MODERN VEHICLE AND PARKING GARAGES: DESIGN TRENDS PRESENT NEW CHALLENGES

Authored by: Victoria Hutchison, Fire Protection Research Foundation, USA
Haavard Boehmer, PE, Combustion Science & Engineering, USA

Introduction

The world’s urban population has risen six-fold since 1950, with over half of the world’s population – approximately 4.2 billion people – living in cities worldwide [1]. As the world undergoes a historic urban growth, ensuring city’s infrastructure keeps pace with the respective population density is critical.

In highly urbanized, developed regions of the world, a lifestyle of mobility is a priority. With mobility, comes the need and desire for vehicles, as evidenced by the nearly 2 billion vehicles registered throughout the world [2]. And this volume of vehicles drives the need for parking solutions. While parking garages are abundant in practically every city on the planet, urbanization is prompting changes to vehicle parking to optimize the quantity that can be parked within a given footprint. As developers look for parking solutions in areas where land is immensely valuable, the area afforded to each vehicle is reduced, and stackable garage configurations are gaining popularity as automation and mechanization become more advanced and affordable.

But parking garages are not the only thing that has changed; vehicles have undergone a substantial transformation in their design over the last few decades as well. Government efficiency standards, in the US, Europe and China, are influencing the trends in modern vehicle design. According to the National Highway Traffic Safety Administration’s (NHTSA) Corporate Average Fuel Economy (CAFÉ) standards, passenger vehicles are expected to average 54.5 miles per gallon (4.3 L/100 km) by 2025 in the US [3]. European standards have set a target of 37.5% reduction in CO₂ emissions between 2021 and 2030 [4]. These global efficiency goals have
pushed automotive manufacturers to increase use of plastics and other synthetic materials to produce lighter and more fuel-efficient vehicles. Likewise, environmental goals have led to increased use of alternative fuel vehicles, such as battery electric, hydrogen fuel cells, liquified natural gas (LNG), and other emerging technologies. With so many changes to materials and fuel sources used in the design of vehicles today, it has been confidently hypothesized that modern vehicles will behave differently in a fire.

Vehicle fires developing into large, out of control events in parking structures have historically been rare [5]. But the catastrophic King’s Dock Car Park fire in Liverpool, England in 2017 caught everyone’s attention in the fire safety community. A 4,930 m² (53,000 ft²), open-air, concrete parking garage was decimated by a fire starting in a single vehicle, which spread to over 1,150 vehicles across eight-stories [6]. The fire brigade was overwhelmed in every sense. Incidents like this have raised questions among the engineering and regulatory communities regarding whether the protection guidance for parking structures has kept pace with the evolution of the vehicle hazards and parking structure designs. While the benefits of fuel-efficient vehicles and spatially optimized parking structures are clear, researchers and code developers remain concerned about what such densely packed arrangements of modern vehicles may mean for fire protection.

To address these concerns the Fire Protection Research Foundation, in collaboration with SFPE Foundation, initiated a research project in 2019 to assess the “Impact of Modern Vehicle Hazards on Parking Structures and Vehicle Carriers” [7]. With the intent to inform fire protection schemes and design parameters for parking structures, this recently released study, led by Combustion Science and Engineering, details an analysis of the fire hazards posed by modern vehicles, the effect of changes in vehicle and parking garage design, and the factors that most significantly impact fire development and spread.

**Current Protection Requirements**

Vehicle parking structures are largely regulated by NFPA 88A, *Standard for Parking Structures* [8], the International Building Code (IBC) [9], or region-specific regulations such as Eurocodes, among others. NFPA 88A and the IBC are aligned on many of the regulations regarding parking structures, such as:

- Open parking structures are defined as those with greater than 20% of the exterior wall area open to the outside, with the openings evenly distributed across the wall area.
- Both standards require sprinklers in enclosed garages if they are underground or over 15 m (50 ft) high. NFPA 88A also requires automated type parking garages, such as stacker systems, to be sprinklered.
- Sprinklers and detection systems are typically not required in open parking garages if they are constructed of non-combustible or limited-combustible materials. The 2021 edition of the IBC will require sprinklers in open garages greater than 48,000 ft² (4,459 m²) or 55 ft (16.8 m) in height. Most national codes within the EU require sprinkler protection in open garages above a certain floor area, height or when located below a hotel or assembly occupancy.
While these standards are regularly updated, the fire protection criteria for open parking structures has seen minimal change over the years. Modern vehicles have evolved greatly since these regulations were originally established, yet garages are still being designed based on data from 50+ year old vehicles. While vehicle-to-vehicle fire spread had a low probability in the 1960’s, this is no longer true today.

Assessment of Modern Vehicle Fire Hazards in Parking Structures

With the pace of technological innovation and material advancement in our society, the evolution of vehicle fire hazards is not surprising. To make vehicles more affordable, safer, lighter and more fuel efficient, parts that were historically metal, cast-iron or aluminum, are now made of plastics or fiberglass. Everything from bumpers to gas tanks to the intake manifold in the engine are now made of plastics, and these trends are expected to continue. On the interior of the vehicle, many combustible and synthetic materials are used, and the increase in electronics presents additional fuel and ignition sources.

Developers and designers predict construction trends to go towards larger garages and increasing integration into other occupancies. Parking density will continue to increase as automation, mechanization and car stacking systems are normalized. Beyond construction changes, many garages are also integrating electric charging stations and photovoltaic systems into their designs – presenting additional hazards. So, what does this mean for the fire hazard of modern vehicles in parking garages?

Modern versus legacy vehicles and changing materials

The peak heat release rates (HRR) of modern vehicles were found to not be significantly higher than legacy vehicles. However, it was found to be highly dependent on the test conditions such as the vehicle size, the type and placement of the ignition source, ventilation conditions and the configuration of the vehicle and its surroundings, as HRR above 7 MW were found in vehicle fire tests from every decade since 1970.
Vehicles more than 15-20 years old show a significant difference in average curb weight and plastic content, when compared to modern vehicles. The average US vehicle in 2018 contained 91% more plastic by weight than the average vehicle in 1970. Using the average heat of combustions of the plastics used, this yields an equivalent increase in potential chemical energy in a fire of approximately 2,300 MJ. While the fire intensity and total energy released from vehicle fires of varied ages has remained relatively constant, the changes in construction materials have reduced the time to ignition, increased the probability of spread, and altered the behavior of fire development.
Historical data has shown that a fire spreading to multiple vehicles was rare. Between 1995 and 1997, 98% of parking structure fires involved less than four vehicles, and none involved more than seven. By contrast, 14% of parking structure fires involved more than five vehicles in 2014 [10]. Past regulations assumed that fire spread from one vehicle to another would not occur, and if it did the fire department would arrive in time to control it [6]. However, the densely packed fuel loads in parking garages heightens the risk of fire spread among modern vehicles due to material changes, increase in vehicles dimensions, and tighter parking arrangements. Although limited, available test data has shown rapid fire spread between vehicles in a parking garage configuration, on the order of 10-20 minutes. Once two or more cars are involved, the time to ignition of additional vehicles is dramatically reduced (less than 5 minutes) [7].

Another concern is that plastic fuel tanks can begin to show signs of failure after a 2-5-minute pool fire exposure, which can result in a flowing liquid fire that exacerbates fire spread. As more vehicles become involved, the prolonged high-temperature exposures on the load-bearing structural elements can threaten the integrity of the structure. At the Liverpool incident, the constant high temperature exposures caused significant spalling of the concrete, which typically occurs when the internal temperature exceeds 374°C (705°F). This created large penetrations in the floor which contributed to vertical fire spread. The ceiling level temperatures experienced from an inferno of modern vehicles can also cause failure of structural steel. Once it exceeds its critical threshold of 538°C (1000°F) the load bearing capacity is reduced to half and may compromise the structure. As seen in the Stavanger Airport fire in Norway (2020), these conditions can lead to structural collapse of a multi-story parking structure.

The trends in contemporary parking solutions combined with the evolving hazard of modern vehicles has the potential to create the perfect storm for catastrophe if the appropriate protection measures are not in place.

**Recommendations for Future Research**

From this analysis, the following areas were identified as needing additional research:

- The factors contributing to a higher probability of vehicle-to-vehicle fire spread.
- Clarity on the “open-parking structure” definition. The location of the opening can have a significant impact on the development of the fire and the hot gas layer. Testing and modeling are needed to evaluate different opening configurations, placements and open percentages to assess its impact on fire behavior.
- Further assessment on the effectiveness of sprinkler protection on modern vehicle fires in normal parking configurations as well as car stackers.
- Impact of wind on sprinkler activation in open garage configurations.
- Impact of vehicle fires on concrete spalling.

**Conclusions**
Based on a review of historical fires and laboratory testing, this analysis of modern vehicle fire hazards in parking structures found that where active protection systems are required, such as in enclosed garages, incipient or fully developed vehicle fires can generally be controlled until the fire department arrives. However, where active protection systems are not required, such as in open parking garages, vehicle fires have a greater probability of developing into large or catastrophic fires due to the increased fire spread rate of modern vehicles. The trends in both vehicle and parking structure designs could lead to more devastating fires, increased property losses, business disruption and adverse environmental impacts if protection schemes do not keep pace with the evolving hazards.

References


