Identifying Real World Barriers to Implementing Lightweighting Technologies and Challenges in Estimating the Increase in Costs

CENTER FOR AUTOMOTIVE RESEARCH

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This document represents CAR's analysis and viewpoint as to the challenges of lightweighting based on CAR expertise with input from a broad population of engineers and other knowledgeable consultants and analysts. CAR is extremely grateful to all those involved for their willingness to contribute their knowledge, insights, examples and critical feedback.

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CENTER FOR AUTOMOTIVE RESEARCH

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Executive Summary

Automakers have made great strides in lightweighting vehicles as a means to help achieve greater fuel efficiency. The purpose of this paper is to present a perspective from the standpoint of automotive manufacturers about the challenges that need to be considered and overcome in implementing new, lightweighting technologies. These technologies range from new low-density material, new joining methods, or processes for optimizing design with less weight. Without exception, automakers have pushed back on independent studies and analyses that have suggested vehicle weight reduction can be achieved quickly at very low cost, or even removing costs, and without risk to performance or safety. No engineer designs a component or system where the only focus is to reduce weight. Automotive engineers have to design new vehicles within the framework of an organization with many complex and often competing objectives. By its nature, the auto industry is risk averse because of the severe consequences of making a mistake. Most components for mass-produced vehicles cannot simply be "optimized" for mass, and a cushion of over-engineering is often warranted given the consequence of a high-volume failure in the marketplace. What is feasible in the laboratory, on a design screen, or in a singular mass optimization study does not necessarily translate to what is practical in production. Robust supply chains are needed with global capabilities, engineering development can take years, and even the repair infrastructure needs to be considered when a new technology is implemented. Researchers at the Center for Automotive Research have over 25 years of experience working to support cost-effectively implementing lightweighting technologies. This paper represents many common manufacturing viewpoints as to the challenges faced for continued lightweighting based on CAR expertise with input from a broad population of engineers and other knowledgeable consultants and analysts. The intent is <u>not to say</u> that additional lightweighting cannot be achieved, but that implementing new lightweight technology for broad scale mass production takes longer and costs significantly more than what many non-automotive producers believe is practical.

Because much of the low-hanging fruit has already been implemented, vehicle manufacturers face real-world challenges in finding cost-effective ways to continue implementing further mass reduction solutions needed to offset weight gains due to increased demand for comfort, convenience, and safety technologies. Regulators are evaluating the potential of lightweighting as a way to improve fuel economy without compromising safety, but among manufacturers and regulators, there is a wide range of opinions about what are the real world costs of achieving greater weight reduction. This is due in large part to the fact that every vehicle model has numerous attributes affecting lightweighting that are unique to that model. "Proof of concept" studies are focused simply on the goal of mass reduction without being constrained by the real world factors such as time and the development process to qualify new materials, the cost of changing over existing manufacturing infrastructure, global platforms, and consumer demand for additional vehicle content.

The result is conflicting information about real-world circumstances impacting lightweighting and how much it may actually cost to achieve. This report is the first in an ongoing analysis by the Center for Automotive Research (CAR) intended to offer perspectives on implementing technologies that can contribute to reducing emissions and improving fuel economy.

The desire to reduce vehicle weight is as old as the vehicle itself. It's difficult to fathom a situation where adding weight and holding everything else constant results in a better vehicle. Lighter cars can be safe and perform better than their heavier counterparts. But in many cases, the heavier counterparts have the advantage of lower cost, and sometimes better drivability in terms of noise, vibration, and stiffness. So, how can the real cost of lightweighting the U.S. fleet be accurately evaluated without adversely affecting important attributes that the consumer demands?

CAR has completed a series of targeted, in-depth interviews with automotive engineers from six automotive manufacturing companies, as well as leaders in multiple consulting organizations to gain greater industry insight into this issue. Feedback from the interviewees consistently focused on the following primary barriers faced by manufacturers:

- The time and development process required to qualify new materials, develop math models for their behavior, and derive appropriate product specifications.
- The industry trend for global automakers to develop global platforms that use common parts across vehicle models made in multiple locations, thus inhibiting individual vehicle model optimization.
- The established infrastructure with its sunk costs favors steel and steel processing, and limits the speed of introduction of new materials. This is true for computer-aided engineering design, simulation tools, prototype builds, fabrication, assembly and the paint shop, for examples.
- Consumer demand (as well as requirements to meet new regulations) for additional vehicle content. Ride and handling quality are highly competitive differentiators in the market. While lighter cars generally handle better, other tradeoffs arise from lightweighting such as structural stiffness issues, transmitted noise, and vibrations that get introduced by the use of lightweight materials.
- The financial, technical and timing resources to develop a new vehicle are significantly constrained, which limits the breadth of alternatives that can be evaluated on a single launch.
- Further, the lack of an established baseline vehicle which viably represents the U.S. fleet in terms of lightweight technologies makes accurately estimating the average technology implementation, and therefore fleet cost, nearly impossible.

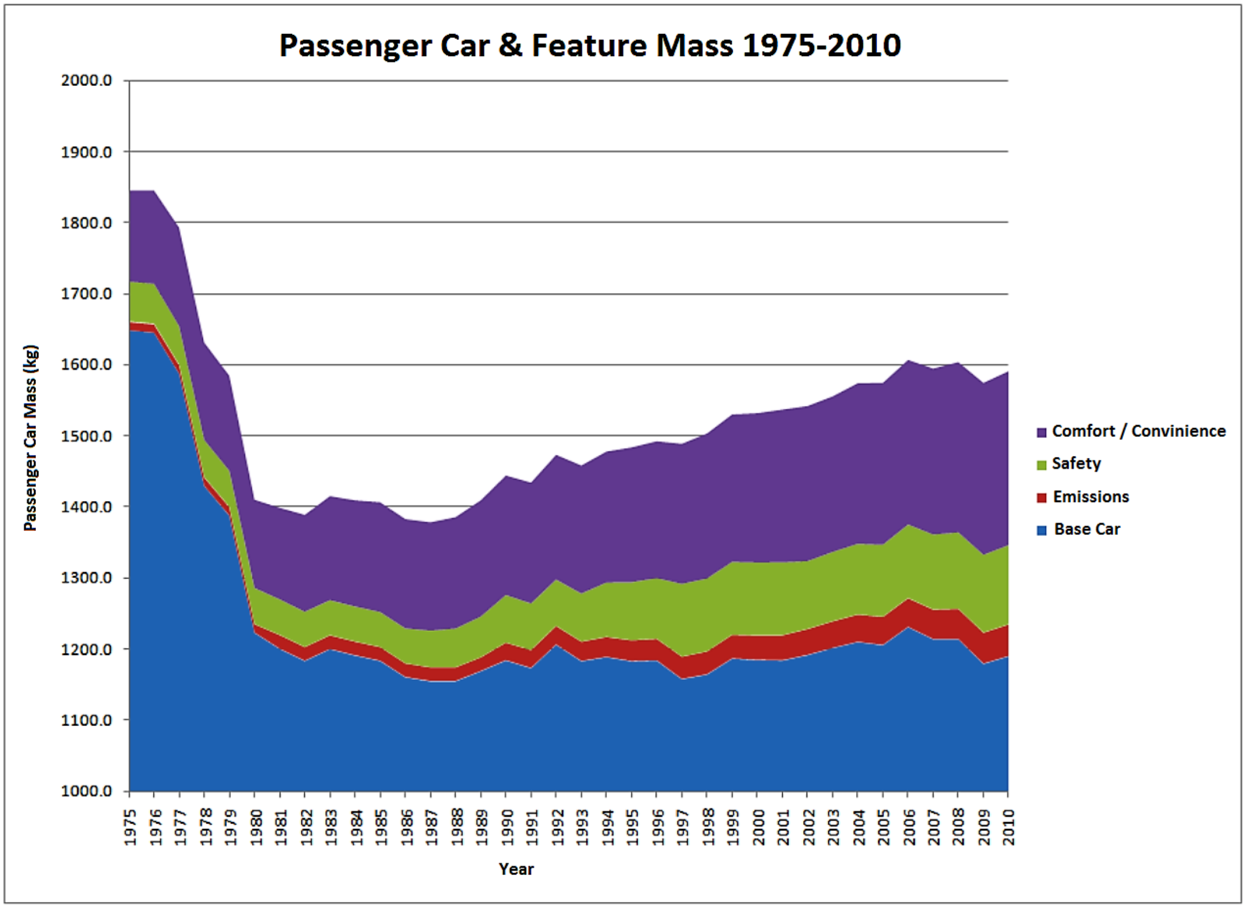
Since it is broadly recognized that lightweighting is cost-constrained, the cost to overcome these barriers is central to the discussion about how much lightweighting is appropriate and cost effective. This overview will provide an introduction to identifying manufacturing barriers and will serve as the backdrop for additional CAR research under way which focuses on quantifying the barriers' impact on cost and timing to implement new lightweighting technologies.

The Drive to Lightweighting:
Implementing Lightweighting Technologies - Real World Barriers and Estimating Increased Cost

Automakers are urgently striving to lightweight cars in the quest to meet aggressive fuel economy and emissions regulations. While there have always been efforts to reduce weight, regulations today are urging greater effort and investment than may have previously been pursued without regulations.

Historically, over the past 30 years, the average vehicle weight has increased as performance features, infotainment and driver support systems have improved along with advancements in safety and emissions reduction. Vehicles today accelerate and stop faster, ride quieter, and handle better than older cars. They are also safer and consume less fuel. The abundance of weight has been added because of consumer demand for comfort and convenience items (see Figure 1).

Figure 1: Mass of passenger cars 1975-2010 and weight attributed to Safety, Emissions, and Comfort/Convenience features (Secondary mass included)



Source: Stephen M. Zoepf, Automotive Features: Mass Impact and Deployment Characterization, Massachusetts Institute of Technology (MIT) 2010

Along with this added content, today's vehicles have evolved with a complex mix of many materials (steel, aluminum, composites, plastics, magnesium, cast iron, etc.), and this increasing use of a variety of materials has mitigated much of the additional weight gain from additional content.

Many factors affect the rate of introduction of new materials, including cost. For this reason, premium vehicles tend to have more advanced materials because the pressure to minimize cost is less. **Lightweighting has been cost constrained – not technology constrained – for conventional automobiles.** The typical strategy by companies to minimize cost and risk from introducing new technologies was to specialize in different materials. For example, some manufacturers developed expertise by specializing in 1) steel (mild and high strength), or 2) aluminum, or 3) advanced materials such as composites. Everything else being equal, vehicles cost more and weigh less along these material subgroups, with low-cost mild steel being least expensive and advanced materials being most expensive. Most vehicle manufacturers are recognized as being very good at one or two of these material subgroups.

Companies that excel in these subgroups learn how to design, source (supply chain), fabricate and assemble these unique and specialized materials cost effectively in mass production. In the United States, there are more than 1,300 vehicle models on the road today with examples from each of these material classifications.

A challenge that this diversity of vehicle technologies creates is trying to estimate today's baseline of lightweighting technology in the overall U.S. fleet. **There is no single cost estimate (cost per pound) for lightweighting that can be applied to the vehicle fleet.** This fact is noted by the recent National Research Council study,[1] Finding 6.9 which identifies the limitations in applying lightweighting cost estimates (derived from vehicle-specific studies) to the average for the U.S. fleet. Automakers are concerned that using cost estimates from a lower-technology automobile (e.g., group 1) and applying it to a vehicle in a higher technology level (e.g., group 2) would significantly understate lightweighting cost.

Two concerns arise when lightweighting engineering analyses are performed by independent (non-automotive) companies in an attempt to estimate lightweighting costs for the U.S. fleet. Independent studies on the Toyota Venza, Honda Accord, and GM Silverado (see references) are all examples where excellent analysis was performed to "optimize" lightweighting possibilities on existing vehicles. However, paper studies conducted by companies that do not manufacture vehicles are not subject to the same constraints as an automotive company. Constraints include, for example, the risk of failure of newly deployed technologies, shared parts and engines across multiple car lines, and the lack of a well-established and competitive global supply chain. Further, the starting level of lightweighting technology inherent in the studied vehicle is dated, and how it compares to the overall U.S. fleet is uncertain. Is the Toyota Venza average, below average, or above average as compared to the fleet? The following section further elaborates on these issues.

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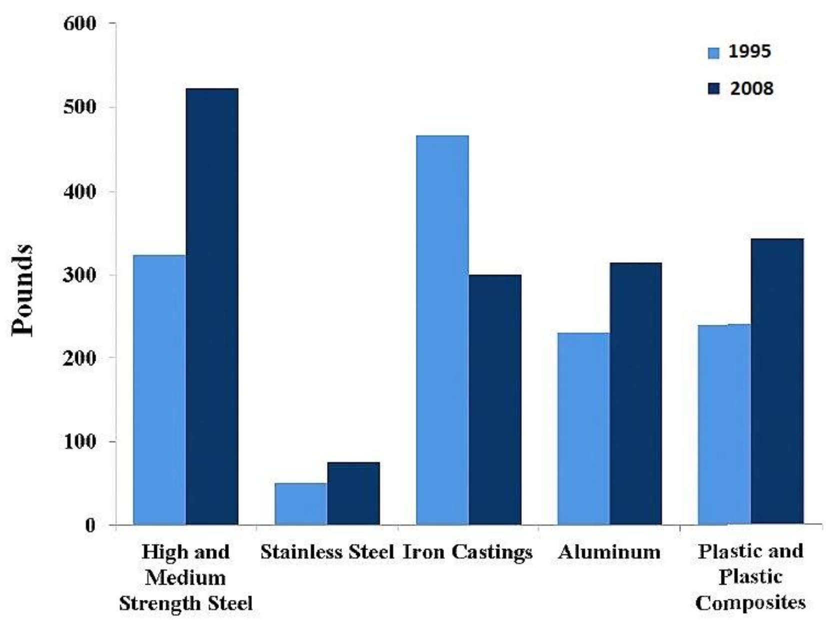
[1] "Cost, Effectiveness, and Deployment of Fuel Economy Technologies for Light-duty Vehicles," National Research Council, June 2015.

Lightweighting is Not New

The objective to reduce vehicle weight is as old as the vehicle itself. It's difficult to fathom a situation where adding weight and holding everything else constant results in better performance. Henry Ford is quoted as saying, "I cannot imagine where the delusion that 'weight means strength' came from." As groundbreaking as the new aluminum body Ford F-150 is, Ford actually introduced an aluminum sedan in 1923.[2] After the aluminum Fordor, Ford experimented with a plastic body in the 1940s, steel bodies in the 1950s, and mixed materials (steel, aluminum and plastic) in the 1960s. New materials with alternative fabrication and joining processes are evolving all the time. The figure below illustrates one estimate for the rate of introduction of advanced materials from 1995 to 2008.[3] Some steel companies consider today's all-steel vehicles a mixed-material vehicle because there are so many different grades of steel in the vehicle based on the functional requirements of each part. According to Arcelor Mittal, there were five grades of steel available in 1960, and today there are over 175 grades, allowing for a much more optimized structure balancing weight, cost, and safety. Materials losing favor are cast iron and mild steel (not shown), which are lower in cost than high-strength steel, aluminum, and most plastic composites, but not as effective at weight reduction than other higher cost materials.

Figure 2: Growth of Advanced Materials in Automotive for Lightweighting and Safety



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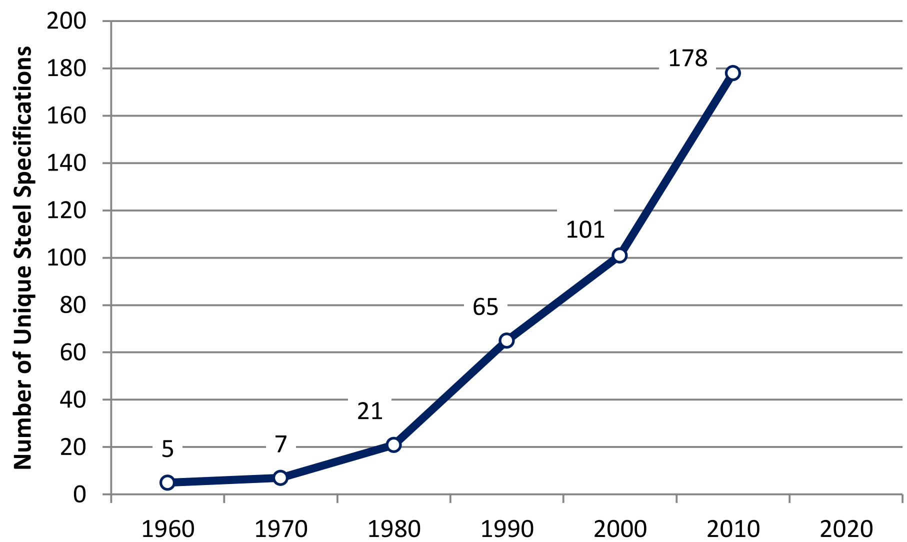
[2] http://www.at.ford.com/SiteCollectionImages/2014_NA/jun/Ltwght%20Innvtn%20Timeline.pdf
[3] NRC: Cost, Effectiveness and Deployment of Fuel Economy Technologies for Light-Duty Vehicles - June, 2015 – Figure 6.1

Figure 3: Growth in Steel Grades – Higher Strength Steels



Source: "The Evolution of AHSS in Automotive Body Structure Design" - Dr. Blake Zuidema, Arcelor Mittal

New Technology Qualification Takes Time

The first high strength low alloy steels for automotive use were developed in the early 1980s. At that time, many problems had to be overcome in design, development, and production. The steel industry has been productive at developing additional grades of high strength steel, with strengths roughly 3 to 4 times the early mild steels. However, every new grade must be qualified. New metal grades of steel and aluminum must be qualified when first introduced into production. The qualification process for testing, setting specifications, developing new modeling software, and repair is even more challenging for newly advanced composite materials.

As new materials (and related processes such as digital modeling, prototyping, tooling and fabrication, and assembly processes) are developed, there is an extensive development lead time before they are introduced into mainstream products. Fragile supply chains, especially if global, for suppliers often take years to materialize. Although the industry can motivate the supply base to mature and become competitive, early innovation is often in the position of a single supplier for several years that, if sourced, has the potential (unintentional or not) to shut down production for an entire platform of vehicles. Known materials today that need development before being designed into a vehicle have a development timeline of approximately four years.

The following 5-phase process is typical for the development timeline of a new material:

1. 3 to 6 months: procure materials for test.
2. 6 months: preliminary characterization of materials: mechanical and strength tests, joining studies, microstructure analysis
3. 12 to 18 months: detailed characterization of materials, strain rate behavior, fracture testing, formability analysis, reliability/fatigue testing, environmental durability
4. 12 to 18 months: production readiness analysis. Validate CAE models, repair capability strategies, develop material specifications, identify sourcing strategies and qualify suppliers
5. 3 to 6 months: Finalize material qualifications. Document material development results.

Total lapsed time for qualification is three to four years.

Consequently, when looking at future readiness of materials, something that may be available in, say, 2017, may not be ready for production until 2021. Since a new material will not be designed into a new vehicle until the new material is known to be ready for mass production, an additional two to four years beyond 2017 would be likely, resulting in a maximum of six- to eight-year total delay before the material is in new vehicles. There are some lightweight materials that are not widely used today in auto that have already been partially qualified and can more speedily be introduced should a manufacturer wish to do so.

Global Platforms Limit Flexibility and Optimization Opportunity

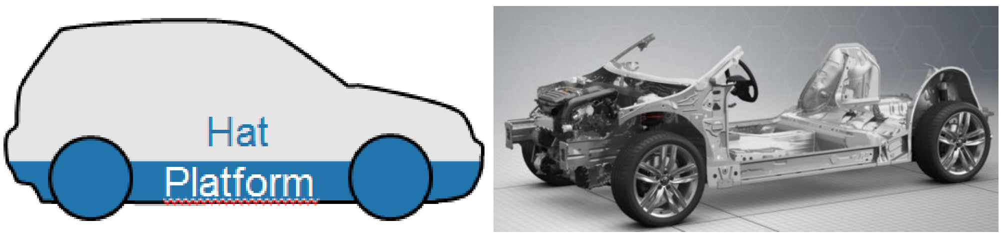
Global platforms are designed by auto manufacturers to enable large scale, high volume mass production which seeks efficiencies through standardized common components with an emphasis on containing cost, reducing risk and ensuring quality. However, this approach naturally limits manufacturers' ability to optimize every component in each vehicle for mass because of common parts and conflicting global market requirements. "Optimized" lightweighting studies that start with a clean-sheet design neglect the reality that many parts/components serve a function on multiple models of vehicles. **In practice, the most optimized vehicles are "one-off" specialty vehicles** such as high performance cars designed for low production quantities. One-off vehicle designs can better bear the risk of failure (or consumer acceptance) of new technologies too. There are insufficient resources to optimize all vehicle models on all global platforms at the same time; this would nullify the objective of the platform strategy. The development of global platforms is resource intensive. Even though the F-150 is a North American vehicle, its development likely required resources drawn from other mainstream vehicle development programs.

Platforms are typically developed with consideration for the models that will be made from them, but usually separately. **Independent development of the platform and the top hat (see Figure 4) prevent design optimization opportunities for the whole vehicle.** It is estimated that 30% of the vehicles produced in 2013 will be made on global platforms (Sedgwick 2014) and this number is continuing to increase.[4] Ironically, as the use of global platforms increases, the number of global platforms has decreased because more vehicle models (also known as top hats) are produced from a given platform.

[4] Global Platforms – David Sedgwick, August 4, 2014, Automotive News

IHS estimated that the top 10 global manufacturers reduced the number of platforms by 20% (from 22 to 18) from 2004 to 2014, while the number of model variants increased 30% (from 2.5 to 3.3) made from global platforms during this time.[5] All global automakers have projected continued growth of global platforms in the coming years.

Figure 4: Typical Global Platform Structure Shown Without the Top Hat



The automotive industry is experiencing significant growth in the use of global platforms motivated as a way to reduce cost and increase engineering efficiency. Recently, Ford announced it will reduce its number of platforms from 15 to nine by 2015, and that those nine platforms will account for 99 percent of the vehicles they manufacture. General Motors announced even more aggressive plans to reduce its number of platforms from 26 to four, and Volkswagen has indicated that it plans to produce 40 different vehicle models globally on a single vehicle platform. Other companies such as Volvo, Nissan-Renault, BMW, and Toyota[6] are in the process of executing their own versions of global platforms. Each manufacturer is developing its own methods and focusing on different areas of the vehicle to standardize. The standardized platform facilitates more efficient sourcing since suppliers can accelerate development because they know aspects of the platform before the vehicle is fully designed. This reduces cost and lead-time for launching the vehicle. While there are potential benefits that may be realized by increasing economies of scale and reducing cost and time to develop new model variations, there are also potential limitations such as the reduction of design flexibility and sub-optimal vehicle design. Vehicle platforms are designed to accommodate certain component modifications, but generally not new major technology advances. By design, the platform constitutes the most complex structural portion of the vehicle for standardization, typically including the underbody, portions of the engine compartment, and chassis. It is estimated that the top 10 global platforms will account for over 200 vehicle models by 2017.

There are a number of methods in which vehicle manufacturers are developing global platforms. For example, the modular transverse matrix (MQB)[7] developed by Volkswagen, established a uniform mounting position for all engines and a standardized front carriage structure while allowing Volkswagen

[5] "Global Platform Shift Creates Opportunity for Aftermarket, IHS Automotive Reports," November 5, 2014, http://press.ihs.com/press-release/aapex/global-platform-shift-creates-opportunity-aftermarket-ihs-automotive-reports
[6] "Like its rivals, Toyota revises product development," Automotive News April 2012
[7] "Volkswagen Group MQB Platform," https://en.wikipedia.org/wiki/Volkswagen_Group_MQB_platform

to produce models with different wheelbases and track widths on the same assembly line.[8] Likewise, Nissan-Renault has developed its common module family (CMF), an architecture based on the assembly of compatible modules for the engine bay, cockpit, front underbody, rear underbody and electrical/electronic architecture. Although these new methods do not necessarily fit the definition of a typical platform, they share the common goal of increasing commonality and standardization across vehicle models (increasing economies of scale and standardizing supply chains). The resulting reduction in unique engineering content and components across different models reduces cost, while maintaining product choices for the consumer. In some cases, this can also result in over-engineered parts (designed for the greatest application load).

Global platforms are engineered to anticipate the introduction of various future modifications to the platform as technology advances or other changes are desired. The platform design might limit the ability to implement some changes, but expedite the implementation of others that fit within the standard design, reducing development costs. However, since global platforms produce vehicles for different countries, usually technologies unique to just one country (powertrain performance, emission controls, etc.) are not included in the platform design. Vehicle manufacturers see global platforms as a way to maximize efficiency and reduce cost over a wide range of vehicle models. Nissan-Renault estimated that it will reduce engineering costs by 30 to 40 percent and part costs by 20 to 30 percent by moving to the CMF system. Volkswagen has also estimated that its MQB could cut production cost by as much as 20%. The primary objective of the global platform is to reduce costs through economies of scale. Some regulatory technologies may benefit from platforms, whereas some may not because of differences in different countries. (For example, different crash standards in one country may prevent a technology from being applicable in another country.) A vehicle platform is essentially the basic building block of components and systems from which a vehicle can be built. Increasing the number of vehicles shared on a single platform – which accounts for nearly half of the product development cost – can significantly reduce engineering cost. Similarly, purchasing and tooling cost can be reduced through economies of scale of component sharing and single sourcing of equipment.

The scale of a platform is a critical factor in implementing change. Global platforms are almost always produced at different facilities and in different countries. One advantage Ford had with converting the F150 platform to high strength steel and aluminum body was that the two plants which produce the vehicle are both located in the United States have similar facilities and the same suppliers. Other platforms can be far more complex. The Honda Accord is produced in six factories in three different countries, and the Chevy Cruze with a global platform is produced in 10 different facilities--in 10 different countries. Not only are the vehicles standardized, certain aspects of manufacturing plants are standardized to reduce cost, improve quality and support faster vehicle launches. Global platforms are sold in different countries with different regulations, road conditions, and consumer needs; all of which constrain a single optimal design. And the ability to coordinate the implementation of changes in a global footprint is extremely difficult. In many cases, each factory has a unique vintage of paint

[8] "Volkswagen plans 4 million cars from one platform: VW's modular unit will be the basis for more than 40 models worldwide," Autoweek, April 2012, http://autoweek.com/article/car-news/volkswagen-plans-4-million-cars-one-platform-vws-modular-unit-will-be-basis-more-40

technology (operating at different speeds and temperatures). Different materials, particularly composites and adhesives, cannot be subject to some paint shop temperatures, so the common design has to be sub-optimized to be producible in all facilities.

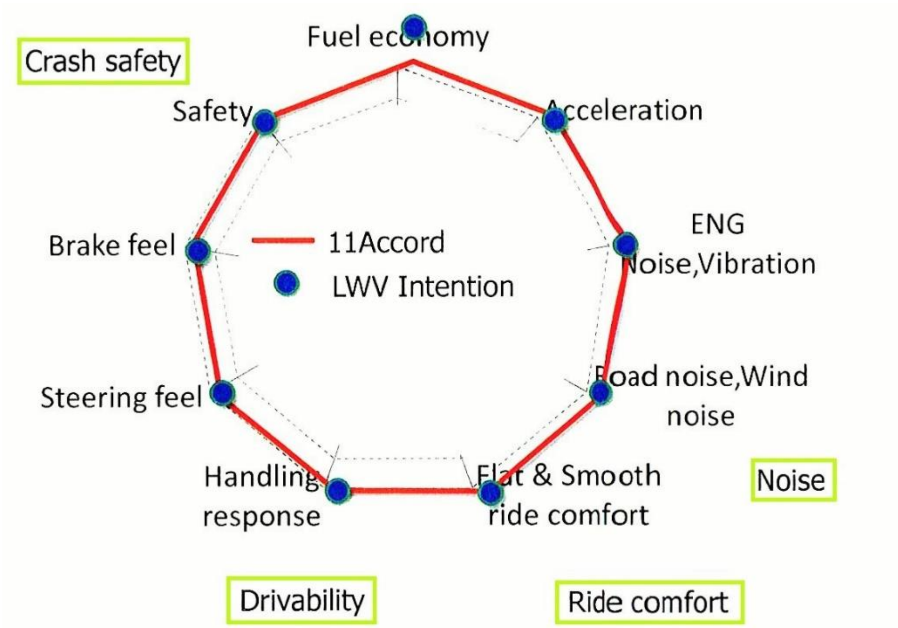
While the impact on lightweighting by global platforms can be mixed, the overwhelming effect is to constrain model optimization. Global platforms are not designed with the intent of adding incremental innovation because of the cross-model complexity and global production differences. Models with smaller powertrains or that are entry level with less content often have over-engineered components because of higher-end models. It would be a rare situation to identify lightweighting technology that is both economically and technically viable across lower- and higher-end models on the platform if it was not designed in from the start. As cited earlier, other hurdles include global availability of materials, differences in manufacturing processes across manufacturing facilities and paint-ability. In some cases the application of a technology must be reduced to the lowest common denominator in terms of functionality, cost and availability.

Vehicles are Designed with Many Attributes

When asked why optimized lightweighting studies can produce more mass efficient vehicles than auto manufacturers, the common answer is, "the consultants are not working with constraints" (the consultants acknowledge this). The typical consultant charge is to design a mass-optimized vehicle with technologies that are likely to be available in the future. Some anticipated materials may be available at the stated date, but may not have passed through the development process described earlier. Auto manufacturers do not design cars to optimize for mass; if they did, consumers would reject those vehicles for performance among other compromises. The majority of new cars have significant carryover content from previous models. In most cases, the powertrain is also a standard powertrain used across many vehicle models (with adjustments). One engineer referred to the co-development of a new vehicle model simultaneous with the development of a dependent powertrain to be a "perfect storm." Seldom do two development schedules coincide.

Vehicle performance represents perhaps one of the most competitive differentiators between different vehicles in which the consumer makes a selection. Given the competitive importance of ride and handling performance, automakers are very sensitive to technologies that affect this metric. Substituting advanced materials may be structurally sufficient, but adversely affect ride and handling, thus requiring various countermeasures to mitigate this unintended impact. In a presentation made by Honda in regards to the independent lightweighting study made on the Accord, Honda identified several metrics where the light-weighted vehicle made compromises including: ride and handling, noise, vibration, handling response, comfort and safety. (See Figure 5.) Honda emphasized that the complexity of structural crashworthiness is extremely difficult (and expensive) to assess because of the many interactions of vehicle subsystems, and rejected aspects of the lightweight design. Several of these compromises would negatively impact consumer acceptance and therefore the vehicle's competitive position.

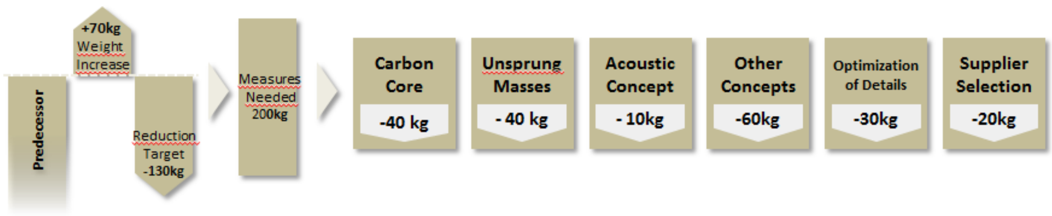
Figure 5: Honda Analysis of EDAG Lightweight Honda Accord



Source: Honda's Study & Report on the Study Commissioned by NHTSA "Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025" - Chuck Thomas, Honda

For competitive reasons, manufacturers design new vehicles with improved performance; these criteria represent major differentiators in meeting consumer preferences. Performance attributes can affect many features, such as those mentioned above for the Honda Accord. As pointed out by Honda, a focus solely on lightweighting will compromise these attributes to the detriment of consumer satisfaction. The new BMW 7-Series was recently launched, with added improvements that lower the vehicles' total weight, lower the center of gravity (to improve handling and safety), improve weight distribution over the two axles (handling), and reduce unsprung mass (ride quality). Achieving these objectives increased mass by 70 kilograms over the previous model, from which new mass reduction technologies were applied to bring the net mass change to -130 kilograms (see Figure 6 below). The lightweighting efforts, while netted at -130 kilograms, actually had to reduce vehicle weight by 200 kilograms after the performance improvements were implemented. **Vehicle manufacturers have to improve vehicle performance to remain competitive, often increasing mass requirements before they apply lightweighting technology**. The idealized mass reduction studies (e.g., 2009 Toyota Venza, 2011 Honda Accord and the 2011 GM Silverado) apply future lightweighting technologies to old vehicle performance levels that are inconsistent and would result in non-competitive vehicles.

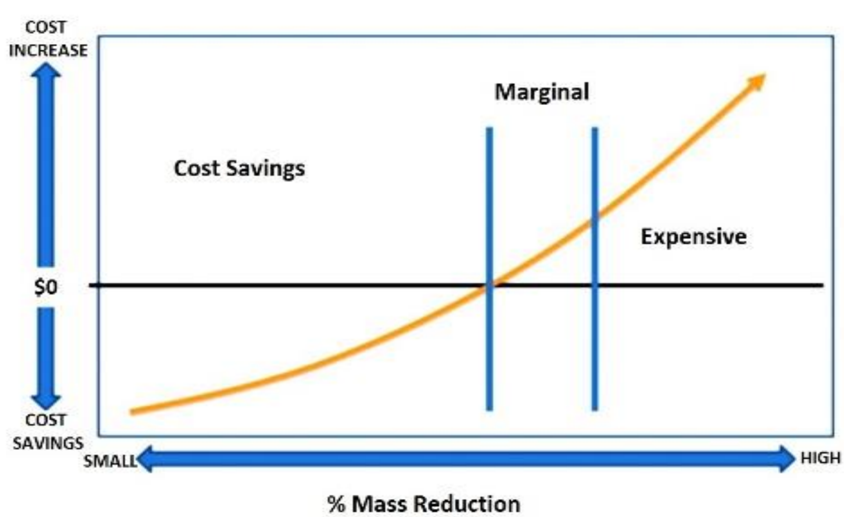
Figure 6: Lightweight Approach of the All New BMW 7 Series



Source: Florian Scheck, BMW, 2015 CAR Management Briefing Seminars

The figure below illustrates a generic cost curve for lightweighting that is broadly supported. There are three phases to lightweighting costs: a cost savings component (due in part to advancements in technology); a marginal area where the automaker can assume additional cost to remove weight; and an expensive range that becomes prohibitively costly as more aggressive technologies are needed to further light weight the vehicle. Most cost studies acknowledge the exponential nature of this cost curve. Clearly, it would behoove an automaker to implement the cost savings technologies to reduce weight, and stop applying technologies someplace in the marginal zone. The reason the automaker accepts some costs in this zone is to achieve advancements in vehicle performance, a major competitive requirement for consumer acceptance. Therefore, if fuel economy regulations necessitate more aggressive lightweighting, beyond what is market driven, the automaker has to move further up the exponential cost curve. **The regulations are therefore causing the automakers to incur exponential cost increases on the most expensive side of this curve, not only the flatter side where there are cost savings and smaller cost increases.** The "Low Most-Likely Cost Estimates" in the NRC report referenced earlier assume that one can achieve 6.3% lightweighting at zero cost – the left side (cost savings) of the cost curve. Essentially, the real-world cost curve should shift to the left to reflect the higher costs per unit of mass reduction that is realized by the manufacturer.

Figure 7: General Auto Manufacturer Cost Curve to Lightweight Vehicles



Sunk Cost and Infrastructure Limit Speed of Introduction

One of the issues raised over holistic, optimized vehicle designs, as practiced by most of the independent lightweighting studies, is that vehicles are seldom designed in this manner for good reason. Incremental technology advancements are less costly and lower risk than total vehicle redesigns. Independent studies are paper studies, conducted by external experts without the constraints confronted by an auto manufacturer. Constraints include, for example:

- Resource constraints (particularly engineering resources, time and financial) that rely on carrying over portions of design from other vehicle models.
- Global platforms that share significant portions of the vehicle over multiple model variants made in different countries with different regulatory and customer requirements and supply chains.
- Real world designs for vehicles that appeal to the consumer focus on multi-attribute performance metrics such as vehicle performance, safety, drivability, and weight. Focusing on just weight is unrealistic because the vehicles have to sell and generate profit for the company.
- Optimized vehicle design, while adequate on paper, are inadequate for a manufacturer when the cost of a mistake that may not be discovered years into a product life can result in millions of defective vehicles on the road. When new technology is added (as in a holistic design), building in a safety factor is considered good engineering practice. (A traditional example of "over-engineering" has been to add additional spot welds and adhesive to insure the integrity of the joined components over the 15-year life of a vehicle as parts vibrate and tend to pull apart with use.) Engineering studies that do not develop prototypes or test vehicle designs will miss weak points in a design.
- A reliable and competitive supply chain is needed to ensure technical support and products (materials, components, etc.).
- Parallel manufacturing of components on different continents to the same quality specifications must be achieved with local supply chains and different levels of automation due to local restrictions.

The body structure is often seen as one of the greatest opportunities on the vehicle to reduce weight because of its complexity and increasing number of technology solutions. There are many parts, broad system complexity and repair considerations, safety implications (and ever-changing regulations), numerous materials and technology advances to be considered. The mass of the body drives many design factors influencing the mass of the chassis and engine. Affordability and strength have traditionally favored all steel bodies, and a significant infrastructure supporting steel already exists, and to a lesser extent, another one supporting aluminum. Making the body out of a monolithic material like steel (of various grades) also lends itself to standardized joining methods, which has been traditionally dominated by cost-effective resistance spot welding. The next favored pathway migration after steel (beyond high strength steel) is to increasingly aluminum-intensive vehicles which provides significant weight savings but at higher material, fabrication and joining costs. Much of the steel infrastructure can accommodate aluminum, but in general, aluminum costs more than steel, the tooling costs more (industry experts indicate that tooling for aluminum costs 10% more than comparable tooling for steel), parts fabricate slower and with less formability, and have to be joined with higher cost technologies. Although aluminum can use much of the same infrastructure as steel, aluminum vehicles have to be designed differently than steel vehicles – typically with castings and extrusions, unlike steel. The substantial sunk costs for one specific metal infrastructure provide a significant hurdle to alternative materials to be introduced cost effectively. This infrastructure includes an engineering knowledge-base, design and systems modeling software, prototype resources, fabrication, assembly and paint processes, and repair.

Leveraging the substantial costs the industry has already invested for designing and processing steel, aluminum and plastic, incremental advancements in any of these materials is the most viable way to migrate to new technologies. Materials, such as aluminum, magnesium, and reinforced composites offer major weight reduction opportunities, but the transition costs for these materials will be much greater if dramatic changes in their use are made abruptly. The introduction of a new vehicle model traditionally carries over a significant portion of the previous model design and equipment (and supporting supply chain/infrastructure). Fifty percent carryover from one model to the next would not be unusual. Some material changes (e.g., steel to aluminum or aluminum to composites) would call for a complete overhaul – at least for the system or subsystem being changed. The transformation by Ford to convert completely from steel to an aluminum body truck is atypical, and the economic consequences tied to lost production, consumer satisfaction, quality, etc. are still in question. Other transition costs such as engineering design, integration costs, production validation, capital equipment, supply chain availability (for both materials and fabricated parts), product reliability, etc. were carefully controlled by Ford. Unlike most auto companies, Ford had 20 years of experience building aluminum vehicles because of its relationship with Jaguar Land Rover in the UK. Few companies have this historical base of knowledge, which allowed Ford to operate non-traditionally with this material decision.

There is no Known Average U.S. Vehicle

One of the primary concerns over external engineering studies to derive the cost of lightweighting is that these studies look only at a single vehicle at one point in time. The industry is continuously advancing the technology. Extrapolating the results from one or two vehicles to others, especially across vehicle segments, is not defensible. The inherent technology in the fleet has not been defined, and the starting point for each model is different, resulting in a different lightweighting pathway and associated cost. The U.S. fleet encompasses hundreds of vehicles covering a spectrum of lightweighting technologies dated 20 or more years to current state-of-the art. **Finding 6.9 in the 2015 NRC study recommends caution in extrapolating the results of a single lightweighting study to the U.S. fleet.** The importance of establishing an appropriate baseline is illustrated by the following two prominent lightweighting studies:

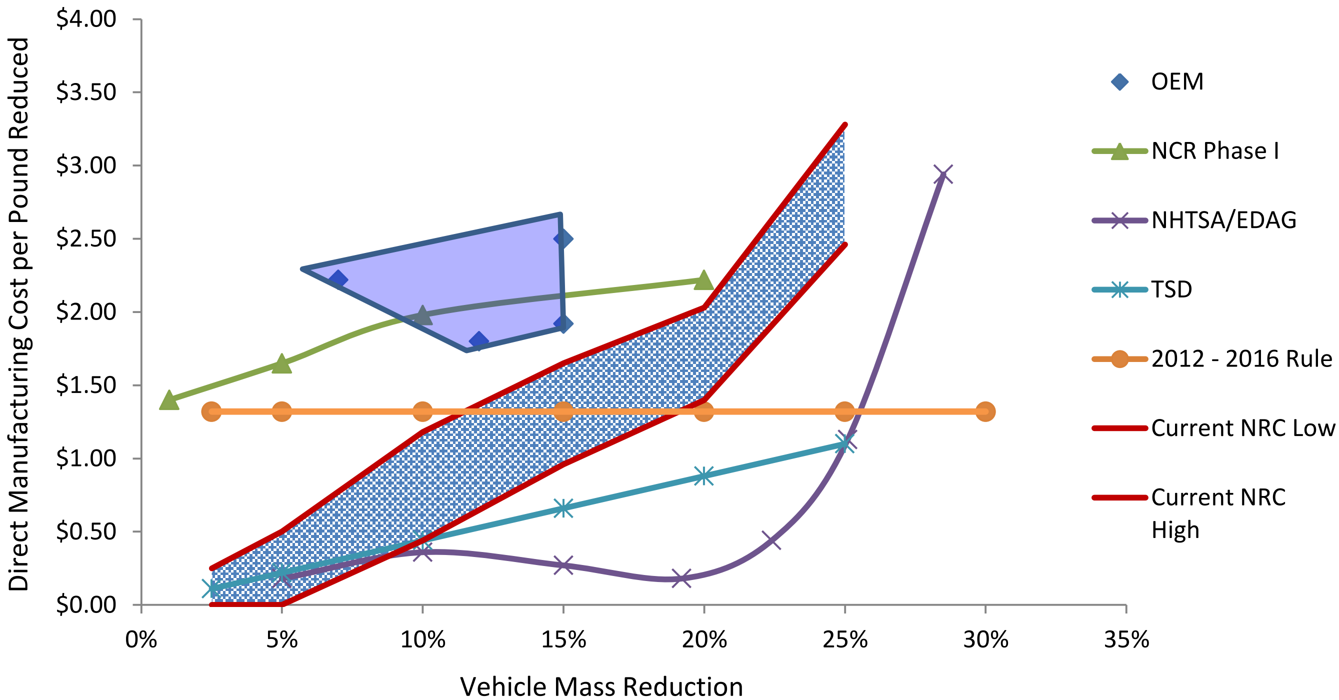
- The Toyota Venza that was studied was launched in 2009 and is not representative of Toyota state-of-the art design. The 2009 Venza was not designed with a clean-sheet approach; it was a modification (carryover) from the Toyota Camry and Highlander crossover vehicles with some unique content of its own. It had significant carryover content designed to fill a niche market.

Additionally, the model selected had the smallest of two engine choices; the least preferred by consumers. The structure is designed to accommodate the heavier of the engine choices, providing easy opportunities to reduce weight for the smaller engine – if each vehicle is optimized for the engine in it. The Venza with the smaller engine was an easy target for mass reduction optimization. The design of a low-volume, mid-priced vehicle with carryover engineering from two other vehicles using an engine least desired by consumers is not representative of lightweighting opportunities.

- A different, but similar scenario is also true with the recently studied 2011 GM Silverado. The Silverado is a second generation vehicle built off the GMT900 platform. The GMT900 was launched in 2006 and was designed from the GMT800 platform. The GMT800 platform was launched in 1998 (and engineered approximately in 1996). The second generation of the platform was launched in 2006 where several parts of high-strength steel (HSLA) were substituted for mild steel (HSLA is about one-half as strong as today's state-of-the-art press hardened steel). The material-substitution upgrade did not modify the architecture; it was not optimized. The 2011 Silverado was engineered 19 years ago for prevailing mild-steel technology, and is an easy target for mass reduction optimization. The new architecture 2014 Silverado is designed with a new platform and a variety of high strength steels including press hardened steel. (And of course the F-150 is light-weighted using an aluminum body and high strength steel frame for a very different lightweight strategy and final weight.) The Silverado history illustrates the evolution of a platform, complexity of extrapolating results to other vehicles, and also the longevity of a platform. The Silverado architecture continued for 13 years before an all new architecture was designed and was able to incorporate up to 13 years of technical advancements.

This lack of a baseline lightweight technology has led to a variety of over simplified and broadly extrapolated cost estimates to lightweight vehicles. However, as illustrated in Figure 8, there is extreme uncertainty since each individual estimate is based on a different vehicle analysis, method or interpretation.

Figure 8: Mass Reduction Direct Manufacturing Cost Estimates



Source: CAR - Different Cost Curve Estimates from Various Sources. Current NRC Low and High represent "most-likely" data from the 2015 NRC report. OEM data is from CAR interviews with auto manufacturers. NCR Phase I data was reported in the 2012 NRC study. NHTSA/EDAG estimates are drawn from the 2011 Honda Accord teardown study. The TSD estimate was used by the technical service document, and the 2012-2016 Rule was proposed in the initial rule-making.

Today, the most commonly accepted cost curve for lightweighting (illustrated in Figure 7) shows an exponentially increasing cost for each percent increase in weight reduction. In other words, each incremental pound of weight reduced costs more than the last pound reduced. This principal is also illustrated in Figure 8 by all estimates except for the estimate used in the 2012 – 2016 rule-making (which showed a constant cost per pound regardless of the amount of mass removed). Straight line or flat curves are indicative of a lack of understanding about the cost to lightweight, especially when extended over a 10%, 20% or even 30% range. The polygon in Figure 8 is a region created by four point-estimates from different auto companies (ranging from about $1.75 to $2.50 per pound for a 10% to 15% level of weight reduction). Cost estimates from non-automotive sources consistently understate the automotive estimates by 30% to 90%.

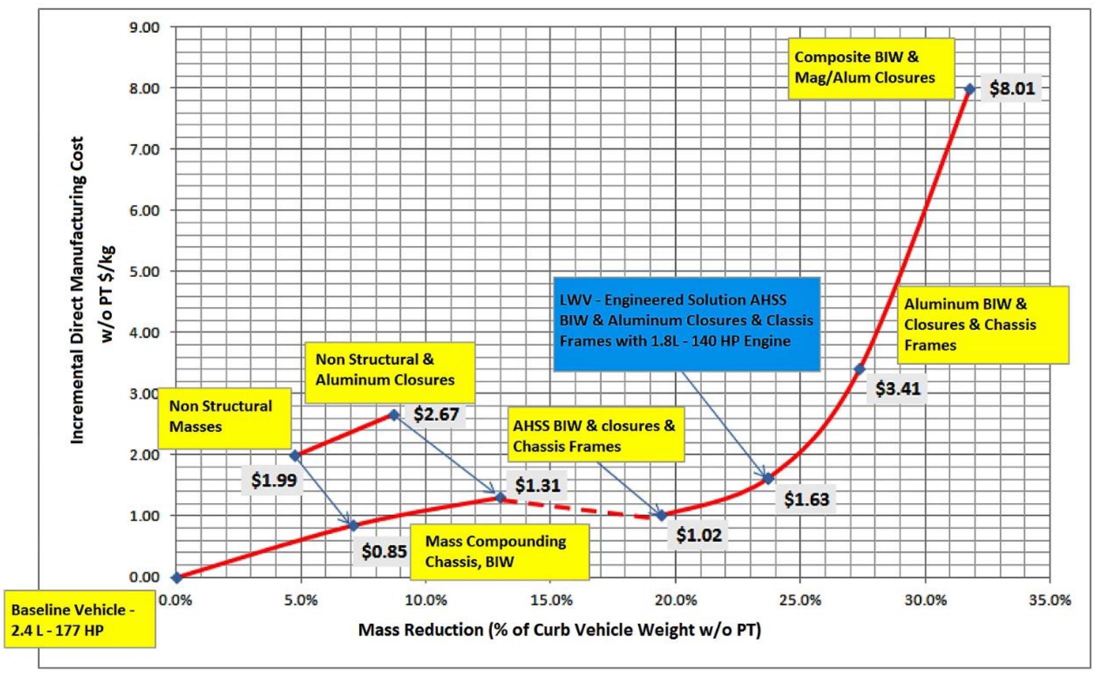
The EDAG study on the Honda Accord and the NRC report developed lightweighting pathways that appear to be broadly supported by the industry. (Note that support of the pathway is much different than support of the cost to progress along the pathway.) Briefly, the progression was based on the amount of mass to remove:

1. Progression to moderate high strength steel (2.5% mass reduction)
2. Aggressive progression with high strength steel (5% mass reduction)

3. Aggressive progression with high strength steel and aluminum closure panels and other key parts (10% mass reduction)
4. Aluminum body (15% mass reduction)
5. Aluminum body, high strength steel and composites (20% mass reduction)
6. Composites intensive structure and advanced metals (25% mass reduction)

Most (or all) vehicles could be fairly classified as currently fitting in one of the above six scenarios. (Note: other complexities arise with body-on-frame vehicles where there may be a hybrid combination like the F-150 aluminum body on a high strength steel frame. But this combination would still fit approximately in scenario 4 above.) Using the EDAG model, with some adjustments for decompounding and vehicle segment requirements (small car, large car, performance, utility, etc.), estimating the distribution of technology of the current fleet and cost to implement additional lightweighting may be practical to establish a U.S. fleet baseline. Accomplishing this would directly address Finding 6.9 in the NRC study. Although not directly addressed in the NRC report, the learning curve to progress through the six levels of mass reduction will have a unique learning curve profile associated with it. The higher the scenario, the greater the long-term learning opportunity.

Figure 9: Cost Curve Developed by EDAG for a Light duty Vehicle



Source: Mass Reduction for Light-Duty Vehicles for Model Years 2017–2025 – EDAG for NHTSA

Conclusion

For the reasons described within this report, automakers generally concur that the actual costs to reduce vehicle weight are much higher and more differentiated (by individual vehicle and vehicle segments) than what has been published by various studies or used by the regulating agencies, National Highway Traffic Safety Administration, Environmental Protection Agency and the Air Resources Board of California. This is shown in Figure 8. Several of these estimates were drawn from teardown analyses supported by the agencies and conducted by engineering consultants. Significant complexities to lightweight that are not well accounted for in these studies include: how new materials and processes are developed; physical facility infrastructure constraints; requirement for globally competitive supply chains; proliferation of global platforms; consumer acceptance and the need to constantly improve ride and handling; and product development processes (and resources) that are not designed to optimize vehicles specifically for fuel economy. The results of several widely referenced light-weighting studies have not adequately addressed the impact of these complexities which add substantial costs and lead-time to technology deployment. It is broadly acknowledged that the realized costs may be significantly higher than the idealized analyses. Finally, a significant challenge to the Agencies is how to fairly determine the actual cost to lightweight the U.S. fleet when there is no known baseline to represent the fleet in terms of lightweight technology. More attention to these issues, including establishing a more comprehensive baseline analysis, is needed to ensure a fair assessment and administration of ongoing regulations.

CAR is continuing data gathering and analysis and intends to publish additional research on this topic in 2016. For additional information, contact Denise Zilch, Executive Assistant to Dr. Jay Baron, President & CEO, dzilch@cargroup.org or 734.929.0461.

References to Studies

2010 Toyota Venza Studies

http://www3.epa.gov/otaq/climate/documents/420r12026.pdf

http://www.theicct.org/sites/default/files/publications/Mass_reduction_final_2010.pdf

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http://www3.epa.gov/otaq/climate/documents/mte/epa-nas-mass-reduction-pickup-study.pdf