x 62' bay configuration in their final recommendations for EUDL analysis, while also concluding that the EUDL was not highly sensitive to bay-size variation. Nevertheless, a study conducted by Kemper, Funke, and Feldmann (2022) evaluated multiple live load models for parking garages based on empirical measurements for Eurocode standard provisions, with post-tensioned column spacings of 24 and 27 ft being the configuration most sensitive to live load effects. Given how common such layouts are becoming in modern garage design, smaller bay configurations should be considered. Within the scope of

this study, two representative cases are analyzed: a primary configuration of 40' x 62', accommodating 10 parking spaces and 4 moving lanes (Wen and Yeo, 2001), and a secondary configuration of 24' x 62', with 6 parking spaces and 2 moving lanes.

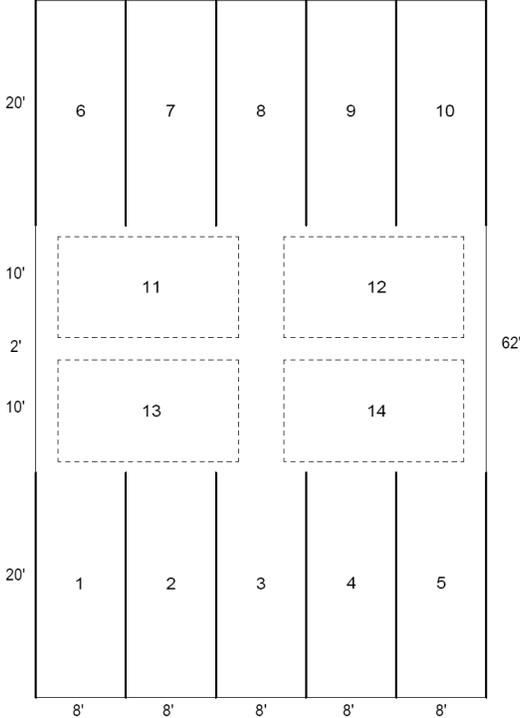


Figure 19: 40' x 62' bay configuration (Wen and Yeo, 2001)

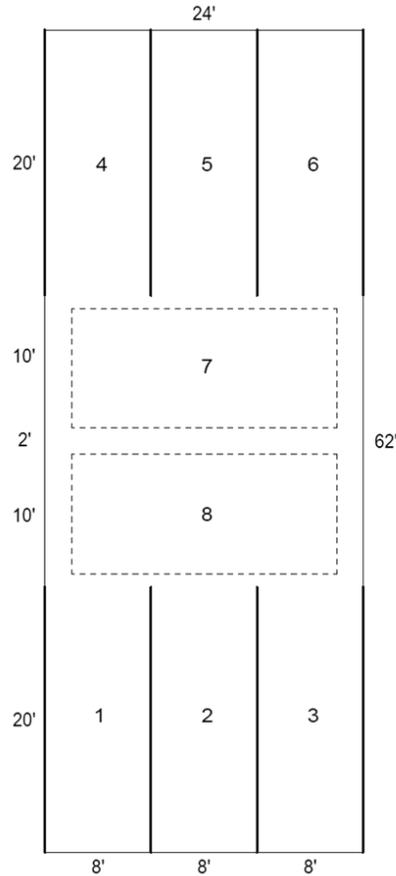


Figure 20: 24' x 62' bay configuration

7.2 List of simulated cases

EUDL calculations following the method of Wen & Yeo (2001) were conducted under the following parameters:

- 50-year design life (differs from 30-year life in Wen & Yeo (2001))
- All parking stalls and moving lane locations occupied
- For parked vehicles, 7% of curb weight is added to represent cargo.
- For moving lanes, 17% of curb weight is added to represent combined passenger and cargo load.
- 5 complete and independent parking turnovers per day
- EV fleet penetration forecast for 20%, 40% and 100%
- 40' x 62' and 24' x 62' bay sizes

The complete dataset used for these simulations, sourced from S&P Global, is summarized in Table 17.

USA	California	Kansas	Wen and Yeo
2023 added pickups	2023	2023	2001
2023 EV only	2020		
2023	2017		
2020	2014		

7.3 Vehicle weight distribution truncation

In the Wen & Yeo (2001) approach, vehicle curb weights are sampled from the best-fit lognormal distribution. Figure 21 shows the critical vehicles that drive EUDL, as sampled from the curb weight lognormal distribution. The heavy upper tail of the lognormal distribution results in some simulated vehicle weights that are larger than 10,000 lbs, in excess of the heaviest non-commercial vehicle in the S&P Global database.

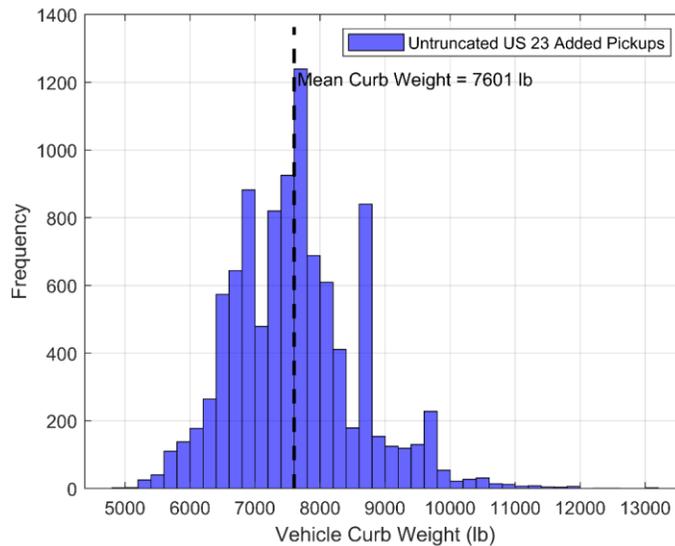


Figure 21: Untruncated critical vehicle on the day that cause lifetime max EUDL

To assess the impact of these non-realistic vehicles on EUDL, truncation of the vehicle weight distribution was investigated (Figure 22). Truncation of the distribution resulted in a reduction of EUDL of less than 1 psf. To remain consistent with the approach of Wen & Yeo (2001), which did not use truncation, and to simplify the calculations, the full upper tail of the vehicle weight distribution is retained in the following simulations.

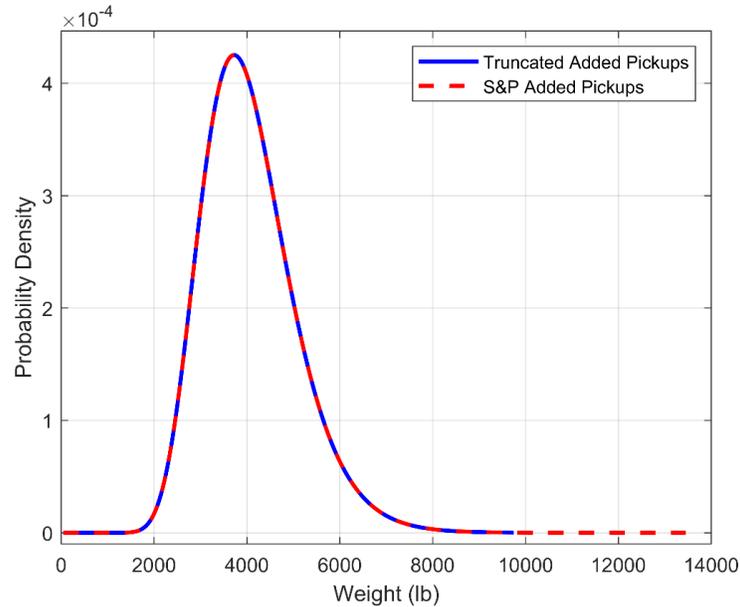


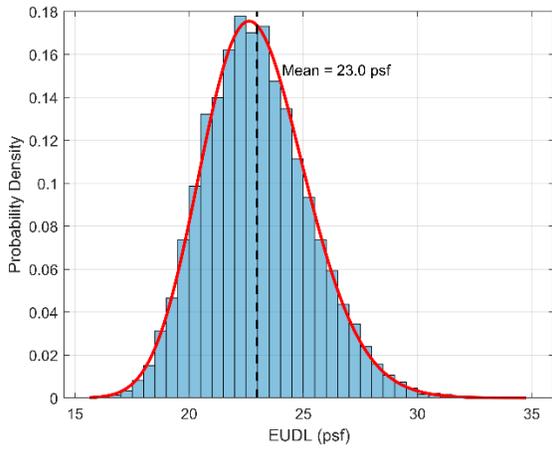
Figure 22: Untruncated and truncated S&P dataset

8. Results

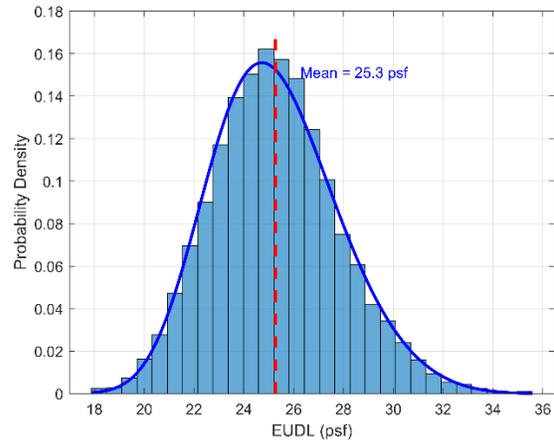
This section presents the comprehensive results of the EUDL analysis for the cases presented in Section 7. This comprehensive set of EUDL values elucidates the sensitivity of EUDL to various model parameters and forms the basis for potential recommendations to ASCE 7. Analysis is presented for the structural effect of axial compression on columns, identified as the critical load effect in Wen & Yeo (2001).

8.1 Daily and Lifetime EUDL

Using the Extreme Value Distribution theory for the 40 ft by 62 ft bay dimension and lognormal parameters derived from 2023 U.S. data with added pickups, the average daily EUDL for a single parking bay can be estimated (Figure 23). Then, by assuming five vehicle turnover per day over a 50-year period ($n = 91,250$), the lifetime EUDL distribution can be obtained (Figure 24). This value of 39 psf represents the best estimate of the appropriate EUDL for the 2023 US fleet.

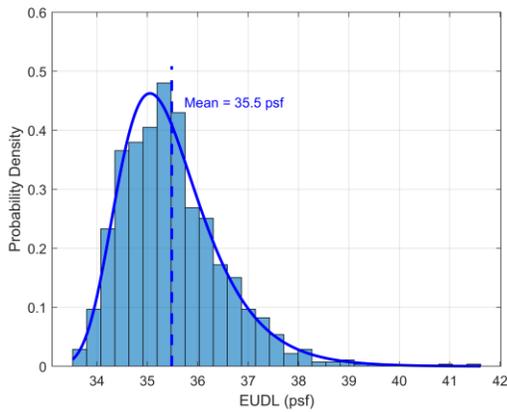


(a) Curb Weight

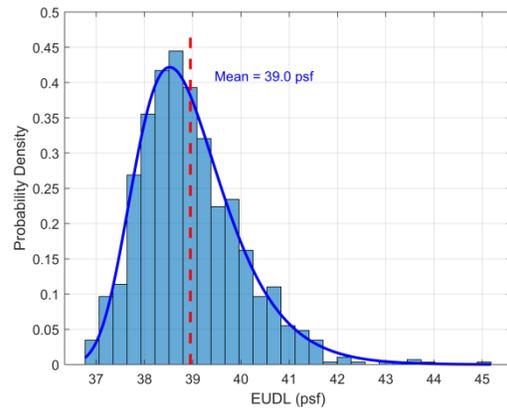


(b) Passenger + Cargo

Figure 23: Histogram of daily EUDL (40'x62' bay) for USA 2023 added pickup – all vehicles



(a) Curb Weight



(b) Passenger + Cargo

Figure 24: Histogram of lifetime EUDL (40'x62' bay) for USA 2023 added pickup – all vehicles

Figure 25 illustrates how the expected lifetime maximum EUDL relates to the daily EUDL, falling well into the upper tail of the daily EUDL distribution.

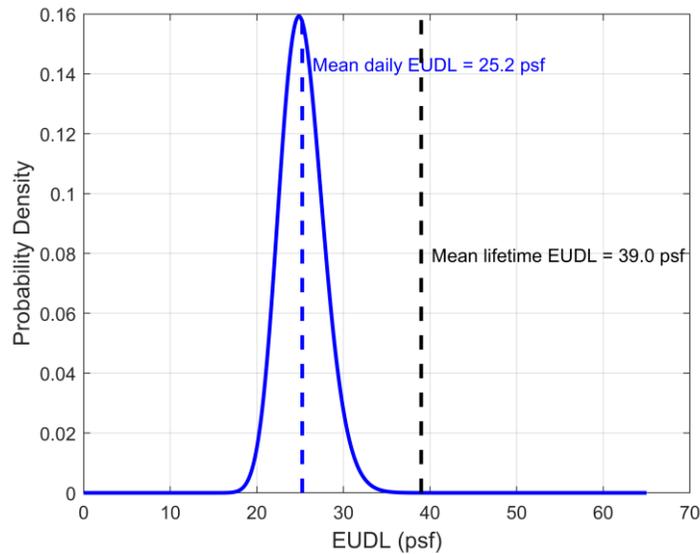


Figure 25: Comparison between daily and lifetime max EUDL (40'x62' bay) for USA 2023 added pickup – all vehicles

8.2 EUDL Sensitivity

The mean and standard deviation of the vehicle weight distribution influence the EUDL to different degrees. Further, it is evident in the data that increases in mean vehicle weight may be accompanied by decreases in vehicle weight standard deviation—e.g. in 2023, the mean of EV weight was higher than that for ICEs, but the standard deviation was lower. Figure 26 shows the relationship between EUDL and vehicle weight mean and standard deviation. Computation of the sensitivity (gradient of the EUDL surface) reveals that the EUDL is twice as sensitive to standard deviation of vehicle weight as it is to mean vehicle weight. This finding results from the fact that the EUDL depends on extremes of the vehicle weight distribution, which are more sensitive to standard deviation than mean.

Without accounting for passenger and cargo, at $\mu = 4000$ lb and $\sigma = 800$ lb the values are:

- EUDL = 29.3 psf
- $d\text{EUDL} / d\mu = 0.005$ psf/lb
- $d\text{EUDL} / d\sigma = 0.011$ psf/lb

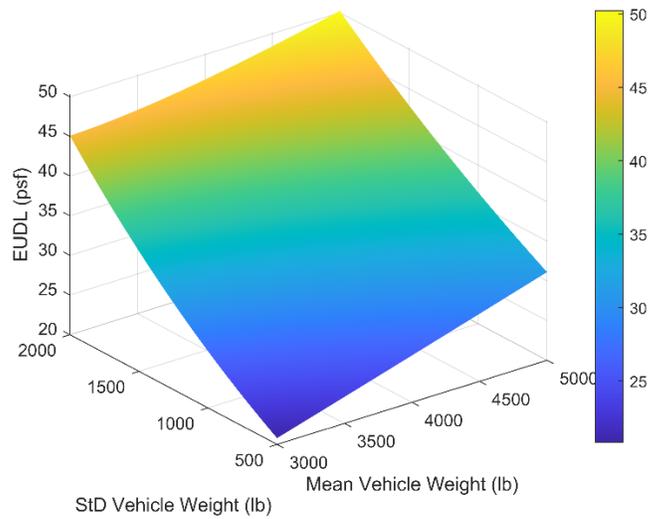


Figure 26: 3D sensitivity of EUDL to the mean and standard deviation of vehicle weight of the 40' x 62' bay

8.3 Effect of EV penetration on EUDL

Figure 27 shows how EUDL changes with increasing EV penetration, up to 100% EV. Recall that current EV penetration is less than 1%. This analysis is based on the conservative 700 lb EV conversion. The relationship between EUDL and EV penetration is nonlinear because the standard deviation of vehicle weight peaks at an EV penetration of 50%. Note also that, even with the conservative 700 lb EV conversion weight, only at fleet, not sales, penetrations of 40% or more is the current ASCE 7 design load of 40 psf exceeded. In all likelihood, it will be many decades before such EV fleet penetrations are reached in the US.

Examining the current US EV fleet, the indicated EUDL is 34 psf. This smaller EUDL (as compared to ICE) results despite the fact that although current mean EV weight is higher than for ICEs. The reason is that the standard deviation of the EV vehicle weight is less than that of ICEs. This value can be considered applicable to the current case of a bay being entirely occupied by EVs drawn from the present-day fleet. Such bay occupation could be caused by the presence of charging stations or other local conditions.

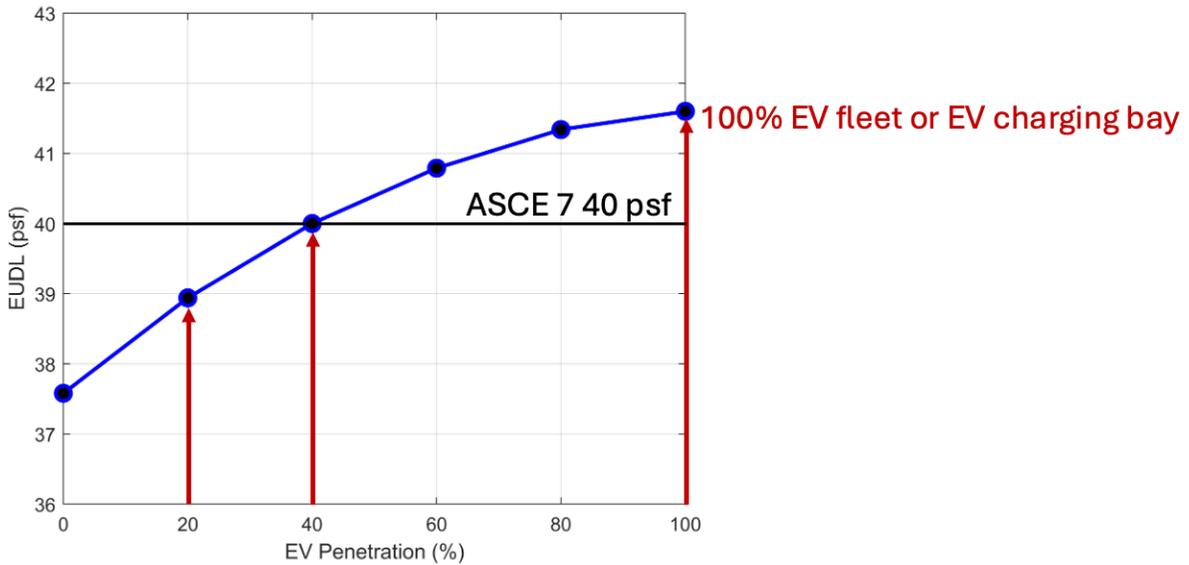
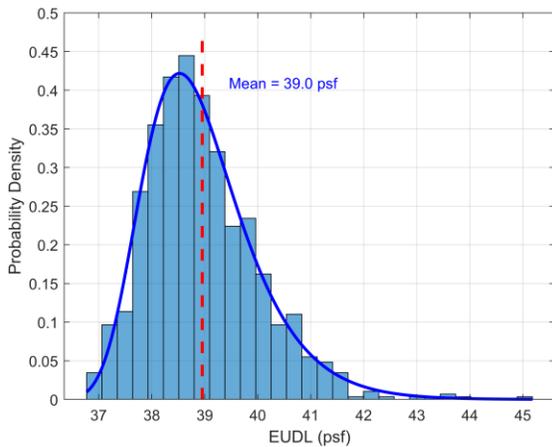


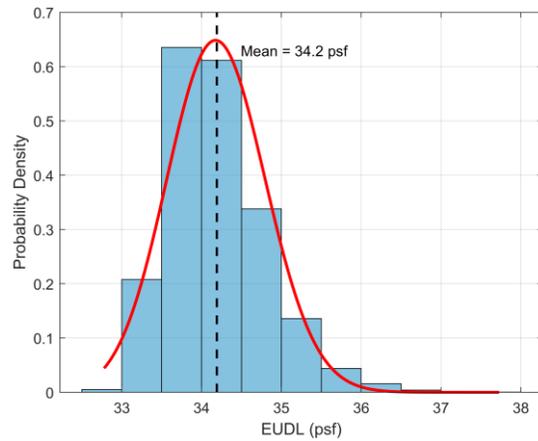
Figure 27: EUDL with different EV penetration (40'x62' bay) for USA 2023 added pickup – all vehicles

8.4 Live load reduction

ASCE 7 currently allows a 20% reduction in live load for structural elements such as columns supporting garage bays on multiple levels since it is unlikely that bays on multiple levels will simultaneously experience their lifetime maximum loads. Though Turkstra's approach, which assumes that the maximum combined loading of two bays will occur at the moment of maximum loading on one of the bays, is commonly used to model combined loading, in this study, direct simulation of the lifetime parking loads on two bays is used to assess the possibility of LL reduction. Figure 28 shows that the mean lifetime maximum load on a column supporting two parking bays corresponds to an EUDL of 34.2 psf, a 12% reduction from the single bay EUDL of 39 psf.



(a) 1 floor lifetime maximum EUDL



(b) Average maximum summation of 2 floors

Figure 28: Histogram of lifetime EUDL (40'x62' bay) for USA 2023 added pickup – all vehicles (five turnovers, passenger + cargo)

In reference to the 20% maximum allowable live load reduction (permitted in section 4.7.4 as an exception), ASCE SEI 7-22 states, “Live loads for members supporting two or more floors are permitted to be reduced by a maximum of 20%, but the reduced live load shall not be less than L as calculated in Section 4.7.2.

The clear intent of this provision would apply to columns supporting two or more parking levels.

The limitation in Section 4.7.2 is based on tributary area. A structural bay 40' x 62' has a tributary area of 2480 square feet, and a column supporting two floors would thus have a tributary area of 4960 square feet. The KLL factor in Equation (4.7-1) is 4 for columns without cantilevers. The limitation of that equation does not control in this case, so that maximum reduction of $0.40L_0$ of the provision controls. Since the Standard only allows a 20% reduction, Section 4.7.2 does not control, and thus the 20% reduction is allowed for columns.

The results of the full 50-year stochastic analysis conducted in this research project indicate that a reduction of 12% is consistent with the current vehicle fleet for a column supporting two floors. A larger reduction would result for three or more floors, but was not investigated.

8.5 List of cases and EUDL results

The simulation cases used to estimate EUDL are based on vehicle datasets from S&P Global, covering the United States, California, and Kansas across multiple years. The primary dataset is the U.S. 2023 data, representing the national vehicle fleet and expected to yield the most critical loading conditions. Using the assumptions from Section 7.2, the EUDL for different simulated cases can be summarized from Tables 18 to 21.

Table 18: EUDL for 40' x 62' bay with passenger + cargo vehicles, one turnover per day

Sample size n	Case	Region	Dataset type	EUDL (psf)
18250	14-stall bay, vehicle in aisles, added passenger and cargo	US	Forecast 100% converted EV (added pickup)	41.60
			Forecast 40% converted EV (added pickups)	40.00
			Forecast 20% converted EV (added pickups)	38.95
			2023 (added pickups, EV only)	34.09
			2023 (added pickups, all vehicles)	37.59
			2023 (EV only)	33.49
			2023 (all vehicles)	36.49
		CA	2020 (all vehicles)	35.75
			2017 (all vehicles)	35.08
			2014 (all vehicles)	34.43
			2023 (all vehicles)	34.63
			2020 (all vehicles)	34.03
			2017 (all vehicles)	33.67
			2014 (all vehicles)	33.32
KS	2023 (all vehicles)	37.72		

Table 19: EUDL for 24' x 62' bay with passenger + cargo vehicles, one turnover per day

Sample size n	Case	Region	Dataset type	EUDL (psf)
18250	8-stall bay, vehicle in aisles, added passenger and cargo	US	Forecast 100% converted EV (added pickup)	43.5
			Forecast 40% converted EV (added pickups)	42.44
			Forecast 20% converted EV (added pickups)	41.39
			2023 (added pickups, EV only)	35.04
			2023 (added pickups, all vehicles)	39.93
			2023 (EV only)	34.3
			2023 (all vehicles)	38.72
		CA	2020 (all vehicles)	37.92
			2017 (all vehicles)	37.22
			2014 (all vehicles)	36.51
			2023 (all vehicles)	36.68
			2020 (all vehicles)	36.05
			2017 (all vehicles)	35.71
			2014 (all vehicles)	35.36
KS	2023 (all vehicles)	40.08		

Table 20: EUDL for 40' x 62' bay with passenger + cargo vehicles, five turnovers per day

Sample size n	Case	Region	Dataset type	EUDL (psf)	
91250	14-stall bay, vehicle in aisles, added passenger and cargo	US	Forecast 100% converted EV (added pickup)	42.92	
			Forecast 40% converted EV (added pickups)	41.46	
			Forecast 20% converted EV (added pickups)	40.40	
			2023 (added pickups, EV only)	34.97	
			2023 (added pickups, all vehicles)	38.98	
			2023 (EV only)	34.32	
			2023 (all vehicles)	37.83	
		CA	2020 (all vehicles)	37.06	
			2017 (all vehicles)	36.37	
			2014 (all vehicles)	35.69	
			KS	2023 (all vehicles)	35.88
				2020 (all vehicles)	35.26
				2017 (all vehicles)	34.90
			2014 (all vehicles)	34.54	
2023 (all vehicles)	39.12				

Table 21: EUDL for 24' x 62' bay with passenger + cargo vehicles, five turnovers per day

Sample size n	Case	Region	Dataset type	EUDL (psf)	
91250	8-stall bay, vehicle in aisles, added passenger and cargo	US	Forecast 100% converted EV (added pickup)	45.29	
			Forecast 40% converted EV (added pickups)	44.45	
			Forecast 20% converted EV (added pickups)	43.38	
			2023 (added pickups, EV only)	36.21	
			2023 (added pickups, all vehicles)	41.84	
			2023 (EV only)	35.40	
			2023 (all vehicles)	40.55	
		CA	2020 (all vehicles)	39.71	
			2017 (all vehicles)	38.98	
			2014 (all vehicles)	38.24	
			KS	2023 (all vehicles)	38.39
				2020 (all vehicles)	37.73
				2017 (all vehicles)	37.40
			2014 (all vehicles)	37.04	
2023 (all vehicles)	42.01				

As an extremely conservative scenario, it is possible to consider all parking stalls occupied by Hummer EVs, the heaviest vehicle in the dataset with an approximate curb weight of 10,000 lb. This condition is highly improbable, however it provides an upper-bound estimate for critical loading. Assuming 7% added cargo in the parking lane and 17% added passenger and cargo in the moving lane, the EUDL comes out to be 62 psf (40' x 62') and 59 psf (24' x 62'). Although this value is higher than the ASCE 7-22 design live load of 40 psf, it is still less than the factored load of $1.6 \times 40 = 64$ psf that would be used in a design calculation. It might also be noted that due to the width of both the Hummer SUV and Hummer truck, with side mirrors, there would be essentially no space between the vehicles.

9.0 Conclusions

As a result of the comprehensive set of calculations reported in Section 8, the following conclusions are reported:

1. Based on the current US vehicle fleet and a 40' x 62' bay, inclusive of passengers and cargo, adjusting for the undercount of pickups in the S&P Global data, and with five parking turnovers per day, an EUDL of 39 psf is indicated.
2. Examining only the current US EV fleet, the indicated EUDL is 34 psf. A smaller EUDL results despite the fact that the mean EV weight is higher than for ICEs due to the fact that the standard deviation of the EV vehicle weight is less than that of ICEs. This value should also be considered applicable to the case of a bay being entirely occupied by EVs drawn from the present-day fleet. Such bay occupation could be caused by the presence of charging stations or other local conditions.
3. Considering a turnover rate of 5 per day instead of 1 per day results in an increase of approximately 1 psf in the EUDL.
4. A smaller bay size (24' x 62' as opposed to 40' x 62') results in an increase of approximately 2.5 psf. Current ASCE 7 specification is based on the larger bay size.
5. Forecasting EV fleet penetration of 20%, 40%, and using a 700 lb per vehicle EV penalty, EUDL values of 40.5 and 41.5 psf are indicated. Those fleet penetrations are likely several decades into the future for the US market.
6. Considering a possible future EV penetration of 100% leads to an EUDL of 43 psf on the large bay size. This is higher than if the bay is full of current EV's, since the current weight difference between EV and ICE is only 164 pounds, whereas the future scenario uses the 700 pound difference. This 100% scenario can be considered to capture the possibility of a bay that is entirely occupied by future EVs due to the presence of charging stations or other local conditions.
7. A full Monte Carlo stochastic analysis of repeated turnovers with simulated data indicates a live load reduction of approximately 10%.

References

Ang, H. S., and Tang, H. 1984. *Probability concepts in engineering planning and design, Vol. 2—Decision, risk and reliability*. Wiley, New York.

Ahmed, R., Hurwitz, L. J., and Boyd, K. 2025. “EV weight: Is it an issue for design loads?” *Post-Tensioning Institute Webinar of 2025*. Accessed March 26, 2025. <https://ptiacademy.post-tensioning.org/AssetListing/Webinar-EV-Weight-Is-it-an-Issue-for-Design-Loads-11529/Webinar-EV-Weight-Is-It-an-Issue-for-Design-Loads-51638>.

ASCE (American Society of Civil Engineers). 2022. Minimum design loads and associated criteria for buildings and other structures. ASCE/SEI 7-22. Reston, VA: ASCE.

Auto Recycling World. 2025. “What is the lifespan of a vehicle in the U.S.?” Accessed May 10, 2025. <https://autorecyclingworld.com/what-is-the-lifespan-of-a-vehicle-in-the-usa/>.

Corotis, R. B. 1972. “Statistical analysis of live load in column design.” *Journal of the Structural Division*, ASCE, 98(8), 1803–1815. <https://doi.org/10.1061/JSDEAG.0003304>.

Corotis, R. B., and Doshi, V. A. 1977. “Probability models for live-load survey results.” *Journal of the Structural Division*, ASCE, 103(6), 1257–1274. <https://doi.org/10.1061/JSDEAG.0004651>.

Edmunds. 2025. “What is the percentage of electric cars in the U.S.?” Accessed March 26, 2025. <https://www.edmunds.com/electric-car/articles/percentage-of-electric-cars-in-us.html?msocid=125d871d6b146d5b18ae954d6a066c96>.

EPA. 2025. *Automotive trends report*. U.S. Environmental Protection Agency. Accessed March 26, 2025. <https://www.epa.gov/automotive-trends>.

Encycarpedia 2025 “Encycarpedia: Car Specs and Performance” <https://www.encycarpedia.com/>, Accessed March 26, 2025

Forbes. 2025. “Car ownership statistics.” *Forbes Advisor*. Accessed March 26, 2025. <https://www.forbes.com/advisor/car-insurance/car-ownership-statistics>.

Goodcarbadcar 2025, “Good Car Bad Car: Automative Sales Data” goodcarbadcar.com. Accessed March 26, 2025

Hedges & Company. 2025a. “Automotive market research statistics: Auto mailing lists and marketing.” *Hedges & Company*. Accessed March 26, 2025. <https://hedgescompany.com/automotive-market-research-statistics/auto-mailing-lists-and-marketing/>.

- Hedges & Company. 2025b. “Most popular trucks in America: Full-size, medium and compact.” Accessed March 26, 2025. <https://hedgescompany.com/blog/2024/01/most-popular-truck-in-america/>.
- Hurwitz, L. J., Fisher, B., and Schneeman, C. 2024. “Electric vehicles and parking structures.” *Structure Magazine*, July, 22–27. Accessed March 26, 2025. <https://www.structuremag.org/article/electrical-vehicles-and-parking-structures/>.
- JD Power 2025 “JD Power Car Buying Report” www.jdpower.com Accessed March 26, 2025
- Kemper, F. H., Funke, A., and Feldmann, M. (2022). “Revaluation of live load models for parking garages based on measurements, simulations, and extreme value determination.” *Structural Safety*, 96, 102177. <https://doi.org/10.1016/j.stsafe.2021.102177>.
- Liu, Y., et al. 2021. “Comparative analysis of non-exhaust airborne particles from electric and internal combustion engine vehicles.” *Science of the Total Environment*, 786: 147463. <https://doi.org/10.1016/j.scitotenv.2021.147463>.
- MarkLines Co., Ltd. 2024. “USA – Flash report, automotive sales volume, 2023.” Accessed April 1, 2025. https://www.marklines.com/en/statistics/flash_sales/automotive-sales-in-usa-by-month-2023.
- McDonald, J., Moody, J., Perkins, M., and Pobiell, M. 2024. “Engineering infrastructure to support societal resiliency.” *Structure Magazine*, January, 1–11. Accessed May 1, 2025. <https://www.structuremag.org/article/engineering-infrastructure-to-support-societal-resiliency/>.
- New York Times. 2024. “BMW and the electric vehicle shift.” Accessed March 26, 2025. <https://www.nytimes.com/2024/03/09/business/bmw-electric-vehicles.html>.
- New York Times. 2024. “Hybrid and electric vehicles’ growing popularity.” Accessed March 26, 2025. <https://www.nytimes.com/interactive/2024/03/06/climate/hybrid-electric-vehicle-popular.html>.
- PCI (Precast/Prestressed Concrete Institute). 2015. *Parking structures: Recommended practice for design and construction*. Chicago, IL: PCI.
- S&P Global. 2025. *Vehicle fleet dataset in U.S., California and Kansas from 2014 to 2023*. Accessed via paid subscription, S&P Global Mobility, New York, NY.
- Statista. 2025. “Change in U.S. car demand by vehicle type.” *Statista Research Department*. Accessed April 1, 2025. <https://www.statista.com/statistics/276506/change-in-us-car-demand-by-vehicle-type>.
- TheDriven 2025 “Australia’s most Trusted EV news site” <https://thedriven.io> > 2024/05/03 Accessed March 26, 2025

The Economist. 2024. “Americans’ love affair with big cars is killing them.” Accessed March 26, 2025. <https://www.economist.com/interactive/united-states/2024/08/31/americans-love-affair-with-big-cars-is-killing-them>.

Turkstra, C. J. 1970. *Theory of structural design decisions (SM Study No. 2)*. Solid Mechanics Division, University of Waterloo, Waterloo, Ontario, Canada.

U.S. Dept. of Transportation, Bureau of Transportation Statistics; and U.S. Dept. of Commerce, Census Bureau. 2023. “Vehicle stats by state, vehicle type, and GVWR: 2021 vehicle inventory and use survey.” Accessed March 26, 2025. <https://www.bts.gov/browse-statistical-products-and-data/surveys/vius/vehicle-stats-state-vehicle-type-and-gvwr>.

Wen, Y. K., and Yeo, G. L. (2001). “Design live loads for passenger-car parking garages.” *Journal of Structural Engineering*, 127(3), 280–289. [https://doi.org/10.1061/\(ASCE\)0733-9445\(2001\)127:3\(280\)](https://doi.org/10.1061/(ASCE)0733-9445(2001)127:3(280)).