An Assessment of Mass Reduction Opportunities for a 2017 – 2020 Model Year Vehicle Program

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Submitted to: The International Council on Clean Transportation

March 2010
Rev 006A

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1. Executive Summary

Introduction

The Energy Foundation funded Lotus Engineering to generate a technical paper which would identify potential mass reduction opportunities for a selected baseline vehicle representing the crossover utility segment. Lotus Engineering prepared this document in collaboration with a number of automotive and regulatory experts and submitted it to the ICCT. The 2009 Toyota Venza was selected as the baseline vehicle for evaluation although the materials, concepts and methodologies are applicable to other vehicle segments such as passenger cars and trucks. They could be further developed in separate studies for other applications. This study encompassed all vehicle systems, sub-systems and components. This study was divided into two categories, allowing two distinct vehicle architectures to be analyzed. The first vehicle architecture, titled the “Low Development” vehicle, targeted a 20% vehicle mass reduction (less powertrain), utilizing technologies feasible for a 2014 program start and 2017 production, was based on competitive benchmarking applying industry leading mass reducing technologies, improved materials, component integration and assembled using existing facilities. The second vehicle architecture, titled the “High Development” vehicle targeted a 40% vehicle mass reduction (less powertrain), targeted for 2017 technology readiness and 2020 production, utilized primarily non-ferrous materials, a high degree of component integration with advanced joining and assembly methodologies. Comparative piece costs were developed; indirect costs, including tooling and assembly plant architecture, were beyond the scope of this study. Both studies showed potential to meet their mass targets with minimal piece cost impact. Structural and impact analyses were beyond the scope of this study; these results could impact the mass and cost estimates. All powertrain related hardware studies were subject to a separate paper referenced herein.

Lotus Background

Lotus’s guiding design philosophy for more than sixty years has been “Performance through Lightweight”. Lotus design principles can be clearly demonstrated by a legacy of iconic product. The Lotus design approach facilitates highly efficient solutions by utilizing well integrated vehicle sub-systems and components, innovative use of materials and process and advanced analytical techniques. Lotus has significant experience in designing low and high volume wheeled transport for a global client base in addition to the engineering and manufacture of high performance Lotus products.

Methodology

A Toyota Venza was torn down and benchmarked to develop a comprehensive list of all components and their respective mass. A baseline Bill of Materials (BOM) was developed around nine major vehicle systems. The powertrain investigation and analysis were performed separately by the U.S. Environmental Protection Agency. This report analyzed the non-powertrain systems. These were divided into the following eight categories:

- Body structure
- Closures
- Front and rear bumpers
- Glazing
- Interior
- Chassis
- Air conditioning
- Electrical

The mass analysis considered engineering methodologies, materials, forming, joining, and assembly. Domestic and international trends in the automotive industry were analyzed, including motorsports. Emerging technologies in numerous non-automotive areas were also investigated, including aerospace, appliance, bicycle, watercraft, motorcycle, electrical and electronics, food container, consumer soft goods, office furniture as well as other sectors traditionally unrelated to the transportation industry. This synergistic approach provided a high level of flexibility in selecting feasible materials, processes, manufacturing and assembly methods.

The mass reductions were accomplished through increased modularization, replacing mild steel with lower mass materials including high strength steel (HSS), advanced high strength steel (AHSS), aluminum, magnesium along with increased utilization of composite materials and the application of emerging design concepts. In many cases, individual parts were eliminated through design integration. The overall approach for both the Low Development and the High Development vehicles was to be conservative relative to a production program, i.e., minimize the technical risk and the component costs for the targeted introduction dates.

Bill of Materials

Target Bill of Materials (BOMs) were created for tracking the mass and cost relative to the Venza.

The BOMs were separated into two categories:

- Low Development, which targeted technologies, manufacturing processes and assembly techniques estimated to be feasible in the 2014 time frame for 2017 MY production; and
- High Development, which targeted technologies, manufacturing processes and assembly techniques estimated to be feasible in the 2017 time frame for 2020 MY production.

Functional Objectives

The functional objectives were to maintain the 2009 Toyota Venza's utility/performance including interior room, storage volume, seating, NVH (Noise, Vibration, Harshness), weight/horsepower ratio, and driving range as well as compliance to current and near term federal regulations. The overall vehicle length was fixed. It was decided that the lightweight vehicle "footprint" (defined by the National Highway Traffic Safety Administration as wheelbase and track) be identical to the 2009 Toyota Venza for the 2017–2020 Low Development design. The wheelbase and track were increased for the High Development model for additional mass reduction and cost savings opportunities. Structural analysis, Federal Motor Vehicle Safety Standards and NCAP compliance verification of both architectures were beyond the scope of this study but may be accomplished in a future phase.

Results

Mass

The total vehicle mass savings (less powertrain) estimates are 21% (277 kg) for the 2017 production target Low Development vehicle and 38% (496 kg) for the 2020 production target High Development vehicle.

Cost

The Low Development vehicle piece cost (less powertrain) is projected to range from 92% to 104% with a nominal estimated value of 98%. The High Development vehicle piece cost (less powertrain) is projected to range from 97% to 109% with a nominal estimated value of 103%.

Both the baseline Venza component costs and the Low and High Development piece costs were estimated using supplier input, material costs and projected manufacturing costs. Metal prices were obtained from Intellicosting, a Detroit area based cost estimating firm experienced in pricing automotive components. Composite material prices were obtained from suppliers. The Venza estimated part costs served as the reference values to establish cost deltas. Current prices as of November, 2009 were used; no material cost projections were made for the 2017-2020 timeframe. The primary areas of focus, the body structure, closures, chassis/suspension and interior, represent approximately 84% of the vehicle non-powertrain cost for a front wheel drive, four cylinder crossover utility class vehicle (with an estimated cost range of +/- 6%). ER&D (Engineering, Research and Development) costs and assembly plant costs were defined to be the same as the current Venza costs although tooling and assembly plant costs could vary significantly depending on the manufacture.

Conclusion
This study indicates that a total vehicle, synergistic approach to mass reduction is feasible and could result in substantial mass savings with minimal piece cost impact.

Recommendations

Lotus recommends additional follow-up and independent studies to validate the materials, technologies and methods referenced in this report for the High and Low Development vehicles or possibly a combination. Many of the Low Development technologies are already used in production vehicle although not in a substantial manner. Additional studies regarding holistic vehicle mass reduction materials, methods and technologies in collaboration with automotive industry, component suppliers, manufacturing specialists, material experts, government agencies and other professional groups would support efforts of further understanding the feasibility, costs (both piece and manufacturing), limitations of this report.

1. A High and/or Low Development body in white (BIW) should be designed and analyzed for body stiffness, modal characteristics and for impact performance referencing the appropriate safety regulations (FMVSS and NCAP) for the time frame. This study should include mass and cost analysis, including tooling and piece cost.

2. High Development closures should be designed and analyzed further. This additional study should include front, rear and side impact performance as well as mass and cost analysis, including tooling and piece cost.

3. High and Low Development models of the chassis/suspension should be designed and analyzed. This study should include suspension geometry analysis, suspension loads, as well as a mass and cost analysis, including tooling and piece cost.

4. A High and Low Development interior model should be designed and analyzed for occupant packaging and head impact performance. This study should include a mass and cost analysis, including tooling and piece cost.

2. Nomenclature

3D
Three dimensional. Something having three dimensions e.g. width, length, and depth.

4WD or 4x4
Four-wheel drive is a four wheeled vehicle with a drivetrain that allows all four wheels to receive torque from the engine simultaneously. 4WD is differentiated from all wheel drive (AWD) as locking all the wheels to rotate at the same velocity and thus can only be used on reduced friction surfaces.

5th Percentile Female
This represents a very small woman; 95 percent of women are larger than a 5th percentile female.

99th Percentile Male
This represents a very large man; this size man is larger than 98% of the male population.

A arm
In automotive suspension systems, a control arm (sometimes called a wishbone or A-arm) is a nearly flat and roughly triangular member (or sub-frame), that pivots in two places. The broad end of the triangle attaches at the frame and pivots on a bushing. The narrow end attaches to the steering knuckle and pivots on a ball joint.

"A" Pillar
An A-pillar is a name applied by car stylists and enthusiasts to the shaft of material that supports the windshield (windscreen) on either of the windshield frame sides. By denoting this structural member as the A-pillar, and each successive vertical support in the greenhouse after a successive letter in the alphabet (B-pillar, C-pillar etc.), this naming scheme allows those interested in car design to have points of reference when discussing design elements.

ABS(system)
An anti-lock braking system, or ABS (from the German, Antiblockiersystem) is a safety system which prevents the wheels on a motor vehicle from locking up (or ceasing to rotate) while braking.

ABS(material)
Acrylonitrile butadiene styrene (ABS) is a common thermoplastic used to make light, rigid, molded products

A/C or AC
Air Conditioning. See HVAC

Al or Alum.
Aluminum

AWD
All wheel drive is a four-wheeled vehicle with a drivetrain that allows all four wheels to receive torque from the engine simultaneously. AWD is differentiated from four wheel drive (4WD) as allowing different rotational velocities of the wheels and thus can be used on all surfaces and can be left on at all time or be "full time".

"B" pillar
See "A" Pillar.

BH or Bake Hardenable Steel

A bake-hardenable steel is any steel that exhibits a capacity for a significant increase in strength through the combination of work hardening during part formation and strain aging during a subsequent thermal cycle such as a paint-baking operation.

B Segment
Vehicle classification used in Europe, equivalent to the American Subcompact.

Belt Line
The beltline, also known (in the UK) as the waistline, is the horizontal or slightly inclined line below the side windows of a vehicle, starting from the hood and running to the trunk. It separates the glass area (called the greenhouse) from the lower body.

BIW
BIW stands for Body in White . All activities in the production of a Vehicle Body or Shell before it goes to the Paint shop are done in a weld shop and the end product of a Weld shop is referred to as a BIW.

BMSB
Blow molded seat back. Blow molding, also known as blow forming, is a manufacturing process by which hollow plastic parts are formed. It is a process used to produce hollow objects from thermoplastic.

BOM
Bill of materials (BOM) is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, components, parts and the quantities of each needed to manufacture an end item (final product).

BSFC
Brake specific fuel consumption is a measure of fuel efficiency within a shaft reciprocating engine. It is the rate of fuel consumption divided by the power produced. BSFC allows the fuel efficiency of different reciprocating engines to be directly compared.

BUS
A bus is a network topology or circuit arrangement in which all devices are attached to a line directly and all signals pass through each of the devices. Each device has a unique identity and can recognize those signals intended for it.

“C” Pillar
See “A” Pillar.

C Segment
Vehicle classification used in Europe, equivalent to the American Compact.

CAD
Computer-aided design (CAD) is the use of computer technology for the design of objects, real or virtual.

CAE
Computer-aided engineering is the use of information technology to support engineers in tasks such as analysis, simulation, design, manufacture, planning, diagnosis, and repair.

CAN-BUS
Controller–area network (CAN or CAN-bus) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other within a vehicle without a host computer.

CCA or CCAW
Copper Clad Aluminum (wire). The primary application of this conductor is for high-quality coils where weight is an issue, such as the voice coils in headphones, portable loudspeakers or mobile coils in other applications.

Center Stack
The center portion of the instrument panel. This area typically contains the radio and HVA/C system controls as well as NAV screens.

CG
Center of Gravity. The center of gravity or center of mass of a system of particles is a specific point where, for many purposes, the system behaves as if its mass were concentrated there.

Class A surface
Term used in automotive design to describe a set of freeform surfaces of high resolution and quality.

CFM
Cubic feet per minute (CFPM or CFM) is a non-SI unit of measurement of the flow of a gas or liquid that indicates how much volume in cubic feet pass by a stationary point in one minute.

CO
Carbon monoxide, with the chemical formula CO, is a colorless, odorless and tasteless, yet highly toxic gas.

CO_2
Carbon dioxide is a chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state.

Composite
Composite materials are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure.

CSA
Cross sectional area. The area of a cross section. In geometry, a cross-section is the intersection of a body in 2-dimensional space with a line, or of a body in 3-dimensional space with a plane, etc. More plainly, when cutting an object into slices one gets many parallel cross-sections.

Cut and Sew
A method of creating automotive seat covers that consists of trimming material from fabric sheets based on selected patterns and joining the separate sections by sewing them together.

CUV
Crossover utility vehicle. Crossover is a marketing term for a vehicle that derives from a car platform while borrowing features from a Sport Utility Vehicle (SUV).

CVT
A continuously variable transmission is a transmission which can change steplessly through an infinite number of effective gear ratios between maximum and minimum values.

“D” Pillar
See “A” Pillar.

DLO
Daylight opening. Automotive industry term for glassed-in areas of a vehicle's cabin

Dm
Deutsche Mark (1948-2002), former official currency of Germany

DP or Dual Phase Steel
Dual-phase steel (DPA) is a high-strength steel that has a ferrite and martensitic microstructure. DPA starts as a low or medium carbon steel and is quenched from a temperature above A1 but below A3 on a continuous cooling transformation diagram. This results in a microstructure consisting of a soft ferrite matrix containing islands of martensite as the secondary phase (martensite increases the tensile strength). The desire to produce high strength steels with formability greater than microalloyed steel led the development of DPS in 1970s.

EC
European Commission. The executive branch of the European Union. The body is responsible for proposing legislation, implementing decisions, upholding the Union's treaties and the general day-to-day running of the Union.

EGR
Exhaust gas recirculation is a nitrogen oxide (NOx) emissions reduction technique used in most petrol/gasoline and diesel engines. EGR works by recirculating a portion of an engine's exhaust gas back to the engine cylinders.

EPA
United States Environmental Protection Agency.

EPDM
EPDM rubber (ethylene propylene diene Monomer (M-class) rubber), a type of synthetic rubber, is an elastomer which is used in a wide range of applications.

EPP
Expanded Polypropylene is a foam form of polypropylene. EPP has very good impact characteristics due to its low stiffness, this allows EPP to resume its shape after impacts.

ESP or ESC
Electronic Stability Program or Electronic Stability Control. Computerized technology that improves the safety of a vehicle's stability by detecting and minimizing skids.

Euro V
Current European Union emission standard for diesel engines implemented in 2008.Euro VI is scheduled to supersede V in 2013.

EVA
Ethylene vinyl acetate is the copolymer of ethylene and vinyl acetate.

FEA
Finite element analysis. A computational method of stress calculation in which the component under load is considered as a large number of small pieces (‘elements’). The FEA software is then able to calculate the stress level in each element, allowing a prediction of deflection or failure

FEM
Front end module. An assembly or complex structure which includes the content of what was previously multiple separate parts.

FMVSS
FMVSS is the acronym for Federal Motor Vehicle Safety Standard. FMVSS norms are administered by the United States Department of Transportation's National Highway Traffic Safety Administration.

FR plastic
Fiber reinforced. Fiber-reinforced plastic (FRP) (also fiber-reinforced polymer) are composite materials made of a polymer matrix reinforced with fibers.

Frt
Front

FWD
Front-wheel drive is a form of engine/transmission layout used in motor vehicles, where the engine drives the front wheels only.

GAWR
Gross axle weight rating is the maximum distributed weight that may be supported by an axle of a road vehicle. Typically GAWR is followed by either the letters F, FR, R or RR which indicate Front or Rear axles.

GPS
The Global Positioning System (GPS) is a U.S. space-based global navigation satellite system. It is commonly used to refer to any device or function that uses the GPS satellites.

GVW or GVWR
A gross vehicle weight rating is the maximum allowable total weight of a road vehicle or trailer when loaded - i.e., including the weight of the vehicle itself plus fuel, passengers, cargo, and trailer tongue weight.

H arm
A type of suspension control arm which attaches to the frame or body at two points and to the wheel carrier or knuckle at two points.

HAN
Human Area Networking is a process by which external devices can transmit signal information through manipulation of the small magnetic field that exists surrounding the human body.

Haptic
Sensory feedback that interfaces to the user via the sense of touch by applying forces, vibrations, and/or motions to the user. This mechanical stimulation may be used to assist in the creation of virtual objects (objects existing only in a computer simulation), for control of such virtual objects, and to enhance the remote control of machines and devices (teleoperators).

HC
Hydrocarbon. In organic chemistry, a hydrocarbon is an organic compound consisting entirely of hydrogen and carbon.

HDPE
High density polyethylene or polyethylene high-density (PEHD) is a polyethylene thermoplastic made from petroleum.

HIC
The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact.

HMI
Human machine interface is the interaction between humans and machines (often computers).

HP
Horsepower (hp or HP or Hp) is the name of several non-SI units of power. One mechanical horsepower of 550 foot-pounds per second is equivalent to 745.7 watts.

HPA
Acronym for Hydraulic Power Assistance which specifies that pressurized hydraulic fluid is used to increase the manual force being applied in a mechanical system.

HSS
High strength steel is low carbon steel with minute amounts of molybdenum, niobium, titanium, and/or vanadium. Is sometimes used to refer to high strength low alloy steel (HSLA) or to the entire group of engineered alloys of steels developed for high strength. .

HVAC or HVA/C
Acronym for the closely related functions of "Heating, Ventilating, and Air Conditioning"- the technology of indoor environmental comfort.

IC
Internal combustion. The internal combustion engine is an engine in which the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber.

ICE
In-Car Entertainment, sometimes referred to as ICE, is a collection of hardware devices installed into automobiles, or other forms of transportation, to provide audio and/or audio/visual entertainment, as well as automotive navigation systems. This acronym can also be used to describe an Internal Combustion Engine, an engine type that burns fuel in a sealed chamber using either spark ignition (SI - gasoline) or compression ignition (CI – diesel).

IEM
Integrated exhaust manifold as used in the report refers to the integration of the exhaust manifold with the cylinder head as used in the Lotus SABRE project.

IIHS
The Insurance Institute for Highway Safety (IIHS) is a U.S. non-profit organization funded by auto insurers. It works to reduce the number of motor vehicle crashes, and the rate of injuries and amount of property damage in the crashes that still occur. It carries out research and produces ratings for popular passenger vehicles as well as for certain consumer products such as child car booster seats.

IMA
Integrated Motor Assist is Honda's hybrid car technology, introduced in 1999 on the Insight. It is a specific implementation of a parallel hybrid. It uses an electric motor mounted between the engine and transmission to act as a starter motor, engine balancer, and assist traction motor.

ISOFIX
The international standard for attachment points for child safety seats in passenger cars. The system is also known as LATCH ("Lower Anchors and Tethers for Children") in the United States and LUAS ("Lower Universal Anchorage System") or Canfix in Canada. It has also been called the "Universal Child Safety Seat System" or UCSSS.

IP
Instrument Panel. A dashboard, dash, "dial and switch housing" or fascia, (chiefly in British English) is a control panel located under the windshield of an automobile. It contains the instrumentation and controls pertaining to the operation of the vehicle. During the design phase of an automobile, the dashboard or instrument panel may be abbreviated as "IP".

IVT
Infinitely Variable Transmission, a type of continuously variable transmission system for motor vehicles and other applications

kg
Kilogram, unit of weight, 1 kg = 2.205 pounds.

km
Kilometer, unit of length, 1 km = 0.6214 statute miles.

kW
The kilowatt equal to one thousand watts, is typically used to state the power output of engines and the power consumption of tools and machines. A kilowatt is approximately equivalent to 1.34 horsepower.

kWh
The watt hour, or watt-hour, (symbol W·h, W h) is a unit of energy equal to 3.6 kilojoules. Energy in watt hours is the multiplication of power in watts and time in hours.

LATCH
Lower Anchors and Tethers for Children. See ISOFIX.

LCA
Lower control arm. See A arm.

LCD
A liquid crystal display (LCD) is a thin, flat panel used for electronically displaying information such as text, images, and moving pictures.

LED
A light-emitting diode, is an electronic light source.

LF
Left Front, e.g. left front door.

LH
Left hand

m^3 or m3 or m^3
Meters cubed or cubic meters, measure of volume.

mJ
Millijoules. The joule (symbol J), named for James Prescott Joule, is the derived unit of energy in the International System of Units. It is the energy exerted by a force of one newton acting to move an object through a distance of one meter. 1 mJ = 2.77×10^{-7} Watt hours

mm
Millimeters, unit of length, 1 mm = 0.03937 inches.

Monocoque
Monocoque, from Greek for single (mono) and French for shell (coque), is a construction technique that supports structural load by using an object's external skin as opposed to using an internal frame or truss that is then covered with a non-load-bearing skin. Monocoque construction was first widely used in aircraft in the 1930s. Structural skin or stressed skin are other terms for the same concept. Unibody, or unitary construction, is a related construction technique for automobiles in which the body is integrated

into a single unit with the chassis rather than having a separate body-on-frame. The welded "Unit Body" is the predominant automobile construction technology today.

LWR
Lower

Mg
Magnesium

MG, MG1 or MG2
A motor-generator (an M-G set or a dynamotor for dynamo-motor) is a device for converting electrical power to another form.

MPa
Mega Pascals, unit of pressure or stress, 1 MPa = 145 Pounds per square inch

MPG
Miles per gallon, is a unit of measurement that measures how many miles a vehicle can travel on one gallon of fuel.

MPV
Multi-purpose vehicle, people-carrier, people-mover or multi-utility vehicle (shortened MUV) is a type of automobile similar in shape to a van that is designed for personal use. Minivans are taller than a sedan, hatchback or a station wagon, and are designed for maximum interior room.

MS
Mild steel or Carbon steel, also called plain carbon steel, is steel where the main alloying constituent is carbon.

MSRP
The (manufacturer's) suggested retail price, list price or recommended retail price (RRP) of a product is the price the manufacturer recommends that the retailer sell it for.

MY
Model year. The model year of a product is a number used worldwide, but with a high level of prominence in North America, to describe approximately when a product was produced, and indicates the coinciding base specification of that product.

NCAP
The European New Car Assessment Program (Euro NCAP) is a European car safety performance assessment program founded in 1997 by the Transport Research Laboratory for the UK Department for Transport and now the standard throughout Europe.

NHTSA
The National Highway Traffic Safety Administration (NHTSA, often pronounced "nit-suh") is an agency of the Executive Branch of the U.S. Government, part of the Department of Transportation.

NO_x
NO_x is a generic term for mono-nitrogen oxides (NO and NO2).

NPI
New product introduction.

NVH
Noise, vibration, and harshness (NVH), also known as noise and vibration (N&V), is the study and modification of the noise and vibration characteristics of vehicles, particularly cars and trucks.

OD
Outside diameter of a circular object.

OEM
Original Equipment Manufacturer. The OEM definition in the automobile industry constitutes a federally-licensed entity required to warrant and/or guarantee their products, unlike "aftermarket" which is not legally bound to a government-dictated level of liability.

OLED
An organic light emitting diode (OLED), also light emitting polymer (LEP) and organic electro luminescence (OEL), is a light-emitting diode (LED) whose emissive electroluminescent layer is composed of a film of organic compounds.

OTR
Outer

PRNDL
Refers to the automatic transmission gear selector based on the letters appearing on most selectors standing for park, reverse, neutral, drive and low.

PA
Polyamide, a polymer containing monomers of amides joined by peptide bonds. They can occur both naturally, examples being proteins, such as wool and silk, and can be made artificially through step-growth polymerization, examples being nylons, aramids, and sodium poly (aspartate).

PC
Polycarbonates are a particular group of thermoplastic polymers.

PCCB
Porsche ceramic carbon brakes

PHEV
A plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle with batteries that can be recharged by connecting a plug to an electric power source. It shares the characteristics of both traditional hybrid electric vehicles (also called charge-maintaining hybrid electric vehicles), having an electric motor and an internal combustion engine, and of battery electric vehicles, also having a plug to connect to the electrical grid (it is a plug-in vehicle).

PM
Particulate matter, alternatively referred to as particulates or fine particles, are tiny particles of solid or liquid suspended in a gas or liquid.

PP
Polypropylene or polypropene is a thermoplastic polymer, made by the chemical industry and used in a wide variety of applications.

PPO
Poly(p-phenylene oxide), or PPO, is a high-performance polymer and an engineering thermoplastic.

PU or PUR
Polyurethane

PVC
Polyvinyl chloride, (IUPAC Poly(chloroethanediyl)) commonly abbreviated PVC, is the third most widely used thermoplastic polymer after polyethylene and polypropylene.

QTR
Quarter

R-value
The R value or R-value is a measure of thermal resistance.

Rad
Radiator

Reinf
Reinforcement

RF
Right Front, as for right front door.

RH
Right hand

ROM
Rough order of magnitude. Term used in analysis equating to 'Estimate'

RR
Rear

RWD
Rear-wheel drive is a form of engine/transmission layout used in motor vehicles, where the engine drives the rear wheels only.

SLA
A Short-long arm suspension is also known as an unequal length double wishbone suspension. The upper arm is typically an A-arm, and is shorter than the lower link, which is an A-arm or an L-arm, or sometimes a pair of tension/compression arms. In the latter case the suspension can be called a multi-link, or dual ball joint suspension.

Stepper Motor
A stepper motor (or step motor) is a brushless, synchronous electric motor that can divide a full rotation into a large number of discrete steps.

System
Nine separate system categories were created that included all vehicle components. The systems are: body structure, closures, front and rear bumpers, glazing, interior, chassis, air conditioning, electrical and powertrain.

Sub-system
A major assembly within a given system, e.g., a seat is a sub-system in the Interior system

SUV
A sport utility vehicle is a generic marketing term for a vehicle similar to a station wagon, but built on a light-truck chassis.

TRIP steel
TRIP steel is an example of high-strength steel typically used in the automotive industry. TRIP stands for "transformation induced plasticity." TRIP steel has a triple phase microstructure consisting of ferrite, bainite, and retained austenite. During plastic deformation and straining, the metastable austenite phase is transformed into martensite. This transformation allows for enhanced strength and ductility.

TRL

TRL is an acronym for “Technology Readiness Level”. TRL is defined, for the purposes of this study, as a technology that is considered feasible for volume production at the inception of a new vehicle program, i.e., approximately 3 years prior to start of production. The technology may be proven at the time of the new vehicle program start or is expected to be proven early in the production design process so that there is no risk anticipated at the targeted timing for production launch.

US or U.S.
United States of America

UTS
Ultimate tensile strength.

UV
Ultraviolet (UV) light is the spectrum of electromagnetic radiation with frequencies higher than those that humans identify as the color violet.

V
The volt is the SI derived unit of electromotive force, commonly called "voltage".

VR
Virtual reality, technology which allows a user to interact with a computer-simulated environment.

Whse
Wheelhouse

YS
Yield strength or yield point of a material is defined in engineering and materials science as the stress at which a material begins to deform plastically.

3. Introduction

OEMs are currently modifying the architecture and design of their entire fleet to better respond to regulatory actions curbing greenhouse gas emissions and to meet consumer demands for substantial improvements in vehicle fuel economy. Accordingly, manufacturers are planning to rapidly expand implementation of advanced vehicle, powertrain and engine technologies. In addition to implementation of new powertrain technologies, the reduction in the mass of the Vehicle system, sub-systems and components has also shown very promising opportunities for decreasing total vehicle GHG emissions.

The Energy Foundation contracted with Lotus Engineering to generate a technical paper which would identify potential mass reduction opportunities for a selected baseline vehicle representing the crossover utility segment. The 2009 Toyota Venza was selected as the baseline vehicle for evaluation although the materials, concepts and methodologies applicable to other vehicle segments such as passenger cars and trucks could be further developed in separate studies. The Venza is a 4-door, 5-passenger vehicle available in all wheel drive (AWD) or front wheel drive (FWD) configurations with a four or six cylinder engine. It achieves five stars in frontal and side crash testing and meets current federal safety standards. The FWD four cylinder version was selected as the baseline vehicle for this project. The Venza is rated at 21 MPG city and 29 MPG highway with the 2.7 liter four cylinder engine with FWD.

This study encompassed all vehicle systems, sub-systems and components. This study was divided into two categories, allowing two distinct vehicle architectures to be analyzed. The first vehicle architecture, titled the “Low Development” vehicle, targeted a 20% vehicle mass reduction (less powertrain), utilizing technologies feasible for a 2014 program start and 2017 production, was based on competitive benchmarking applying industry leading mass reducing technologies, improved materials, component integration and assembled using existing facilities. The second vehicle architecture, titled the “High Development” vehicle targeted a 40% vehicle mass reduction (less powertrain), targeted for 2017 technology readiness and 2020 production, utilized primarily non-ferrous materials, a high degree of component integration with advanced joining and assembly methodologies. Both studies showed high potential to exceed their mass targets with minimal cost impact. All Powertrain related hardware studies were subject to a separate paper referenced herein completed by the EPA.

To determine the program commercial & technical target criteria a Toyota Venza was disassembled and categorized to establish the baseline targets for the vehicle system, sub-systems and components.

A number of sub-systems were carried over from the Venza to the target mass reduced vehicles:

- The mass of supplemental restraints (i.e., inflatable protective systems) remained at the current Venza level to maintain safety criteria.
- The HVA/C system mass was unchanged from the Venza system to maintain passenger comfort.
- The front and rear suspension architecture was maintained to ensure no change to the baseline vehicle’s ride and handling performance.

Using the Venza baseline data as a target datum, two distinct objectives were developed for production intent mass reduced vehicles.

1. Low Development mass reduction - this model assumed a target total vehicle mass reduction of 20% to be achieved with a +20% upper limit constraint on total vehicle system piece cost relative to the baseline Venza data. The Low Development vehicle application was intended for a 2017 Model Year launch. All technologies used to reduce mass at the system, sub-system & component level had to achieve a Technology Readiness Level (TRL) of 2014 year or earlier.

2. High Development mass reduction - this model assumed a target total vehicle mass reduction of 40% to be achieved with a +50% upper limit constraint on total vehicle system piece cost relative to the baseline Venza data. The High Development vehicle application was intended for a 2020

Model Year launch. All technologies used to reduce mass at the system, sub-system & component level had to achieve a Technology Readiness Level (TRL) of 2017 year or earlier.

Key deliverables from the study were:

1. Benchmark a 2009 Toyota Venza and establish baselines for system, sub-system and component mass & piece cost;

2. Investigate emerging/current technologies & opportunities for mass reduction for vehicle system, sub-systems and components that comply to Technology Readiness Levels for both the Low & High Development Vehicles.

3. From the analysis carried out in item 2, define the systems and their mass reduction opportunities for the Low Development vehicle and the High Development vehicle.

4. From the system analysis of Item 3 and total vehicle system level piece cost target criteria, carry out detailed mass reduction study on systems, sub-systems and components for the Low Development and the High Development vehicles.

5. Generate a Bill of Materials for full vehicle, systems, sub-systems and components for the Low Development and the High Development vehicles.

6. From the project conclusions determine next step recommendations.

4. Workscope

4.1. Methodology

Overview

A generic methodology was applied across the vehicle systems, sub-systems and components to look for mass reduction opportunities. This methodology consisted of two main approaches.

- Benchmarking existing vehicles and technologies to establish the Low Development (LD) mass reduction opportunities.
- Reviewing current 'high end' technologies that may become mainstream with respect to cost and volume manufacturing constraints for the 2017 timeframe, exploring future and advanced technologies that are anticipated to be market ready in the required 2017 timeframe to support the High Development (HD) mass reduction opportunity.

The baseline vehicle, a 2009 Toyota Venza, parameters and functional performance had to be maintained or exceeded – i.e. a reduced mass solution could not be simply derived by reducing the vehicle size, footprint or occupant space.

The methodology guideline is shown in Table 4.1.a below:

Table 4.1.a; Methodology Guideline

	Low Development		**High Development**	
	Mass Reduction Target	Relative cost to Baseline Venza Piece Cost	Mass Reduction Target	Increased cost to Baseline Venza Piece Cost
Vehicle	20%	+20%	40%	+50%
System Level	20%	+20%	40%	+50%
Sub-system	20%	Not cost constrained	40%	Not cost constrained
Component Level	20%	Not cost constrained	40%	Not cost constrained

At the outset of this study it was recognized that a holistic approach to the vehicle mass down effort would yield the best opportunity to meet the vehicle mass targets. The vehicle systems interdependency was a key factor not only in considering the application of advanced and future technologies but also when applying the benchmarking approach of selecting low mass sub-systems and components.

A vehicle systems mass distribution analysis highlighted the predominant vehicle systems with respect to mass. Based on this analysis, it was determined that the highest mass vehicle systems should be the primary focus of this mass down effort. These systems were: 1. Chassis, including suspension; 2. Body structure; 3. Closures and 4. Interior. The powertrain and driveline systems were considered under a separate study undertaken by the EPA. The results of this powertrain study are summarized in section 13 of this report.

Within the vehicle systems, the sub-systems and components were reviewed in the same manner whereby the highest mass sub-system and components were prioritized for mass reduction opportunity.

Figure 4.1.a shows the mass distribution across the vehicle systems excluding the powertrain.

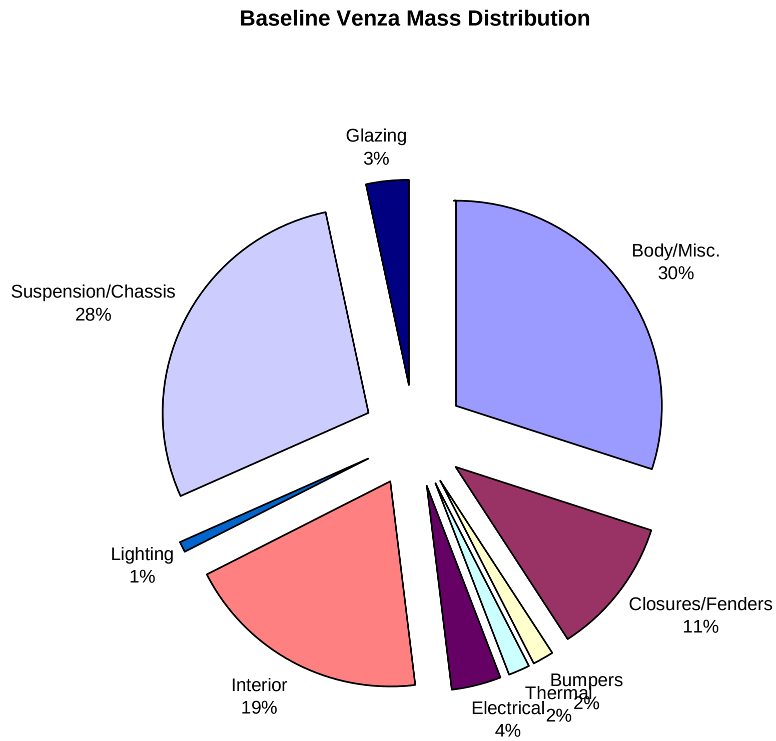


Figure 4.1.a: Baseline Venza Mass Distribution

In the process of iterating through studies of vehicle systems and sub-system for mass reduction, further mass reduction opportunities became available – e.g. on the basis of a 20% overall vehicle mass reduction target, the vehicle powertrain requirements were reduced and in turn the chassis and suspension mass capability could be reduced. This phenomenon of a circular cascading effect of mass reduction at a whole vehicle level, resulting in further vehicle sub-systems and components mass reductions, allowed for further mass efficiencies as the sub-systems and components can be down sized or reduced in capacity. This effect is referred to as 'mass decompounding'.

A study of vehicle trends with respect to mass efficiency and technology application in Europe was conducted in parallel with the mainstream methodology discussed here. The results of this study are summarized in the Appendix.

Benchmarking

A third party entity, A2Mac1, was contracted to conduct a complete teardown of the baseline vehicle, a 2009 Toyota Venza. The teardown was documented, categorized by vehicle system and component description, including overall dimensions, mass, materials used and in some instances, material properties.

The number of teardown vehicles catalogued by A2Mac1 was 138 vehicles at the time of this study. This database was used as a source of vehicle systems and component benchmark data. Vehicles outside this database were also included where prior experience had shown them to have a particular technology or component that was mass optimized.

A benchmarking study was undertaken with respect to vehicle system, sub-system and component level mass. The baseline Venza mass data was compared against a normalized database derived from the A2Mac1 library of vehicles. The lightest corresponding mass parts were selected from the database. The normalization methodology for mass and costing is discussed later in this section under the sub-heading 'Cost and Mass Overview'.

Technology Readiness

Analysis was carried out to assess the potential impact of current and emerging technologies on vehicle mass. This involved investigating widely diverse fields including appliance, electronic goods, the food container industry, aerospace, watercraft, motorsports, motorcycles, furniture, bicycles as well as traditional automotive hardware and processes.

Potential combinations were assessed and then selected based on their relative feasibility. This process resulted in non-traditional but feasible technology combinations. One example was combining a food container injection molding process used in Europe with an office chair material weaving process to create a lightweight door trim panel. This combination of materials and processes could allow a higher level of styling flexibility at a potentially lower cost.

Additionally, materials forming and shape were considered. Composite sheets formed with variable thickness (horizontal and transverse axis) can also reduce mass and cost. Mag IAS (a division of Cincinnati Machine, LLC) has developed a system for varying the horizontal and transverse thickness of composite materials that is now in production. See Section 18 for an illustration of this technology.

The high level of integration and multi-functionality required to reduce mass synergistically requires a re-thinking of the traditional engineering methodology. The High Development door concept is an example of the engineering process needed to fully optimize the mass reduction process. The High Development door concept started with the question: "what is the lightest door that could be designed that could potentially meet all performance, durability, NVH, quality and cost requirements?" This questioning process led to eliminating many add-on elements and to a high level of part integration. The target for each component was to incorporate multiple functions, typically four or more. The final door design consisted of four modules: 1. magnesium structure; 2. window module/trim; 3. semi-structural door outer; and 4. interior trim panel. The mass savings was projected to be over 40%.

This concept eliminated the wiring by relocating all electrical devices normally incorporated in the door to other areas. The door latch was moved to the "B" pillar. A release system using "powerless" control integrated into the trim locks and unlocks the door. The structural casting incorporated a tunable door beam and integrated the hinge elements into the casting. The trim panel utilized a low cost, light weight material and trim cloth woven to a net shape that has zero scrap and requires no cutting or sewing. The trim panel also functions as the window module complete with the regulator assembly. This concept eliminated the current discrete electrical, audio, hinge/latch, and window regulator hardware normally associated with a door. Faurecia has executed this concept in production doors at no additional cost, on the Dodge Nitro and Jeep Liberty vehicles.

Cost and Mass Overview

Cost and mass targets were based on the 2009 Toyota Venza.

Mass

The weight targets were set by disassembling a Venza, weighing each component and organizing them on a system basis. Eight primary vehicle systems were created. Powertrain was treated separately. These established the target masses for each major system, less powertrain. The Venza mass was defined as 100%. A lighter system/sub-system or component was defined relative to 100% i.e., a lighter weight part would have a mass < 100%, e.g., 77%. The fenders were consolidated with the closures.

Cost

There is significant variability in cost for a given sub-system or component as quoted by different suppliers to different OEM's. This may be accounted for by a number of factors - utilization rates, overhead costs, volumes, OEM business relationships to name a few. A typical piece cost range may vary by +/-10%. Estimated nominal values are reported in this study.

Each Venza system/subsystem was evaluated and assigned a cost. Suppliers experienced in specific systems and sub-systems provided cost information. Material costs were provided by industry experts. Costs for all comparative lightweight systems, sub-systems and components were then assigned a value relative to the cost of the Venza component by the original system assessor. All costs were tabulated based on the Venza components representing 100%, i.e., a less expensive lightweight part would cost < 100% e.g., 91%; a more expensive lightweight part would cost > 100%, e.g., 107%. Costing was based on piece cost only. Some components, such as the body in white, require OEM investment. These costs were beyond the scope of this study; as a result, tooling amortization was not included. Tooling costs vary depending on the OEM, the material selected, the process required and the supplier. In many cases, OEM's The OEM financial strategy for tooling amortization also affects piece cost.

Increased levels of component integration typically reduce the number of tools and the number of components that make up systems and sub-systems. Component integration also reduces the number of welds and fasteners required. This can potentially reduce tooling and piece costs. In many cases, lower mass individual components will become more expensive due to material cost increases. High level system integration and the reduced amount of material required can contribute to offsetting increased material costs.

5. Body Structure

5.1. Overview

The approach for reducing the body structure mass of the Toyota Venza was based on the following:

- Using the benchmarking exercise to establish the mass and estimated cost of the body and its significant components
- Considering the primary functional requirements of the body,
- Looking at the current methods of manufacture and the possible alternatives,
- Reviewing the available materials for cost and manufacturing/engineering feasibility.
- Reviewing competitor vehicles in the Venza market sector.

The factors listed above were applied to the Low Development and High Development parts of the study.

The Low Development body structure (20% mass reduction target) investigated a range of alternative materials which are currently in use in the automotive industry including composites, cast and stamped aluminum, conventional high strength steels and the evolving material technologies such as ultra high strength and dual phase steels. Other opportunities investigated as part of the Low Development process included the integration of multiple stamped parts into a single component and a higher level of modularization to improve the efficiency of the production process. The Venza NVH mass was retained; this mass may change as a result of tuning for the reduced mass body.

The High Development body structure (40% mass reduction target) used a broader range of materials and technologies than the Low Development model. Although not widely used in current mass production operations, the selected materials and technologies are beginning to appear in niche or high end vehicles. This segment traditionally incorporates advanced technologies before they are transferred to lower cost, higher volume vehicles. This is done because the luxury class is better able to support the additional piece cost of these technologies. Advanced technologies typically become less expensive as a function of time and volume. It is anticipated that cast aluminum magnesium components along with advanced high strength steel will reduce in price as the technologies develop and the requirement for lighter weight structures intensifies. The Venza NVH mass was retained; this mass may change as a result of tuning for the reduced mass body. There are also electronic noise cancellation technologies under development that could impact the NVH mass in this timeframe.

5.2. Trends

There are many new technologies starting to be used on production vehicles, particularly in niche and high end products. Some of the more significant technologies are covered below.

High Strength Steel

Steel has been the base choice of material for auto bodies in many cases for OEMs due to its combination of strength, ductility and low cost. This has led to the development of a vast knowledge of the material and processing properties and of how to design efficient structures using steel.

As the demands for increased fuel efficiency and safety have increased together with competition from other materials the steel suppliers have responded by developing more grades and types of high strength steels as shown in Table 5.2.a below (from the Auto Steel Partnership web site)

Table 5.2.a: Steel Grades

Steel Description	SAE Grade	Available Strengths Yield or Tensile MPa
Dent Resistant Non Bake Hardenable	A	180, 210, 250, 288 (YS)
Dent Resistant Bake Hardenable	B	180, 210, 250, 280 (YS)
High Strength Solution Strengthened	S	300, 340(YS)
High Strength Low Alloy	X&Y	300, 340, 380, 420, 490, 550 (YS)
High Strength Recovery Annealed	R	490, 550, 700, 830 (YS)
Ultra High Strength Dual Phase	DN & DL	500, 600, 700, 800, 950, 1000 U(TS)
Transformation-Induced Plasticity (TRIP)	None	700, 800, 600, 1000 U(TS)
Ultra High Strength Low Carbon Martensite	M	800, 900, 1000, 1100, 1200, 1300, 1400, 1500 U(TS)

These developments have been matched by the auto industry in developing greater levels of sophistication in design and engineering using these advanced steels.

Although the steels have become more specialized in their application the material cost has remained competitive when compared to other materials such as aluminum and magnesium. Recent studies by ThyssenKrupp[1] have indicated that it is possible to save approximately 24% of BIW mass by using high strength steels and also by redesigning the body structure to take advantage of material and mechanical properties.

Studies by Honda[2] and Volvo[3] have shown how different grades of steel ranging from mild steel with a yield of 180MPa through 288MPa to ultra high strength with yields from 800MPa upwards are used in different areas of the body as required. For example mild steel is used where the panel is not subject to any impact or other extreme loads. The higher strength steels are used in progressively increasing grades to manage loads coming from front crash and roof strength requirements where the use of mild steel to meet the requirements would have a significant effect on the mass of the body.

Aluminum

Aluminum stampings have been used for weight saving on such items as hoods, deck lids and door skin panels for a number of years. The Jaguar XJ series used an aluminum body structure to reduce the BIW weight by approximately 200kg[4].

Aluminum castings have also been used for areas that sustain high forces such as shock towers and nodal points in structures that use extruded sections such as the Audi A8.
There are a number of factors that restrict the wider use of aluminum in volume production. Cost is one consideration. Joining methodology is another.

The most common joining technologies are:

1. Spot welding, which requires high power levels and intense quality control to achieve acceptable reliability; and

2. Riv-bonding, which is expensive due to the cost of the rivets.

The viability of using aluminum in lower cost vehicles will be a function of the targeted weight savings and the opportunities to offset the material cost with the use of simpler, less costly joining methods such as friction stir welding[5] (a method of joining light alloy materials using rotational friction to locally melt and join two pieces) This process has been investigated with Kawasaki Robotics; the Kawasaki process is called friction spot joining and is currently used on production items such as the aluminum Ford Mustang hood and the tailgate of the Toyota Prius.

Magnesium Castings

Magnesium alloy castings are being used on a limited number of production vehicles. These castings provide a significant mass saving and are currently being used to achieve shapes that are not feasible using stamping techniques and to integrate numerous small parts that would otherwise require fixturing and welding. Large scale castings can eliminate a significant number of stamping tools for individual parts.

Applications of magnesium castings include the roof frame for the Chevrolet Corvette ZO6, the dash panel for the Dodge Viper, the liftgate inner for the Lincoln MKT and the front end module for the Land Rover LR3. Meridian Lightweight Technologies Inc.[6], the supplier of these castings, estimates that a magnesium casting similar to that used on the Lincoln liftgate combined with an aluminum outer panel is approximately 40% lighter than the same Venza components made from equivalent steel stampings.

The 2003 Dodge Viper SRT10 dash panel, shown below in Figure 5.2.a, had a mass of 9.5 kg vs. 30 kg for the original steel panel. This was a savings of 20.5kg or 68% compared with the steel panel. Figures supplied by Meridian Lightweight Technologies, the manufacturer of the Viper magnesium casting.

Figure 5.2.a: Dodge Viper Dash Panel

Composites

Although composites have been used on high volume production vehicles such as the Saturn and early GM mini vans which were fundamentally space frame architecture, the applications are now being expanded into structural areas on niche and specialty vehicles where materials such as:

- Sheet composite materials,
- Multi layer composites using sheet materials such as aluminum or glass fiber on either side of a foam, or cellular core
- Carbon fibers are being used or proposed in structural applications.

The Aston Martin Vanquish front crush structure shown in Figure 5.2.b is predominantly carbon fiber.

Figure 5.2.b: Aston Martin Vanquish Front Crush Structure

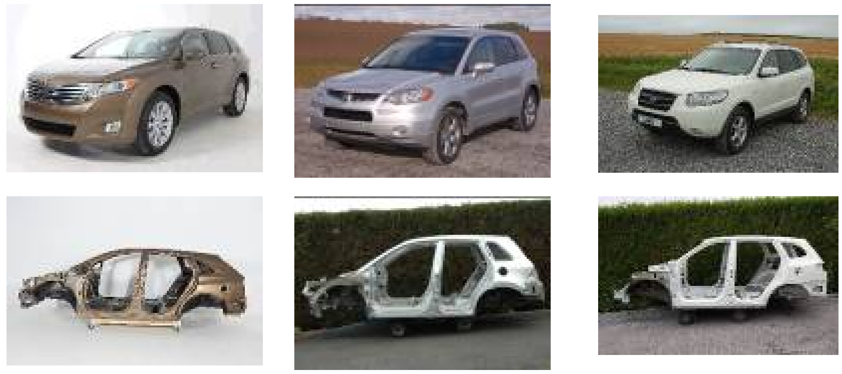
Other potential applications include:

- Using long fiber reinforced polypropylene for the trunk floor area as proposed by the European study headed by Volkswagen[7]
- The use of long fiber reinforced polyurethane[8] for load floors which has been investigated with Bayer Material Science and shows promise in reducing part count and assembly time while maintaining structural stiffness.

5.3. Benchmarking

In order to determine where the opportunities for weight saving were it was necessary to understand both how the weight of the chosen benchmark vehicle was distributed and how it compared with the competition. In order to achieve this, the Toyota Venza was disassembled into its component parts and each part was weighed and measured. Complete disassembly of the body structure was beyond the scope of this study. The major components were identified and measured in sufficient detail to estimate their mass which enabled a baseline mass to be created for the major assemblies of the body.

The Toyota Venza body was also benchmarked against other production body structures by selecting light weight production body shells as well as the body shell of a similar class vehicle. These bodies were then normalized for mass against the Venza using the volume created by the overall length, width and height measurements. Vehicles of similar shapes were selected to minimize volume differences due to styling. A mass/volume ratio was then calculated. Figure 5.3.a shows the benchmarked body structures.



	2009 Toyota Venza	2007 Acura RDX 2.3	2008 Hyundai Santa Fe
Body Weight (kg)	382.5	336.0	359.5
Width (mm)	1925	1870	1870
Height (mm)	1370	1380	1420
Depth (mm)	4583	4260	4360
Volume (m^3)	12.09	10.99	11.58
# Doors	5	5	5
# Seats	5	4	5
Mass/Volume Ratio (kg/m^3)	31.65	30.56	31.05
Normalized mass	**382.5**	**348**	**375.3**

Figure 5.3.a: Body Benchmarking

Figure 5.3.a shows that the Toyota Venza body structure has a higher specific mass/volume than either selected example. The mass savings on a percentage basis are 9.02% for the normalized Acura and 1.88% for the normalized Santa Fe.

Although the 2007 Acura is shown to have the lowest mass/volume ratio it is not possible to establish the rationale for the difference between the Acura body and the Venza body. This is due to there being no data available on the grades of steel used in the Acura or the structural targets used when designing the Acura. A complete material analysis for the 2007 Acura was beyond the scope of this study.

5.4. Analysis

5.4.1. Baseline Body

The primary construction material used in the Toyota Venza was mild steel supplemented by a small amount of high strength steel where necessary to meet particular functional requirements.

The method used to establish the base cost was to scan the body and create a model of all visible panels.

This data was used to:

- Establish the area of major panels
- Measure the material thickness of each panel
- Calculate the mass using this data and the material density.
- The mass and area were then used as the basis for calculating the blank size.
- This together with the material cost was used to estimate the part cost.

Cost recovery from waste material recycling is not included in the cost estimate. The major panels that make up the body were estimated separately in order to understand how the cost is distributed.

Additionally, there are local reinforcements inside box sections. The mass of these parts was estimated by using typical sections and material thickness estimates.
The estimated cost of the current Venza parts established the baseline cost factor (set at 100%).

The Venza body was chemically analyzed using a spectrometer; the chemical composition was then reviewed by a team from the United States Steel Corporation to determine the material type.

A variety of alternative materials were then examined relative to reducing mass and cost for the BIW. The estimated cost of the proposed alternative(s) is stated as a proportion of the base cost.

Table 5.4.1.a shows the mass analysis of the complete painted production Venza body including the body shell and radiator supports/front cross-member. The paint mass was estimated based on the body area and standard paint thicknesses.

Table 5.4.1.a: Venza Body Mass Breakdown

System	Sub system	Standard Venza	% of Body Structure
		kg	
Body structure		383.8	
	Radiator crossmember upper & reinforcement	1.298	
Sub total		382.5	
	Underbody & floor	113.65	29.71
	Dash panel	15.08	3.94
	Front structure	25.15	6.58
	Body side LH	65.22	17.05
	Body side RH	65.22	17.05
	Roof	27.83	7.28
	Inner Structure	58.35	15.25
	NVH	8	2.09
	Paint	4	1.05
	Total	382.5	100.00

The masses quoted for the various assemblies were calculated using CAD models created from scan data of the Venza body. The total mass is the measured mass of the Venza body in white.

The breakdown shown in Table 5.4.1.a includes the bolt-on parts that complete the front end structure including the front upper crossmember, mountings for the hood latch and upper radiator locators.

The estimated material usage is shown in Figure 5.4.1a; the estimated material distribution is shown in Figure 5.4.1.b.

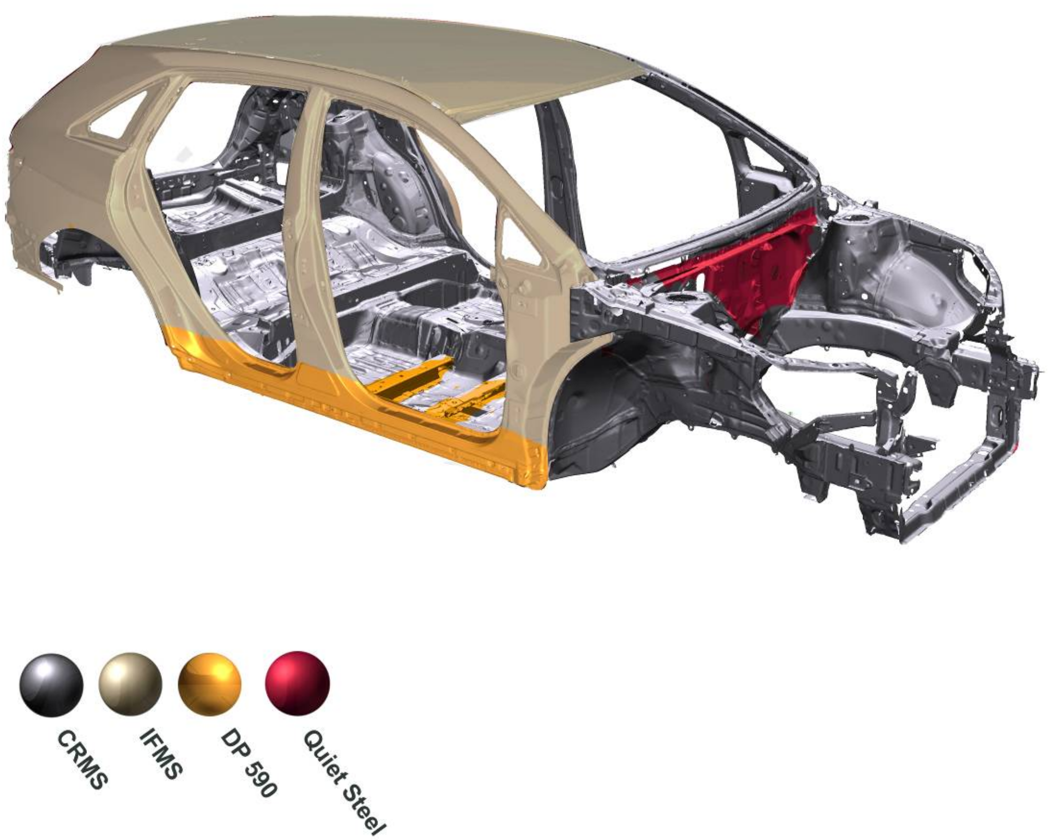


Figure 5.4.1.a: Venza Baseline Steel Grade Distribution

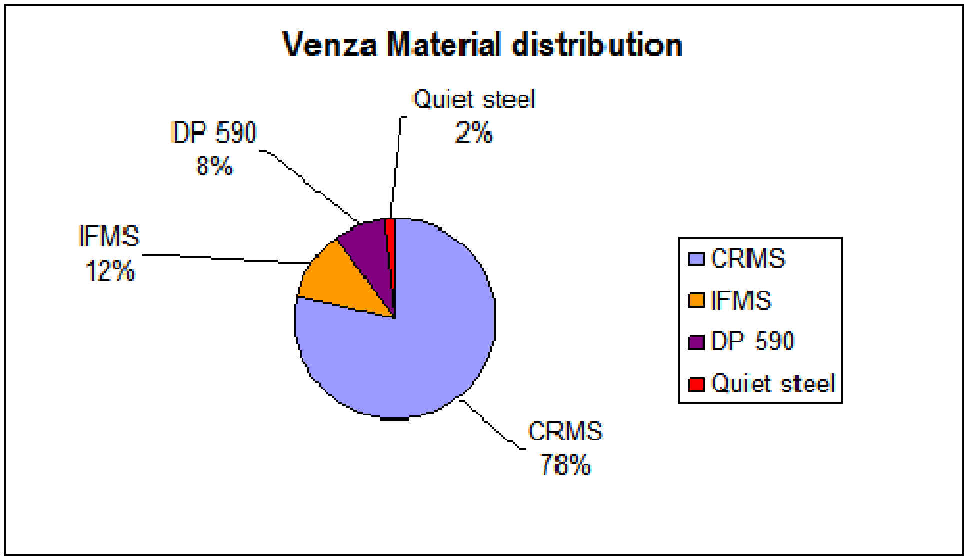


Figure 5.4.1.b Material Distribution % by Mass

5.4.2. Low Development

The Low Development body study investigated production low mass body systems and sub-systems and applied the selected systems and sub-systems to the Venza baseline.

Previous industry studies have shown that the use of various grades of high strength steels can yield useful weight savings for a limited cost increase. Two such studies, sited previously in this report, are the NewSteelBody concept by ThyssenKrupp Steel AG and the Superlight-CAR project, a recently completed, four year $26.5 million project led by Volkswagen AG which involved seven European automakers.

The ThyssenKrupp study used high strength steels, tailor welded blanks and closed tubular sections and projected a BIW mass saving of 24% with a 3% cost increase. This mass reduction study was carried out in Europe on an Opel Zafira. The Zafira specific body density, calculated in the same manner as the Venza, is 34.92 Kg/m^3. This is approximately 10% higher than the Venza value of 31.65Kg/m^3 and indicates that the body of the production Zafira was less efficient than that of the Venza.

The European Super Light Car project showed that a steel intensive Golf could save 88 lbs. (40 kg) at a cost penalty of less than $3.50/lb(< $308).

The two studies cited above together with previously mentioned studies by Volvo and Honda indicate that high strength steel of various grades can be used to manage crash loads and stiffness requirements while maintaining/reducing body mass. The specific grades of steel selected are dependent on the loads being handled and the efficiency of the load paths that dissipate the impact energy. This is further illustrated by the use of 72% high strength steel in the 2010 Mercedes Benz E class body[9].

Although the final choice of steel grades applied to the Venza body structure must be verified using CAE analysis of the body structure and appropriate load cases, it is expected that low range steels (280MPa to 350MPa) will be used where the strength increase can be effective in enabling gauge reductions. High strength steels (350MPa to 500MPa) will be used in areas where crushing is required to absorb energy. Ultra high strength steels (>500MPa) will be used where resistance to deformation is required. Bake hardenable steels are proposed for outer panels where a gauge reduction would normally affect dent resistance.

The proposed Low Development solution for the Venza is to use various grades of high strength steel as shown in Figure 5.4.2a below.

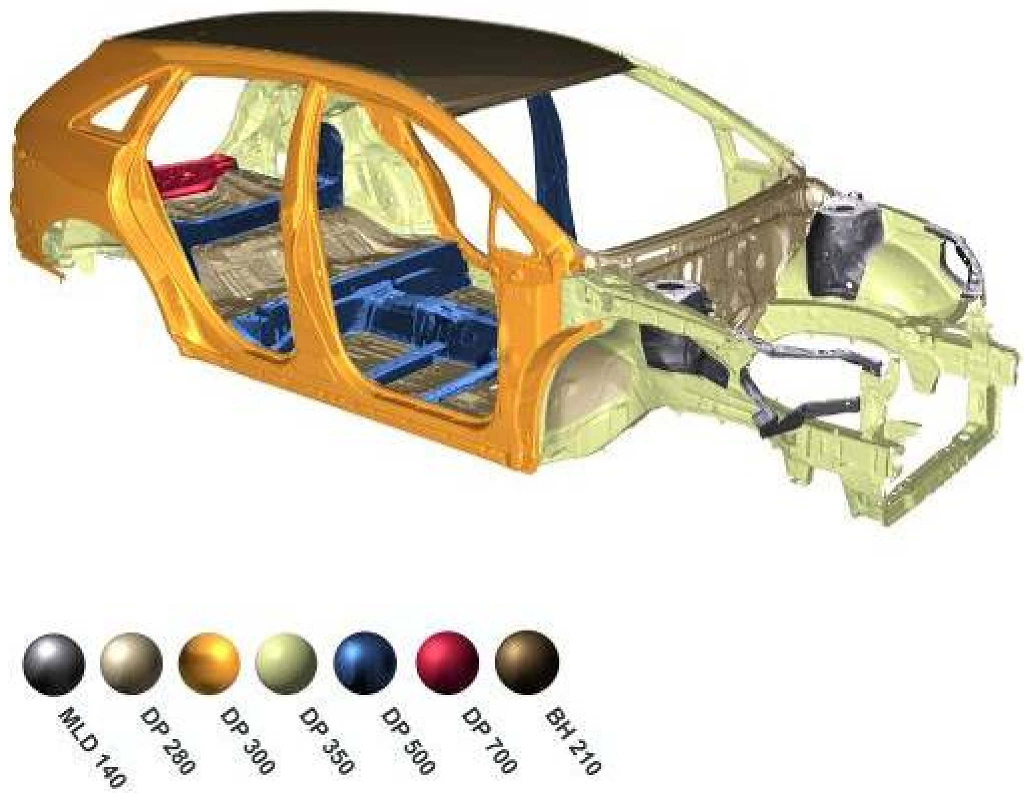


Figure 5.4.2.a: Venza Low Development Steel Grade Distribution

The properties for the steel grades specified are shown in the Appendix in Section 17.2.

The key areas of mass reduction focus are the underbody and floor, the front structure and the body sides. A more detailed study of the parts making up these assemblies is shown in the tables in the Appendix in Section 17.2. A materials summary is shown below in Figure 5.4.2.b.

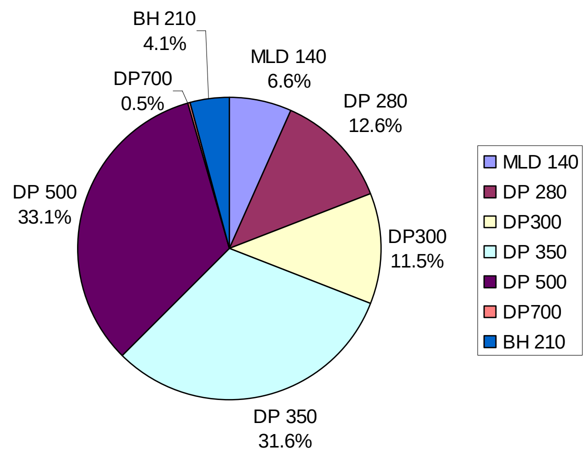


Figure 5.4.2.b: Material Distribution % by Mass

The referenced studies utilized higher levels of design and analysis. The estimated mass savings could increase or decrease by applying FEA optimization techniques to the Venza Low Development body structure.

5.4.3. High Development

The High Development body structure mass savings was targeted at 40% with a technology readiness date of 2017 capable of supporting 2020 MY volume production. The High Development approach considered both existing and emerging technologies that are being commercialized for higher manufacturing volumes in both automotive and non-automotive sectors.

In order to take the most advantage of different material properties and emerging manufacturing processes, while maintaining the required levels of functionality, a variety of materials were used in the body structure.

The High Development study examined the body structure against the material and process options with the objective of integrating parts, reducing redundancy, reducing mass and simplifying the manufacturing process.

The European Super Light Car (SLC) project showed that a combination of steel and non-steel materials could reduce the mass of a 2005 Volkswagen Golf body by 36%, a reduction of 101 kg vs. the baseline weight of 281 kg. The projected cost increase for the 101 kg mass reduction was $705/car in high volume production[10]. The cost factor for the most advanced body structure (a mass savings of 114 kg) was $13.85/kg (July 2009 exchange rates). A breakdown of materials utilization for the SLC was published as part of the Super Light Car report[11].

The High Development model started with defining the fundamental structural and functional requirements for a body structure, which included:

- Bending and torsional stiffness considerations
- Load paths that manage the required levels of impact energy
- Acceptable modes of vibration
- Sufficient strength to manage the loads imparted by the mounting of various vehicle systems
- Sufficient stiffness to maintain door and glazing apertures
- Appropriate shapes and contours to maintain continuous sealing and mounting surfaces

Architecture

The High Development body utilized a high level of modularization. The body was divided into major assemblies which combine functional and manufacturing requirements, including production volumes. This enabled the various assemblies to be built and then be brought together to form the complete body. The work was broken down to suit the required cycle time[12] for assembly for the individual modules as well as the complete body structure. Figures 5.4.3.a and 5.4.3.b depict the exterior vehicle design.

Figure 5.4.3.a: High Development Body Design Proposal

Figure 5.4.3.b: High Development Body Design Proposal

Figure 5.4.3.c depicts the basic body structure, less roof module, for the High Development model shown in Figures 5.4.3.a and 5.4.3.b.

Figure 5.4.3.c: High Development Body In White Structure

The body structure was broken out into the following sections:

- Floor and underbody
- Dash panel assembly
- Front structure
- Body sides
- Roof assembly

Floor and Underbody

The primary functions of the floor and underbody are:

- Create a stable platform for mounting rear suspension and other components
- Make a major contribution to the body stiffness
- Provide a dimensionally stable base for the construction of the body
- Provide a significant portion of the load path for energy absorption under impact conditions
- Provide support for occupants, seats and other interior components
- Provide anchorage points for seat belts
- Create a barrier between the road surface and the occupants

With the traditional floor and underbody being flat and linear it lends itself to manufacturing methods that are compatible with this type of layout. This includes rolled sections, extrusions and one or two piece molded composite panels.
The alternatives that have been considered include:

- Aluminum extrusions for the sill/rocker sections
- A constant aluminum roll form section and extrusions for the center tunnel
- Molded composite floor
- Local aluminum or magnesium castings for transition areas with complex geometry.

A molded composite load floor using long glass fiber reinforced polypropylene under development by Bayer[13] is used for the High Development model. Figure 5.4.3.d illustrates the floorpan. It provides:

- An approximate 7.0% reduction in weight compared to the Venza steel floor pan
- A reduction in component count and assembly time/cost
- The ability to create the desired contours
- A reduction in sealing and sound deadening requirements
- The integration of the lower rear seat structure into the floorpan
- Appropriate structural properties with potential for local molded in reinforcements such as seat belt anchors and seat mounting provisions

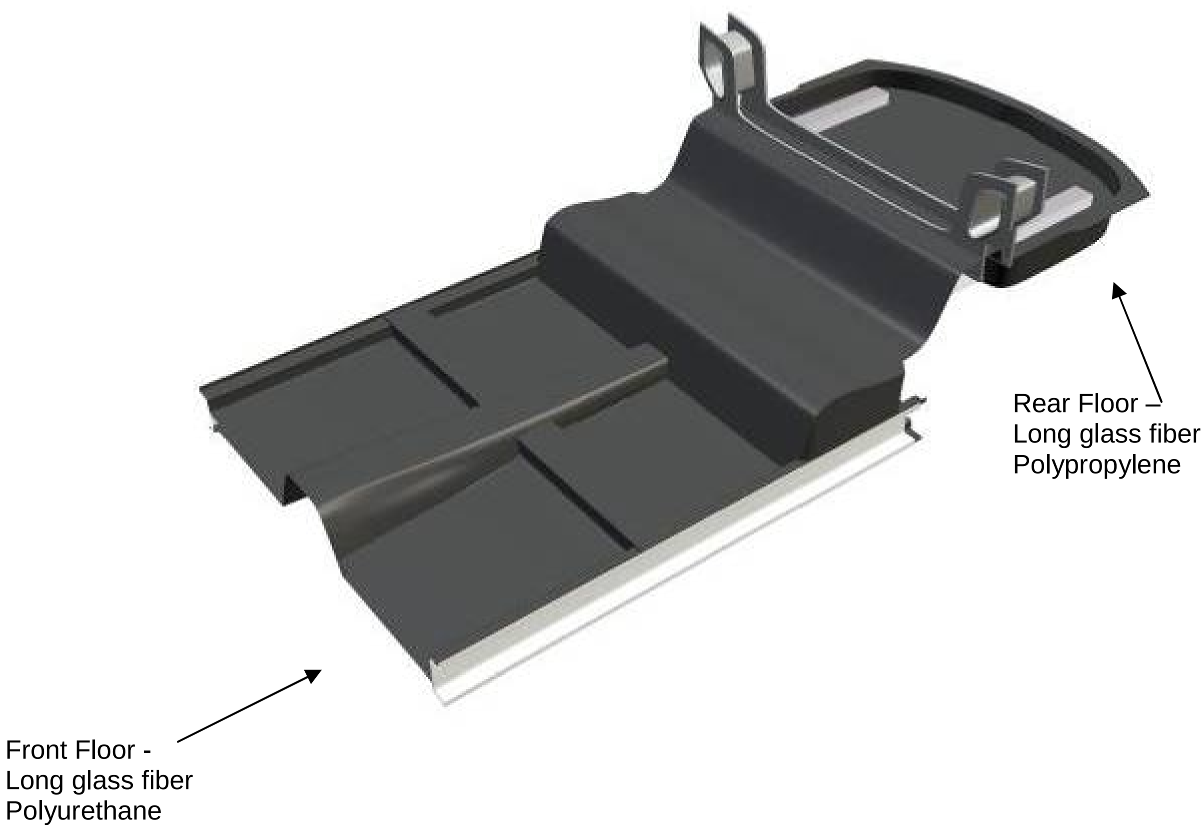


Figure 5.4.3.d: Molded Floor Panel

Dash Panel and Front Structure Assembly

The functional requirements for the dash panel include:

- Structural shear panel
- Barrier for noise, fumes and impact intrusion between the engine compartment and the body interior
- Provide a stable mounting surface for the IP, HVAC system and steering column on the interior and the wiper system and brake booster etc. on the outside.
- Transfer loads from the suspension into the body structure
- Absorb impact energy
- Provide a stable mounting platform for the engine, suspension and steering systems
- Provide mounting points and load transfer functions for the front end module

The Toyota Venza uses multi-piece welded steel stampings with additional noise inhibitors added on the interior and engine compartment surfaces.

The proposed solution uses a single magnesium casting for the dash panel using an over-mold [11] process to incorporate the NVH materials prior to body assembly, as required. A magnesium front of dash is used on the Dodge Viper; the Viper meets both federal and internal OEM safety requirements.

The dash and front structure is a combination of castings, extrusions and stampings.

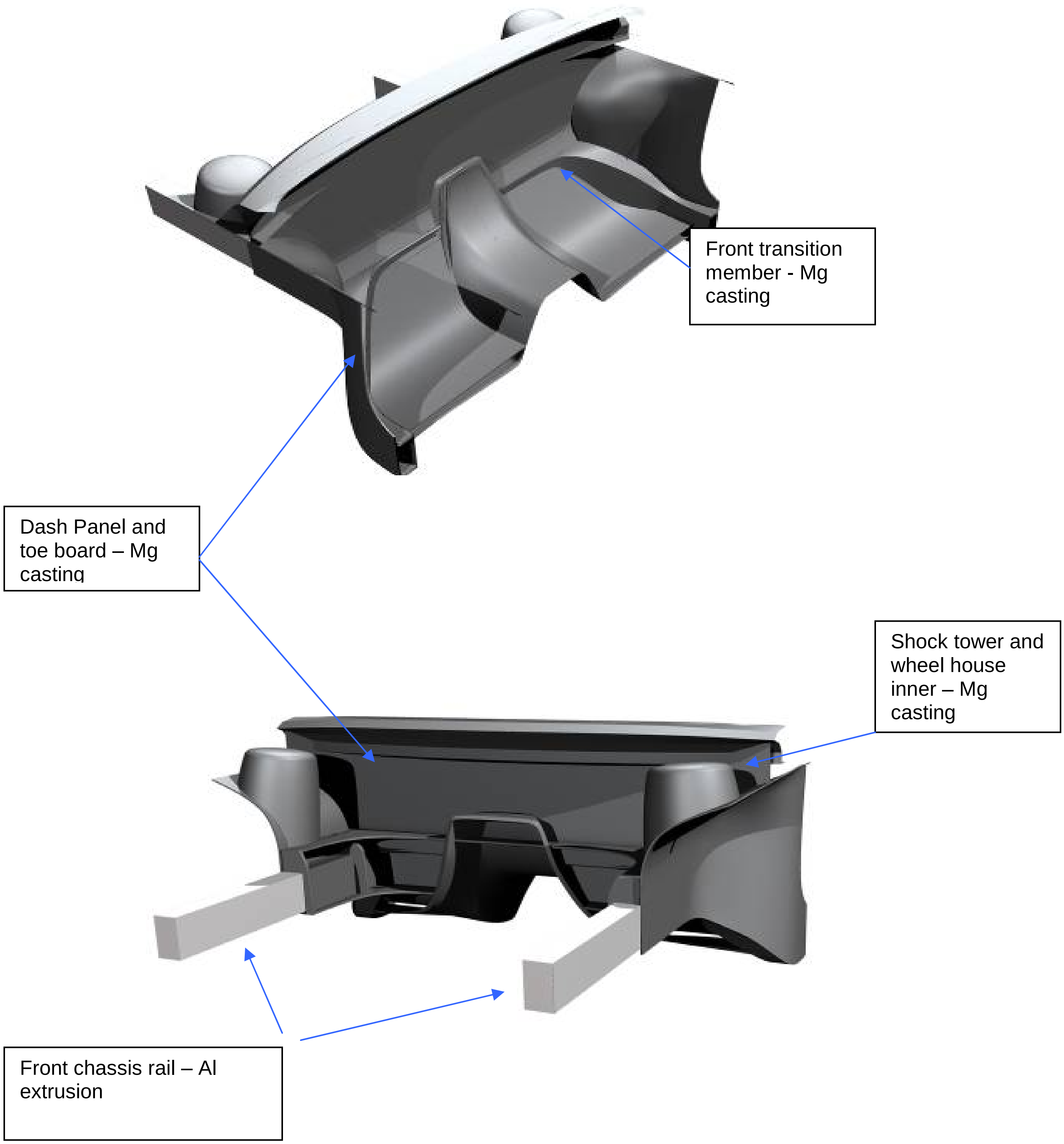


Figure 5.4.3.e: Dash Panel and Front Structure Assembly

Front End Module

The primary functions of the front end module are to:

- Provide mounting points for the front fascia, headlamps, hood latch and upper radiator mountings
- Act as a dimensional control for the front end structure
- Transmit loads from the front end into the front structure and on into the body
- Provide a structure across the front end of the body to control the position of the front rails and to add stiffness to the front end

The current Toyota Venza uses a series of steel stampings welded together to create this structure which also includes the lower radiator mountings and headlamp mountings.

The proposed architecture will use a separate cast magnesium front end module (FEM) which will provide stiffness across the front end of the body. This will be connected to the sides of the front structure to create a load path from the front end into the A pillar and body sides. Figure 5.4.3.f shows the magnesium front end module.

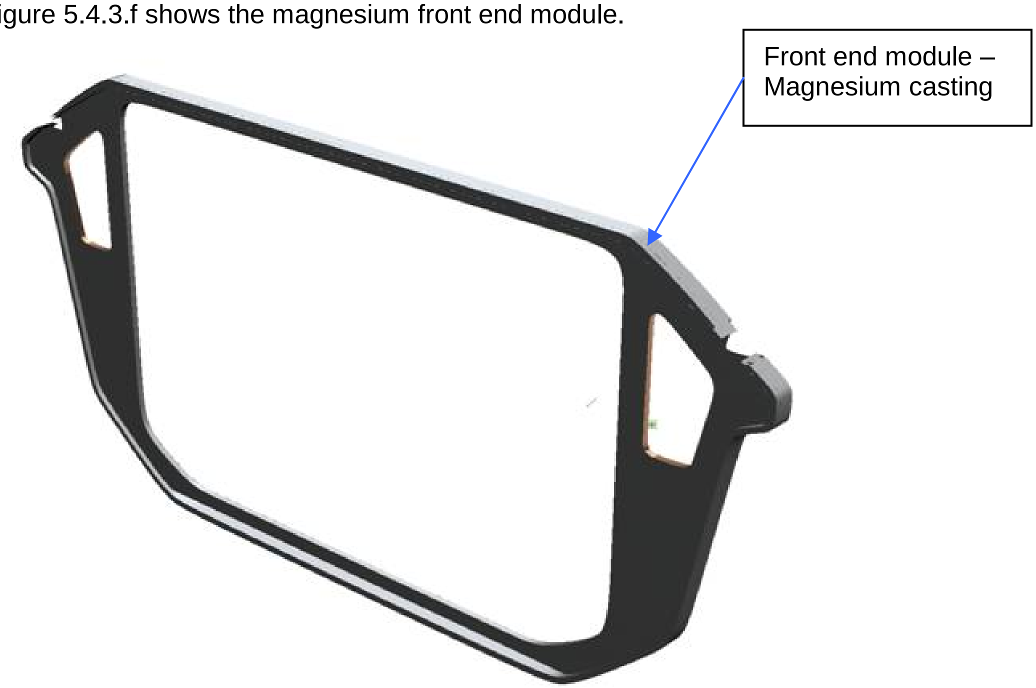


Figure 5.4.3.f: Front End Module

Body Side

The primary functional requirements of the body side include:

- Providing stable repeatable door apertures
- Providing stable mounting points for hinges and latches
- Creating a smooth surface to interface with the door seals
- Providing adequate structure to meet side impact and roof strength requirements
- Providing mounting points and surfaces for the interior trim.

The body side structure is traditionally built using a series of steel stampings and reinforcements on the interior which are covered with trim with a one piece outer (exterior) panel stamping providing a door aperture and seal surface.

Although the one piece body side outer meets functional and manufacturing requirements, the two large openings for the doors creates substantial waste material.

The use of an all aluminum structure was investigated but rejected on the grounds of cost (approximately 1.8 times the cost of steel) and stamping feasibility due to the very deep draw conditions and multiple steps in the door apertures.

The proposed architecture uses a hybrid approach for the body side to incorporate both the structural reinforcements and the door apertures. A series of magnesium castings provides the base structure which would be over molded with a structural plastic. The over-molding process positions the metallic components in the molding die and then injection molds the structural plastic around them. In this process the properties of the two materials are combined enabling them to structurally complement each other and achieve a weight reduction. This structure must meet the functional requirements of repeatable geometry door apertures and smooth sealing surfaces. It must also provide structural continuity between the various castings. The aluminum panels would be attached to flanges incorporated on the magnesium castings using friction stir welding. Analysis and testing is required to verify this design.

The class ‘A’ surface for the rear quarter panel would be created using an aluminum stamping. The mass savings using this manufacturing method were estimated to be 52.52kg per body. Figure 5.4.3.f shows the body side assembly.

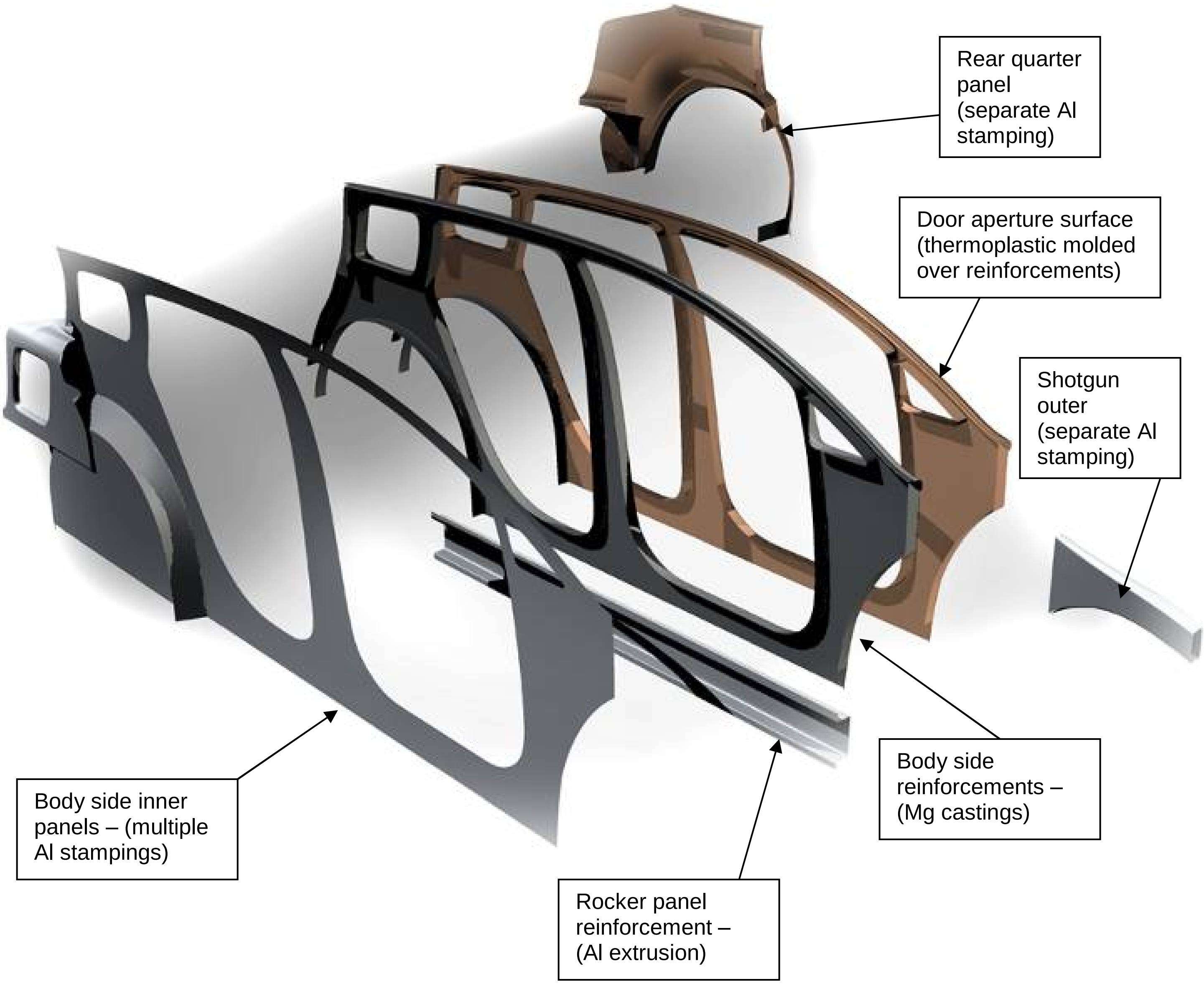


Figure 5.4.3.f: Body Side Assembly

Roof Assembly

The primary functional requirements for the roof and roof structure are to:

- Provide protection for the occupants from the elements
- Meet federal roof crush regulations (FMVSS 216)
- Contribute to the structural performance of the body
- Contribute to maintaining the dimensional accuracy of the body

The current Toyota Venza uses a series of steel stampings welded to the body. This process typically requires complex fixturing to achieve the required level of repeatability.

The Venza roof panel weighs approximately 13.7kg and together with the associated roof bows and headers contributes approximately 27.8kg to the mass of the body structure.

The proposed architecture is to change the roof panel to an aluminum stamping and to create the structure using three magnesium castings providing a weight saving of approximately 11.0 kg. Figure 5.4.3.g shows the roof module.

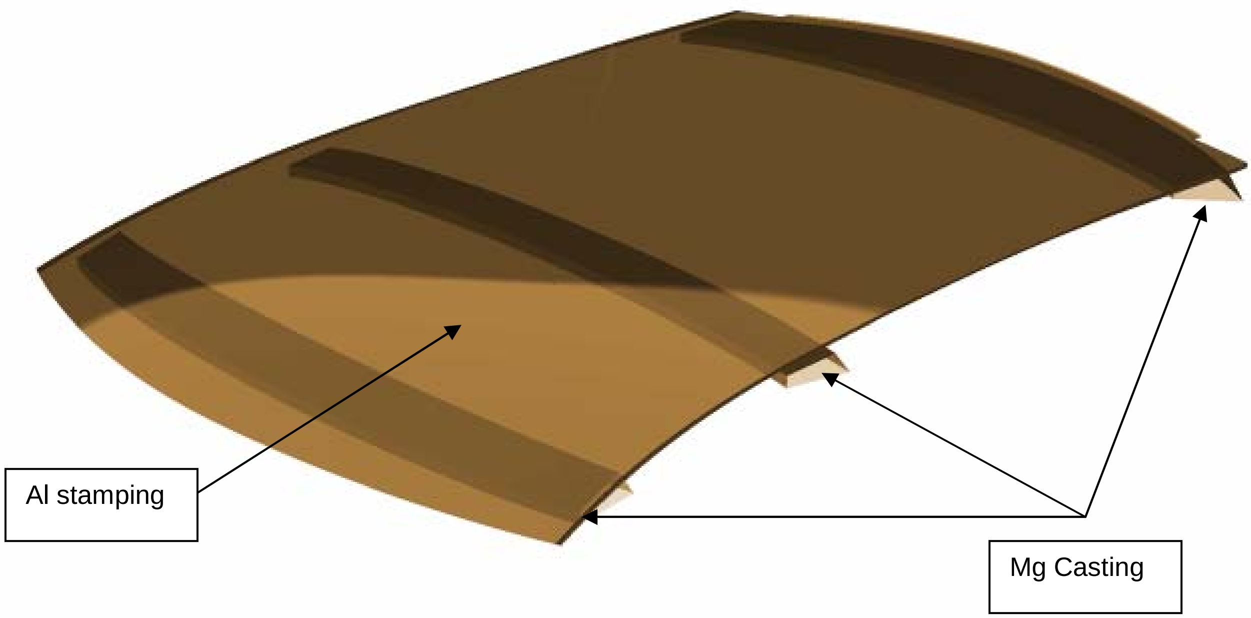


Figure 5.4.3.g: Roof Module Concept

In order to achieve the target mass reduction all assemblies have been subject to careful study with the results shown in the table below.

A more detailed study of the parts making up these assemblies is shown in the Appendix.

5.5. Results

5.5.1. Low Development

The Low Development summary shown below in Table 5.5.1.a showed an estimated 15.9% reduction in mass for the Low Development body structure and although this does not meet the stated target of 20% it was considered the most realistic approach until detailed structural analysis could be carried out to assess the opportunities in more detail. The continued use of mild steel for components such as the intermediate roof bows which have little benefit to the mass reduction or on components such as the shock tower that may not be formable in higher strength steels. The estimated cost factor was 98%.

Table 5.5.1.a: Summary of Body Structure Mass Reductions

System	Sub system	Standard Venza	% of Body Structure	Material Mass (kg)			Revised Body	Cost relative to Venza
		kg		MS	HSS	Mg	kg	
Body complete		403.24					339.33	
	Windshield wipers/washers	9.15					8.00	
	Body exterior trim items	11.59					6.55	
Body structure		382.50						
	Underbody & floor	113.65	29.7	0.2	93.78	0	93.98	94%
	Dash panel	15.08	3.9	0.62	11.84	0	12.46	98%
	Front structure	25.15	5.78	2.88	13.95	5	21.83	117%
	Body side LH	65.22	17.1	4.51	49.41	0	53.92	98%
	Body side RH	65.22	17.1	4.51	49.41	0	53.92	98%
	Roof	27.83	7.3	3.19	19.18	0	22.37	97%
	Internal reinforcements	58.35	15.3	23.5	30.8		54.3	100%
	NVH	8	2.0				8	100%
	Paint	4	1.0				4	100%
Total		**382.5**		**39.51**	**291.87**	**5**	**324.78**	**98%**
Mass Savings %							**15.9%**	

5.5.2. High Development Summary

Table 5.5.2.a shows the results of the complete High Development body structure mass reductions. The body mass was reduced from 382.5 kg to 221 kg; the estimated cost factor was 135%.

Table 5.5.2.a: Summary of High Development Body Structure Mass Reductions

System	Sub system	Standard Venza	% of Body Structure	Material Mass (kg)				Revised Structure Total	Cost relative to Venza
		kg		Composite	Steel	Al	Mg	kg	
Body complete		403.24						235.61	
	Windshield wipers/washers	9.15						8.00	
	Body exterior trim items	11.59						6.55	
Body structure		382.50						221.06	
	Underbody & floor	113.65	29.71	32.4	14.5	24.46	12.4	83.76	110%
	Dash panel	15.08	3.90	0	0	0	12	12.00	141%
	Front structure & radiator crossmember	25.15	5.78	0	0	7.6	11.0	18.6	167%
	Body side LH	65.22	13.56	6.96	0	19.69	12.3	38.95	117%
	Body side RH	65.22	13.56	6.96	0	19.69	12.3	38.95	117%
	Roof	27.83	4.22	0	0	10.3	6.5	16.80	298%
	Internal Structure	58.35	15.25						
	NVH	8	2.09					8	100%
	Paint	4	1.05					4	100%
Total		**382.5**		**46.32**	**14.5**	**81.74**	**66.5**	**221.06**	**135%**
Percentage reduction relative to base								**42.2%**	

The mass was reduced 42.2% relative to the baseline Venza body structure and although this is slightly above the 40% target, it was a function of a number of factors:

- Minimizing the mixing of metals and thereby reducing corrosion risks
- Using castings creates a step function (non-linear) in the relationship between the material and manufacturing technique vs. the mass saved
- The material thicknesses used in the mass estimates; they typically require adjustment when an all new design is subjected to CAE analysis

It is expected that as the design is developed and the structure is refined using analytical tools, the mass saving percentage may change slightly.

5.5.3. Body Structure Mass Distribution by Material

The Body structure materials for the baseline, Low Development and High Development models are shown in Charts 5.5.3.a. through 5.5.3.c. The Low Development body structure was an all steel construction. The High Development body structure utilized aluminum, magnesium and composite materials and a high level of component integration.

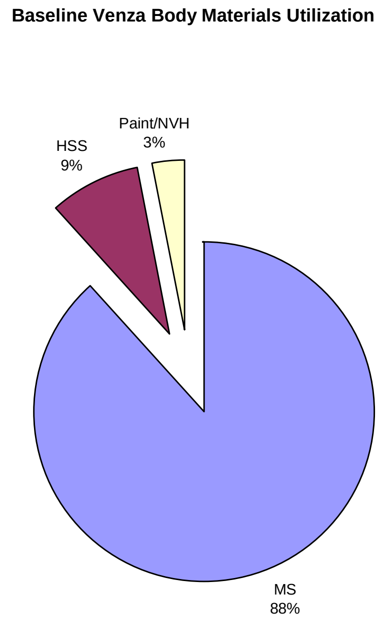


Chart 5.5.3.a

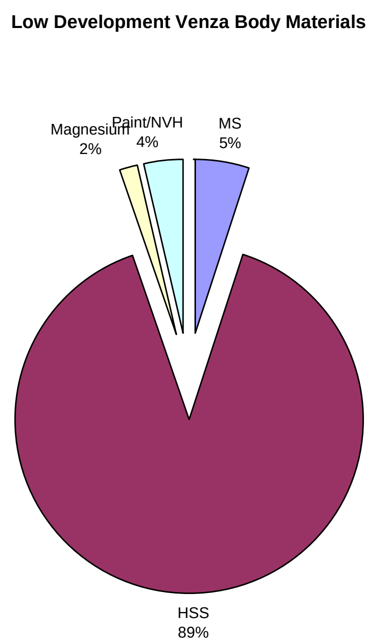


Chart 5.5.3.b

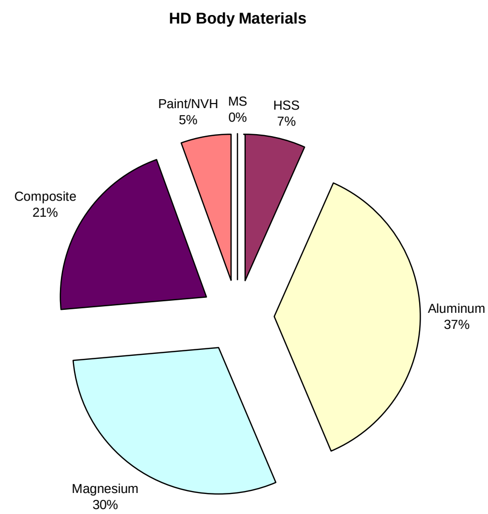

HD Body Materials
Paint/NVH
5%
MS
0%
HSS
7%
Composite
21%
Aluminum
37%
Magnesium
30%

Chart 5.5.3.c

6. Closures

6.1. Closures (Doors, Hood, Liftgate) Overview

The structural requirements and cost impact of reduced mass closures are typically less complex than those of a complete body structure. As a result, closures have become an initial focus point for weight reduction on many vehicles. This has led to increased use of lightweight materials in the design of closures rather than in the design of lighter weight body structures.

The ready availability of lightweight materials and proven manufacturing methods for closures allowed these to be used on the Low Development model. The High Development model investigated more advanced manufacturing methods and the use of alternative materials that allowed greater integration of function into the various components. Closures and fenders accounted for 143.02 kg of the Venza mass.

The Low Development body structure (20% mass reduction target) investigated a range of alternative materials which are currently in use in the automotive industry including composites, cast and stamped aluminum, conventional high strength steels and the evolving material technologies such as ultra high strength and dual phase steels. Other opportunities investigated as part of the Low Development process were the integration of multiple stamped parts into a single component and a higher level of modularization to improve the efficiency of the production process. The Venza production closure latches, hinges and related mounting hardware were retained; the Venza hardware mass was used for these components.

The High Development body structure (40% mass reduction target) used a broader range of materials and technologies than the Low Development model. Although not widely used in current mass production operations, the selected materials and technologies are beginning to appear in niche or high end vehicles. This segment traditionally incorporates advanced technologies before they are transferred to lower cost, higher volume vehicles. This is done because the luxury class is better able to support the additional piece cost of these technologies. Advanced technologies typically become less expensive as a function of time and volume. It is anticipated that cast aluminum and cast magnesium components will come down in price as the technologies develop and the requirement for lighter weight structures intensifies. The Venza production masses for the closure latches, hinges and related mounting hardware were used for the High Development model.

6.2. Trends

More advanced technologies have been used in closure designs than in the primary body structure. This was due to the less stringent performance requirements and a lower cost as opposed to creating a lightweight body structure using the same materials. This has led to the greater use of aluminum alloys, magnesium and composites in closures. An aluminum hood is available on the Ford Mustang while specialty low volume cars, such as the Corvette ZR1, has a carbon fiber hood.

The use of magnesium castings for inner panels has increased on higher end vehicles such as the 2010 Lincoln MKT where it is used for as the primary tailgate structure. This technology is expected to be viable for Venza class vehicles in the timeframes being considered.

Additional mass reductions are projected to come from a conceptual shift in the parts design that emphasizes the integration of multiple functions into one part.

Doors have traditionally consisted of a stamped or molded outer panel, a stamped or molded inner panel plus the necessary reinforcements which are then assembled, painted, have the glass and other components added and covered with a molded interior trim panel. The process has been developed to the point where the door components are pre-assembled into a module which is then installed into the door as a unit. Module design and material development is at a point where some production modules[14] now contain the majority of the door operating components. The door module provides the functions of hardware carrier, interior trim as well as contributing to the door structure.

Fenders have used a variety of materials from traditional steel through a variety of plastics the majority of which are thermoplastics such as a polyphenylene oxide/polyamide alloy (PPO/PA) which has the ability to readily accept automotive paint and a density of 1.10 g/cm^3 compared with 7.86 g/cm^3 for steel.

6.3. Benchmarking

The current Toyota Venza closures were benchmarked against other production closures by selecting the lightest closures and then normalizing them for mass against the Venza using the area created by the overall length and height measurements. The door depth was also investigated; it was not a significant contributor to door mass. Tables 6.3.a. and 6.3.b below show the benchmarked front and rear doors.

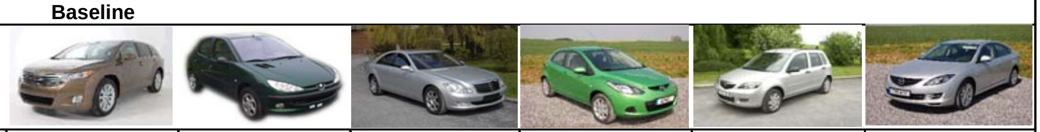
Several European doors were considered; European vehicles must meet side impact standard EC R95 rather than the U.S. FMVSS 214 side impact requirement. A review of the two regulations showed that although there are some differences they both require providing survival space with a common objective of reducing injuries. A complete side impact analysis showing the relative differences between these tests was beyond the scope of this study.

Furthermore, it was recognized that the proposed Low Development and High Development door structures will require analysis for compliance to FMVSS 214. This analysis was beyond the scope of this study.

Table 6.3.a: Front Door Benchmarking

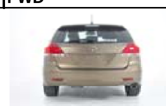
	Baseline					
						
	Toyota Venza 2.7 FWD	Audi A2 1.4 16V Pack	Mercedes S Class 350	Peugeot 206 X Line 2.0 HDI	Volkswagen Golf 2.0 TDi 140 Carat	Suzuki Ignis 1.3 VVT
						
Weight Kg	20.082 kg	6.51	9.498	10.842	11.254	11.412
						
Width	1070	970	1317	1200	1280	1034
Height	1270	730	1145	1000	1100	1154
Depth	315 mm	135 mm	210 mm	198 mm	181 mm	180 mm
Materials	Steel	Aluminum	Aluminum	Steel	Steel	Steel
Adjusted weight		**12.49**	**8.56**	**12.28**	**10.86**	**13.00**

Table 6.3.b: Rear Door Benchmarking

Rear Door	Baseline					
						
	Toyota Venza 2.7 FWD	Peugeot 206 X Line 2.0 HDI	Mercedes S Class 350	Mazda 2 1.3 Elegance	Mazda 2 1.25L Harmonie CLIM	Mazda 6 1.8 Elegance
						
Weight Kg	**14.58**	**8.28**	**9.136**	**9.581**	**9.706**	**9.806**
						
Width	1036.9	815	1200	1000	910	1065
Height	1272	1000	1145	1120	1180	1080
Depth	295 mm	198 mm	210 mm	250 mm	190 mm	290 mm
Materials	Steel	Steel	Aluminum	Steel	Steel	Steel
Adjusted weight		**13.40**	**8.77**	**11.28**	**11.92**	**11.24**

Five production tailgates that were lighter than the Venza were selected as benchmarks. These tailgates were then normalized to the Venza tailgate area by multiplying the width and height of the part and dividing it by the area of the Venza part. The weight of the comparative parts was then adjusted according to the derived adjustment factor. The depth of the tailgate was also considered but distorted the results by bringing the curvature of the body into the calculation and was therefore discounted. In addition to the curvature the size of the glass aperture also becomes a factor when considered as a proportion of the overall size of the tailgate. Table 6.3.c shows the benchmarked tailgates.

Table 6.3.c: Tailgate Benchmarking

Tailgate						
	Baseline					
						
	Toyota Venza 2.7 FWD	**Audi A2 1.4 16V Pack**	**Toyota Prius 1.5 Base**	**Honda Jazz 1.4 G5 LS**	**Alfa Romeo 147 1.9l JTD Multijet**	**Fiat Panda 1.2 Class**
						
Weight Kg	**14.487**	**6.254**	**7.638**	**8.036**	**8.06**	**8.414**
						
Width	1415	1130	1125	1300	1170	1180
Height	1115	980	840	950	1190	900
Depth	292 mm	260 mm	875 mm	190 mm	210 mm	140 mm
Materials	Steel	Aluminum	Steel	Steel	Steel	Steel
Adjusted weight		**8.91**	**12.75**	**10.27**	**9.13**	**12.50**

Five production hoods that were lighter than the Venza were used as benchmarks. These hoods were then normalized to the Venza hood area by multiplying the width and height of the part and dividing it into the area of the Venza part. The weight of the comparative parts was then adjusted according to the derived adjustment factor. The depth of the hood was also considered but distorted the results by bringing the curvature of the body into the calculation and was therefore discounted. Table 6.3.d shows the benchmarked hoods.

All benchmarked hoods were aluminum except for the Toyota Yaris. The normalized weights were 50% lighter than the Venza steel hood. This weight savings has an estimated cost factor of 1.85; aluminum was not used for the Low Development hood because of the high cost factor.

Table 6.3.d: Hood Benchmarking

Hood						
	Baseline					
						
	Toyota Venza 2.7 FWD	**Renault Modus 1.6 16v privilege luxe**	**Audi A2 1.4 16V Pack**	**Renault Clio III 1.6l 16V**	**Citroen C4 Grand Picasso 2.0 HDi Exclusive**	**Toyota Yaris 1.4 D-4D Sol**
						
Weight Kg	**16.796**	**3.19**	**4.36**	**4.384**	**5.169**	**5.676**
						
Width	1633	1385	1365	1390	1530	1320
Height	1063	640	800	760	875	631
Depth	111.8	110	160	70	110	100
Materials	Steel	Aluminum	Aluminum	Aluminum	Aluminum	Steel
Adjusted weight		**6.25**	**6.93**	**7.20**	**6.70**	**11.83**

Table 6.3e below summarizes the total estimated closure weight savings using the lightest adjusted mass. The closure mounting hardware, including hinges and fasteners, is not included.

Table 6.3e Closure Benchmarking Summary

Closure	Venza	Lightest adjusted	Saving
	kg	kg	kg
Front Doors	40.06	17.12	22.94
Rear Doors	29.16	17.54	11.62
Tailgate	14.49	8.91	5.58
Hood	16.8	6.25	10.55
Total	100.51	49.82	50.69

This ROM (rough order of magnitude) analysis shows a mass reduction of about 50% using current production closure technology and materials. This was an indicator that substantial closure weight savings were achievable. The Low Development and High Development closure studies investigated potential mass savings in detail.

6.4. Analysis

6.4.1. Low Development

In the context of Low Development the material and process options available for the design of the closures are greater than those for the body structure because closures have generally been the first item considered when looking for mass reductions in a body.

This study has considered a number of options for materials and processes in various combinations, including:

- High strength steel stampings for the inner and outer panels
- Aluminum stampings for the inner and outer panels
- Aluminum outer panels with stamped steel inner panels
- Aluminum outer panels with cast magnesium inner panels
- Thermoplastic outer panels with high strength steel inner panels

Each combination provides a different combination of mass reductions and increased costs which have to be evaluated against the mass and cost of the complete vehicle.
Using this approach it is possible to achieve a more optimized solution than would be possible if each system were evaluated in isolation.

The following sections provide more detail on the study of the main closures:

- Side doors
- Tailgate
- Hood
- Fenders

Side Doors

For the Low Development study the architecture of the side doors remains predominantly the same as the Venza which uses an inner panel, an outer panel, separate reinforcements, separate side intrusion beam and a separate upper glass run channel. The data shown in Table 6.4.1.a was used as part of a total vehicle analysis for mass and cost. The door hardware incorporated the Faurecia integrated door module which eliminated a portion of the door inner stamping, uses plastic run channels and a cable operated regulator (shown in Figure 6.4.1.a). This saved approximately 4Kg per vehicle. The side door mass and cost summary is shown in Table 6.4.1.a below.

Table 6.4.1.a: Side Door Material Study

Material Combination	Total Mass	Mass Saving	Mass Reduction	Cost Factor
	Kg	Kg	**%**	
High strength steel stampings for the inner and outer panels	61.51	3.90	5.96	1.08
Aluminum stampings for the inner and outer panels	52.10	13.31	20.35	1.61
Aluminum outer panels with stamped steel inner panels	58.96	6.45	9.86	1.25
Aluminum outer panels with cast magnesium inner panels	37.98	27.43	41.94	1.21
Thermoplastic outer panels with high strength steel inner panels	53.17	12.24	18.71	0.93

Faurecia Dodge Nitro Door Module – Wet Side

Faurecia Dodge Nitro Door Module – Dry Side

Figure 6.4.1.a: Faurecia 2009 Dodge Nitro Door Module

This integrated module is much less complex than the Venza design which was constructed using a piece by piece process and incorporates a complete door inner panel and steel glass run channels as shown in Figure 6.4.1.b.

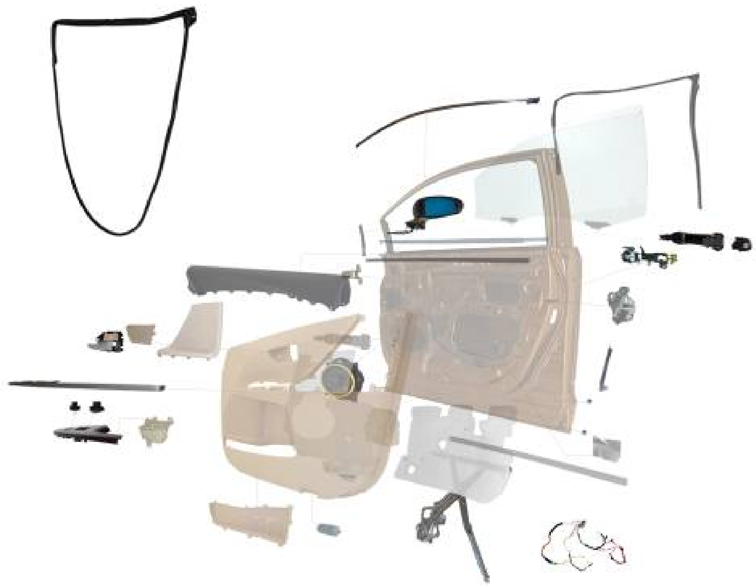


Figure 6.4.1.b : Toyota Venza Front Door

Tailgate

For the Low Development study the architecture of the tailgate was reviewed against the need to achieve the minimum mass due to it being hinged at the top. A unit with minimum mass will subsequently reduce the size of the hinges, the gas struts and the body mounting structure. The study of the materials and processes shown above provided the data that guided the final tailgate proposal. The tailgate mass and cost summary is included in Table 6.4.1.b.

Table 6.4.1.b: Tailgate Material Study

Material Combination	Total Mass	Mass Saving	Mass Reduction	Cost Factor
	Kg	Kg	%	
High strength steel stampings for the inner and outer panels	13.15	1.33	9.19	1.01
Aluminum stampings for the inner and outer panels	11.22	3.26	22.51	1.84
Aluminum outer panels with stamped steel inner panels	13.12	1.36	9.39	1.51
Aluminum outer panels with cast magnesium inner panels	8.70	5.78	39.91	1.96
Thermoplastic outer panels with cast magnesium inner panels	6.60	7.88	54.42	1.48
Thermoplastic outer panels with high strength steel inner panels	10.38	4.10	28.31	0.86

From the detailed study of the tailgate and the overall study of the vehicle mass it was concluded that although the mass savings provided by the thermoplastic outer and high strength steel inner satisfy the basic requirements the additional mass savings provided by the magnesium inner were necessary to help meet the overall mass reduction objective. Figure 6.4.1.c illustrates a typical cast magnesium inner tailgate structure.

Figure 6.4.1.c: Typical Cast Magnesium Tailgate Inner

Hood

The factors used when considering the hood architecture were:

- The attitude of the panel (horizontal),
- The need to manage under hood temperatures,
- The need to manage crash loads and to deform in a predictable manner and
- The need to open for access to the engine bay.

The study of the materials and processes considered for the hood provided input that guided the final proposal. The hood mass and cost summary is included in Table 6.4.1.c below.

Table 6.4.1.c: Hood Material Study

Material Combination	Total Mass	Mass Saving	Mass Reduction	Cost Factor
	Kg	Kg	%	
High strength steel stampings for the inner and outer panels	15.30	1.50	8.93	1.02
Aluminum stampings for the inner and outer panels	13.01	3.79	22.56	1.85
Aluminum outer panels with stamped steel inner panels	14.26	2.54	15.12	1.37

The use of thermoplastic for the hood outer panel was considered but discounted due to the potential for distortion under hot soak conditions and the need for additional underside support which would increase the mass of the inner panel. From the detailed study of the hood and as part of the overall vehicle mass it was concluded that although the cost factor for the all aluminum solution was high it was necessary to absorb this in order to achieve the overall mass reduction target.

Fenders

The current material for the Venza fender is steel which is attached to the body using separate brackets and bolts. There are numerous vehicles in production using various plastic fenders that reduce mass vs. steel fenders. Both the Low and High Development fender use a non metallic PPO-PA[15] material which would be attached using methods similar to the steel part except that the brackets may be molded into the part. The estimated mass saving per car is 2.59kg. The cost factor is 0.44. The fender mass and cost summary is included in Figure 6.4.1.d.

Table 6.4.1.d: Fender Material Study

Material Combination	Total Mass	Mass Saving	Mass Reduction	Cost Factor
	Kg	Kg	%	
High strength steel stampings	4.93	0.7	12.43	1.0
Aluminum stampings	4.22	1.41	25.00	1.49
Injection molded plastic	3.38	2.59	43.38	0.44

6.4.2. High Development

In order to achieve a 40% mass reduction, higher levels of functional integration and a reduction in the amount of material used in the structure were required.
Alternative construction and assembly methods were also utilized. The proposed changes to the closure architecture necessary to achieve an estimated 40% mass reduction are reviewed below.

Side Doors

The traditional door inner panel was replaced with a molded composite part that also created the major portion of the interior trim and carried the major operating mechanisms such as the window regulator and dropping glass. See Section 9.6 (interior) for the detailed explanation.

The primary door structure was a one piece magnesium casting incorporating the mounting points for door hinges, door latch, and exterior mirror (if required). It also incorporated the side intrusion beam and a framework that supported the glass run channels being built into the inner door panel molding. Figure 6.4.2.a illustrates the magnesium front and rear door inner castings. The side intrusion beam section requires further development using FEA techniques. This analysis is beyond the scope of this study.

Figure 6.4.2.a: Door inner castings

The outer panel will be a composite molding that incorporates the outer release mechanism and will be bonded to the cast magnesium frame.

The door hardware will be changed to the Faurecia advanced integrated door module which will save approximately 7Kg per vehicle. This module is currently under development and will incorporate the functions of the Audi A2 window regulator and the Dodge Nitro module shown in Figures 6.4.2.b and 6.4.2.c below. This allowed the door design to be similar to the concept shown in Figure 6.4.2.d. The additional mass reduction is achieved by incorporating more of the door "inner" into the module and using a fiber reinforced thermoplastic instead of aluminum for the outer panels.

Figure 6.4.2.b: Audi A2 window regulator module

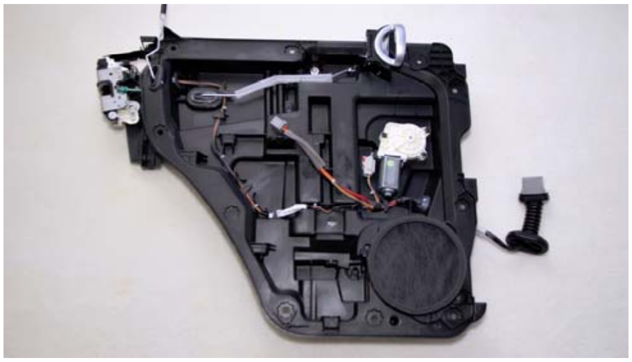


Figure 6.4.2.c: Dodge Nitro Door Module

Figure 6.4.2.d: Cast doors with module

Tailgate

The tailgate concept is similar to the side doors and uses a molded interior panel to function as the both trim and inner panel surface. Figure 6.4.4.e shown below depicts the High Development tailgate concept.

A cast magnesium frame was utilized to create the interface between the outer panel and the inner molding. This frame will also incorporate the reinforcements for hinges, gas struts and latch mountings.

The outer skin is a one piece composite panel which will be bonded to the cast frame and will be made from a material similar to that used on the original Saturn vehicles.

This combination of materials has an estimated mass of 7.96kg compared with a mass of 14.48kg for the current steel construction and a cost factor of 1.48.

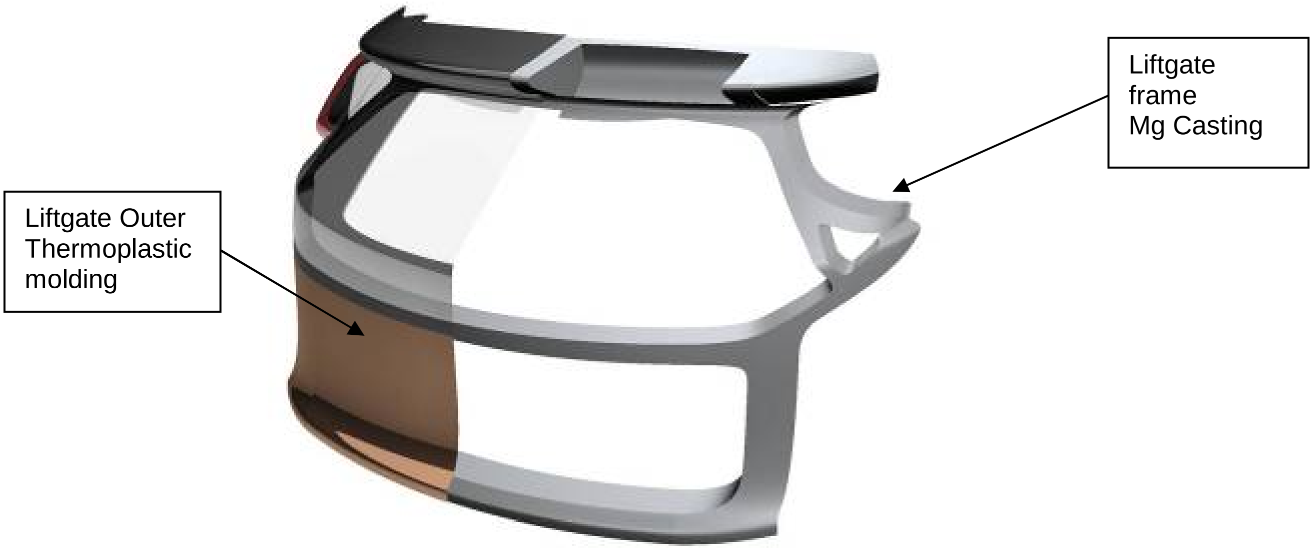


Figure 6.4.2.e: Cast Liftgate Frame with Molded Skin

Hood

The High Development hood used a stamped aluminum outer panel and a stamped aluminum inner panel. The hood assembly will require extensive engineering analysis to ensure that it performs predictably during frontal impact events.

This assembly is attached using a conventional rear hinging strategy and a conventional two stage latch at the front. This hood is shown in Figures 6.4.2.f. and 6.4.2.g. The production Venza hinges and latches were used.

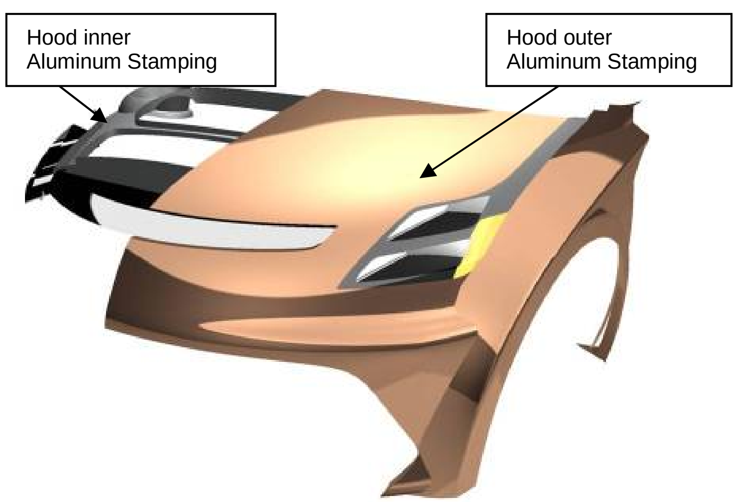


Figure 6.4.2.f: Hood and Fender Assembly and Front End Module

Figure 6.4.2.g: Hood Assembly (as installed)

6.5. Results

6.5.1. Low Development

The Low Development closure summary results are shown in Table 6.4.2a below. The estimated mass savings was 19.9% and the estimated cost factor was 108%. Supporting background details are included in section 6.5.

Table 6.5.1.a: Low Development Closure & Fender Mass Reduction Summary

Sub-System	Component	Standard Venza	Revised Design	Revised mass	Mass saving	Material	Cost factor
		kg		kg	kg		
Exterior panels							
	Front Fender LH	3.04	Injection molding	1.69	1.35	PPO-PA	44%
	Front Fender RH	3.03	Injection molding	1.69	1.34	PPO-PA	44%
Side door front							101%
	Front Door Outer LH & RH	11.30	Injection molding	5.44	5.86	Thermoplastic	
	Front Door Inner LH & RH	8.48	Stamping	7.53	.95	High strength steel	
	Glass run channel front LH & RH	4.91	Carry over	4.91	0	Mild steel	
	Door reinforcements LH & RH	13.01	Stampings	9.92	3.09	High strength steel & MS	
	Side intrusion beam LH & RH	2.36	Carry over	2.36	0		
	Door Hardware LH & RH	13.76	Module	10.86	2.9		
Side door rear							102%
	Rear Door Outer LH & RH	9.04	Injection molding	4.03	5.01	Thermoplastic	
	Rear Door Inner LH & RH	4.71	Stamping	4.40	0.31	High strength steel	
	Glass run channel rear LH & RH	4.91	Carry over	4.91	0	Mild steel	
	Door reinforcements LH & RH	8.5	Stampings	7.67	0.83	High strength steel & MS	
	Side intrusion beam LH & RH	2.00	Carry over	2.00	0		
	Door Hardware LH & RH	12.24	Module	10.14	2.1		
Tailgate							148%
	Tailgate Outer	5.41	Stamping	1.96	3.45	Glass Reinf. Thermoplastic	
	Tailgate Inner	5.86	Casting	4.64	1.22	Magnesium	
	Reinforcements	3.21	Part of casting		3.21		
	Tailgate Hardware	8.77	Carry over	8.77	0		
Hood							102%
	Hood Outer	8.34	Stamping	6.25	2.09	Aluminum	
	Hood Inner	6.82	Stamping	5.12	1.20	Aluminum	
	Hood reinforcements	1.64	Stampings	1.64	0	Steel	
	Hood Hardware	1.68	Carry over	1.68	0		
Total		**143.02**		**107.61**	**35.41**	**24.75%**	**108%**

6.5.2. High Development

The High Development closure summary results are shown in Table 6.4.2.a below. The estimated mass savings was 39.8% and the estimated cost factor was 76%. The application of conventional modeling and analysis techniques could reduce or increase the mass. Supporting background is included in section 6.6.

Table 6.5.2.a: High Development Closure & Fenders Mass Reduction

System	Sub system	Standard Venza	Baseline material	Revised Design	Revised mass	Mass saving	Material	Cost Factor
		kg			kg	kg		
Exterior panels								
	Front Fender LH	3.04	Mild steel	Injection molding	1.69	1.35	PPO-PA	
	Front Fender RH	3.03	Mild steel	Injection molding	1.69	1.34	PPO-PA	
Side door front								
	Front Door Outer LH & RH	11.30	Mild steel	Molding	5.44	5.86	Thermo plastic	38%
	Front Door Inner LH & RH	8.48	Mild steel	Casting	12.00	6.56	Magnesium	57%
	Glass run channel front LH & RH	4.91	Mild steel	Part of module				
	Door reinforcements LH & RH	13.01	Mild steel	Part of casting				
	Side intrusion beam LH & RH	2.36	Mild steel	Carry over	2.36	0		
	Door Hardware LH & RH	13.76	Various	Module	10.06	3.7		
Side door rear								
	Rear Door Outer LH & RH	9.04	Mild steel	Molding	4.03	5.01	Thermo plastic	28%
	Rear Door Inner LH & RH	4.71	Mild steel	Casting	10.00	2.26	Magnesium	61%
	Glass run channel rear LH & RH	4.91	Mild steel	Part of module				
	Door reinforcements LH & RH	8.5	Mild steel	Part of casting				
	Side intrusion beam LH & RH	2.00	Mild steel	Carry over	2.00	0		
	Door Hardware LH & RH	12.24	Various	Module	8.94	3.3		
Tailgate								
	Tailgate Outer	5.41	Mild steel	Molding	1.96		Thermo plastic	52%
	Tailgate Inner	5.86	Mild steel		4.64			195%

				Casting		1.22	Magnesium	
	Reinforcements	3.21	Mild steel	Part of casting				
	Tailgate Hardware	8.77	Various	Carry over	8.774	0		100%
Hood								
	Hood Outer	8.34	Mild steel	Molding	3.83	4.51	Thermo plastic	64%
	Hood Inner	6.82	Mild steel	Stamping	5.12	1.70	Aluminum	181%
	Hood Reinforcements	1.64	Mild Steel	Carry over	1.64			
	Hood Hardware	1.68	Various	Carry over	1.688	0		100%
Total		**143.02**			**83.98**	**59.04**	**41.3%**	**76%**

6.5.3. Closure Mass Distribution by Material

The closure materials for the baseline, Low Development and High Development models are shown in Charts 6.5.3.a. through 6.5.3.c. The Low Development doors utilized a modular window glass frame and track assembly. The High Development doors incorporated a non-ferrous primary structure and a four piece modular construction. The rear deck lid utilized a cast magnesium frame for the Low and High Development models.

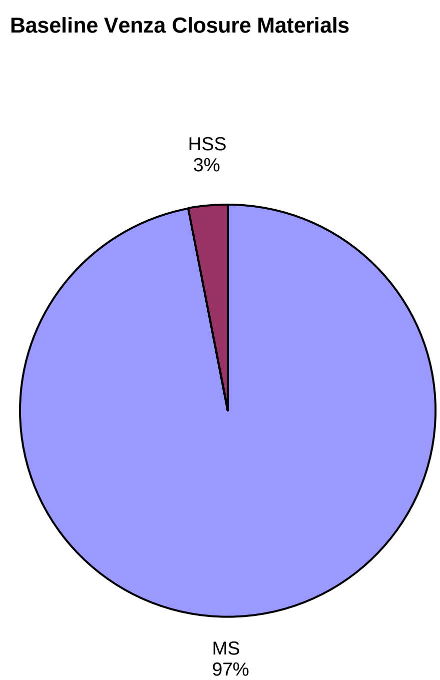


Chart 6.5.3.a

Low Development Venza Closure Materials

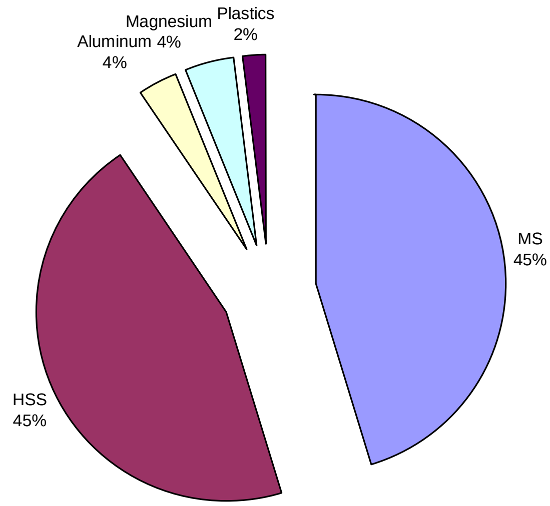


Chart 6.5.3.b

High Development Closures Materials Distribution

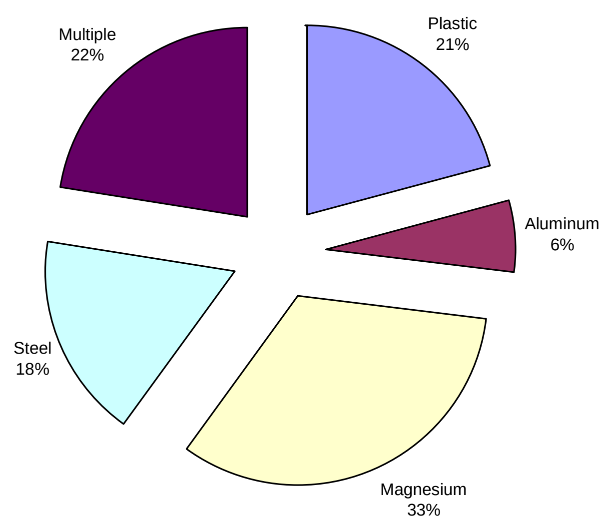


Chart 6.5.3.c

Mass Sensitivity

The design of closures has developed into what is essentially a shallow twin walled box with openings in the inner surface to allow access and to reduce the amount of material in the finished part. The outer surface has to conform to the exterior shape of the body and is predominantly an uninterrupted surface except where openings for visibility are required.

The large surface areas of the outer panels make a significant contribution to the mass of each particular closure and also to the mass of the body in general. The closure and fender sheet metal on the Venza accounts for 106.57kg of the body mass with the outer panels being between 30% and 40% of that total. The remaining mass is distributed across the inner panel and the structural reinforcements. This indicates that reductions to the weight of the outer panels will provide the best per panel weight reduction. Table 6.5.3.a. below summarizes these masses.

Table 6.5.3.a: Baseline Venza Exterior Panel Mass Analysis

Sub System	**Component**	**Standard Venza**	**% of Closure Mass**
		kg	
Exterior panels			
	Front Fender LH	3.04	2.85
	Front Fender RH	3.03	2.84
Closures			
	Front Door LH	20.03	18.80
	Front Door RH	20.03	18.80
	Rear Door LH	14.58	13.68
	Rear Door RH	14.58	13.68
	Hood	16.80	15.76
	Tailgate	14.48	13.59
Total		**106.57**	**100**

Table 6.5.3.b below compares the baseline Venza material mass (mild steel) to high strength steel. The difference is in the material thickness; the thickness was reduced by 10%.

Table 6.5.3.b Comparison of Venza closures in MS & HSS

System	Sub system	Standard Venza	Revised mass	Mass saving	Total %
		kg	kg	kg	
Side door front					
	Front Door Outer LH & RH	11.30	9.89	1.41	
	Front Door Inner LH & RH	8.48	7.53	.95	
	Glass run channel front LH & RH	4.91	4.91	0	
	Door reinforcements LH & RH	11.19	9.92	1.27	
	Side intrusion beam LH & RH	2.36	2.36	0	
	Door Hardware LH & RH	13.76	10.86	2.9	
Side door rear					
	Rear Door Outer LH & RH	9.04	7.91	1.13	
	Rear Door Inner LH & RH	4.71	4.40	.31	
	Glass run channel rear LH & RH	4.91	4.91	0	
	Door reinforcements LH & RH	8.50	7.67	.83	
	Side intrusion beam LH & RH	2.00	2.00	0	
	Door Hardware LH & RH	12.24	10.14	2.1	
Tailgate					
	Tailgate Outer	5.41	4.74	.67	
	Tailgate Inner	5.86	5.21	.65	
	Reinforcements	3.21	3.21	0	
	Tailgate Hardware	8.77	8.77	0	
Hood					
	Hood Outer	34	7.29	1.05	
	Hood Inner	6.82	6.37	.45	
	Hood Reinforcements	1.64	1.64	0	
	Hood Hardware	1.68	1.68	0	
Total		**135.13**	**121.41**	**13.72**	**10.2%**

7. Front and Rear Bumpers

7.1. Overview

The current Venza uses a conventional bumper system with a molded exterior panel that matches the styling of the vehicle with internal bumper beams that are connected directly to the body structure. A steel beam is used in front and an extruded aluminum beam is used in the rear.

7.2. Trends

Bumper systems must meet specific legislative requirements. Simple beams and styled cosmetic fascias are adequate to pass the federal bumper test procedure. There are concepts under development that use lighter materials such as magnesium for the bumper beams.

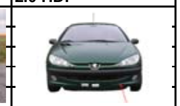
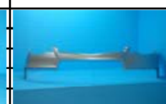
Meridian Lightweight Technologies and DOW Automotive are developing magnesium castings and energy absorbing foams (respectively) that are suitable for bumper systems.

7.3. Benchmarking

Table 7.3.a below lists bumpers benchmarked vs. the Venza.

Table 7.3.a: Bumper Benchmarks

Bumpers

	Baseline					
						
	Toyota Venza 2.7 FWD	**Audi Q5 2.0 TDi Base**	**Honda CR-V 2.0 Comfort**	**Mini Cooper S**	**Acura RDX 2.3 Technology Package**	**Peugeot 206 X Line 2.0 HDI**
						
Fascia Weight Kg	**3.749**	**2.13**	**1.637**	**1.756**	**2.256**	**2.488**
						
Width	1888	758	1860	1595	1830	1605
Height	588	523	365	370	420	330
Depth	645	568	435	355	780	430
Adjusted fascia weight		**3.39**	**3.97**	**6.00**	**2.69**	**7.82**
Beam Weight Kg	**5.981**	**2.532**	**3.451**	**5.608**	**3.38**	**1.45**
						
	1223 mm	1130 mm	1150 mm	1056 mm	1195 mm	1235 mm
	164,4 mm	114 mm	142 mm	380 mm	86 mm	140 mm
	139 mm	94 mm	240 mm	188 mm	134 mm	225 mm
Material	Steel	Aluminum alloy	Steel	Steel	Aluminum	
Adjusted Beam Weight Kg		**2.434**	**3.830**	**8.060**	**3.223**	**2.226**
Total adjusted weight Kg	**9.73**	**5.820**	**7.799**	**14.062**	**5.918**	**10.048**

The method used to benchmark the front bumper was to consider the front fascia and the bumper beam as a system. The volume created by the overall dimensions of the part and the beam was compared to the mass of the vehicle. This was done to recognize the fact that the bumper beam provides protection during low velocity impacts and the design is, therefore a function of the vehicle mass. Bumper beams are typically similar in size and shape to meet the U.S. 2.5 MPH “no damage” requirements.

A full analysis of bumper systems is required to verify performance. This is beyond the scope of this study.

7.4. Analysis

The benchmark study of the fascias indicated that they are all similar and any differences are probably more related to styling than to any engineering or material factors. The Low and High Development models both used the mass and cost of the Venza fascias.

The study of the beam indicates that lighter weight materials can be used to achieve the same result as steel and that material decisions will be based on how critical the use of a lightweight part is in relation to the overall vehicle weight. The potential alternative materials for bumper beams were aluminum alloy and magnesium alloy. An estimated mass reduction of 2.2Kg on the front and 0.81Kg on the rear of the Venza could be achieved using magnesium as a substitute for the Venza steel (front) and aluminum (rear) bumper beams. An aluminum front beam saved 2.0 kg.

The following calculation was used to define the relative cost of the steel and alloy bumper beams.

Weight of steel beam assembly	5.981kg
Average cost per kg (material and process)	$4.30
Estimated cost of beam assembly	$25.71
Estimated aluminum beam mass saving	2.0kg
Estimated cost of processed extrusion	$6.87/kg
Estimated cost of extrusion	$27.34
Cost factor	106%

Based on supplier input, the estimated cost factor for a magnesium beam that saved an additional 0.2 kg vs. the aluminum beam was more than double the 1.06 factor. A front aluminum beam was used because of the significant mass savings and the acceptable cost factor. Verification through modeling and testing is required to validate the lighter weight bumper system. This is beyond the scope of this study.

The mass of the aluminum Venza rear bumper beam was 4.01 kg and the mass of the rear fascia was 4.21 kg. The supplier estimated cost for a magnesium rear beam that would save 0.81 kg has a cost factor greater than 2.5.

7.5. Results

The Low and High Development models incorporate an aluminum front and an aluminum rear bumper beam. The estimated mass savings was 2.0 kg. The Venza bumper system mass was 17.95 kg. The bumper system mass with an aluminum front beam was 15.95 kg. The estimated weighted cost factor was 103% for the front and rear bumper systems.

8. Glazing (windshield, backlight, doors, sunroof, fixed)

8.1. Overview

The glazing of the current Venza was classified into two groups:

- Fixed
- Moving

The fixed glass is bonded into position using industry standard adhesives and was classified into two sub groups:

- Wiped
- Non wiped

Factors involved in making decisions about glazing materials include:

- Legislative requirements for light transmissibility/abrasion (FMVSS 205)
- Legislative requirements for passenger retention and ejection mitigation (FMVSS226)
- Contribution it will make to interior noise abatement

8.2. Trends

The specific gravity of glass is 2.6 and the thickness of a windshield is usually between 4.5mm and 5.0mm so the mass per square meter of 5mm glass is approximately 13kg. This is almost double the weight/area of 0.8mm thick steel (the mass per square meter of 0.8mm steel is 6.24kg).

The high mass of glass provides a strong incentive to: 1.reduce the glazed area of the body; 2. reduce the thickness of the glass; or 3. to find a suitable substitute that is lighter.

The industry has, for some time, been researching and developing polycarbonate as an alternative to glass but it is more expensive and is not yet developed to the point of providing the required level of abrasion resistance that would allow its use on wiped surfaces such as windshields or moving door windows. It has been used in Japan for a fixed glass application. Based on supplier information on the current state of development[16], the fixed glass on the side of the vehicle offers the best opportunity for mass reduction. Exatec[17] and Bayer[18] are suppliers of polycarbonate glazing.

8.3. Benchmarking

The benchmarking study showed that the current Venza was competitive in terms of mass for the windshield, lift-gate glass and door dropping glass.

8.4. Analysis

8.4.1. Low Development

The current Venza glass represented a reasonable tradeoff in terms of mass per unit area and was used for the Low Development model. Although it is possible that glass may get thinner and that polycarbonate may be acceptable for fixed windows in the future, a conservative approach was used for this study.

8.4.2. High Development

The High Development model also used the Venza glass. This represented a conservative approach.

8.5. Results

8.5.1. Low and High Development

Table 8.5a below shows the results for the Venza glazing components.

Table 8.5a: Low and High Development Glazing

Item	Mass	Quantity	Vehicle mass	Revised Mass	Cost factor
	Kg		Kg	Kg	
Windshield glass	14.848	1	14.848	14.848	
Front side glass	1.090	2	2.180	2.180	
Rear side glass	2.181	2	4.362	4.362	
Front drop glass	4.402	2	8.804	8.804	
Rear drop glass	3.267	2	6.532	6.532	
Tailgate glass	6.982	1	6.982	6.982	
Total			43.710	43.710	100%

9. Interior

9.1. Overview

The primary philosophy of the mass reduction of the interior module was to produce mass savings that were consumer neutral or positive, meaning the interior retained design, comfort, function and consumer acceptance compared to the 2009 Venza interior. These considerations generally did not scale with vehicle size or mass. Additionally the basic ergonomic requirements were independent of vehicle size and mass. A Low Development and a High Development interior were created.

The Low Development model retained a majority of the Toyota assembly process at the system and vehicle level. In some cases, the component processes were altered based on materials technology and process improvements. Lower mass components were selected from benchmarked production interior hardware. Materials were revised based on mass and cost objectives. Some architectural changes were also incorporated, e.g., mounting the front seats to the sill and tunnel rather than to the floorpan. Safety systems were carried over at the current Venza mass.

The High Development model incorporated major architectural changes to minimize mass while retaining the functionality of the Venza IP and maintaining an acceptable appearance. It used a higher level of systems integration than the Low Development model and leveraged numerous technologies that were used outside of automotive or were emerging for automotive applications. Materials were based on the Low Development model and were revised as appropriate to achieve the mass and cost targets. Safety systems were carried over at the current Venza mass.

The Venza interior was benchmarked to determine the mass of each system and subsystem and to create baseline masses for the Low Development and High Development lower mass interiors. System cost was also considered. The Venza mass and cost were set at 100%. The Low Development and High Development proposals were indexed relative to this value. The interior sub-systems were analyzed for cost impact by Faurecia, an international Tier 1 automotive interior supplier. These values were shown as a percentage of the projected Venza costs and were included with each Low and High Development sub-system mass summary. A partial listing of Faurecia production interiors is listed in Section 18; their customers include Audi, BMW, General Motors, Mercedes Benz, Volkswagen and Volvo.

Table 9.1.a below lists major sub-systems in the Venza interior, the baseline total mass, the sub-system masses and rank orders the sub-systems as a percentage of the total interior system mass. This analysis established the priorities for mass savings opportunities.

Table 9.0.a: Interior Mass Breakdown By Major System

	Curent Mass and % of Interior	
Seats	97.9	39%
IP+Console+Insulation	43.4	17%
Hardtrim	41.4	17%
Controls	22.9	9%
Safety	17.9	7%
HVA/C & Ducting	13.7	5%
Closure Trim	13.3	5%
Mass Totals	**250.5**	**100.0%**

Based on the sub-system hierarchy outlined in Table 9.0.a, a sensitivity analysis was created to target the mass reduction required from each interior sub-system. Table 9.0.b below provides mass targets for each of the Low Development interior sub-systems. These targets were used to select lighter weight sub-systems, including sub-systems currently in production either in the U.S. or internationally. All selected components were normalized to the Venza baseline equipment level, e.g., a power mechanism was added to the driver seat if the seat being analyzed was a manual seat. Additionally, automotive and non-automotive technologies considered feasible for 2017 production were included in the Low Development mass analysis.

Table 9.0.b Low Development Interior Sub-System Mass Targets

	Curent Mass and % of Interior		**Net System Target** (kg)	**Target Reduction** (kg)
Seats	97.9	39%	78.3	19.6
IP+Console+Insulation	43.4	17%	34.7	8.7
Hardtrim	41.4	17%	33.2	8.3
Controls	22.9	9%	18.4	4.6
Safety	17.9	7%	14.3	3.6
HVA/C & Ducting	13.7	5%	10.9	2.7
Closure Trim	13.3	5%	10.7	2.7
Mass Totals	**250.5**	**100.0%**	**199.4**	**50.1**

As an example, table 9.1.b above indicated that seats made up 39% of the total Venza interior mass and that 19.6 kg needed to be removed from the Venza seats in order to meet the 20% lighter Low Development criteria. The 20% lighter seat mass target is the Venza seat mass (97.911 kg) minus the Target Reduction mass (19.6 kg) or 78.3 kg.

A High Development sensitivity analysis was created to target the mass reduction required from each interior sub-system. These sub-system mass targets are shown in Table 9.0.c below. The

High Development model utilized a new architecture, low mass materials, and a high level of component integration to achieve the below mass targets for 2020 production.

Both Low Development and High Development vehicle interior safety systems maintained the Venza mass as they are likely to stay the same or possibly increase if new safety requirements are legislated in the future. Today's safety systems are highly developed for function and mass.

A holistic approach to mass reduction was used for both the Low Development and the High Development models. The individual sections detail this technique.

Table 9.0.c High Development Interior Sub-System Mass Targets

	Curent Mass and % of Interior		Net System Target (kg)	Target Reduction (kg)
Seats	97.9	39%	58.7	39.2
IP+Console+Insulation	43.4	17%	26.1	17.4
Hardtrim	41.4	17%	24.9	16.6
Controls	22.9	9%	13.8	9.2
Safety	17.9	7%	10.7	7.1
HVA/C & Ducting	13.7	5%	8.2	5.5
Closure Trim	13.3	5%	8.0	5.3
Mass Totals	**250.5**	**100.0%**	**149.3**	**100.2**

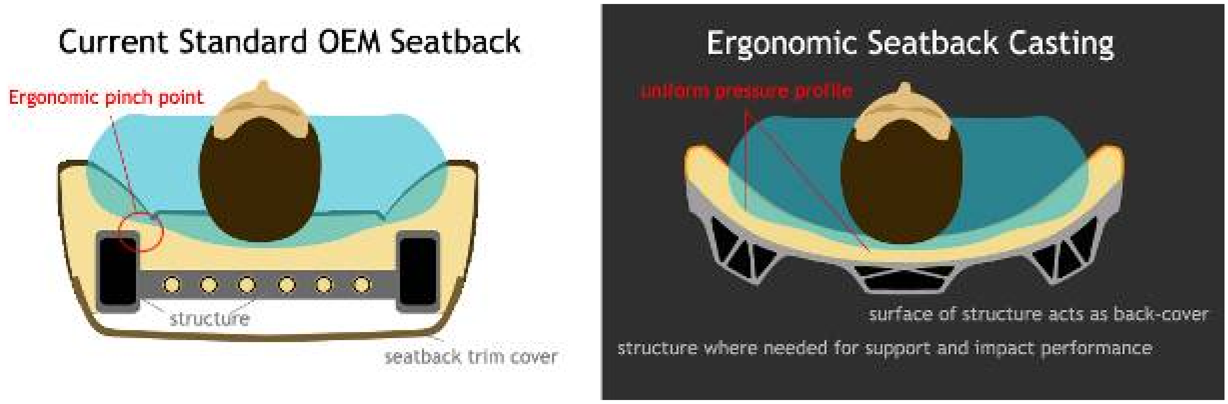
9.2. Seats

9.2.1. Seat Trends

There were many technologies emerging in seating for simplification of construction and mass reduction. The most promising opportunities were related to systems integration. Typical seat systems, e.g., the Venza, were created using numerous individual steel components welded together to form the frame and suspension assemblies. Figure 9.2.2.a shows the Venza front seat construction. Production foaming and co-molding processes reduce system complexity and achieve the required comfort levels with foam based suspension systems. Lightweight cast frames, such as the Hyundai Azera front seat magnesium structure, provide appropriate structural rigidity with integral fastening features. This design allows more ergonomic shapes for the structure which can reduce "pinch points" in the stack-up of structure to foam to occupant contact.

Figure 9.2.2.a: Toyota Venza Driver's Seat Exploded View

Many current seats utilize closed box section frames which can cause pressure points that have to be compensated for with additional suspension and foam to provide an ergonomically correct seating position. This approach adds mass due to the increased foam density and size and increases the overall seat size. Figure 9.2.2.b illustrates a pinch point condition for a closed box section structure vs. the uniform loading of a cast seat back.



ERGONOMIC FOAM SEAT SUSPENSION

Figure 9.2.2.b: Section of Typical Current Seatback vs. Ergonomic Design

Ergonomic Seat Frame

An ergonomically cast seat frame structure can reduce seat size and mass while retaining structure, safety and comfort. Using the frame structure to form the basis of the ergonomic surface of the seat foams creates a thinner, more comfortable seat structure. The Hyundai Azera magnesium seat frame was used as the basis for the Low Development seat model. The Hyundai Azera is a midsize vehicle with an MSRP range of $24,970 (base) and a fully optioned cost of $32,590; this pricing is comparable to the Venza.

The Mercedes SLK also utilized a cast magnesium seatback with a thin profile that is ergonomically shaped for comfort. This design reduces package space and mass. See Figure 9.2.2.c for an image of the Hyundai Azera seat structure and a picture of the Mercedes SLK magnesium cast seatback structure.

Figure 9.2.2.c: Hyundai Azera Magnesium Cast Seat Structure and Mercedes SLK (2008-current) Seatback

The Azera magnesium seat structure saved 4.2 kg per seat using a typical boxed section design. Optimizing the seat frame to create ergonomically correct shapes on the face of the structure would reduce the amount of foam required to provide comfort. Combining this frame design with multi-density foam would provide additional mass savings opportunities.

There is potential to create a seat structure using composites. Per International OEM seat supplier Faurecia[18], initial capability has been shown with composite seat structures made of polyamide glass filled composites. While the magnesium cast seat frame offered mass reduction for the Low Development model, the magnesium material and tooling costs would likely produce a 50% cost increase per Faurecia estimates. In order to produce Class-A surface that is paint ready and appearance grade, Faurecia recommended tooling with a die cast tool. This would be a more expensive tool than a typical welded seat structure tool, but offered some cost offset in part reduction or part elimination. A composite seat frame offered the same level of integration and reduction as a magnesium casting with possibly increased part integration. A composite seat frame could be grained and provide a class A surface at a cost parity, per Faurecia's current level of development, with steel frames. Complete seatback trim parts can be eliminated with a cast or molded ergonomic seat frame. The back of the seat frame would become the appearance surface of the seatback. The lower cost tooling and easily grained surface could offer cost savings but would require significant development to meet the functional requirements.

Lear Corporation has introduced a system called DECS which uses multiple foam layers for seating suspension and comfort. This eliminated the steel springs used in most automotive seats.

From an online Lear/ Automotive Engineering news post: reference as endnote – web link
"*New features and functions can make seats more attractive, but the foams and coverings continue to play a huge role in a seat's overall appeal. These material technologies continue to evolve, helping lower weight and improve the look and feel of an interior. Rear seats don't get the same level of*

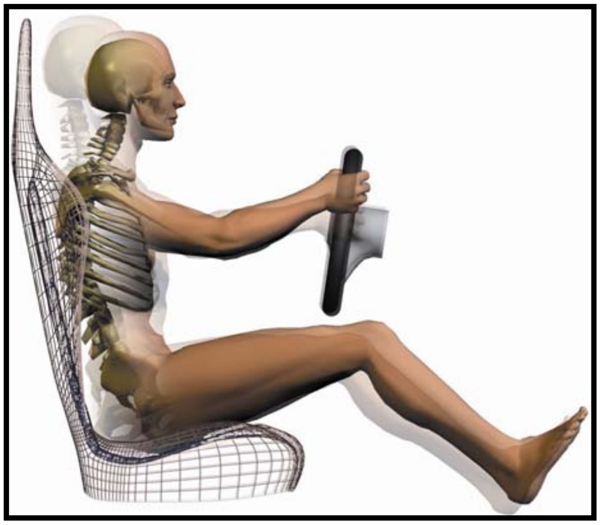
marketing attention as front seats, but they are also changing rapidly. The emergence of foams that are strong and supportive yet still soft make it possible to eliminate metal frames and trim weight. "With structural foam, we replaced a rear seat system that used steel wire frames," said Don Bernhardt, Vice President, Product Engineering for Lear's Seating Systems Division. That saved about 7 kg (15.4 lb), he noted. Foams that aren't based on petroleum products are gaining acceptance helping product designers meet environmental goals by using materials that are more readily recycled. Though usage is still small, sustainability is an important factor for many automakers. While foams evolve, seat coverings are also changing. Leather has moved from luxury vehicles into the mainstream, now accounting for 35-40% of seating sales in the U.S. As usage has grown, suppliers have come up with new ways to let designers set their seats apart from the crowds[19]"

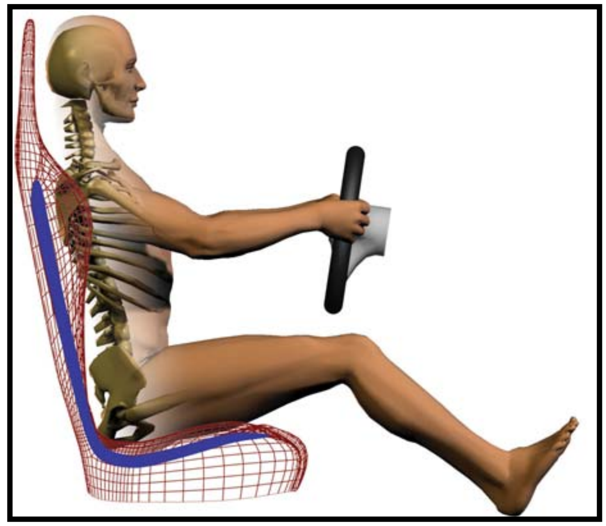
A seat base cushion with varying density foams used as the core suspension could eliminate the springs and retainers in the seat base and save 0.6kg suspension per seat (1.2kg savings per vehicle). The NuBax ProBax system used on the Lotus Elise utilizes a foam support; there is no steel seat structure. The NuBax seat cushion improved the driver's posture using ergonomic foam placement and tuned foam densities in the seat cushion. Per the Nubax study:

"*The body needs to be supported by:*

- *its skeletal structure*
- *ProBax insert supports ischial tuberosities to rotate occupant pelvis forward— Forward rotation of the pelvis acts to correct seated spinal posture from kyphotic (C-shaped) to lordotic (S-shaped) --*
- *ProBax design works for a very wide range of human sizes because there are minimal physiological differences in the sit bones despite wide variations in body size and weight"* [20]

Per NuBax "Reducing separation of cranium from head restraint is a key factor in reducing whiplash injury". Using a fixed headrest and seat foam to correct posture could reduce or eliminate the need for an expensive active headrest system. A fixed headrest can eliminate from 0.4kg - 1.95kg depending on the type of system (from A2Mac1 headrest database); the Venza active headrest system currently weighs 1.13kg.





Standard Lotus Seat **ProBax Lotus Seat**

Figure 9.2.2.d: Head Position / Driver Posture with Standard (Left image) vs. ProBax Seat Design

This design may also allow an OEM to completely eliminate active or manual lumbar adjustments and any wiring/switches due to the improved seating posture created by the ProBax seat cushion. Systems for lumbar adjustment currently installed on the Venza weigh 0.558 kg. Typical masses for lumbar systems vary from 0.26-1.8kg (from A2Mac1 headrest database). If these added systems could be eliminated, the ProBax system could potentially eliminate 1.8kg – 4.13kg depending on the seat design.

Overall seatback recline angle adjustment may also be reduced or eliminated for additional weight savings. However, a thorough design study with structural analysis must be undertaken to fully understand the effect the weight reduction would have in an impact scenario. In addition, consumer response must be factored into the equation. This is a standard feature on most automobiles. Because of these concerns, the seatback recliner feature has not been deleted from either the Low Development or the High Development models. However, there are many vehicles being introduced to market without this feature. These vehicles are mostly performance oriented vehicles with fixed back performance style seats. The Lotus Elise/Exige and the Porsche GT3 are examples of fixed back seats.

Integrated Seat Track and Rails

Front seats are typically mounted on steel seat risers and tracks. These assemblies are bolted to the floor; the floor is reinforced to accommodate the seat loads which include impact forces. Eliminating floor mounted seat attachments and the floor reinforcements could reduce the seat system mass significantly.

The sill and tunnel are areas engineered for a high level of structural integrity; seat mounts can be integrated into the sill and tunnel with minimal impact and eliminate conventional seat risers. The lower seat cushion frame can be designed with slide mounts integrated directly into the casting of the seat lower pan. This eliminates the parts needed to mount the seat to the structure of the car and the need for panels and trim that hide those parts. Volkswagen Corporation mounted seats to the sill and tunnel for many vehicles produced in the 1980s, including the Golf, Jetta and the Audi 4000Q. Figure 9.2.2.e shows the Audi 4000 integrated seat tracks.

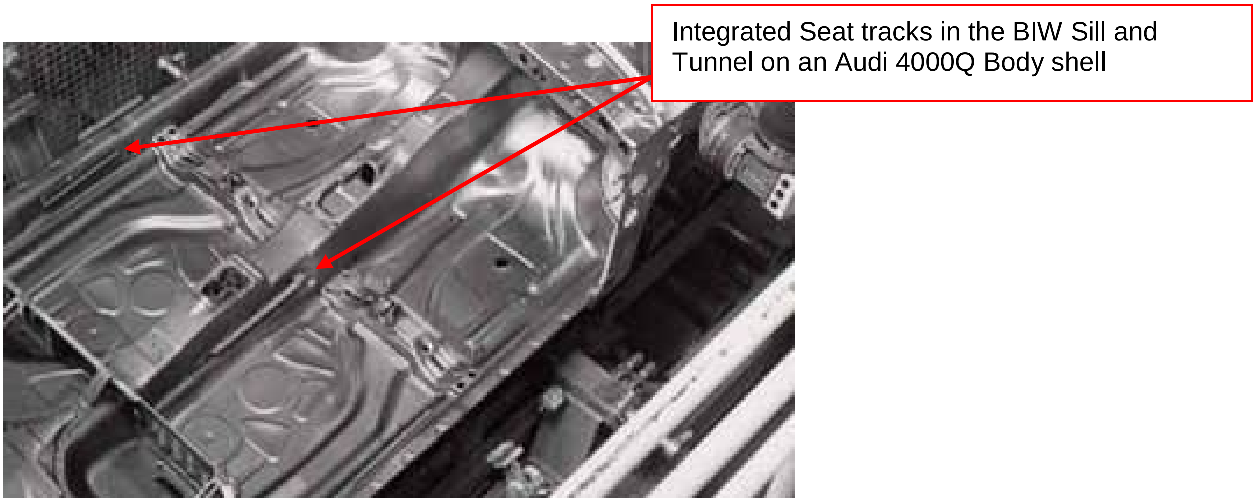


Figure 9.2.2.e: Audi 4000Q BIW with integrated seat tracks

Digital Looming

The cost and time intensive process of cut and sew seat covers can be eliminated through an innovative new digital looming process called "Teknit" by True Textiles in Grand Rapids, MI. A process of this type weaves the seat cover to the exact shape required. There is no material scrap and no cutting and sewing required. It also allows a wide range of options, e.g., custom seat lettering, integrated woven storage areas, and multi-colored seat patterns. Material scrap rates are proprietary; one Tier 1 automotive interior supplier has estimated a 15% - 25% scrap rate for cut and sew operations depending on material type and design construction.

From the <u>True Textiles</u> Website:

"Teknit is a unique knitting process that produces made-to-measure, form-fitting fabric covers that wrap our customers' chairs like a glove. And no one else offers like True Textiles.

Teknit covers are extremely fast and easy to apply to chairs. Some manufacturers report up to 50% labor-savings per chair compared to using conventional fabrics. Since there's no cutting, Teknit eliminates fabric waste. And Teknit can be specified with recycled polyester yarns that go easier on the environment, as well.

Teknit sits well with design connoisseurs and end-users, too. These 3-D seating fabrics can create impressive designs such as wrap-around logos that can't be done with flat-woven fabrics. And Teknit *delivers one-of-a-kind seating comfort – especially when covering today's high-performance ergonomic cushions"*[21]

True Textiles currently makes seat covers for use in commercial applications, e.g., office furniture. The Teknit process capability allows seat suppliers to produce closed shape knit to form 3D seat covers in one looming process, virtually eliminating the need to cut and sew separate parts together. This process also allows the flexibility to knit different patterns, colors, materials, with mechanical flexibility topographically across the span of a finished part. This is accomplished with a proprietary digital looming process which can knit one part after another that are completely unique using software input. This process, in combination with a more ergonomic seat frame design, would allow reduced complexity in the seat covers. The seat covers do not have to make transitions from ergonomic human shapes to orthogonal boxed frame shapes and sections. Currently, seat manufacturers do not use digitally knit covers due to problems with wrinkling and trench tie down related to current seat frame design and the transition from vehicle grid aligned structures to natural human contours. An ergonomic seat designed to human contours using a digitally knit seat cover would yield a lighter seat with a potential cost benefit to the OEM. Each seat cover could be produced with a unique color, pattern, texture, material and even include photographic patterns. The knit cover would include integrated fastening features as a complete part that would be installed over a foam substrate to form a seat cushion/suspension module. This cushion module would be fastened to an ergonomically cast magnesium or composite frame. The images below compare the baseline Venza seat construction to a seat using an ergonomically designed frame, True Fabrics digitally knit covers and varying density foam suspension and cushions.

Figure 9.2.2.f Digitally Loomed Cover Based Seat

Figure 9.2.2.g: Current Toyota Venza Production Seat vs. Digitally Knit Seat Proposal

The capability of digitally knitting a 3D part to shape and creating differing levels of "suspended" material structures creates other potential mass savings opportunities. It may be possible with this concept to create lumbar support without the extra mass of padding and adjustable structures integrated into the seat design as in today's seats. There are knitting machines that are currently used in Europe capable of performing both 3D knitting and mono-filament based structural knitting concurrently. These machines can create a 3D finished part and add topographical structural changes to the fabric. This process could weave a single piece seatback cover with "knit-in" lumbar support. Development would be required to determine if the knit-in lumbar support seat cover could meet functional and durability requirements.

Digitally knit fabrics create a significant cost reduction because they eliminate the high scrap rates of the "cut and sew"[6] seat cover process. The capability to increase the variety of the visual designs for the seat covers with little or no cost increase to the processing or materials costs is another significant advantage. The digital knitting process can alter seat covers thread by thread which provides a wide range of colors and patterns. This could provide trim level changes within the product range without appreciable tooling or material stocking costs. Digitally knit fabrics offer the capability to: 1. produce custom seat patterns per individual order; 2. make running design changes, i.e., change a seat cover pattern or door trim pattern quickly and without any tooling costs; 3. eliminate material stocking considerations present in today's seat production process; 4. virtually eliminate scrap; and 5. create low cost, production quality rapid prototypes.

Steel Seatbacks

Faurecia has developed a roll formed and laser welded rear seat back frame that is currently in production on the Chevrolet Malibu and Buick LaCrosse. The current seatback frame mass is in the range of 10-11kg with a projected 8-9 kg mass possible with development (projections per Faurecia) . As a reference, the Venza rear seat back frame shown in Figure 9.2.2h weighs 13 kg. The Audi A6 uses a stamped steel seat frame as shown in Figure 9.2.2.i.

Figure 9.2.2.h: Toyota Venza Seat Frame

Figure 9.2.2.i: Audi A6 Stamped Steel Seat Frame

Cast Aluminum and Magnesium Seatbacks

Aluminum and magnesium castings offer significant mass savings compared to steel stampings. Increased levels of component integration could create cost savings vs. a stamped welded assembly. Figure 9.2.2.i shows a Ford Expedition aluminum rear seat frame.

Figure 9.2.2.i: Ford Expedition Aluminum Rear Seat Frame

Blowmolded Rear Seat Back

A recent seat back development using blow molding could create both cost and mass savings. Dow Automotive and Audi and Lear have produced a lightweight blow-molded plastic seatback frame. Blow molded seatbacks have yet to be developed for rear seats with integrated seatback anchors. However, Faurecia confirmed that it would be a small step to produce a blow molded seatback with the capability to mount retractors. The Audi TT blow-molded seatback is shown in Figure 9.2.2.k..

Audi AG and Dow Automotive, Auburn Hills, Mich., received an Innovation Award from the Society of Plastics Engineers International (SPE) in the Safety category for a blow-molded seatback (BMSB).[22]

For the Audi TT seatback, the material and design were developed by Dow Automotive in its Engineering Centre in Germany and was improved using CAE techniques to fulfill ECE R17 and Audi requirements. The parts were adjusted for blow molding and then produced by Moellertech GmbH. Finished seats go to Audi AG from Lear Corp., Southfield, Mich.

The recently commercialized part is for rear seats in the Audi TT. Several other major manufacturers are also looking at it.

Figure 9.2.2.k: Audi TT Blow Molded Seatback

The new BMSB technology uses Pulse PC-ABS that was developed specifically for Dow Automotive blow molding. It gave Audi designers a significant, 2.4-kg/vehicle weight reduction and more design freedom. "Blow-molded seatbacks meet global safety requirements and improve passenger comfort," says Mike Shoemaker, Dow Automotive market development manager, plastics. "The lumbar support is built into the plastic molding in the Audi TT. And future generations of this product may incorporate additional interior conveniences, including map pockets." This innovation can also be important in vehicles where seats are frequently removed or moved.

Expanded Polypropylene (EPP) FOAM SEATS

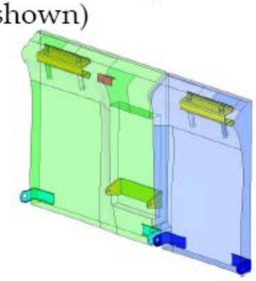
Expanded polypropylene foam seat bottoms replace welded steel frame assemblies. The Fiat Croma, Nissan Titan, BMW X5, Audi A2, VW Golf, Chevy Impala, Porsche Cayenne, VW Touareg, and the Ford 500 have all utilized an EPP foam for seat supports. EPP offers significant mass reduction, the capability to integrate structural and functional multiple material inserts in one tool, and a cost advantage over welded and assembled seat systems. Figure 9.2.2.l illustrates the BMW X5 EPP 2nd row seat support.

Figure 9.2.2.l: Example of JSP EPP Foam Rear Seats – BMW X5

JSP, an EPP foam seat supplier is developing EPP foam seatbacks. EPP foam is used as the matrix that holds seat reinforcements for headrests, hinges, latches and structure while providing a foundation for ergonomic comfort foam. Figure 9.2.2.m shows a JSP table showing the mass savings of EPP vs. HDPE, a plastic used in current seat backs.

Current Development: Seat Back

Original Seat Back – HDPE Blow Mold (brackets not shown)



EPP Seat Back Design with Insert Molded Brackets

40% Rear Seat Back

Description	Weight (g)	Total weight (g)	% Saving
Wt of Original PU Foam	1542.2	4399.9	37.6
Wt of Original Blow Molded Seat Back	1905.1		
Wt of Original Metal Brackets	952.5		
Wt of New EPP Design	804.0	2744.2	
Wt of New PU Foam Design	1079.6		
Wt of Insert Molded Metal Brackets	860.6		

60% Rear Seat Back

Description	Weight (g)	Total weight (g)	% Saving
Wt of Original PU Foam	1678.3	4944.2	26.4
Wt of Original Blow Molded Seat Back	2268.0		
Wt of Original Metal Brackets	997.9		
Wt of New EPP Design	1203.6	3636.8	
Wt of New PU Foam Design	1206.0		
Wt of New Imbedded Metal Structure	1227.2		

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Figure 9.2.2.m: Example of JSP EPP Foam Rear Seatbacks[23]

Roof/D-Pillar Mounted Retractors

A mass reduction can be accomplished by relocating the seatbelt anchors to the roof or upper structural pillars rather than the seat structure. The Nissan Qashqai and Chrysler Minivans have incorporated this approach in production models. Roof/pillar mounted retractors transfer impact loads into the upper C and D Pillars of the vehicle, areas engineered to manage high loads. This approach reduces the seat loads and allows the seat structure to be lighter and less complex.

9.2.2. Seat Benchmarking

The seat benchmarking process:

1) Compared seat masses
2) Selected feature content by applying a lower mass version of the same feature
3) Scaled cushion and frame sides relative to Venza dimensions
4) Normalized safety engineering systems by analyzing seat frame designs to understand side impact features; seats without side airbags were normalized using the Venza airbag mass; seats were filtered by safety architecture

Seat designs which had counter-measures for upcoming safety requirements engineered into their architecture were selected. These seats were normalized to the Venza baseline size and feature content. Cushion volume ratios were calculated and scaled to the Venza; Venza features not included in the selected seats were added to normalize the feature content. For example, Venza power systems were added to a manual seat to normalize it as a power seat. By using this process, the feature content of the compared seats was normalized as a comparative starting point. The greatest mass reduction areas were filtered from the list of seats and applied to the Venza baseline. Table 9.2.3.a shows the selected driver seats as well as the baseline Venza driver seat.

Table 9.2.3.a: Driver's Seat Simple Mass Benchmarking

Venza 2.7 FWD BASELINE	Fiesta 1.6 TDCI Titanium	Prius 1.5 Base	Astra III 1.8I	2 1.3 Elegance	Navara ST-X 2,5 Di	Yaris 1.4 D-4D Sol
VENZA BASELINE	*1*	*1*	*1*	*1*	*1*	*1*
26.92	**18.472**	**17.87**	**18.568**	**18.761**	**19.104**	**19.261**

The selected seats were then normalized based on content, sizing and safety systems to create a baseline for the Low Development model. The content normalization was a result of benchmarking the seats and applying it to the specified seat. For example, the power systems for the seat were normalized using the Chrysler 300C unit which was lower mass than the Venza power system. The side airbag system was normalized back to the Venza baseline, to coordinate with the safety systems methodology. The following chart shows results from the benchmarking. The results were not altered by the normalization; the Toyota Prius was determined to be the lightest seat. However, further investigation revealed that the Prius seat was in fact an older architecture. The Ford Fiesta seat included a more advanced level of safety engineering due to its recent new release for future regulatory increases for side impact. The Ford Fiesta seat was lighter when normalized for safety features and was therefore chosen as the starting point for normalization. Table 9.2.3.b shows the normalized driver seat masses.

Table 9.2.3.b: Driver's Seat Normalized Mass Benchmarking

					
	Venza 2.7 FWD BASELINE	**Fiesta 1.6 TDCI Titanium**	**Prius 1.5 Base**	**Astra III 1.8l**	**2 1.3 Elegance**
	VENZA BASELINE	***1***	***1***	***1***	***1***
Weight	26.92	**18.472**	**17.87**	**18.568**	**18.761**
Front					
					
Normalization to Venza					
Best a2mac1 Power Equipment (300C+Venza Lumbar)	--	6.735	6.735	6.735	6.735
Safety Equipment delta to From Fiesta - Venza	--	0.442	0.442	0.442	0.442
Azera Frame	--				
Composite Seat Frame	--				
Sizing Adjustment	--	*7.177*	*7.177*	*7.177*	*7.177*
Back	--	5.722			
Cushion	--	5.981			
Lightweighting Content (Benchmark based)					
300C Power equipment replacement (with Venza lumba	--				
Remove springs (back and cushion)	--				
Remove Foam volume (ergo foam replacement	--				
	--				
Remove Garnish and trim	--				
	--				
		0.668			
Adjusted Weight	***26.92***	***25.649***	***25.047***	***25.745***	***25.938***

9.2.3. Seat Analysis

Safety systems inside the seat include airbags and active headrests. They are relatively mass efficient and offer little mass savings opportunity. The reclining seat frame transfers loads through the seat and contributes to the overall mass of the structure. The masses of the sub-systems and components of the Toyota Venza driver's seat are shown in Figure 9.2.4.a.

Figure 9.2.4.a: Exploded View of Toyota Venza Driver's Seat

Table 9.2.4.a is a sensitivity analysis for the driver's seat. Based on this analysis, the key areas that could provide mass and cost savings are:

Power adjusters:	9.652 kg,
Frame structure:	7.210 kg,
Bottom cushion:	4.322 kg,
Seat back:	3.277 kg.

Table 9.2.4.a: Toyota Venza Driver's Seat Sensitivity Analysis:

Mass in Kg

Driver	**1**	**26.920**				
Head rest	1		0.834			
Cover	1			0.159		
Padding	1			0.179		
Frame	1			0.423		
Reinforcement	1			0.073		
Back			3.277			
Cover	1			0.582		
Pad	1			1.120		
Suspension	1			0.267		
Head rest support bracket				0.038		
Inner side support	1				0.019	
Outer side support	1				0.019	
Rear storage	1			0.369		
Plastic back trims	1			0.901		
Cushion			4.322			
Cover	1			0.446		
Pad	1			1.430		
Suspension	1			0.344		
Base assembly	1			1.039		
Garnish				0.950		
Inner side	1				0.171	
Central	1				0.195	
Outer side	1				0.584	
Under trim	1			0.113		
Safety			1.625			
Side airbag	1			0.452		
Side airbag actuator	1			0.040		
Headrest anti-choc mechanism	1			1.133		
Power adjusters			9.652			
Longitudinal				5.807		
Motor	1				0.386	
Mechanism	2				0.247	
Rails					5.174	
Inner side	1					2.678
Outer side	1					2.496
Longitudinal & Height				0.017		
Control	1				0.017	
Height				1.598		
Front	1				1.083	
Motor	1					0.306
Mechanism	1					0.184
Coupling bar	1					0.593
Rear					0.515	
Motor	1					0.323
Mechanism	1					0.192
Swivel				0.874		
Control	1				0.007	
Motor	1				0.325	
Mechanism	1				0.542	
Lumbar				0.558		
Control	1				0.025	
Motor	1				0.206	
Mechanism	1				0.327	
Wiring harness	1			0.411		
Control module	1			0.151		
Connection support	1			0.236		
Cushion and back structure	1		7.210			

Low Development Driver's Seat

For the Low Development model, an initial benchmarking study was completed to define readily accessible technologies from other OEM seat designs that would be feasible for the Low Development driver seat mass reduction. Feasible low mass production components were incorporated into the seat as well as near term technologies.

Production seat systems were benchmarked, including seats, frames, adjustment mechanisms, cushions and safety systems. This study indicated that the Ford Fiesta front seat had a significantly lower mass than the Venza front seat. The Fiesta seat incorporated Ford's latest side impact structure in the seat frame design which the Venza does not have. The Fiesta seat was also similar in size to the Venza seat; most passenger car seats are similar in size and shape since they are designed for the same occupant ranges, typically from a 5th percentile female to a 95th percentile male. The Ford Fiesta seat was selected as the starting point (see below chart). It would be straightforward to modify this seat or any new seat design to match the Venza mounting bolt pattern for assembly plant installation. The mass was reduced using the following components to replace the Venza hardware:

1) Baselined Ford Fiesta seat based on mass, safety structure and size
2) Removed steel frame and replace with Hyundai Azera magnesium frame
3) Added 300C power adjusters to the manual Fiesta driver's seat
4) Incorporated Venza side airbag unit
5) Adjusted seat size based on cushion volumes
    i. Lower cushion scaled up in size to match Venza size
    ii. Seatback cushion scaled down in size to match Venza size

Low Development Passenger Seat

The Venza baseline passenger seat included manual adjustment for fore and aft travel and recline; there was no vertical adjustment. The Low Development seat incorporated this same functionality. The Ford Fiesta manual adjustment passenger seat housed the adjusters in the lower seat frame. The floor risers were also integrated into the longitudinal adjustment assembly. This integration offered a significant mass savings vs. the Venza manual seat adjustment mechanism. The passenger seat integrated the longitudinal tracks into the sill and tunnel, and one half of the adjustment rails into the magnesium cast frames and integrated the rails and mounting into the cast frame and body. This increased level of integration created a larger mass reduction for the non-power passenger seat (-41%) than for the power driver seat (-24%). The rear seatback angle adjuster, cushion and cover incorporated the Fiesta masses; the Venza side airbag replaced the Fiesta unit. The process used to reduce the Low Development passenger seat mass was:

1) Baselined the Ford Fiesta seat based on safety structure and size
2) Removed the Fiesta steel frame and replaced it with the Hyundai Azera magnesium frame
3) Added one side of longitudinal adjustment rails from the 300C (other half built into the sill and tunnel structures)
4) Removed the mass of the Fiesta airbag and added the mass of the Venza side airbag unit
5) Adjusted seat size based on the cushion volumes
    i. Lower cushion scaled up in size to match Venza size
    ii. Seatback cushion scales down to match Venza size

The Fiesta passenger seat integrated most of the seat lower structure into the adjustment mechanisms. The Fiesta seat used with the Azera magnesium cast structure yielded a 7.5kg mass reduction of the seatback and headrest structures. Half of the 300C longitudinal adjustment rail mass was added for this feature. The remaining half was integrated into the sill and tunnel structures. The Fiesta equipment was used for all other adjustment mechanisms including the manual release lever at the front of the seat and the recliner hinges and levers.

Recliner hinges have very severe duty cycles and must pass high impact loads from the seatback into the lower and out to the body structure. Per seat supplier Faurecia, recline hinges are very standard across the industry and have been highly developed for mass and cost. The Hyundai Azera magnesium frame used a steel retractor hinge.

The results showed a significant mass savings by using a magnesium cast structure combined with a Ford Fiesta passenger seat. The cost for the Low Development seat was estimated at 88% of the Venza passenger seat based on a cost analysis performed by seat supplier Faurecia. The processed frame cost of the magnesium was estimated at 1.5 times the cost of the steel Venza frame. The overall savings was due to a high level of integration in the cast frame that eliminated many individual components.

Low Development Rear Seat

The Venza rear seat incorporated a 60/40 split folding and a rear compartment release that allowed the seats to fold forward. The Nissan Qashqai was selected as a representative low mass rear seat. The Venza rear seat carried 8.2kg of mass dedicated to packaging a production Toyota Highlander rear seat in the new body. The Highlander rear seat was carried over from the Lexus RX350. There were large stamped steel assemblies and a four bar linkage used to create fold flat rear seats. The Qashqai utilized an all foam lower seat with a simple floor mounted pivot for fold flat capability. In order to normalize the functionality to the Venza, the remote folding mechanism and handle were added to the mass build up. As described in section 9.2.2., interior supplier Faurecia reduced the seat back mass using roll forming and laser welding. The Malibu/LaCrosse production seat back mass was approximately 3kg lighter than the benchmarked Qashqai rear seat back frame mass. Per Faurecia, this offered an even greater mass reduction at no added cost. This system was incorporated in the Low Development model.

High Development Seats

The High Development seats utilized a high degree of system integration using several technologies discussed in the seat “Emerging Technologies” section. Thin polyamide composite seatback frames with a multilayer foam suspension and a digitally knit covering replaced the typical seat suspension, foam and cover construction. Faurecia is currently developing a composite seatback which absorbs rear passenger head impact energy, absorbs front impact loads for the driver, creates a grained class A surface molded in color, and provides a packaging advantage over current seat construction. Faurecia estimated the cost to be equivalent to the Venza seat cost.

The structure mass was reduced by using digitally knit suspension fabrics as the main seating surface and as the lumbar and suspension support. The HD proposal utilized foam in the bolster regions to provide support and spine posture based on the NuBax study results[24].

The frame of the High Development seat incorporated a structure that tied into the vehicle sill and tunnel structures and eliminated the need for typical bolted on, stamped steel risers. The power adjusters for the High Development proposal replaced the power seat mechanisms and linkages with rack and pinion style drives in the sill and tunnel structures. These adjusters were driven by small “stepper” motors; stepper motors are smaller due to their reduced friction and mechanical advantage versus a kinematic system. The High Development proposal incorporated channels with an integrated gear rack in the tunnel and sill structure for the seat tracks and mounts. The drive motors were integrated into the roller on the seat frame with a pinion to create the necessary adjustment motions. Height adjustment mechanisms were similar to the current Venza system. The HD design proposal utilized a pan in the seat frame to adjust height in the vertical direction. The mass of the lighter weight 300C power seat system was used as the mass for the High Development proposal. This mass included the power mechanism and the motors for the 8 way 300C power seats. This was a conservative approach; a lower mass may be possible through design optimization. This model includes the potential mass savings achieved by building the seat tracks into the sill and tunnel sections. A detailed engineering analysis, beyond the scope of this study, is required to accurately determine the seat track mass for the High Development model.

An additional mass savings opportunity may exist for the High Development front seat that would take advantage of digital looming technology. It may be possible to create a complete seatback center section consisting of knit monofilament based suspension materials. Current office chairs such as the “Aeron” Chair by Herman Miller use knit seats. This technology has not been applied to an automotive product. Additional development is needed to establish its viability. Key areas include material durability specs for UV protection, abrasion protection for automotive applications, front and rear impact performance and consumer acceptance for comfort. True Textiles has already done development in the arena of UV and abrasion durability, but it has not been applied to automotive applications. Depending on the source fibers, it is possible that within the next two to three years a wide range of knit fabrics could be available for automotive implementation that meets all current standards. Impact performance could be benchmarked and bench tested offline relative to current seats for basic component and system validation. An optimized design could then be implemented over the next two product cycles before 2020 for vehicle integration level testing. Consumer acceptance has been proven through the commercial furniture market, with many manufacturers offering suspension knits that offer comfort levels commensurate with foam filled knits. The largest consumer appeal development items that would need to be validated are consumer comfort during dynamic conditions, and long term durability of seats with fabrics meeting acceptable comfort levels. The effects of heat, weather and stress cycles as the material ages would need to be proven with rigorous testing and analysis. A key benefit of the knit suspension materials was manufacturing simplicity and easy installation/replacement. This technology allowed seat fabric upgrades or custom designs at relatively low plus cost.

The current High Development seat proposal does not include the knit suspension seat technology as no development has been done to determine if a knit suspension seat could meet the FMVSS safety standards. The High Development front seat model consisted of a composite seatback, a multilayer foam seating surface and a digitally knit cover. This approach still accounted for a large mass savings using conservative, near term technologies. A composite seatback could reduce tooling costs versus a magnesium casting. Additionally, part integration could reduce costs further by eliminating the seatback trim and lower seat cover trim and garnishes.

High Development Driver Seat

Figure 9.2.4.4.1a illustrates the High Development driver’s seat compared to the baseline Venza seat. The High Development front seat mass reductions were based on the Low Development model with additional mass reductions created by eliminating the garnish and trim used to cover seat risers and seat frames, removing the seat springs, reducing the total foam volume by using ProBax technology and using an ergonomic seat frame design. Figure 9.2.4.4.1.b shows an exploded view of this seat.

Figure 9.2.4.4.1.a: High Development Driver Seat (Venza seat in tan for reference)

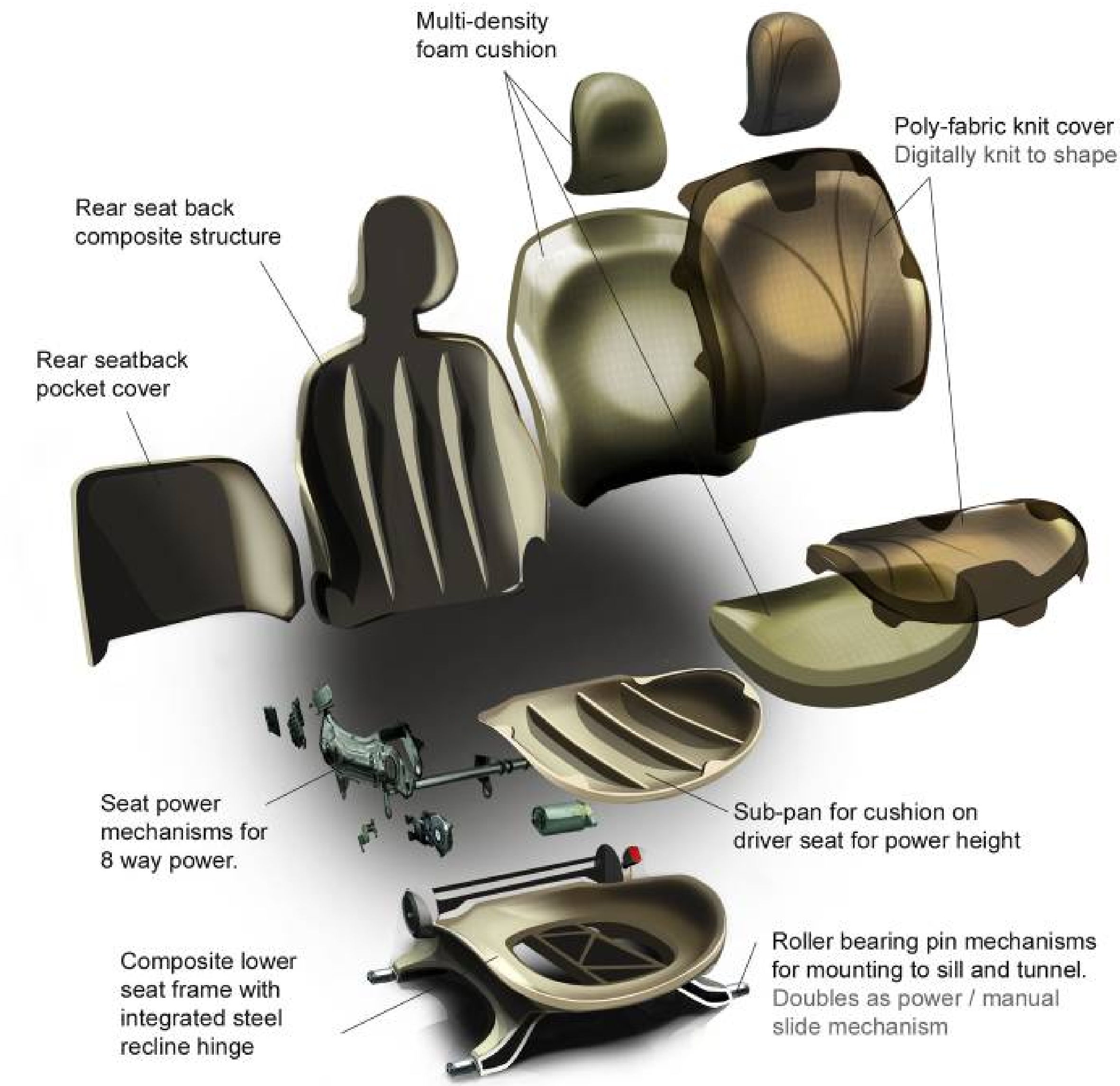


Figure 9.2.4.4.1.b High Development Driver's Seat Model

High Development Passenger Seat

The High Development manual adjustment passenger seat used an approach similar to the High development driver seat. Figure 9.2.4.4.2a illustrates the High Development driver's seat. The High Development passenger seat proposal included mass reductions for eliminating the garnish and trim used to cover risers and seat frames, removing the seat springs, and reducing the foam volume due to ProBax technology and an ergonomic seat frame design. Longitudinal adjustment tracks were integrated into the sill and tunnel, with one half of the 300C longitudinal adjustment rails accounted for. A composite seat frame under development by Faurecia could offer the same mass reduction as magnesium with no cost increase relative to the baseline Venza seat frame.

Figure 9.2.4.4.2a   High Development Passenger Seat Model

High Development Rear Seat

The High Development rear seat added a blow molded upper seatback frame to the Low Development model. Figure 9.2.4.5a shows an exploded view of the High Development rear seat. Dow Automotive has introduced blow molded seatback technology that created a 30% reduction in mass relative to a typical stamped steel frame. There were also promising technologies emerging with EPP (Expanded Poly Propylene) foam seatback designs. As discussed in the emerging technologies section, this was a very cost effective solution, allowing hinges, brackets, anchors, and other structural elements to be poured and bonded together with the EPP foam seatback cushions, virtually eliminating all the current seatback buildup.

For the purpose of this study, the High Development rear seat proposal consisted of the baseline benchmarked Nissan Qashai rear seat, which already utilizes EPP foam seat lowers, adding the Venza center seatbelt anchors back into the mass and adding the remote unlatching system found in the rear quarter trim of the Venza. The Qashqai mounts the center retractor and anchor into the D pillar. This cannot be done with either the Low or High Development model because it places the retractor zone too far rearward relative to the Qashqai location. The distance from the Venza D pillar to the Venza second row occupant is longer than the Qashqai distance. This relationship was carried over as part of the packaging requirement for both the Low and High Development models. The longer Venza D pillar to occupant position does not meet the SAE recommended retractor zone set up for meeting NHTSA passenger crash performance requirements. A further mass reduction was achieved by integrating the seat cushion lower frame into the composite floor. Currently, due to the manufacturing constraints of stamped steel floor pans, seat lowers must contain a separate frame to hold the cushions and covers together for assembly, take impact loads, and integrate LATCH anchors, seatbelts and hinges. These features could be molded into the Bayer glass fiber composite floor pan that is used in the High Development body system, with brackets, hinges and anchors inserted into the tooling for the floor pan, and over molded to create a finished lower seat frame. Only the cushion and cover would then need to be installed, reducing the mass of the rear seat system. LATCH system anchors, seatbelt retractors, and hinges were used from the Qashqai. The lower seat frame mass was eliminated for the High Development rear seat since these systems were moved to the floor pan. The Body section included the rear lower seat mass. This generated a cost savings; the blow molded seatbacks have reduced costs in production applications as have EPP foam lower seat cushions. Integrating the seat lower frame into the composite floor pan created an additional cost savings for the rear seat system. The High Development proposal offered high levels of mass reduction at a reduced cost compared to the Venza baseline.

The current Venza rear seat utilized an existing design described in the Low Development rear seat section. The use of carryover parts is a key OEM consideration for final vehicle system selection. However, this resulted in a large mass penalty associated with the adaptation of this seat system to the Venza body. With an all new design, based on benchmarked systems and emerging technologies, the Venza seat could be much lighter if it were designed specifically for the Venza architecture.

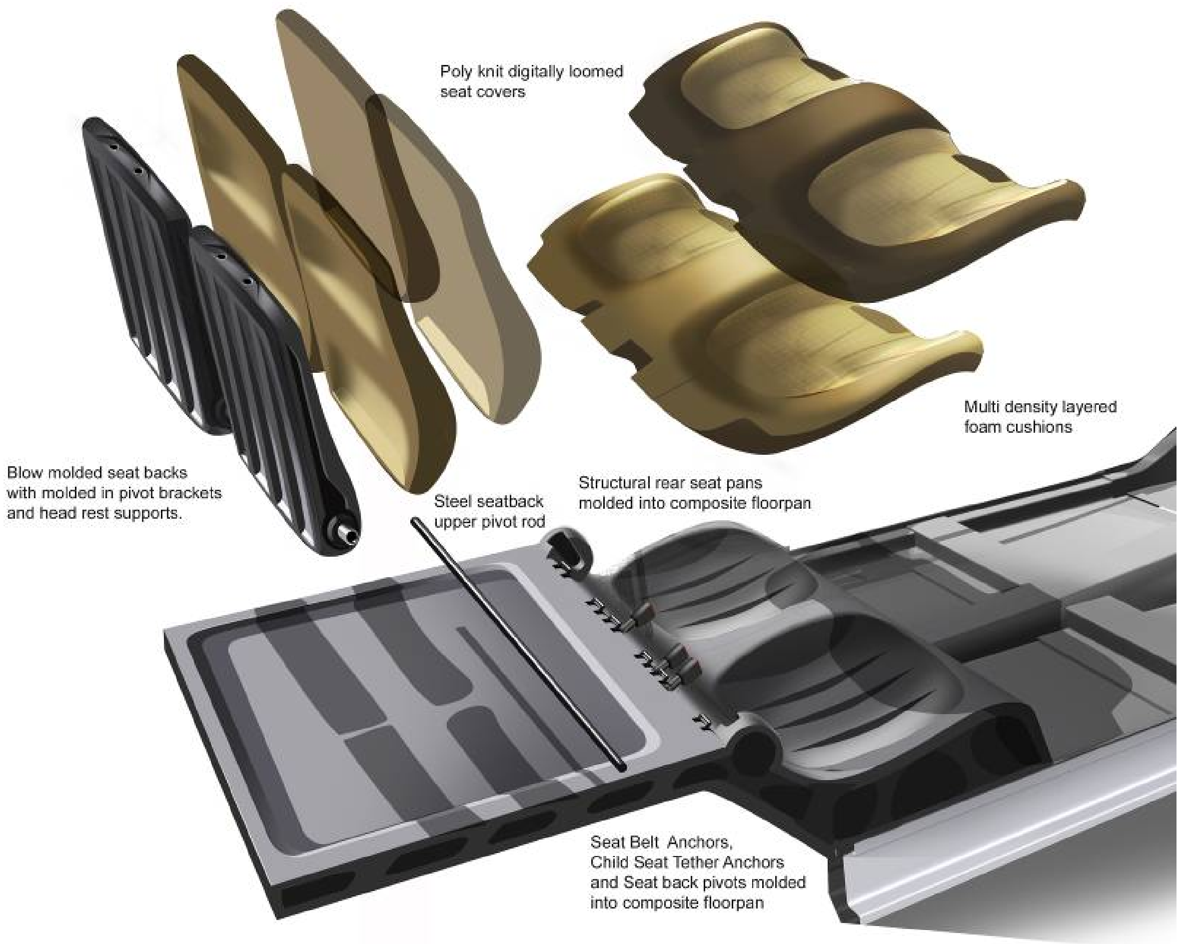


Figure 9.2.4.5a High Development Rear Seat Concept Assembly

9.2.4. Seat Results

9.2.4.1. Low Development Drivers Seat

The mass of the Fiesta based Low Development model was 20.5kg. versus 26.92kg for the Venza seat (6.4 kg savings). This represents a 24% mass reduction compared to the baseline. See Table 9.2.4.1a below for the detailed mass analysis. The cost factor was 88%; this is a projected savings of 12% compared to the baseline Venza seat.

Table 9.2.4.1.a: Toyota Venza Driver's Seat Mass Reduction Analysis:

Driver's Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Ford Fiesta Seat Starting Point (kg)
Starting Mass (kg)	26.92	18.47
Itemized Mass Deltas to baseline		Low Development
Normalization to Venza		
Best A2MAC1 Power Equipment (300C+Venza Lumbar	--	0.00
Safety Equipment delta to From Fiesta - Venza	--	-0.12
Azera Frame	--	-3.64
Composite Seat Frame	--	0.00
Sizing Adjustment	--	
Back	--	-1.52
Cushion	--	0.66
Light weighting Content (Benchmark based)		
300C Power equipment replacement (with Venza lumba	--	6.74
Remove springs (back and cushion)	--	0.00
Remove Foam volume (ergo foam replacement	--	0.00
	--	0.00
Remove Garnish and trim	--	0.00
	--	
Mass Results (kg)	**26.92**	**20.59**
Mass Reduction (kg)		**-6.33**
Mass Reduction Percentage		**-24%**

9.2.4.2. High Development Drivers Seat

The High Development seat mass was 18.8kg; this reduces the driver's seat mass by 30%, or 8.1kg compared to the baseline Venza seat. The cost factor was 94%; this was a projected savings of 6% compared to the baseline Venza seat. Table 9.2.4.2a lists these results.

Table 9.2.4.2.a High Development Driver Seat Mass Reduction Summary

Driver's Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Ford Fiesta Seat Starting Point (kg)
Starting Mass (kg)	26.92	18.47
Itemized Mass Deltas to baseline		High Development
Normalization to Venza		
Best A2MAC1 Power Equipment (300C+Venza Lumbar	--	0.00
Safety Equipment delta to From Fiesta - Venza	--	-0.12
Azera Frame	--	0.00
Composite Seat Frame	--	-3.25
Sizing Adjustment	--	
Back	--	-1.52
Cushion	--	0.66
Light weighting Content (Benchmark based)		
300C Power equipment replacement (with Venza lumba	--	6.74
Remove springs (back and cushion)	--	-0.27
Remove Foam volume (ergo foam replacement	--	-0.39
	--	
Remove Garnish and trim	--	-1.50
	--	
Mass Results (kg)	**26.92**	**18.81**
Mass Reduction (kg)		**-8.11**
Mass Reduction Percentage		**-30%**

9.2.4.3. Low Development Front Passenger Seat

The Low development passenger seat weighed 13.6 kg; this was a mass savings of 9.6kg, or 41%. The cost factor was 88%; this was a projected savings of 12% compared to the baseline Venza seat.

Table 9.2.4.3.a: Toyota Venza Passenger Seat Mass Reduction Analysis

Passenger's Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Ford Fiesta Seat Starting Point (kg)
Starting Mass (kg)	23.18	16.96
Itemized Mass Deltas to baseline		Low Development
Normalization to Venza		
Safety Equipment delta to From Fiesta - Venza	--	-0.12
Azera Frame replacement	--	-3.93
Composite Seat Frame	--	0.00
Longitudinal Rails from 300C (Fiesta is a hybrid rail/str	--	1.61
Sizing Adjustment	--	
Back	--	-1.52
Cushion	--	0.66
Light weighting Content (Benchmark based)		
300C Power equipment replacement (with Venza lumb	--	0.00
Remove springs (back and cushion)	--	0.00
Remove Foam volume (ergo foam replacement	--	0.00
Add Manual Seat Adjustment Bar	--	0.00
Remove Garnish and trim	--	0.00
	--	
Mass Results (kg)	**23.18**	**13.65**
Mass Reduction (kg)		**-9.53**
Mass Reduction Percentage		**-41%**

9.2.4.4. High Development Front Passenger Seat

The high development front passenger seat reduced the passenger seat mass by 53%, or 12kg, making the total High Development front passenger seat mass 11kg. The cost factor was 94%; this was a projected savings of 6% compared to the baseline Venza seat.

Table 9.2.4.4.a High Development Passenger Seat Mass Reduction Summary

Passenger's Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Ford Fiesta Seat Starting Point (kg)
Starting Mass (kg)	23.18	16.96
Itemized Mass Deltas to baseline		High Development
Normalization to Venza		
Safety Equipment delta to From Fiesta - Venza	--	-0.12
Azera Frame replacement	--	0.00
Composite Seat Frame	--	-3.25
Longitudinal Rails from 300C (Fiesta is a hybrid rail/str	--	0.00
Sizing Adjustment	--	
Back	--	-1.52
Cushion	--	0.66
Light weighting Content (Benchmark based)		
300C Power equipment replacement (with Venza lumb	--	0.00
Remove springs (back and cushion)	--	-0.26
Remove Foam volume (ergo foam replacement	--	-0.39
Add Manual Seat Adjustment Bar	--	
Remove Garnish and trim	--	-1.10
	--	
Mass Results (kg)	**23.18**	**10.98**
Mass Reduction (kg)		**-12.20**
Mass Reduction Percentage		**-53%**

9.2.4.5. Low Development Rear Seat

The Low Development rear seat mass was 27.4kg; the rear seat mass reduction was 20.5 kg, or 43%. The cost factor was 88%; this was a projected savings of 12% compared to the baseline Venza seat.

Table 9.2.4.5.a Low Development Rear Seat Mass Reduction Summary

Rear Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Nissan Qashqai starting point (kg)
Starting Mass (kg)	47.808	26.478
Itemized Mass Deltas to baseline		Low Development
Normalized to Venza Volume	47.81	28.27
Normalization to Venza		
Remote Rear Cargo unlocking system	--	0.33
Back Frame normalized for center seatbelt (2-3)section	--	0.00
Add Venza Seatbelt Anchor		1.75
Modular seatback Laser welded roll formed		-3.00
Mold seat lower into composite floor proposal		
Utilize blow molded reinforced seatback frame (30% reduction)		
Mass Results (kg)	**47.81**	**27.35**
Mass Reduction (kg)		**-20.46**
Mass Reduction Percentage		**-43%**

9.2.4.6. High Development Rear Seat

The High Development rear seat reduced the mass of the Venza rear seat by 22.4 kg. This was a 47% mass savings vs. the Venza baseline mass of 47.8 kg. The cost factor was 94%; this was a projected savings of 6% compared to the baseline Venza seat. Table 9.2.4.6a shows the mass analysis for the High Development rear seat.

Table 9.2.4.6.a High Development Rear Seat Mass Reduction Summary

Rear Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Nissan Qashqai starting point (kg)
Starting Mass (kg)	47.808	26.478
Itemized Mass Deltas to baseline		High Development
Normalized to Venza Volume	47.81	28.27
Normalization to Venza		
Remote Rear Cargo unlocking system	--	0.33
Back Frame normalized for center seatbelt (2-3)section	--	0.00
Add Venza Seatbelt Anchor		1.75
Modular seatback Laser welded roll formed		
Mold seat lower into composite floor proposal		-1.22
Utilize blow molded reinforced seatback frame (30% reduction)		-3.70
Mass Results (kg)	**47.81**	**25.43**
Mass Reduction (kg)		**-22.38**
Mass Reduction Percentage		**-47%**

9.3. Instrument Panel, Console and Insulation

9.3.1. Instrument Panel, Console and Insulation Trends

There were numerous opportunities on the Venza for combining components and simplifying through integration, especially in the Human Machine Interface (HMI) and controls areas. Due to the division of core components along functional boundaries, many vehicle manufacturers create individual modules for the HMI between functional sub-systems and control inputs from consumers. For example, the HVAC controls, the radio and the auxiliary control inputs all use individual modules. Some vehicles have as many as 10 separate control modules and switch-banks that are all independently powered, switched, controlled, and communicated with on a CAN-BUS system. The consumer electronics market has technologies that can eliminate multiple discrete modules through integration. These technologies have the potential to be applied to vehicle interiors. As an example, the electronics associated with the average mobile phone on the market today has the electronic capability to control a current production interior, e.g., an Iphone has 16 bit processing capability. Additionally, some consumer goods electronics have been developed for severe duty, including shock, vibration and thermal, that may have the potential to meet OEM NVH and environmental requirements. Based on these current trends, it is anticipated that there should be electronics with 64 bit processing capability and adequate memory for automotive interior applications in the 2017 timeframe at a competitive cost.

Wi-Fi and WiMAX Communications

WiFi (Wireless Fidelity 120ft radius) – WiMAX (WiFi with 10-30mi radius)[25]

Wireless network technologies could save mass by eliminating major electrical systems in the instrument panel. The Venza wiring and signals processing technology used power leads, as well as signal wiring, that were channeled through a communications “BUS” architecture. This BUS is responsible for processing information through the network of wiring and sensors, ultimately using a processor to make output “decisions” based on input conditions. While this system is efficient and optimized in it’s current evolution, it may be possible to use wireless technology to eliminate the signals processing wiring necessary to execute these output decisions. Also, this type of system may be utilized to accept remote inputs from drivers and passenger to a central control system. This would eliminate typical switch bank assemblies. Wireless fidelity has been used and developed to a mature state in the consumer electronics industry for almost ten years. The application of this mature technology to automotive interiors for the 2017 time period appears to be feasible. The widespread elimination of interior wiring could also reduce cost.

Wi-Fi and WiMAX Entertainment, solid state memory

WiFi (Wireless Fidelity 120ft radius) – WiMAX (WiFi with 10-30mi radius)

In addition to the communications function, WiFi technology could also allow information and entertainment opportunities from sources outside the vehicle. This could allow elimination of on board hardware such as CD and DVD players, radio and other media drives in general. Even hard-drive storage capacity would be minimized, creating an opportunity to eliminate motor driven hard-drives with solid state media drives. This could result in reduced playback system power consumption. Apple offered a 128 GB solid state memory drive in the 2009 AirBook© laptop that eliminated spinning drive technology and an internal network antenna captures wireless media sources. This drive has the potential to meet automotive durability, heat and vibration requirements and could be integrated into automotive entertainment systems. Chrysler and Autonet have combined to provide in car

WiFi reception, and have partnered with Sirius© satellite services to offer Sirius Backseat TV©. Streaming media over a satellite feed, WiFi, or even the eventual WiFi replacement, WiMAX would allow consumers to choose from any virtual library of music and entertainment without the need for on-board media storage or spinning disc media playback drives. Online and satellite based services such as iTunes©, Pandora©, and Sirius© provide custom play-lists, favorites, and rated channel selection options. iTunes© and Pandora© could offer services to consumers without the need for a subscription of service fee. Peripheral devices can be plugged in through a USB or similar type connection, or even via a Bluetooth wireless connection, which would allow a user to provide their own media device (such as a CD player, tape deck, DVD player etc). A single, touch screen with a small amount of onboard solid state memory could serve as the interface. This technology would also allow media to be wirelessly synchronized from a home computer, to a vehicle in the garage or driveway, through a wireless home network. Software makers have already created products, such as "Simplify Media" which gives consumers WiFi access to songs and media stored on their home iTunes© account, anywhere in the world. With these technologies already available commercially, and the trend toward online only services, it seems probable that entertainment media will likely shift the same direction. Current hard media producers and distributors have already called for the elimination of solid media by the 2015 timeframe.

Voice Activation Technology and Microsoft SYNC.[26]

Ford Motor Company and Microsoft have already developed a robust and highly integrated voice activated infotainment system called "SYNC©". Figure 9.3.1.a shows a SYNC© screen and its functions. While SYNC© is currently under exclusive license to Ford Motor Company, the system will eventually be available for other OEMs. Hyundai and Kia will offer a version of the Microsoft system under another brand name in the near future. The SYNC system allows users to voice operate the car's audio system, mobile phone, and any installed USB media device, such as iPod©, iPhone©, Zune©, or even a USB memory stick with songs installed. This system not only reduced mass by eliminating redundant mechanical control buttons, but was a safety enhancement to current mobile entertainment because it reduced distraction times for driver's interfacing with the entertainment system. Ford currently uses multiple redundant radio and entertainment system controls, as well as an on-board CD and DVD player. It is probable that a majority of vehicle owners in the 2017-2020 timeframe will likely utilize digital media as a major source of entertainment in car, either though online subscription, satellite subscription, or an installed media device. Owner's wanting a CD player could purchase a dealer installed USB driven player. Ferrari has replaced the audio head unit entirely with the installation of an iPod Touch© in the Scuderia F430 16M; this system is shown in Figure 9.3.1.b. Ferrari is one of many automakers that currently purchases head units from many sources, due to the high costs of developing their own unit. The iPod Touch© reduced the F430 mass. The current Chrysler MyGig© head unit with an integrated spinning 30 GB hard drive option cost is approximately $1000. An iPod Touch© is about $299 and offers more features so there could be a cost savings to the consumer. Integration of the iPhone could also offer more features through available software applications including GPS, accelerometer, Bluetooth and WiFi integration. This could result in more features at potentially less cost. This also saves space in the instrument panel area, an area that is traditionally very densely packaged.

Figure 9.3.1.a: Ford SYNC integration into the Instrument Panel

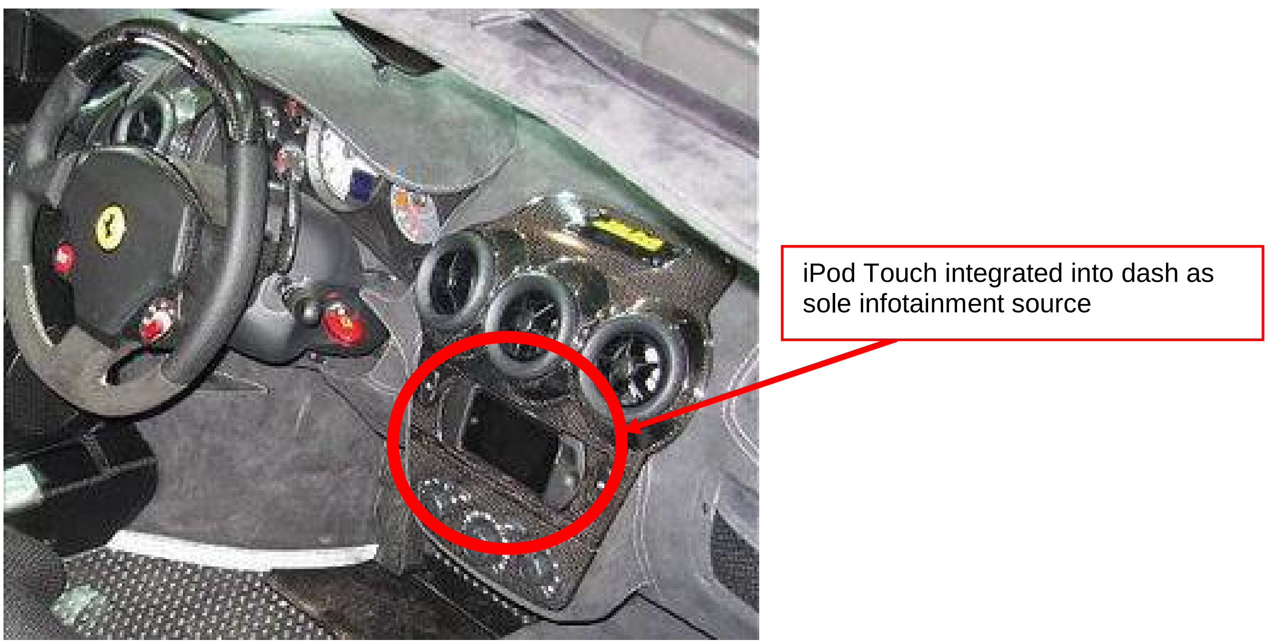


Figure 9.3.1.b: Ferrari iPod Touch integration into the Instrument Panel[27]

OEMs could source Apple or other producers of these devices. They could also develop their own devices for on-board media and entertainment, or include USB interfaces for any media transfer device. This would allow mass and cost reduction, reduce media playback system obsolescence, and provide faster response to changes in consumer entertainment choices used in their automobiles.

LCD Cluster - Information Display

There are many OEM's beginning to currently introduce LCD screens as the primary source of displaying driver information. Figure 9.3.1.c below shows typical examples. The main advantages of this system are flexibility in display information and properties, the ability to rapidly change priority of information relayed to drivers, time based design and information relay, and fast production design changes through elimination of hard tooled instruments.

Figure 9.3.1.c: Mercedes-Benz S-Class (2006) and Jaguar XJ (2010) LCD Cluster, Touch Screen and Information systems[28]

OEMs can produce one common unit for all vehicles, using software rather than hardware, to create distinct model based design and engineering changes. This also allows occupants to customize the display to suit their individual preferences. Mercedes uses the LCD information center in the cluster area to display night vision camera information when necessary to alert driver's of oncoming objects, which then switches back to a speedometer display. Several drawbacks of this technology include larger cluster brow packaging for daytime display performance, cost of the screens, and flat, two dimensional cluster appearance when the display is off. Consumers are currently used to seeing the cluster as a part of the interior design jewelry, associating it with value. Several manufacturers, including Ferrari, General Motors and Toyota, are using a combination of mechanical and LCD technology to create unique cluster designs. However, retaining an all LCD cluster allows for greater cost reduction through volume of units, and associated development costs with hard tooled cluster modules, packaging of unique mechanical cluster elements, and design model and model year changes.

Transparent OLED (Organic Light Emitting Diodes)

The ability to create displays on translucent materials would allow vehicle information to be displayed for navigation and other functions in the driver sightline. This would eliminate the typical LCD screen assembly and mounting hardware. A transparent OLED display could reside in a thin plastic part adjacent to the windshield. This could reduce driver distraction and possibly lower cost vs. a projector based heads up display technology. A thin transparent OLED layer could be applied to the inside of the windshield with in-situ type display graphics. Windshield replacement costs would be increased with this system. A transparent OLED has mass and packaging advantages vs. digital LCD display technology[29].

Flexible OLED

A single touch screen input unit is an alternative to voice activated on-board electronics that could also allow integration of low mass media devices and electronics. Using technologies such as a standard touch screen, advanced haptic (touch) feedback, and flexible Organic Light Emitting Diodes, OEMs could potentially eliminate many mechanical control switches currently housed in the interior module. OEMs could offer a secondary slave device allowing consumers to operate media devices of their choice. The vehicle interface would be a flexible input platform that could accommodate advances in consumer electronics. It would contain onboard wireless, universal bus, or other forms of digital integration.

Flexible OLED displays (see Figure 9.3.1.d) are emerging as a possible view/touch screen technology. Current LED screens are rigid, have dimensional and thickness limitations, and require, expensive, heavy and complicated packaging solutions to integrate them into the instrument panel surfaces. IP's are rarely flat nor do they always have packaging space available in an orientation acceptable for good visibility. Flexible OLED technology would allow contouring the display screen to the designed surfaces. This could allow full integration into the top pad material of the IP, negating the need for bezels, trim and the center stack surfacing required to accommodate a flat screen. This high level of integration with the center stack trim could eliminate many current switch banks and buttons. It could also create better down angle visibility without creating the IP styling and engineering issues of a flat screen LCD.

"simpler than the ... ion blaster technique Samsung used to produce their flexible OLED display, adapting the 'traditional' process of manufacturing OLED displays (UDC uses vacuum thermal evaporation) in a more 'benign' way so that it can be implemented directly on a soft piece of plastic, hence the potential for mass production. Essentially, the plastic substrate is glued to a piece of glass while they process it, and then it's carefully peeled off. What you end up with is an OLED implemented directly on plastic.
That said, while FDC believes 'most of the key manufacturing roadblocks have been

Figure 9.3.1.d: Flexible OLED

addressed and it's time to start thinking seriously about commercial production,' commercial gadgets with flexible OLED displays are still a few years away. And we're talking like 4-6 inches, not even 8-10 for a (flexible tablet). On the upside, they think they can get the price premiums down to 'no more than 10 percent' above existing display prices within the first 5 years of commercial production...'

Flexible OLEDs are designed to target a number of military and commercial applications that require more rugged displays. With Universal Display's PHOLED technology and materials, the new display achieves the same brightness as traditional displays with extremely low power consumption. Additional advantages of the technology include lower operating temperature due to less heat being generated, easier to drive, longer battery life, and more stable transistors. The integration of Universal Display's PHOLED front plane delivers a key enabling technology for the flexible OLED. The PHOLED materials allow the OLED to convert up to 100 percent of the electrical energy into light, as opposed to traditional fluorescent OLEDs which convert only 25 percent, providing up to four times more energy efficiency. Universal Display integrated the FDC backplane designed for its PHOLED front plane to produce the display.**"**[30]

Wood Fiber (Faurecia)

The Faurecia "Light Attitude" [31]report documented that wood fiber based interior panels have shown significant mass reductions with no cost increase vs. standard polypropylene hard plastics used in current vehicle interiors. Per this report, wood fiber panels were also more ecologically sound. Wood Fiber panels are made up of wood powder or pulp mixed with poly-olefin or small amounts of polypropylene as a fill and binder. These materials are sourced in sheet stock form and are formed using low pressure tooling. The finish can be raw, varnished, or covered with another cover stock material molded over the wood fiber substrate. The disadvantages were that structural ribs and fastening towers or male fastener provisions were difficult if not impossible to mold into the parts. These features would have to be added to the substrate in a separate operation. The structural integrity of the added bosses would need to be evaluated. Wood fiber top pad and skin panels were used in production applications and reduced the mass of these components vs. polypropylene parts.

Low Pressure Tooling

Low pressure tooling enabled wood fiber usage and many other appearance grade substrate and soft goods parts to be manufactured. Vantage Technologies[32], a Michigan based supplier of low volume interior components, has developed a very low cost, OEM quality process for tooling interior trim parts with composite based tools. This process reduced tooling costs by a factor of 10 compared to typical steel tools. The low pressure forming process utilized constant pressure to create repeatable parts. Headliners, door substrate panels and instrument panel top pads are typical components suited for low pressure tooling/forming. Other components suitable for low pressure forming included pillar trim panels, lower IP parts, seatbacks, and rear cargo area load floors. Low pressure forming offers potential mass and cost savings for lightly stressed interior appearance parts.

INPAMO

INPAMO is a system developed by interior supplier Faurecia that replaced the normal steel cross car tube in the instrument panel with a smaller metal structure for steering column and center stack support on the driver's side of the vehicle. The passenger side support was made up of structural composite ventilation ducts. Faurecia indicated that this approach created a 10% mass reduction for a current BMW 3 series Instrument Panel. Faurecia has developed this technology and tested it internally with BMW. The IMPAMO 3 series panel was sled tested for side impact performance and passed all BMW requirements.

WEMAC Vents

The HVAC vents represented an opportunity for possible mass and cost reduction. A/C outlets typically incorporate multiple vanes and drive mechanisms and are complex and costly to produce and assemble. They are also relatively inefficient due to the airflow restriction created by the multiple internal turning vanes. A vent technology that is used in military and aviation applications is the WEMAC unit. It opens and closes using an internal rotary valve; flow efficiencies can exceed 90% depending on the diameter. The low restriction is due to the thin section of the internal valve in the full open position; it is typically less than 2mm thick relative to the airflow direction. This is a significant reduction in cross sectional area compared to the multiple primary and secondary vanes used in typical A/C outlets. Because a vent must meet a minimum "effective open" area, a smaller physical size WEMAC vent can be packaged while meeting the area requirements. The duct aiming is accomplished via a ball and socket mated to a surrounding mounting flange. It is possible for duct sizes to be reduced when using a WEMAC vent because of the vent's large open area vs. its physical size. They are easy to operate; they can be aimed and modulated in one step vs. two (Venza) or three adjustments required for some outlets. Figure 9.3.1.e shows the standard Toyota Venza outlets and a WEMAC rotary vent. The front view shows the significant difference in effective open area for the two vent styles.

Figure 9.3.1.e WEMAC vents vs. Stock Venza vents

Wireless Control

Another emerging control technique was the application of wireless motion and gesture sensing. Microsoft has adapted this technology to the upcoming XBOX 360 gaming system. This wireless technology converts simple gestures made by the human body into instructions for a gaming system. Users of this gaming controller simply move their body and the cameras and sensors in the transceiver unit recorded those gestures and instantly interpret them as maneuvers for the game. No special knowledge of the buttons to press or combinations for movement where necessary. If the user wants the "game player" to box, he/she simply punches in air, and the sensor picks that up and converts that into a motion for the "game player" on the screen. This technology could offer a unique way for a driver to initiate or validate operations on the vehicle in concert with voice commands. This could allow the elimination of switches and mechanical switch banks but would add sensors and a camera to the vehicle to operate wireless control. More information is posted below[33]:

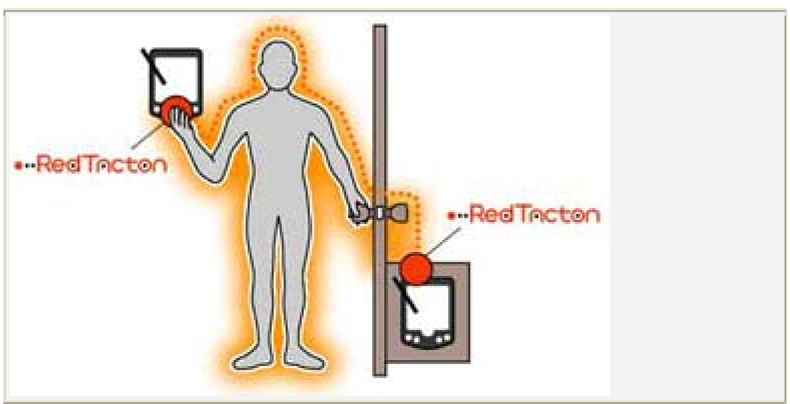
"Players will no longer need a control pad or joystick to control on-screen video game action, after Microsoft launched "Project Natal", a motion-sensing control system for its Xbox 360 video games console.

The announcement was made as Microsoft unveiled new technology and a formidable video game line-up for the Xbox 360**.** The device will do away with the need for a traditional control pad or joystick in favor of a high-tech camera that can pick up movement.

The sensor enables gamers to score goals by kicking at a virtual football and fire at enemies by pulling an imaginary trigger. It uses a camera, depth sensor, microphones and special software to build a three-dimensional map of body movement. It can also respond to voice commands, directions, and a change in the player's tone of voice. There is a large potential that a system of this nature could completely eliminate all mechanical control interfaces on the interior altogether. Sensing of body motion, voice commands and intonation references could ultimately be the entire control strategy for secondary systems such as climate control, navigation and entertainment systems*."*

HUMAN AREA NETWORK

Human Area Networking is a process by which external devices can transmit signal information through manipulation of the small magnetic field that exists surrounding the human body. Figure 9.3.1.f illustrates this concept.



Next time you have a problem transferring files, here's how to go about it.
All you need is RedTacton. (Photo courtesy RedTacton.com)

Figure 9.3.1.f: Human Area Network (HAN) Diagram

Several small companies, such as RedTacton, have begun research and started development on the required sensors and transmitters necessary to take advantage of this theory. With this process, it may be possible to completely eliminate switches in the interior altogether, using graphic contact points and basic sensors to transmit signals, rather than electro-mechanical means. This concept has the potential to pass customized data from individual users for vehicle preferences and settings by using this type of data transmission to pass the personalized setting information to the vehicle through HAN. Furthermore, this could also be a great security and identity feature that would immobilize the car in case of theft, owing to a non-approved personalized profile. Below is a summary of this emerging technology from a web article: [34]

"NTT Firmo transmits data through skin
24 Apr 2008
RedTacton human area network -- NTT has begun selling a device that transmits data across the surface of the human body and lets users communicate with electronic devices simply by touching them, the company announced on April 23.

The new product, called "Firmo," consists of a card-sized transmitter carried in the user's pocket. The card converts stored data into a weak AC electric field that extends across the body, and when the user touches a device or object embedded with a compatible receiver, the electric field is converted back into a data signal that can be read by the device. For now, Firmo transfers data at 230kbps, but NTT is reportedly working on a low-cost 10Mbps version that can handle audio/video data transfers.

Firmo is based on NTT's RedTacton human area network (HAN) technology, which is designed to allow convenient human-machine data exchange through natural physical contact — even through clothing, gloves and shoes.

NTT initially hopes this human area network technology will appeal to organizations looking to boost convenience and security in the office. Obvious applications include secure entrances and keyless cabinets that recognize employees when they touch the door handle (thus bypassing the need for card-swipers and keys), or secure printers that operate only when you touch them.

For now, a set of 5 card transmitters and 1 receiver goes for around 800,000 yen ($8,000), but NTT expects the price to come down when mass production begins."

Electronic Park Brake Systems

One major emerging trend for many vehicles already sold in the US and in Europe was the application of an electronically actuated park brake system. Volkswagen has introduced this system in the current Passat, a mid-size production sedan ($19-$29K MSRP). The system has many mass saving advantages compared to hand and pedal mechanical systems. Many OEM's do not currently produce electronic park brake assemblies due to perceived cost increases and legacy engineering constraints. The system replaced many mechanisms, cables and heavy systems with an electronic switch, wiring and two servo based solenoids that operate the existing rear brake caliper for parking brake application. The Volkswagen system cannot be taken out of Park position without first disengaging the system. The electronic logic locks out the transmission until it senses park brake release signals for the electronic switch, making it virtually impossible to drive the car without removing the park brake. The Venza interior mounted parking brake components weigh 3.1 kg. This does not include the mass of the chassis/suspension based assemblies required for parking brake operation. There are long cables, brackets, springs and mechanisms under the body on the chassis side that drive the park brake system from the mechanical lever or pedal interior inputs in the cabin. The Volkswagen electronic park brake system used two lightweight servos and a single switch. Table 9.3.1.a lists the Venza parking brake components and masses.

Table 9.3.1.a: Interior Parts for Mechanical Park Brake system on Toyota Venza

Parts Eliminated by Electronic Park Brake	Mass (kg)
Park Brake Foot Pedal	3.191
Pedal	2.202
Position switch	0.010
Locking cable	0.979

The electronic parking brake driver control can be integrated into an existing control screen and eliminate a dedicated switch. Additional mass can saved by eliminating the mechanical structure required to support park brake operation in the center console (hand operated) or the body structure (foot operated). Current mechanical systems must withstand high input forces that are transferred through brackets and reinforcements to the primary body structure. These robust parts add mass and limit critical space for consumer packaging and content. Storage, cupholder space, appearance, fit, finish and quality are often compromised because of parking brake apply/release system packaging requirements. Electronic parking brake systems operate at the touch of a button; foot or hand operated mechanical systems are more cumbersome to operate and are not as precise in driver feedback for on/off positions.

The primary cost incurred by an electronic system is the cost of switching the mechanical system components to an electronic system (adding servos to the rear calipers). Many OEMs commonize park brake systems across many platforms to minimize costs. Typically only a small percentage of the total system can be carried over due to vehicle packaging and architecture constraints. Many cars share pedal based assemblies, sometimes intermediate cables and actuators. Handle based systems can share handle mechanisms, but for appearance and integration reasons, rarely share full handle assemblies. Electronic park brake systems offer an opportunity for sharing across platforms, as the actuation is electronic and the controls can be packaged for varying interior designs. An electronic parking brake button incorporated into an existing interior screen or surface does not typically require mechanical kinematic or ergonomic studies and takes up much less interior space than a mechanical apply/release system. Many center console designs are functionally compromised due to the mechanical park brake handle placement.

Full Electronic Transmission Control

Electronic transmission control systems, including the gear selector and the transmission control, have eliminated mechanical shift control mechanisms from the center console and the transmission. Several auto manufacturers have incorporated electronic shifting controls; the 2010 Jaguar XJ electronic shifter control is shown below in Figure 9.3.1.g. It is important to note that electronic controls must be applied to a transmission system that is ready for full electronic input versus a transmission setup for mechanical gear change inputs. This is important because although an electronic system can eliminate the mass, package volume, and structural reinforcement needed for a mechanical shift lever, most of that mass will be added back into the overall system if a servo needs to be added to convert electronic inputs from the cockpit controls into mechanical inputs at the transmission. A full electronic system offered potential packaging, mass and cost advantages through parts elimination and reduced local structure required to support the shift mechanism.

Figure 9.3.1.g: Interior Electronic Shift Controls on 2010 Jaguar XJ Sedan[35]

BMW and Mercedes-Benz offered full electronic shifting in their top end models, the BMW 7-Series, and the Mercedes-Benz S-Class. The BMW electronic shifter was a mechanical shift system with electric drives. The shift module converted mechanical user inputs to electronic signals and converted those inputs to mechanical cable motions under the transmission tunnel. These components are shown in Figure 9.3.1.h.

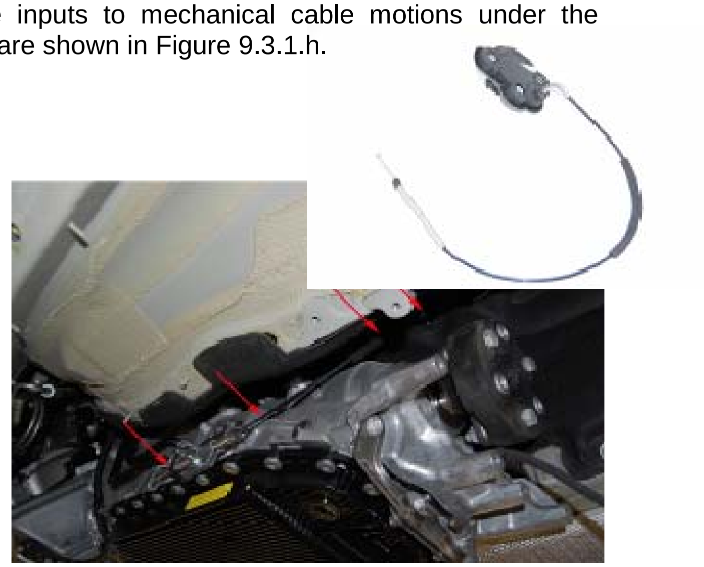


Figure 9.3.1.h: BMW 7-Series Mechanical-Electrical Shift System

Although the BMW system had low mass (0.993 kg) and incorporated a short, lightweight cable (0.292kg), it was mass intensive and inefficient compared to the Jaguar electronic system (see Chassis section for additional details). Figure 9.3.1.j shows the Mercedes system.

Figure 9.3.1.i: Mercedes S-Class Electronic Shift System

Mercedes Benz also utilized fully electronic transmission actuation on the M and R class. The interior contained a small stalk mounted on the steering column that controlled the transmission. This electronic steering column control is shown in Figure 9.3.1.k below.

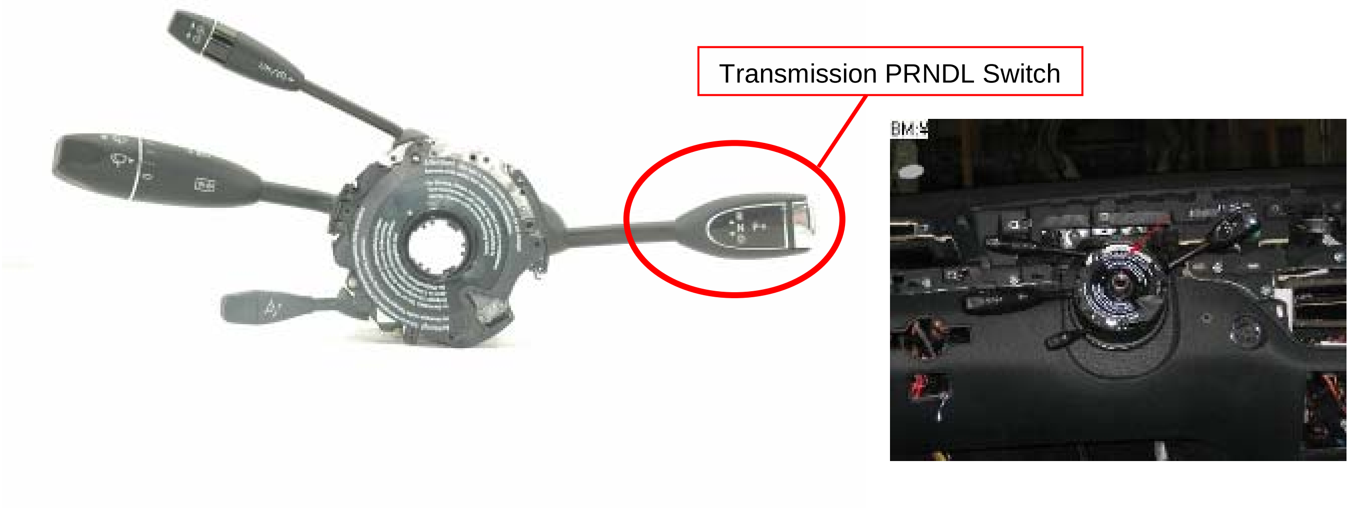


Figure 9.3.1.k Mercedes S-Class Electronic Shift Interior Stalk Switch

Although some mechanical shifters were similar in mass to an electronic shifter module, the key advantage was in the reduction of brackets and mass needed to support the loads of a mechanical shifter in the center console and at the transmission. The additional packaging space created by eliminating the shifter mechanism and support structure could be used for storage and added consumer convenience features.

The Toyota Venza shifter incorporated an electronic actuator on the transmission. An electronic transmission control selector could replace the mechanical unit to create a lower mass system.

Capacitive Switch and Touch Technology

Capacitive switching technology is an emerging technology for automotive application but has been utilized in other industries for several decades. Examples are shown in Figure 9.3.1.l. Capacitive switches use pressure and the change in pressure causes on an inductive bladder to create switching signals. Several cellular phone models have used capacitive switching to reduce package thickness and mass. The WACOM tablet, used by designers and digital artists, has a capacitive touch strip for zoom and scrolling functions. This allows input based on sliding a finger across the surface rather than pressing a button.

WACOM "touch slider"

iPhone "touch screen"

Motorola RAZR (Capacitive buttons)

Figure 9.3.1.l: WACOM Tablet (Capacitive Slider Switch)**, iPhone** (touch screen) **and RAZR Phone**
Photos courtesy of www.maximumcpu.net, www.apple.com, www.66modbile.com

Most flat panel touch screens, such as the iPhone and ATM screens, use capacitive touch technology to transmit signals to the processor.

In the automotive arena, Chevrolet has introduced the production Volt precursor model which incorporated capacitive switches in the center stack module (see Figure 9.3.1.m below). This had the advantage of creating multiple switches in one component. Capacitive switches can reduce tooling costs & mass and increase perceived quality by eliminating the typical gap and reducing the fit/flushness dimension to zero. The LCD touch screen at the top of the center stack could also use capacitive touch sensitive inputs. This technology could be utilized anywhere there is switching required for any interior component or module. Milliken Fabrics, an automotive material supplier, has started research and development for soft goods based switches. They incorporated a flexible bladder imbedded in knit materials that would function using capacitive switching technology. The knit material would have switch icons knit as patterns into the top material and the bladder would provide signal processing and lighting for night time appearance. Per Milliken, this technology could be available within a 5 year time frame.

Figure 9.3.1.m: Chevy Volt Capacitive Touch Screen and Center Stack

9.3.2 Instrument Panel | Console | Insulation Benchmarking

Instrument Panel

The Low Development Instrument Panel model started with a search for low mass instrument panels. The lightest panels were then normalized by volume to the Toyota Venza dimensions. The Toyota Venza instrument panel had the lightest specific mass although it also had a high level of content, styling and materials utilization. Table 9.3.2.a below shows the results of the initial benchmark data for the baseline Toyota Venza panel.

Table 9.3.2.a Instrument Panel Normalized Volumetric Mass Benchmarking

		Toyota Venza	Mazda 5	Toyota Prius	Nissan Qashqai
					
	Number of parts	1	1	1	1
	Weight	28.49	24.70	19.61	23.11
	Width	1640	1440	1410	1410
	Height	760	770	575	680
	Depth	960	880	790	680
m3	Volume	1.20	0.98	0.64	0.65
Kg/m3	Weight/Volume	23.81	25.31	30.62	35.45
					

This analysis indicated that the Venza instrument panel was a relatively low mass design. The Venza utilized a new architecture style with the waterfall and nose of the console built into the instrument panel module. This center console section also included the shifter module, which is typically in the center console sub-system. The Venza IP was used as the starting point for further mass reductions.

Center Console

The center console is a feature intensive system and it was important to choose competitive consoles that had similar feature content. This was especially true for the armrest section which has specific load bearing requirements. All benchmarked consoles were selected for equivalent content. Table 9.3.2.b shows the center console benchmarking summary.

Table 9.3.2.b Center Console Mass Summary

	Venza 2.7 FWD	S 40 2.5 turbo	CLS 350 CGi	C4 Exclusive 1.6l HDI 16V	Primera 1.8 16V Visia	Tucson 2.0 CRDi	5 Series 3.0 i Sport	Prius 1.5 Base
ENTIRE CONSOLE								
Number of parts	1	1	1	1	1	1	1	1
Weight	**8.711**	**3.904**	**6.382**	**6.406**	**2.799**	**5.004**	**6.454**	**5.476**
Width	735	-	-	-	-	-	-	-
Height	384.4	-	-	-	-	-	-	-
Depth	232	-	-	-	-	-	-	-
Manufacturer	-	-	-	-	-	-	-	-
Materials	-	-	-	-	-	-	-	-
MAIN BODY	-	1	1	1	1	1	1	1
Weight	**-**	**2.072 kg**	**3.275 kg**	**1.308 kg**	**0.931 kg**	**1.398 kg**	**2.378 kg**	**0.829 kg**
Width	735	325	350	333	160	180	229	150
Height	384.4	310	350	205	246	315	223	360
Depth	232	950	1040	997	650	675	845	640
Manufacturer	-	FAURECIA	DRAXLMAIER	VISTEON	-	KORYO	-	-
Materials	-	P/E-MD20	ABS	P/E-M20	-	PPF	ABS+PC GF 10	PP-T10
Fasteners	-	4 Staple 0,008 kg + 4 Torx screw 0,022 kg	7 Female torx screw 0,032 kg	3 Torx screw 0,008 kg + 3 Clips 0,004 kg	-	6 Screw 0,02 kg	2 Screw 0,012 kg + 4 Torx screw 0,006 kg + 2 Staple 0,002 kg	4 Self-drilling screw 0,006 kg + 6 Self-drilling screw 0,007 kg

Noise Insulation

The Venza noise insulation mass was maintained. There may be future opportunities to reduce NVH countermeasure mass. Faurecia's Light Attitude study[36] indicated there may be an opportunity to reduce the mass of acoustic material by 25%. There were also active noise reduction systems under development such as the system being developed by Lotus and Harman International[37] that uses existing vehicle speakers and specific software to attenuate interior noise. An active noise cancellation system could potentially eliminate a significant amount of the current NVH countermeasure mass.

9.3.3 Instrument Panel, Console and Insulation Analysis

Table 9.3.3.a below lists the mass breakdown of the Instrument Panel sub-systems.

Table 9.3.3.a: Toyota Venza Instrument Panel Sensitivity Analysis

		Total Mass (kg)	Component Mass (kg)				
Instrument panel	**1**	**28.488**					
Dashboard	1		6.191				
Dashboard covers			1.771				
Garnish center				0.905			
Right	1				0.512		
Left	1				0.393		
Driver side trim				0.571			
Lower trim	1				0.571		
Passenger side trim				0.257			
Unfinished trim	1				0.257		
Central trim				0.038			
Support	1				0.038		
Storage compartments			3.436				
Glove box system	1			3.082			
Storage	1				1.801		
Glovebox Support	1				1.257		
Opening cylinder	1				0.024		
Driver side				0.148			
Left	1				0.148		
Passenger side				0.206			
Lower storage system	1				0.206		
Cross car beam			9.675				
IP reinforcement	1			7.684			
IP support bracket				1.991			
Right	1				0.483		
Left	1				1.027		
Middle	1				0.481		
Air vent			0.823				
Central				0.247			
Left side	1				0.012		
Right side	1				0.111		
Center bezel	1				0.124		
Left				0.283			
Air vent	1				0.283		
Right	1			0.293			
Instrumentation			6.592				
Heating system				0.570			
Heating control	1				0.330		
Support	1				0.240		
Odometer				1.140			
Odometer assembly	1				0.970		
Odometer bezels	1				0.170		
Audio system				3.687			
Radio	1				2.885		
Radio support	1				0.090		
Second radio support (right)	1				0.090		
Speakers system					0.622		
Tweeter						0.345	
Right	1						0.172
Left	1						0.173
Tweeter grill						0.277	
Left	1						0.102
Right	1						0.102
Central	1						0.073
Column switch system				0.418			
Directional switch-light	1				0.207		
Wiper switch	1				0.154		
Cruise control	1				0.057		
Central lock control	1			0.013			
Power mirror controls				0.035			
Control	1				0.035		
Covers	2			0.006			
Electronics ignition system				0.103			
Ignition switch					0.103		
Control	1					0.044	
Bezel	1					0.059	
E.S P.System				0.013			
ESP control	1				0.013		
Accessory plug in	1			0.021			
Multifunction control	1			0.091			
Lock control back doors	1			0.012			
Multi-function display	1			0.483			

Center Console

Table 9.3.3.b below lists the mass breakdown of the Center Console sub-systems.

Table 9.3.3.b: Toyota Venza Center Console Sensitivity Analysis

Item	Qty	Total Mass (kg)	Component Mass (kg)		
Center console	**1**	**8.711**			
Rear cover	1		0.247		
Rear storage compartment			4.976		
Compartment	1			3.565	
Cover	1			0.740	
Lock	1			0.259	
Hinge	1			0.412	
Mounting bracket			2.022		
Front	1			0.078	
Rear (single/left)	1			1.944	
Instrumentation			0.062		
Electric outlet	1			0.022	
Lighting system	2			0.019	
Lighting support	1			0.021	
Ashtray			0.355		
Front ashtray				0.355	
Ashtray	1				0.017
Mounting bracket	1				0.151
Bezel	1				0.121
Cover	1				0.066
Front storage			0.258		
Pan	1			0.100	
Support	1			0.107	
Cover	1			0.051	
Air vent	1		0.154		
Cup Holder system			0.601		
Front				0.601	
Cup Holder	1				0.247
Box	1				0.062
Support	1				0.292
Air vent trim	1		0.036		

Insulation

Table 9.3.3.c below lists the mass breakdown of the Noise insulation sub-systems.

Table 9.3.3.c: Toyota Venza Insulation Sensitivity Analysis

Item	Qty	Total Mass (kg)	Component Mass (kg)	
Noise insulation		**6.230**		
Sound insulation engine side (single/main)	1		0.246	
Draining system insulation			0.203	
Draining system insulation (single/main/left)	1			0.203
Sound insulation (cockpit side)	1		2.101	
Interior floor insulation system			3.521	
Front left floor insulation	1			0.335
Second rear left floor insulation	1			0.029
Third front left floor insulation	1			0.062
Front right floor insulation	1			0.368
Center console	1			0.765
Rear left floor insulation	1			0.493
Rear right floor insulation	1			0.466
Rear seat carpet insulation	1			1.003
Front fender insulation			0.159	
Left	1			0.083
Right	1			0.076

Instrument Panel

Table 9.3.3.d lists a prioritized mass breakdown of the Instrument Panel sub-systems. The cross car structure is a major contributor to the overall IP system mass. The top pad (dashboard), instrumentation and the storage systems are also significant contributors. A higher level of integration could eliminate separate systems for dashboard covers and air vents.

Table 9.3.3.d: Toyota Venza Instrument Panel Sub-system Analysis

Instrument panel	Mass (kg)
Cross car beam	6.37
Dashboard	6.19
Instrumentation	3.55
Storage compartments	3.06
Dashboard covers	1.53
Air vent	0.68
Total	**21.39**

Center Console

The Venza center console mass was located primarily at the rear of the console. The main storage bin and the support for the armrest loads were located there. Faurecia stated that this section is highly developed in current production consoles. The Venza mounting bracket can be eliminated; it's function was to adapt the Camry floor-pan design to the Venza armrest package. The console cup holder system was also a significant mass in the center console. Table 9.3.3.e lists a prioritized mass breakdown of the Center Console sub-systems

Table 9.3.3.e: Toyota Venza Center Console Sub-system Mass Analysis

Center console	Mass (kg)
Rear storage compartment	3.55
Mounting bracket	1.75
Cup Holder system	0.42
Rear cover	0.25
Front storage	0.19
Air vent	0.15
Instrumentation	0.04
Air vent trim	0.04
Ashtray	0.04
Total	**6.43**

Noise Insulation

The major mass of the noise insulation was in the dash/IP insulation system. The floor insulation had the next highest system mass. A dual mass/damper system was used for the Low Development model. Table 9.3.3.f lists a prioritized mass breakdown of the Noise Insulation sub-systems

Table 9.3.3.f: Toyota Venza Noise Insulation Sub-system Analysis

Noise insulation	Mass (kg)
Sound insulation (cockpit side)	2.10
Interior floor insulation system	2.03
Sound insulation engine side (single/main)	0.25
Draining system insulation	0.20
Front fender insulation	0.08
Total	**4.66**

Low Development Instrument Panel

The Low Development proposal for the instrument panel utilized the same build methodology as the current Venza panel with additional electronics systems integration. The Faurecia IMPAMO system (reviewed in Section 9.3.1.) reduced the IP mass by 10% when applied to a BMW 3 series with no cost penalty. Combining the IMPAMO technology with a wood fiber based instrument panel top pad design could reduce the IP mass by a total of 25% with no cost penalty. Using MuCell for the IP retainer and miscellaneous IP components could save another 10% in mass; Faurecia expected a 5% cost increase for this added mass savings. There was an additional 2% **mass** savings created by replacing the current radio and radio/HVAC control head support brackets. The total Low Development mass savings was 37%.

The exterior appearance of the Venza panel was not changed due to these technologies. Figure 9.3.3.a illustrates the Low Development IP vs. the production Venza assembly. The Low Development IP was expected to be consumer and assembly process neutral. Tier one suppliers build instrument panels to OEM broadcast build specs for color and options and supply a completed, sequenced module to the assembly point. The Low Development IP technologies should not affect the supplier build nor the OEM assembly plant installation procedure.

The Volvo S40 and European Ford Focus, C-Max and Mazda 3 share a Faurecia SYNTES system which eliminated the traditional cross car beam and resulted in a mass savings. This also allowed cross car beam communization across these four models.

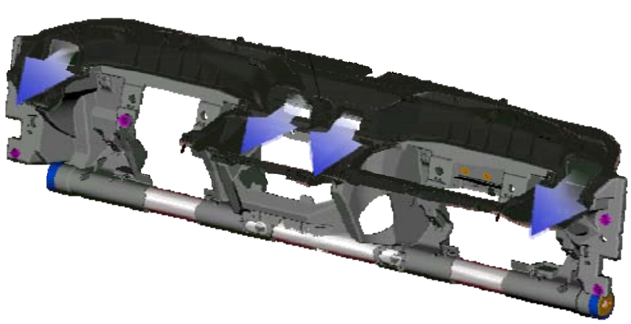


Figure 9.3.3.a: Faurecia SYNTES modular Hybrid Metal/Plastic IP Structure

The Low Development rendering in Figure 9.3.3.b (lower figure) illustrates the Low Development instrument panel appearance vs. the production Venza IP. The electronics and switches, as well as the ventilation system, transmission and park brake controls have been reduced in complexity. Storage space has also been increased, e.g., the storage area on the lower RH side of the console is significantly larger than the current Venza.

Current Production Toyota Venza Instrument Panel

Low Development Model Instrument Panel

Figure 9.3.3.b: Toyota Venza Current and Low Development Instrument Panels

The control interface for the Low Development model was a combination of an indexed touch screen and voice input activation. This system eliminated many parts from the center stack, improved ergonomics, reduced cost and mass and simplified the driver environment. There could also be a perceived quality improvement created by using a single touch screen interface that eliminated the fit and finish alignment requirements for individual controls and switches. It is important to note that flat touch screen technology, without haptic feedback such as indexes for finger tip guidance or voice input integration, would be difficult to execute with high consumer appeal and safety. The proposed touch screen panel in Figure 9.3.3.c below combined indexed guides for main control inputs (to facilitate “no-look” control inputs), voice recognition/activation technology, and haptic feedback in the form of virtual “clicks” and vibrations.

Figure 9.3.3.c: Low Development Central Touch Screen Control Unit

It was important to consider haptic feedback as part of the solution; i.e., the touch screen technology needed to maintain ease of use and flexibility. A change to touch screen technology may increase short term cost but should reduce long term development costs. This is because software programming and adaptation replace the need for all new parts and the associated tooling. Furthermore, an open source electronic and software platform for this device would allow rapid integration of new consumer electronics technologies. A knowledgeable non-automotive user base could make the adaptation to automotive applications occur seamlessly. Mechanical fingertip indexes would provide tactile feedback for highly utilized interfaces, such as radio tune, ventilation control, and volume. Consumers could program a custom layout of their most used “buttons” to increase the ease of use. This trend has already started; the Ford Mustang has driver selectable lighting colors for the gauges and controls. This approach would eliminate the fixed, mechanical control layout used in current vehicles. A touch screen system would help reduce the cost of model changes and development and allow investment in other mass critical areas. The largest mass reduction was the elimination of the standard mechanical shifter and park brake assembly. This approach created package space that can be used for storage and other features to improve the interior functionality. A touch-screen feature could eliminate multiple switch modules throughout the interior and on the IP. Table 9.3.3.g below details components eliminated through the use of a touch screen control interface.

Table 9.3.3.g: IP Control System Mass Eliminated by Central Touch Screen

Electronics eliminated by Central Control touch screen.	Total Mass (kg)	Component Mass (kg)	
Park Brake Foot Pedal	**3.191**		
Pedal		2.202	
Position switch		0.010	
Locking cable		0.979	
Instrumentation	**1.225**		
Heating system		0.570	
Heating control			0.330
Support			0.240
Central lock control		0.013	
Power mirror controls		0.035	
Control			0.035
Accessory plug in		0.021	
Multifunction control		0.091	
Lock control back doors		0.012	
Multi-function display		0.483	
Shift lever mechanism	**2.762**		
Gear selector system		0.437	
Gear selector knob			0.107
Gear selector base			0.330
Shift housing assembly		1.548	
Gearshift lever bellows support		0.440	
Gears selection control unit		0.137	
Linkage on gearbox support		0.200	
TOTAL CONTROLS MASS ELIMINATED ON IP	**7.178**		

Electronic Shifter

The shifter mechanism was a significant contributor to the IP mass. The Venza utilized several redundant control systems to manage the gear selection function. The shifter itself is a mechanical unit which converts the mechanical motions of the operator into electronic signals. These actuate a solenoid on the transmission to shift the gear lever at the transmission to the selected gear. There is a large mass associated with translating mechanical force inputs to electronic signals and back to mechanical actuation of the transmission. The IP mounted shifter uses a robust bracket made of stamped steel to resist driver input loads. An electronic shift control eliminates the need for this bracket and the lever and mechanism under the instrument panel. Table 9.3.3.g shows a 2.762kg mass for the shift mechanisms. The support bracket mass is 0.417kg. The total mass savings created by using an electronic shifter would be 3.179 kg. Figures 9.3.3.d, 9.3.3.e and 9.3.3.f depict components eliminated through use of a digital shift interface.

Figure 9.3.3.d: Shift Lever and Interior Controls

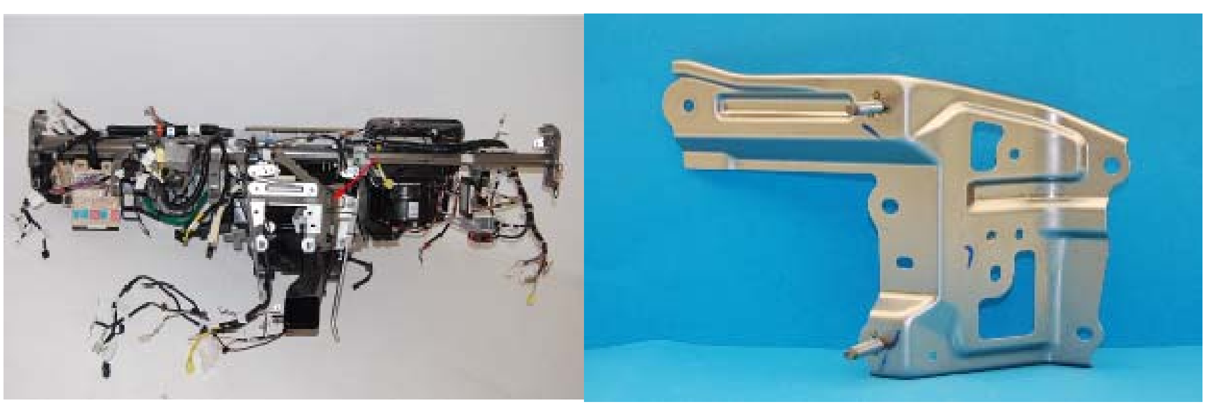


Figure 9.3.3.e: Toyota Venza Reinforcement Brackets for Shifter Loads

Figure 9.3.3.f: Toyota Venza Transmission Linkages and Actuators

HVAC Vents

The HVAC vents were a significant mass and cost reduction opportunity. The Venza vents incorporate multiple vanes and adjustment mechanisms and are costly to produce with accuracy and quality. They are also relatively inefficient for a given volume due to internal restriction. A vent technology used in military applications as well as in the aviation industry is the Wemac style outlet. It is a circular design that opens and closes via a rotary operated flap internal to the duct section. It can exceed an airflow efficiency of 90% (vs. an open tube) depending on the barrel diameter and inlet duct size. The low restriction is due to the thin sectional profile of the airflow modulating valve in the full open position and the small diameter of the valve control rod which is also in the airstream. Additional flow gains are possible by changing the valve and the control rod geometries to teardrop shapes. The Wemac design reduces the blocked area substantially compared to the multiple primary and secondary vanes used in typical automotive vents. The Wemac duct incorporates a ball and socket style construction. The circular Wemac outlet can be incorporated into square or rectangular housings to provide increased styling flexibility. It can be molded in matching or contrasting colors. A Wemac vent can be adjusted with one motion vs. two for the Venza vent. A Wemac type outlet can decrease the mass and cost of the vents and reduce the required duct area. There are numerous other circular designs used by industry that minimize air flow blockage; Figure 9.3.1.c (in previous IP section) showed a circular Jaguar design. Figure 9.3.3.g below shows the standard Toyota Venza vents and the Low Development IP with a Wemac rotary vent design with a contrasting bright surface. The difference in restriction can be seen in the front view pictures; the light background visible behind the vents is the unrestricted flow area.

Figure 9.3.3.g: Wemac Vents vs. Venza Vents

Table 9.3..1.a in the next section shows the Low Development instrument panel mass savings vs. the Venza IP. The changes included simplified shifter and parking brake controls, the Faurecia IMPAMO structure and wood fiber top pad surfaces and foamed plastic base substrate and inner panel parts molded using a new molding process called MuCell developed by Trexel Corporation. The Low Development IP model reduced mass, and, in certain sub-systems on the IP, cost. The Low Development model maintained the Venza IP features and functionality; consumers may perceive the increased storage space and revised control inputs as desirable enhancements. The final Low Development Instrument Panel mass reduction was 37%, or 10.5 kg. The total Low Development Instrument Panel mass was 17.98 kg. The Low Development IP cost factor was 110% or an estimated increase of 10% vs. the Venza instrument panel.

High Development Instrument Panel

The IP (Instrument Panel) High Development model utilized the cowl structure of the body to manage cross car loads and eliminated the cross car beam. Figure 9.3.3.h below illustrates the High Development instrument panel; Figure 9.3.3.i shows an exploded view of the High Development instrument panel. The cast magnesium and composite dash panel used for the High Development body integrated of the ventilation system cross car duct into the molded dash panel composite module. On the driver's side of the instrument panel, the steering column became the main support using a cast magnesium steering column and an integrated tripod bracket to transfer loads to the dash and cowl. The center stack cover was constructed of wood fiber using a digitally knit covering. The cover served as a dust shield and appearance item. This panel contained the wireless flexible OLED touch-screen based infotainment unit, the WEMAC style center vent outlets and the trim plate. On the passenger side of the instrument panel, the base structure and the knee blocker area were formed by the composite cowl panel that included the integrated ducts. The lower panel was fixed and could be tuned for frontal impact. The lower portion formed the storage area, and would be accessed via the soft trim cover. This upper panel would be stitched leather or digitally knit poly fabric with a wood fiber backing panel and composite structural skeleton for handling loads and NVH requirements. This upper panel would also allow for a soft airbag door which would be seamless and located up against the windshield touchdown. This technology is currently used by Faurecia and reduced the mass by 0.5kg compared to a typical metal airbag door system by using a spacer knit fabric. This spacer fabric creates a strong "sandwich" of knit materials and allows a seamless airbag exit top pad. The composite ducts of the integrated dash unit end with trim plates that carry Wemac style vent outlets.

Figure 9.3.3.h High Development Instrument Panel Proposal

Figure 9.3.3.i illustrates the High Development major sub-assemblies in the interior system.

Figure 9.3.4.2.i High Development Instrument Panel Concept Assembly

Low Development Center Console

The Volvo S40 Center console was initially selected as the starting point for the Low Development model center console because of its low mass. The mass was then normalized after adjusting the content to match the Venza. The most cost effective mass reduction approach was to use Trexel MuCell for the Venza console material. The mass reduction was due to the thickness reduction and the improved tool filling which minimized the material thickness needed to insure proper material flow. Table 9.3.4.3.a shows the mass reductions applied to the Toyota Venza components due to MuCell processing.

The majority of the parts in the center console are hidden and do not require graining or a class A surface finish. The MuCell molding technology can reduce mass by up to 30% when a part has been designed for the process. The parts that require graining and a class A surface finish need a covering or a thicker surface and gas injection to accommodate enough material for graining. These parts would provide a 20% mass reduction vs. current PC+ABS or Polypropylene parts.

High Development Center Console

The High Development center console design was a significant departure from the Low Development model. Figure 9.3.3.k shows the High Development center console assembly. The High Development center console incorporated a soft good type storage compartment rather than a hard plastic unit. The console was reduced to an armrest, arm rest support, and a soft storage compartment. The front of the Venza console, including cup holders and a phone/electronic device storage area, was integrated into the HVAC module case. Mass was added to the HVAC case to accommodate a grained surface and bleed air, thermally assisted cup holders, a storage tray, and a central LCD unit. The MuCell process was used for the remaining plastic components.

Figure 9.3.3.k High Development Center Console Model

Figure 9.3.3.l shows the components of the center console that have not been integrated into the nose of the HVAC unit. The exploded assembly view illustrates the simplicity and low component count of the proposed High Development model.

Figure 9.3.3.l High Development Center Console Exploded View

Low Development Noise Insulation

The Low Development model utilized materials substitution proposed by Faurecia (reviewed below) and a design that utilized the dash insulation as a spring/damper system. The projected mass savings for the interior side was 25%. The same principle could be applied to other systems to reduce noise insulation mass.

From Faurecia's "Light Attitude" design study:
Faurecia Light Attitude at the 2008 L.A. Auto Show » 11
"*Faurecia has developed and patented a lightweight concept to replace the conventional dash insulator, which reduces noise between the engine and the vehicle body. Conventional dash insulators consist of two layers: a thick heavy layer—composed of materials such as chalk, ethylene propylene diene monomer (EPDM) and ethyl vinyl acetate (EVA)—and a layer of insulation foam. The Faurecia concept comprises three layers: a layer of absorbing polyurethane foam, attached to a thinner lightweight "heavy layer," with a third layer composed again of polyurethane foam to serve as an insulation spring. Faurecia's concept insulator is able to use a thinner "heavy layer" because of the properties of the spring foam and absorbing foam. Instead of dampening sound with a hard and heavy barrier, Faurecia uses lightweight foam to help do the job equally well. Compared with standard insulators, Faurecia's three-layer configuration reduces the weight of he insulator by 25 to 30 percent on average by combining excellent absorbing and insulating properties. A traditional dash insulator for a vehicle may weigh around 12 kg, but the lightweight insulator can bring that weight down by approximately 3.5 kg in*

some instances. The Faurecia concept insulator maintains the same sealing performance as heavier insulators and the same overall thickness. Its acoustic performance equates to that of conventional insulators, as well, but in a much lighter-weight package. The Faurecia dash insulator is also highly recyclable. The polyurethane foam may be recycled for use in carpet padding, and Faurecia is working long–term toward recycling end-of-life materials and reusing them in its own production. "[38]

High Development Noise Insulation

The High Development noise insulation model was the same as the Low Development model. Faurecia's mechanical solution is a feasible technology to reduce mass in an area that is highly evolved.

A technology with potential to reduce the mass of NVH materials further is active noise cancellation technology discussed in section 9.3.2. This technology uses a network of noise sensors or microphones to receive input and a series of speakers to produce output. The existing vehicle audio system speakers are typically utilized. The input noise signatures received would be analyzed through a processor, with unwanted noise signatures being identified and defined. The processor would then produce the exact opposite noise signature, reversing the noise wave of the undesired input, and send that sound out to the speakers. This process effectively cancels sounds produced by engine and road inputs. This technology eliminates undesirable sounds waves and creates what would be perceived as silence by the vehicle occupants. Noise cancellation would effectively eliminate the need for sound deadening mass. Anti-vibration and harshness treatments would ultimately still be needed to produce smooth and comfortable ride characteristics but the noise reduction material mass could be significantly reduced through noise cancellation. This technology is of interest due to the low noise levels of modern electric and hybrid powertrains. Active noise cancellation could also be used for conventional internal combustion engine noise cancellation. This technology could reduce or eliminate the need for engine sound deadening materials and reduce vehicle mass. This technology could allow powertrain engineers to run engines closer to peak BSFC (Brake Specific Fuel Consumption, a value that measures the mass of fuel consumed per horsepower hour – this number describes relative fuel efficiency). Optimized BSFC tends to create increased NVH levels. Active noise control could permit engines to use air/fuel ratios more conducive to lower emissions and higher fuel economy without a noise penalty. The mass of the sensors, processors, and speakers and their power network would have to be assessed and added to the vehicle mass. For this proposal, mass reductions for active noise cancellation were not considered because of cost concerns.

9.3.4 Instrument Panel, Console and Insulation Results

9.3.4.1 Low Development Instrument Panel, Console and Insulation

The final Low Development Instrument Panel mass reduction was 37%, or 10.5 kg. The total Low Development Instrument Panel mass was 17.98 kg. The Low Development IP cost factor was 110% or an estimated increase of 10% vs. the Venza instrument panel. Table 9.3.4.1.a summarizes this data.

Table 9.3.4.1.a Low Development Instrument Panel Mass Reduction Summary

Instrument panel	LD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	17.984 kg	**-37%**	**-10.50** kg		
Dashboard	3.096			***50%***	Wood Fiber
Dashboard covers	1.533				
Garnish center		0.815			MuCell + simplification
Right			0.461	***90%***	
Left			0.354	***90%***	
Driver side trim		0.457		***80%***	MuCell
Lower trim			0.571		
Passenger side trim		0.231		***90%***	MuCell
Unfinished trim			0.257		
Central trim		0.030		***80%***	MuCell
Support			0.038		
Storage compartments	3.057				
Glove box system		2.774		***90%***	MuCell
Storage			1.801		
Glovebox Support			1.257		
Opening cylinder			0.024		
Driver side		0.118		***80%***	MuCell
Left			0.148		
Passenger side		0.165		***80%***	MuCell
Lower storage system			0.206		
Cross car beam	6.374				
IP reinforcement		5.379		***70%***	FAURECIA IMPAMO
IP support bracket		0.996		***50%***	FAURECIA IMPAMO
Right			0.483		
Left			1.027		
Middle			0.481		
Air vent	0.741				
Central		0.222		***90%***	Wemac Vents
Left side			0.012		
Right side			0.111		
Center bezel			0.124		
Left		0.255		***90%***	Wemac Vents
Air vent			0.283		
Right		0.264		***90%***	Wemac Vents
Instrumentation	3.183				
Heating system		0.456		***80%***	LCD based infotain_Module
Heating control			0.330		
Support			0.240		
Odometer		0.798		***70%***	MuCell
Odometer assembly			0.970		
Odometer bezels			0.170		
Audio system		1.475		***40%***	LCD based infotain_Module
Radio			2.885		
Radio support			0.090		
Second radio support (right)			0.090		
Speakers system			0.622		
Tweeter			0.345		
Right			0.172		
Left			0.173		
Tweeter grill			0.277		
Left			0.102		
Right			0.102		
Central			0.073		
Column switch system		0.293		***70%***	MuCell
Directional switch-light			0.207		
Wiper switch			0.154		
Cruise control			0.057		
Central lock control		0.013		***100%***	
Power mirror controls		0.000		***0%***	LCD based infotain_Module
Control			0.035		
Covers		0.000		***0%***	LCD based infotain_Module
Electronics ignition system		0.103		***100%***	
Ignition switch			0.103		
Control			0.044		
Bezel			0.059		
E.S P.System		0.013		***100%***	
ESP control			0.013		
Accessory plug in		0.021		***100%***	
Multifunction control		0.000		***0%***	
Lock control back doors		0.012		***100%***	
Multi-function display		0.000		***0%***	LCD based infotain_Module

9.3.4.2 High Development Instrument Panel, Console and Insulation

Table 9.3.4.2.a below shows a complete Bill of Materials for the High Development Instrument Panel and the details of the proposed mass reductions. The final High Development Instrument Panel mass reduction was 45%, or 12.9kg. The total High Development Instrument Panel mass was 15.6kg. The cost factor was 110%; this was a projected increase of 10% compared to the baseline Venza instrument panel.

Table 9.3.4.2.a: High Development Instrument Panel Mass Reduction Summary

Instrument panel	HD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	15.571 kg	-45%	-12.9 kg		
Dashboard	3.096			*50%*	
Dashboard covers	1.533				
Garnish center		0.815			MuCell + simplification
Right			0.5	*90%*	
Left			0.4	*90%*	
Driver side trim		0.457		*80%*	MuCell
Lower trim			0.6		
Passenger side trim		0.231		*90%*	MuCell
Unfinished trim			0.3		
Central trim		0.030		*80%*	MuCell
Support			0.0		
Storage compartments	2.749				
Glove box system		2.466		*80%*	MuCell
Storage			1.8		
Glovebox Support			1.3		
Opening cylinder			0.0		
Driver side		0.118		*80%*	MuCell
Left			0.1		
Passenger side		0.165		*80%*	MuCell
Lower storage system			0.2		
Cross car beam	4.638				
IP reinforcement		3.842		*50%*	DOW Alum/Plastic study
IP support bracket		0.796		*40%*	DOW Alum/Plastic study
Right			0.5		
Left			1.0		
Middle			0.5		
Air vent	0.741				
Central		0.222		*90%*	Wemac Vents
Left side			0.0		
Right side			0.1		
Center bezel			0.1		
Left		0.255		*90%*	Wemac Vents
Air vent			0.3		
Right		0.264		*90%*	Wemac Vents
Instrumentation	2.815				
Heating system		0.456		*80%*	LCD based infotain_Module
Heating control			0.3		
Support			0.2		
Odometer		0.798		*70%*	MuCell
Odometer assembly			1.0		
Odometer bezels			0.2		
Audio system		1.106		*30%*	LCD based infotain_Module
Radio			2.9		
Radio support			0.1		
Second radio support (right)			0.1		
Speakers system			0.6		
Tweeter			0.345		
Right			0.172		
Left			0.173		
Tweeter grill			0.277		
Left			0.102		
Right			0.102		
Central			0.073		
Column switch system		0.293		*70%*	MuCell
Directional switch-light			0.2		
Wiper switch			0.2		
Cruise control			0.1		
Central lock control		0.013		*100%*	
Power mirror controls		0.000		*0%*	LCD based infotain_Module
Control			0.0		
Covers		0.000		*0%*	LCD based infotain_Module
Electronics ignition system		0.103		*100%*	
Ignition switch			0.1		
Control			0.044		
Bezel			0.059		
E.S P.System		0.013		*100%*	
ESP control			0.0		
Accessory plug in		0.021		*100%*	
Multifunction control		0.000		*0%*	
Lock control back doors		0.012		*100%*	
Multi-function display		0.000		*0%*	LCD based infotain_Module

9.3.4.3 Low Development Center Console

The combination of MuCell and a revised support structure created a 6kg savings for the Low Development center console. This represented a 31% mass reduction compared to the Venza console. The cost factor was 100%. Table 9.3.4.3.a summarizes these results.

Table 9.3.4.3.a Low Development Center Console Mass Reduction Summary

Center console	LD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	6.035 kg	**-31%**	**-2.68** kg		
Rear cover	0.198			80%	
Rear storage compartment	3.635				
Compartment		2.496		70%	MuCell
Cover		0.592		80%	MuCell
Lock		0.259		100%	MuCell
Hinge		0.288		70%	MuCell
Mounting bracket	1.027				
Front		0.055		70%	MuCell
Rear (single/left)		0.972		50%	Reduced due to Body integration
Instrumentation	0.050				
Electric outlet		0.018		80%	MuCell
Lighting system		0.015		80%	MuCell
Lighting support		0.017		80%	MuCell
Ashtray	0.267				
Front ashtray		0.267			
Ashtray			0.012	70%	MuCell
Mounting bracket			0.106	70%	MuCell
Bezel			0.097	80%	MuCell
Cover			0.053	80%	MuCell
Front storage	0.196				
Pan		0.080		80%	MuCell
Support		0.075		70%	MuCell
Cover		0.041		80%	MuCell
Air vent	0.154				
Cup Holder system	0.481				
Front		0.481			
Cup Holder			0.198	80%	MuCell
Box			0.050	80%	MuCell
Support			0.234	80%	MuCell
Air vent trim	0.029			80%	MuCell

9.3.4.4 High Development Center Console

The mass reductions for the High Development Center Console . This represented a 36% mass reduction compared to the Venza console. The cost factor was 100%. Table 9.3.4.4.a summarizes these results.

Table 9.3.4.4.a: High Development Center Console Mass Reduction Summary

Center console	HD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	5.571 kg	**-36%**	**-3.14** kg		
Rear cover	0.148			60%	
Rear storage compartment	3.483				
Compartment		2.496		70%	MuCell
Cover		0.518		70%	MuCell
Lock		0.181		70%	MuCell
Hinge		0.288		70%	MuCell
Mounting bracket	1.750				
Front		0.000		0%	MuCell
Rear (single/left)		1.750		90%	MuCell
Instrumentation	0.000				
Electric outlet		0.000		0%	MuCell
Lighting system		0.000		0%	MuCell
Lighting support		0.000		0%	MuCell
Ashtray	0.000				
Front ashtray		0.000		0%	MuCell
Ashtray			0.017		
Mounting bracket			0.151		
Bezel			0.121		
Cover			0.066		
Front storage	0.000				
Pan		0.000		0%	MuCell
Support		0.000		0%	MuCell
Cover		0.000		0%	MuCell
Air vent	0.154				
Cup Holder system	0.000				
Front		0.000		0%	MuCell
Cup Holder			0.247		
Box			0.062		
Support			0.292		
Air vent trim	0.036				

9.3.4.5 Low and High Development Noise Insulation

Table 9.3.4.5.a below details mass reductions to the noise insulation systems based on Faurecia input. The Low and High Development models used the same noise insulation. The mass savings was 25% or 1.6kg; the cost factor was 100%.

Table 9.3.4.5.a Low and High Development Noise Insulation Mass Reduction

Noise Insulation	LD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	4.664 kg	**-25%**	**-1.57** kg		
Sound insulation engine side (single/main)	0.246				
Draining system insulation	0.203				
Draining system insulation (single/main/left)		0.051		25%	
Sound insulation (cockpit side)	2.101				
Interior floor insulation system	2.035				
Front left floor insulation		0.184		55%	Faurecia Estimates
Second rear left floor insulation		0.016		55%	Faurecia Estimates
Third front left floor insulation		0.034		55%	Faurecia Estimates
Front right floor insulation		0.202		55%	Faurecia Estimates
Center console		0.421		55%	Faurecia Estimates
Rear left floor insulation		0.296		60%	Faurecia Estimates
Rear right floor insulation		0.280		60%	Faurecia Estimates
Rear seat carpet insulation		0.602		60%	Faurecia Estimates
Front fender insulation	0.080				
Left		0.042		50%	Faurecia Estimates
Right		0.038		50%	Faurecia Estimates

9.4. Interior Trim

9.4.1 Interior Trim Trends

The interior trim is made up of the interior panels fitted to the interior not included in the Instrument Panel, Seats, Center Console and Closure Trim. This includes hard plastic trim and soft panels. These trim parts are typically utilized to cover and protect the body structure, noise insulation, sunroof drain hoses and electrical wiring bundles from passengers. Due to the predominantly stamped steel body structure, and the bundled wiring and sprayed noise insulation, it is necessary to cover these systems for protection and aesthetics. Stamped panels also offer little capability to integrate storage or appearance grade surfaces. These panels are typically made of molded polypropylene and other injection molding capable plastics and require appearance grade surface characteristics including grained textures. They also typically include touch points for human interface and inputs and functional storage areas. Panels below the belt line are typically designed for both mechanical and surface durability to meet kick and scuff requirements. The cargo area is typically constructed with load floor and storage systems that are reconfigurable and allow access to the spare tire and emergency repair systems. The Toyota Venza has a multiple load floor system that doubles as access to the spare tire system. The Venza hard trim integration and system mass was competitive; see Table 9.4.2.a. The Low Development model focused on materials and processing to create mass reductions. Ancillary sub-system masses, which included lighting modules, sun visors and grab handles, were not changed because these are typically core components shared corporate wide. The Low Development hard trim reductions focused on vehicle specific panels to allow an OEM to take incremental steps to lower mass without extensive re-alignment and re-design of core components. Figure 9.4.1.a below illustrates the Venza hard trim system.

Figure 9.4.1.a Current Toyota Venza Hard Trim
(areas not included in the Hard Trim Sub-System are faded to white in these images)

MuCell by Trexel[39]

The most promising emerging technology for hard trim is being developed and used in the consumer goods industry. The MuCell process (reviewed in the seating and IP/Console sections) utilized unique tooling to aerate plastic as it is injected into the tool cavity. This aeration or "foaming" process reduced mass by replacing solid material with air which reduces the material density. The MuCell foaming process also allowed for faster fill times in tooling cavities due to the reduced material viscosity. The current MuCell process cannot create a Class-A surface; it requires a surface treatment of either a fabric covering or extra material at the part exterior skin to produce a class A appearance. This process has the potential to reduce mass by up to 30% when applied to non-class A surface components or grained panels. The Trexel foaming process reduces the material thickness necessary to meet mold fill requirements and allows a higher ratio of rib thickness to material thickness without creating sink marks in the show surface.

A potential performance benefit of the MuCell process is improved thermal performance of HVAC ducting due to the increased insulation factor. The air chambers formed during the aeration process increase the insulation value (R factor) of the MuCell material vs. solid plastic. The reduced heat loss would need to be validated through testing and development; an increased R value is desirable for HVAC ducting systems.

Wood Fiber Composite Formed with Low Pressure Tooling

Faurecia has proposed using wood fiber based trim panels in their " Light Attitude" study[40]. These panels are made up of wood fibers or powders combined with a plastic binder solution. The panels start as flat pieces of material stock, with heat responsive resins or plastics as a binder, and are heated and pressure formed into a final panel shape. The appearance can be a raw wood look or a variety of varnishes and finishes. Vinyl, leather, and poly-based skins could also be heat bonded to the Woodstock sheet as a final finish material. The drawbacks to this technology include: 1. parts require additional fastening elements to be added to the final part; 2. parts require fastening towers molded and attached as separate pieces; and 3. the long term durability of wood fiber components for high traffic and scuff areas. Wood fiber is promising for top pads in the instrument panel, upper pillar trims, and door upper belt trim and decorative spears. Using this technology for the high durability sections of the interior hard trim could have durability issues due to the need to bond fastener features separately. The durability of unprotected wood fiber panels is another potential issue. Figure 9.4.1.b shows examples of wood fiber hard trim.

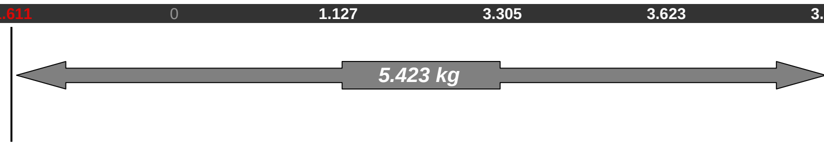
Figure 9.4.1.b: Wood Fiber Hard Trim Examples
(From the Faurecia Light Attitude Study Report)

9.4.2 Hard Trim Benchmarking

Interior hard trim materials, molding and assembly techniques are similar throughout the automotive industry. There was only a 5 kg range from the smallest to the largest SUVs (Sport Utility Vehicle) and CUV s (Crossover Utility Vehicle). Luxury vehicles such as the Land Rover LR3 (58kg) and the Porsche Cayenne (61kg) had heavier trim systems than the Venza (42 kg). These luxury interiors were much higher in cost and content than the Venza and were not used for benchmarking. Small and micro sized SUVs and CUVs in the B and C vehicle segment size were also considered. These vehicles were much smaller than the Venza but their interior masses were similar. The Acura RDX interior hard trim system was only 1.6kg less than the Venza even though it is a full size class smaller. Table 9.4.2.a below shows hard trim masses for vehicles in the Venza segment.

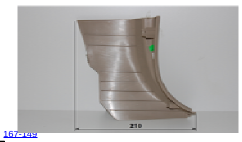
Table 9.4.2.a Hard Trim Mass Comparison

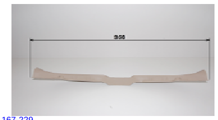
Weight	**39.835**	**41.446**	**42.573**	**44.751**	**45.069**	**45.258**
DELTA	-1.611	0	1.127	3.305	3.623	3.812



The Toyota Venza baseline represented typical hard trim materials, build and processing. This study focused on materials and process changes to reduce mass. There were no mass reduction opportunities as a result of the benchmarking study. Many of the panels in the hard trim system are molded using lightweight polypropylene plastic. There are technological developments underway that could reduce mass but none are currently in production hard trim. Table 9.4.2.b below shows the Venza interior trim components.

Table 9.4.2.b Toyota Venza Hard Trim

Part Name	Total W. (Kg)	nk	
Door step inner panel>Front>	0.226		
Door step inner panel>Rear>	0.137	1(	
>A pillar upper panel>	0.326	1(	
A pillar lower panel>	0.191	167-149	
B pillar upper panel>	0.367	1(	
B pillar lower panel>	0.534	167	
Door step inner panel>Front>	0.224	167-	
>Door step inner panel>Rear>	0.139	167-10	
A pillar upper panel>	0.328	167-214	
A pillar lower panel>	0.193	167-146	
B pillar upper panel>	0.370	167-147	
B pillar lower panel>	0.529	167-148	

Part Name	Total W. (Kg)	nk	
Central compartment>	0.387	167-229	
Right side compartments>Panel>I	1.322	167-2	
Right side compartments>Panel>I	2.006	167-257	
Right side compartments>Access	0.038	167-2	
>Left side compartments>Panel>U	1.326	167-272	
Left side compartments>Panel>L	1.935	167-2	
Left side compartments>Access p	0.038	167-267	
Removable floor system>Main flo	3.636	167-108	
>Removable floor system>Front>	1.336	167-136	
Trunk>Removable floor system>L	0.893	167-111	
Trunk>Removable floor system>R	0.941	167-11	
Trunk>Removable floor system>F	1.511	167-13	
Trunk>Storage hook system>Tie I	0.033	167-243	

9.4.3 Interior Trim Analysis

Table 9.4.3.a below shows the mass breakdown of the sub-systems for the interior trim.

Table 9.4.3.a Toyota Venza Interior Trim Sensitivity Analysis

		Total Mass (kg)	Component Mass (kg)				
Trim parts		**41.446**					
Headliner filler			3.401				
Filler	1			3.401			
Interior components			2.251				
Sun visors				1.064			
Driver side	1				0.505		
Passenger side	1				0.512		
Sun visor light					0.047		
Driver	1					0.024	
Passenger	1					0.023	
Side upper handle				0.522			
Front	2				0.250		
Rear	2				0.272		
Reading light				0.665			
Front	1				0.495		
Rear	1				0.170		
Panels			19.181				
Left side				1.781			
Door step inner panel					0.363		
Front	1					0.226	
Rear	1					0.137	
A pillar upper panel	1				0.326		
A pillar lower panel	1				0.191		
B pillar upper panel	1				0.367		
B pillar lower panel	1				0.534		
Right side				1.783			
Door step inner panel					0.363		
Front	1					0.224	
Rear	1					0.139	
A pillar upper panel	1				0.328		
A pillar lower panel	1				0.193		
B pillar upper panel	1				0.370		
B pillar lower panel	1				0.529		
Trunk				15.617			
Central compartment	1				0.387		
Right side compartments					3.366		
Panel						3.328	
Upper	1						1.322
Lower	1						2.006
Access panel	1					0.038	
Left side compartments					3.299		
Panel						3.261	
Upper	1						1.326
Lower	1						1.935
Access panel	1					0.038	
Removable floor system					8.317		
Main floor	1					3.636	
Front	1					1.336	
Left	1					0.893	
Right	1					0.941	
Floor support						1.511	
Central	1						1.511
Storage hook system					0.248		
Tie bracket 1	4					0.215	
Tie bracket 2	2					0.033	
Mirror system			0.479				
Rear view mirror	1			0.374			
Stand	1			0.033			
Stand support	1			0.072			
Parcel tray system			3.907				
Parcel tray	1			3.907			
Floor carpeting			12.227				
Interior				8.562			
Front	1				2.575		
Rear	1				2.636		
Floor mats					3.144		
Driver	1					0.808	
Passenger	1					0.891	
Rear right	1					0.711	
Rear left	1					0.734	
Front left support	1				0.133		
Front right support	1				0.074		
Trunk				3.665			
Central	1				3.665		

The interior trim sub-systems that have the most opportunity for mass and cost reduction are shown in Table 9.4.3.b below.

Table 9.4.3.b Toyota Venza Hard and Soft Trim Sub-system Analysis

Trim parts	Mass (kg)
Panels	19.18
Floor carpeting	12.23
Parcel tray system	3.91
Headliner filler	3.40
Interior components	2.25
Mirror system	0.48
Total	**41.45**

The sub-system "Panels" referred to the major hard trim panels such as the A-pillar trim, B-Pillar trim, rear quarter trim and the major interior panels that cover inner body sheet metal and the cargo area. Most of these panels are currently designed as grained polypropylene panels using molded-in color. The panel size, the material needed to properly fill the tool and the backing structure combine to create higher mass parts despite using a relatively light material.

Soft trim is defined as the headliner, rear parcel tray, carpeting and floor mats for purposes of this study. The floor carpeting system is a major contributor to mass largely due to the material area and density. Carpet density is on the higher end of materials in the interior system because of noise insulation requirements and the rigid backing. The parcel tray system is a rear cargo area feature that creates a false floor above the spare tire well. These components manage loads and require durability to reduce scuffing and surface damage. These requirements make the carpet and rear parcel tray mass intensive systems.

Low Development Hard Trim

The Low Development mass reductions for the hard trim utilized the foam tooling process applied to the current Venza hard trim. The part mass is reduced because the material density is lower due to the addition of air or gas into the material. Slight modifications for the foam tooling process would be required but do not affect function or aesthetics. Typical hard trim molding processes add mass to the hard trim system due to the excess material necessary to flow all the material into all the regions of the tool cavity and create proper grain definition. The back side structural reinforcements, typically ribs, also drive the material mass. Material thickness must be adjusted to eliminate sink marks caused by the backside reinforcements and fastening features, such as bosses. These reinforcements and fastening features also carry excess thickness to insure acceptable material flow into the mold. The MuCell foaming process discussed in section 9.3.2. reduced the amount of thickness necessary for mold flow considerations, allowing parts to be optimized in their design for function and structure with minimal additional thickness required for meeting material flow requirements for acceptable part molding. This process also allows ribs to be thicker relative to the base material; this can reduce the base part thickness.. A part made with a foamed plastic does not impact the basic Venza trim design or the assembly process.

The current MuCell process creates non-Class A surface characteristics and requires a surface treatment of either a fabric covering, or extra surface material that could be grained to create a Class A appearance. One possibility for creating a high quality surface finish would be to add a thin polypropylene film to the tool's A-Side that would be bonded to the foamed substrate. This process is currently employed by Mercedes-Benz and Johnson Controls in the new 2010 E-Class door inner trim panel. This process allowed for mass reductions and perceived quality improvements for grain, gloss and color matching. Trexel analyzed the hard trim system of the Venza and estimated that the process could ultimately reduce the mass of the components by 30%; there would be a mass increase for any surface treatment. The hard trim mass was initially reduced by 30%. A 10% mass was added back to account for surface finish. Fasteners were then added back in at their 100% mass. The net mass reduction was 20%. The cost factor was 105%. Table 9.4.3.c below summarizes the mass reduction results.

Table 9.4.3.c Low Development MuCell Hard Trim Analysis Results

	LD	Group2	Part Name	Count	Part W. (Kg)	Fastener W. (Kg)	MuCell %	Mucell_Redux	Total W. (Kg)	% TOTAL REDUCTION
-11%	Hard Trim									
36.756	Interior	Trims parts	Interior>Trims parts>Headliner filler>Filler>	1	3.400	0.001	0%	0.000	3.401	0.00%
-4.690	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Driver side>	1	0.488	0.017	0%	0.000	0.505	0.00%
-11%	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Passenger side>	1	0.494	0.018	0%	0.000	0.512	0.00%
	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Sun visor light>Driver>	1	0.024	0.000	0%	0.000	0.024	0.00%
	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Sun visor light>Passenger>	1	0.023	0.000	0%	0.000	0.023	0.00%
	Interior	Trims parts	Interior>Trims parts>Interior components>Side upper handle>Front>	2	0.227	0.023	0%	0.000	0.250	0.00%
	Interior	Trims parts	Interior>Trims parts>Interior components>Side upper handle>Rear>	2	0.246	0.026	0%	0.000	0.272	0.00%
	Interior	Trims parts	Interior>Trims parts>Interior components>Reading light>Front>	1	0.488	0.007	0%	0.000	0.495	0.00%
	Interior	Trims parts	Interior>Trims parts>Interior components>Reading light>Rear>	1	0.170	0.000	0%	0.000	0.170	0.00%
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>Door step inner panel>Front>	1	0.224	0.002	20%	0.045	0.181	-19.82%
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>Door step inner panel>Rear>	1	0.136	0.001	20%	0.027	0.110	-19.85%
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>A pillar upper panel>	1	0.322	0.004	20%	0.064	0.262	-19.75%
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>A pillar lower panel>	1	0.189	0.002	20%	0.038	0.153	-19.79%
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>B pillar upper panel>	1	0.361	0.006	20%	0.072	0.295	-19.67%
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>B pillar lower panel>	1	0.532	0.002	20%	0.106	0.428	-19.93%
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>Door step inner panel>Front>	1	0.222	0.002	20%	0.044	0.180	-19.82%
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>Door step inner panel>Rear>	1	0.138	0.001	20%	0.028	0.111	-19.86%
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>A pillar upper panel>	1	0.324	0.004	20%	0.065	0.263	-19.76%
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>A pillar lower panel>	1	0.192	0.001	20%	0.038	0.155	-19.90%
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>B pillar upper panel>	1	0.364	0.006	20%	0.073	0.297	-19.68%
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>B pillar lower panel>	1	0.527	0.002	20%	0.105	0.424	-19.92%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Central compartment>	1	0.384	0.003	20%	0.077	0.310	-19.84%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Right side compartments>Panel>Upper>	1	1.307	0.015	20%	0.261	1.061	-19.77%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Right side compartments>Panel>Lower>	1	2.000	0.006	20%	0.400	1.606	-19.94%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Right side compartments>Access panel>	1	0.038	0.000	20%	0.008	0.030	-20.00%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Left side compartments>Panel>Upper>	1	1.309	0.017	20%	0.262	1.064	-19.74%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Left side compartments>Panel>Lower>	1	1.930	0.005	20%	0.386	1.549	-19.95%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Left side compartments>Access panel>	1	0.038	0.000	20%	0.008	0.030	-20.00%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Main floor>	1	3.636	0.000	20%	0.727	2.909	-20.00%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Front>	1	1.332	0.004	20%	0.266	1.070	-19.94%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Left>	1	0.893	0.000	20%	0.179	0.714	-20.00%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Right>	1	0.941	0.000	20%	0.188	0.753	-20.00%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Floor support>Central>	1	1.507	0.004	20%	0.301	1.210	-19.95%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Storage hook system>Tie bracket 1>	4	0.188	0.027	20%	0.038	0.177	-17.49%
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Storage hook system>Tie bracket 2>	2	0.033	0.000	20%	0.007	0.026	-20.00%
	Interior	Trims parts	Interior>Trims parts>Mirror system>Rear view mirror>	1	0.374	0.000	20%	0.075	0.299	-20.00%
	Interior	Trims parts	Interior>Trims parts>Mirror system>Stand>	1	0.033	0.000	20%	0.007	0.026	-20.00%
	Interior	Trims parts	Interior>Trims parts>Mirror system>Stand support>	1	0.071	0.001	20%	0.014	0.058	-19.72%
	Interior	Trims parts	Interior>Trims parts>Parcel tray system>Parcel tray>	1	3.907	0.000	20%	0.781	3.126	-20.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Front>	1	2.572	0.003	0%	0.000	2.575	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Rear>	1	2.636	0.000	0%	0.000	2.636	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Driver>	1	0.808	0.000	0%	0.000	0.808	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Passenger>	1	0.891	0.000	0%	0.000	0.891	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Rear right>	1	0.711	0.000	0%	0.000	0.711	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Rear left>	1	0.734	0.000	0%	0.000	0.734	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Front left support>	1	0.132	0.001	0%	0.000	0.133	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Front right support>	1	0.073	0.001	0%	0.000	0.074	0.00%
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Trunk>Central>	1	3.665	0.000	0%	0.000	3.665	0.00%

This approach achieved the targeted 20% mass reductions for the trim panels. Trexel reported that several production projects have created 30-40% mass reductions with significant cost savings. This indicates that it may be possible to exceed a 20% mass savings. Core components remained at 100% of their current mass; these included the headliner, carpeting, mirrors, and assist straps.

High Development Hard Trim

The High Development mass reductions for the interior trim system utilized increased system integration, component elimination and lighter weight materials vs. the current Venza trim. The traditional floor carpeting was replaced with carpeted inserts. The combination of grained composite flooring (from the High Development body system) and expanded coverage floor mats provided a high quality appearance and reduced mass. The floor mats covered most areas that are typically carpeted. These mats would have noise and vibration treatments and slightly thicker carpeting than typical. Even with the extra mass for the floor mats, there would be a considerable reduction in mass from a conventional floor carpeting system with a dramatic increase in perceived quality of the flooring system due to a more luxurious feel in the floor mat areas. A mass reduction of 100% was applied for the removed carpeting. The front and rear floor mats were added in at 110% and 115% of the Venza mass to account for the extra coverage and thickness. Another technology utilized in the High Development proposal was a modular roof panel using low pressure headliner processing. The High Development roof module used a stamped aluminum panel; a translucent polycarbonate panel could be substituted as an option. The aluminum roof panel combined with magnesium cross bows reduced the body mass. This construction could possibly reduce head impact counter measure mass due to the softer roof bow and panel materials. There could also be an opportunity to reduce the section height between the outer roof exterior panel and the inner roof headliner trim panel. This would reduce the CG height of the vehicle, reduce the cross sectional area for aerodynamics (drag is proportional to frontal area) and reduce the mass of the headliner trim system. It may be possible to glaze signal processing antennae and in car network processors into a composite or polycarbonate roof panel if that material were used. This could eliminate wiring in the roof system as well as the external antennae for both GPS and radio systems. SABIC/Exatec is developing technology for this approach; it could be available for production within 2-3 years. Some current production cars such as the Mercedes GL SUV have used a similar approach for roof antennae, although not as extensive. Utilization of a composite roof panel would allow the interior of that panel to be over molded, or insert molded with an interior finish or fabric panel that could replace the headliner. The headliner could then be designed to cover only the roof bows and side rails and create a significant mass reduction. Table 9.4.3.d below details the MuCell study results by component. The estimated mass savings was 42%; the estimated cost factor was 105%.

Table 9.4.3.d: High Development MuCell Hard Trim Analysis Results

	Group1	Group2	Part Name	Count	***Part W. (Kg)***	Fastener W. (Kg)	MuCell %	Mucell_Redux	**Total W. (Kg)**	***% TOTAL REDUCTION***
-42%	**Hard Trim**									
23.965	Interior	Trims parts	Interior>Trims parts>Headliner filler>Filler>	1	***3.400***	0.001	0%	0.000	**3.401**	*0.00%*
-17.481	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Driver side>	1	***0.488***	0.017	0%	0.000	**0.505**	*0.00%*
-42%	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Passenger side>	1	***0.494***	0.018	0%	0.000	**0.512**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Sun visor light>Driver>	1	***0.024***	0.000	0%	0.000	**0.024**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Interior components>Sun visors>Sun visor light>Passenger>	1	***0.023***	0.000	0%	0.000	**0.023**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Interior components>Side upper handle>Front>	2	***0.227***	0.023	0%	0.000	**0.250**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Interior components>Side upper handle>Rear>	2	***0.246***	0.026	0%	0.000	**0.272**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Interior components>Reading light>Front>	1	***0.488***	0.007	0%	0.000	**0.495**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Interior components>Reading light>Rear>	1	***0.170***	0.000	0%	0.000	**0.170**	*0.00%*
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>Door step inner panel>Front>	1	***0.224***	0.002	20%	0.045	**0.181**	*-19.82%*
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>Door step inner panel>Rear>	1	***0.136***	0.001	20%	0.027	**0.110**	*-19.85%*
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>A pillar upper panel>	1	***0.322***	0.004	20%	0.064	**0.262**	*-19.75%*
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>A pillar lower panel>	1	***0.189***	0.002	20%	0.038	**0.153**	*-19.79%*
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>B pillar upper panel>	1	***0.361***	0.006	20%	0.072	**0.295**	*-19.67%*
	Interior	Trims parts	Interior>Trims parts>Panels>Left side>B pillar lower panel>	1	***0.532***	0.002	20%	0.106	**0.428**	*-19.93%*
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>Door step inner panel>Front>	1	***0.222***	0.002	20%	0.044	**0.180**	*-19.82%*
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>Door step inner panel>Rear>	1	***0.138***	0.001	20%	0.028	**0.111**	*-19.86%*
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>A pillar upper panel>	1	***0.324***	0.004	20%	0.065	**0.263**	*-19.76%*
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>A pillar lower panel>	1	***0.192***	0.001	20%	0.038	**0.155**	*-19.90%*
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>B pillar upper panel>	1	***0.364***	0.006	20%	0.073	**0.297**	*-19.68%*
	Interior	Trims parts	Interior>Trims parts>Panels>Right side>B pillar lower panel>	1	***0.527***	0.002	20%	0.105	**0.424**	*-19.92%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Central compartment>	1	***0.384***	0.003	20%	0.077	**0.310**	*-19.84%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Right side compartments>Panel>Upper>	1	***1.307***	0.015	20%	0.261	**1.061**	*-19.77%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Right side compartments>Panel>Lower>	1	***2.000***	0.006	20%	0.400	**1.606**	*-19.94%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Right side compartments>Access panel>	1	***0.038***	0.000	20%	0.008	**0.030**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Left side compartments>Panel>Upper>	1	***1.309***	0.017	20%	0.262	**1.064**	*-19.74%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Left side compartments>Panel>Lower>	1	***1.930***	0.005	20%	0.386	**1.549**	*-19.95%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Left side compartments>Access panel>	1	***0.038***	0.000	20%	0.008	**0.030**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Main floor>	1	***3.636***	0.000	25%	0.909	**2.727**	*-25.00%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Front>	1	***1.332***	0.004	20%	0.266	**1.070**	*-19.94%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Left>	1	***0.893***	0.000	20%	0.179	**0.714**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Right>	1	***0.941***	0.000	20%	0.188	**0.753**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Removable floor system>Floor support>Central>	1	***1.507***	0.004	20%	0.301	**1.210**	*-19.95%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Storage hook system>Tie bracket 1>	4	***0.188***	0.027	20%	0.038	**0.177**	*-17.49%*
	Interior	Trims parts	Interior>Trims parts>Panels>Trunk>Storage hook system>Tie bracket 2>	2	***0.033***	0.000	20%	0.007	**0.026**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Mirror system>Rear view mirror>	1	***0.374***	0.000	20%	0.075	**0.299**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Mirror system>Stand>	1	***0.033***	0.000	20%	0.007	**0.026**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Mirror system>Stand support>	1	***0.071***	0.001	20%	0.014	**0.058**	*-19.72%*
	Interior	Trims parts	Interior>Trims parts>Parcel tray system>Parcel tray>	1	***3.907***	0.000	20%	0.781	**3.126**	*-20.00%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Front>	1	***2.572***	0.003	100%	2.572	**0.003**	*-99.88%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Rear>	1	***2.636***	0.000	100%	2.636	**0.000**	*-100.00%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Driver>	1	***0.808***	0.000	110%	0.889	**-0.081**	*-110.00%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Passenger>	1	***0.891***	0.000	110%	0.980	**-0.089**	*-110.00%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Rear right>	1	***0.711***	0.000	115%	0.818	**-0.107**	*-115.00%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Floor mats>Rear left>	1	***0.734***	0.000	115%	0.844	**-0.110**	*-115.00%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Front left support>	1	***0.132***	0.001	100%	0.132	**0.001**	*-99.25%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Interior>Front right support>	1	***0.073***	0.001	100%	0.073	**0.001**	*-98.65%*
	Interior	Trims parts	Interior>Trims parts>Floor carpeting>Trunk>Central>	1	***3.665***	0.000	100%	3.665	**0.000**	*-100.00%*

The MuCell process achieved a 20% mass reduction for the High Development trim; as noted in the Low Development trim section, higher mass savings have been achieved in other applications. It may be possible in the future to reduce hard trim mass more than 20% using this technology.

9.4.4 Interior Trim Results

9.4.4.1 Low Development Interior Trim

Table 9.4.4.1.a below details the mass reductions for the Low Development interior trim. The MuCell process produced a 4.7kg mass reduction in the hard trim system, which constituted an overall mass reduction of 11% for the interior hard and soft trim. The total interior trim mass was 36.7 kg; this represented a mass savings of 11%. The cost factor was 105%.

Table 9.4.4.1.a Low Development Interior Trim Sub-system Mass Reduction Results

Trim Parts	LD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	36.733 kg	-11%	-4.71 kg		
Headliner filler	3.401				
Filler		3.401		100%	
Interior components	2.251				
Sun visors		1.064			
Driver side			0.505	100%	
Passenger side			0.512	100%	
Sun visor light			0.047		
Driver			0.024	100%	
Passenger			0.023	100%	
Side upper handle		0.522			
Front			0.250	100%	
Rear			0.272	100%	
Reading light		0.665			
Front			0.495	100%	
Rear			0.170	100%	
Panels	#####				
Left side		1.425			
Door step inner panel			0.290		
Front			0.181	80%	MuCell
Rear			0.110	80%	MuCell
A pillar upper panel			0.261	80%	MuCell
A pillar lower panel			0.153	80%	MuCell
B pillar upper panel			0.294	80%	MuCell
B pillar lower panel			0.427	80%	MuCell
Right side		1.426			
Door step inner panel			0.290		
Front			0.179	80%	MuCell
Rear			0.111	80%	MuCell
A pillar upper panel			0.262	80%	MuCell
A pillar lower panel			0.154	80%	MuCell
B pillar upper panel			0.296	80%	MuCell
B pillar lower panel			0.423	80%	MuCell
Trunk		12.494			
Central compartment			0.310	80%	MuCell
Right side compartments			2.693		
Panel			2.662		
Upper			1.058	80%	MuCell
Lower			1.605	80%	MuCell
Access panel			0.030	80%	MuCell
Left side compartments			2.639		
Panel			2.609		
Upper			1.061	80%	MuCell
Lower			1.548	80%	MuCell
Access panel			0.030	80%	MuCell
Removable floor system			6.654		
Main floor			2.909	80%	MuCell
Front			1.069	80%	MuCell
Left			0.714	80%	MuCell
Right			0.753	80%	MuCell
Floor support			1.209		
Central			1.209	80%	MuCell
Storage hook system			0.198		
Tie bracket 1			0.172	80%	MuCell
Tie bracket 2			0.026	80%	MuCell
Mirror system	0.383				
Rear view mirror		0.299		100%	
Stand		0.026		100%	
Stand support		0.058		100%	
Parcel tray system	3.126				
Parcel tray		3.126		100%	
Floor carpeting	#####				
Interior		8.562			
Front			2.575	100%	
Rear			2.636	100%	
Floor mats			3.144		
Driver			0.808	100%	
Passenger			0.891	100%	
Rear right			0.711	100%	
Rear left			0.734	100%	
Front left support			0.133	100%	
Front right support			0.074	100%	
Trunk		3.665			
Central			3.665	100%	

9.4.4.2 High Development Interior Trim

Table 9.4.4.2.a below details the mass reductions for the High Development interior trim. The combination of the MuCell process and the High Development system integration produced a 17.1 kg mass reduction in the hard and soft trim system. This was a 41% mass reduction. The total mass was 24.3 kg. The cost factor was 105%.

Table 9.4.2.2.a High Development Interior Trim Mass Reduction Results

Trim Parts	HD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	24.319 kg	**-41%**	**-17.13** kg		
Headliner filler	3.231				
Filler		3.231		95%	Low Pressure (Vantage)
Interior components	2.251				
Sun visors		1.064			
Driver side			0.505	100%	
Passenger side			0.512	100%	
Sun visor light			0.047		
Driver			0.024	100%	
Passenger			0.023	100%	
Side upper handle		0.522			
Front			0.250	100%	
Rear			0.272	100%	
Reading light		0.665			
Front			0.495	100%	
Rear			0.170	100%	
Panels	11.797				
Left side		1.134			
Door step inner panel			0.000		
Front			0.000	0%	
Rear			0.000	0%	
A pillar upper panel			0.261	80%	MuCell
A pillar lower panel			0.153	80%	MuCell
B pillar upper panel			0.294	80%	MuCell
B pillar lower panel			0.427	80%	MuCell
Right side		1.136			
Door step inner panel			0.000		
Front			0.000	0%	Composite floor
Rear			0.000	0%	Composite floor
A pillar upper panel			0.262	80%	MuCell
A pillar lower panel			0.154	80%	MuCell
B pillar upper panel			0.296	80%	MuCell
B pillar lower panel			0.423	80%	MuCell
Trunk		9.527			
Central compartment			0.310	80%	MuCell
Right side compartments			2.693		
Panel			2.662		
Upper			1.058	80%	MuCell
Lower			1.605	80%	MuCell
Access panel			0.030	80%	MuCell
Left side compartments			2.639		
Panel			2.609		
Upper			1.061	80%	MuCell
Lower			1.548	80%	MuCell
Access panel			0.030	80%	MuCell
Removable floor system			3.637		
Main floor			2.545	70%	MuCell
Front			0.000	0%	MuCell
Left			0.714	80%	MuCell
Right			0.000	0%	MuCell
Floor support			0.378		
Central			0.378	25%	Composite floor
Storage hook system			0.248		
Tie bracket 1			0.215	100%	
Tie bracket 2			0.033	100%	
Mirror system	0.383				
Rear view mirror		0.299		80%	MuCell
Stand		0.026		80%	MuCell
Stand support		0.058		80%	MuCell
Parcel tray system	3.126				
Parcel tray		3.126		80%	MuCell
Floor carpeting	3.531				
Interior		3.531			
Front			0.000	0%	Composite floor
Rear			0.000	0%	Composite floor
Floor mats			3.531		
Driver			0.889	110%	Expanded coverage
Passenger			0.980	110%	Expanded coverage
Rear right			0.818	115%	Expanded coverage
Rear left			0.844	115%	Expanded coverage
Front left support			0.000	0%	
Front right support			0.000	0%	
Trunk		0.000			
Central			0.000	0%	Composite floor

9.5. Control Systems

9.5.1 Control System Trends

The interior controls system is comprised of the primary vehicle controls which include the steering wheel, brake pedal, accelerator pedal, park brake and related electronic systems. Many of these systems integrate directly with the chassis system using either direct mechanical actuation with the pedals or cable actuation, e.g., the park brake system. The steering column on the interior side connects directly with the steering gear via a direct mechanical connection. Components inside the body structure were considered part of the interior system. Any component under the body or in the engine box was considered part of the chassis system. This includes the steering column up to the intermediate shaft, the pedals, park brake pedal and cable, steering wheel, cover, electric power steering system and steering wheel mounted electronic controls.

Capacitive Switch and Touch Technology

Capacitive switching technology is an emerging technology for automotive applications but has been used by other industries for several decades. Capacitive switches use pressure that acts on an inductive bladder to create switching signals. Several Cellular phone models have used capacitive switching to reduce thickness and mass. The Motorola RAZR phone is one example. Another example is the WACOM tablet; it has a capacitive touch strip for zoom and scrolling functions that creates input based on a finger sliding across the surface. Figure 9.5.1.a shows these electronic devices.

WACOM "touch slider"

iPhone "touch screen"

Motorola RAZR (Capacitive buttons)

Figure 9.5.1.a: WACOM Tablet (Capacitive Slider Switch)**, iPhone** (touch screen) **and RAZR Phone**

Most flat panel touch screens, such as the iPhone, and any ATM screen, use capacitive touch technology to transmit signals to the processor. Figure 9.5.1.b shows the Chevrolet Volt touch screen. This technology was previously reviewed in detail in Section 9.3.1.

Figure 9.5.1.b: Chevy Volt Capacitive Touch Screen and Center Stack

9.5.2 Control Systems Benchmarking

Pedal Systems

There are several lightweight pedal systems in production today that utilize electronic park brake systems, and composite pedal sets. The Audi Q5 has an electronic park brake with a plastic pedal assembly and a lightweight aluminum case pedal bracket. This system weighs 3.28kg. Table 9.5.2.a below shows low mass park brake systems.

Table 9.5.2.a Benchmark Analysis of Pedal Systems

	 Venza 2.7 FWD	 Q5 2.0 TDi Base	 XC60 2.4D Basis	 X3 3.0D Sport	 Z4 3.0i Cabriolet
Weight and Measurements ***Pedals System Mass***	*2.767*	*3.278*	*2.572*	*2.028*	*1.948*
					
Weight and Measurements ***Hand Brake Mass***	*3.191*	*0.045*	*1.024*	*1.912*	*2.784*
					

The Audi Q5 park brake system is very low mass system because of its electronic park brake (which is the same basic system used on the VW Passat), its aluminum pedal bracket and composite pedals for the clutch (manual transmission) and accelerator. Although the Audi park brake system is lighter than the Venza, it has an additional pedal for the clutch. This extra pedal, required for the benchmarked Audi's manual transmission, makes the Audi pedal sub-system without the park brake heavier than the Venza brake/accelerator. The Venza offers only an automatic transmission. Figure 9.5.2.b below shows the Q5 system vs. the Toyota Venza system.

Audi Q5 Pedals: 3.278 kg –
Clutch, Brake, Accelerator

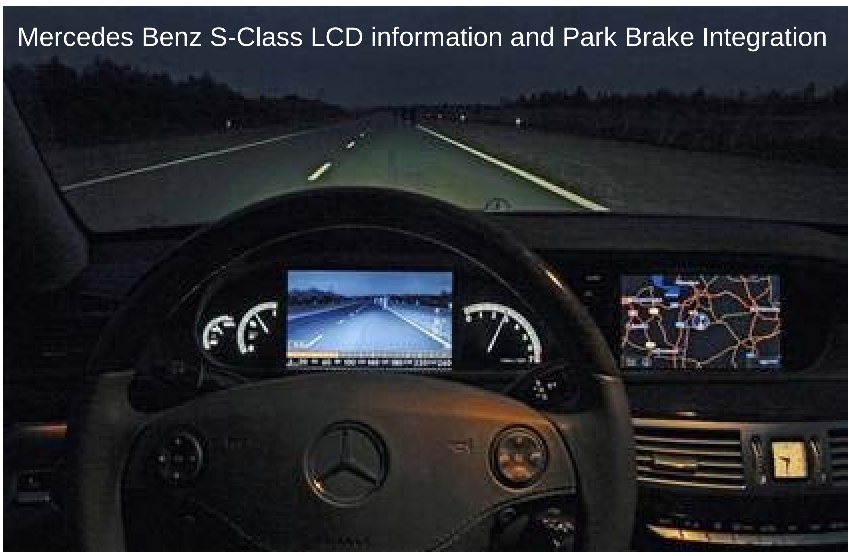
Toyota Venza Pedals 2.767 kg –
Brake and Accelerator

Audi Q5 Park Brake: 0.045 kg –
Electronic Park Brake Button

Toyota Venza Park Brake 3.191 kg --
Park Brake Pedal Assembly

Figure 9.5.2.b: Audi Q5 vs. Toyota Venza Pedal Assemblies

An additional mass reduction was incorporated into the Low Development model by eliminating the dedicated switch bank and control unit from the electronic switch bank and integrating the functions into the center stack LCD control unit. This is similar to what Mercedes Benz implemented on the 2006 S-Class sedan. The park brake is automatically set when the car is engaged in park mode; the LCD displays the parking brake status. With the advent of electronic park brakes and computer based actuation schemes it is necessary to provide a backup release as well as a mechanical override system for towing and repair personnel. These backup release systems are used on current mechanical park brake systems. They are redundant to the mechanical systems that operate the park brake normally. The Low Development model included the redundant portion of the system. These redundant systems are low mass as they are designed for occasional use versus daily use. Figure 9.5.2.c shows the S-Class LCD Park brake integration, the emergency brake release lever that disengages the park brake when the vehicle is towed, and the emergency kit which contains the emergency park brake release lever.


Mercedes Benz S-Class LCD information and Park Brake Integration


Mercedes Benz S-Class
Emergency Park Brake Release Lever


Mercedes Benz S-Class Emergency Car Kit

Figure 9.5.2.c: Mercedes-Benz S-Class LCD Control and Emergency Park Brake Release

Steering Wheel

Table 9.5.2.d shows the steering wheel benchmarking results. This study indicated there was no significant mass reduction opportunity by using a different production steering wheel. The mass of 1.68 kg on the Venza is in the middle of the high and low range for the steering wheels.

Table 9.5.2.d: Steering Wheel Benchmarking

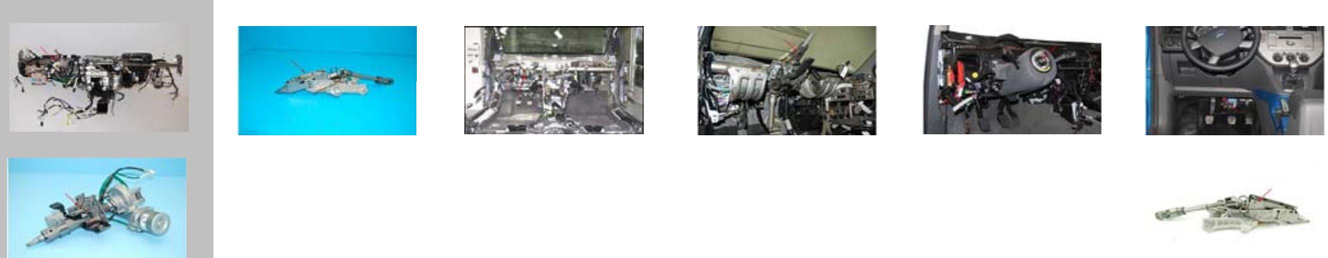
Weight and									
Weight	***1.683***	***1.019***	***1.046***	***1.084***	***1.093***	***1.181***	***1.759***	***2.422***	***2.444***
Width	132,7 mm	385 mm	370 mm	390 mm	372 mm	380 mm	384 mm	395 mm	375 mm
Height	-	385 mm	370 mm	390 mm	372 mm	380 mm	384 mm	395 mm	375 mm
Depth	383 mm	130 mm	120 mm	133 mm	132 mm	142 mm	125 mm	132 mm	146 mm
Manufacturer	-	AUTOLIV	-	TRW	-	-	BADGÉE DU CONSTRUCTEUR	-	-
Materials	>PUR<	MgA16	Mg>AM50< ; PUR	Non Ferreux	COMPOSANTS MULTIPLE	MgAl5 ; PUR-E	MgAl6 ; Pastique	PUR	-
Fasteners	1 Flange nut 0,02 kg	1 Screw 0,037 kg	1 Hexagon screw 0,042 kg	1 Hexagon nut 0,014 kg	1 Hexagon screw 0,046 kg	1 Hexagon screw 0,025 kg	1 Hexagon screw 0,052 kg	1 Screw 0,05 kg	1 Screw 0,059 kg
System and Function	-	System	Steering	Steering	Steering	Steering	-	Steering	Steering
	-	Function	-	-	-	-	-	-	-
Pictures Location									
Front	Add to basket	Add to basket	Add to basket	Add to basket	Add to basket	Add to basket	Add to basket	Add to basket	Add to basket

When the spoke mounted controls are factored in, the Venza steering wheel is a relatively low mass wheel. The steering wheel mass was set at 100% for both the Low Development and High Development models

The Venza had a low mass steering column sub-system even with the electronic steering module built into the column. No mass reductions were used for this sub-system. Table 9.5.2.e below shows the benchmarking study for the Steering Column sub-system.

Table 9.5.2.e Steering Column Benchmarking

	Venza 2.7 FWD	XC60 2.4D Basis	zafira 1.6l Twinport	RDX 2.3 Technology Package	Q5 2.0 TDi Base	Kuga 2.0 TDCi Titanium
Weight and	***BASELINE***					
Weight	***2.621***	***1.676***	***2.746***	***2.89***	***3.101***	***3.256***



9.5.3 Control Systems Analysis

Table 9.5.3.a below shows the control system masses. The Venza electric power steering system is the highest mass component. The total mass is 19.38 kg; the cost factor is 110%.

Table 9.5.3.a Control System Sensitivity Analysis

		Total Mass (kg)	Component Mass (kg)			
Brake pedal		**2.415**				
Stop light switch			0.022			
Switch	1			0.022		
Bracket + pedal	1		2.393			
Accelerator pedal		**0.352**				
Accelerator pedal	1		0.352			
Park Brake Foot Pedal		**3.191**				
Pedal	1		2.202			
Position switch	1		0.010			
Locking cable	1		0.979			
Steering shaft assembly		**3.806**				
Steering column	1		2.621			
Column covers			0.679			
Steering switch cover				0.299		
Steering switch covers Upper	1				0.087	
Steering switch covers Lower					0.212	
Cover	1					0.212
Lower parts bezel	1			0.144		
Bezel	1			0.236		
Ignition switch assembly system			0.033			
Keys car	1			0.033		
Steering adjuster cover	1		0.034			
Steering adjustment lever			0.248			
Handle	1			0.248		
Angle transmitter	1		0.191			
Steering wheel	**1**	**1.683**				
Steering wheel controls		**0.105**				
Left	1		0.069			
Right	1		0.036			
Steering wheel cover		**0.116**				
Steering wheel rear trim	1		0.116			
Electric Power Steering system		**7.454**				
Electric motor system			5.852			
Electric motor	1			2.555		
Mechanism	1			3.297		
EPS control box	1		1.283			
Management Unit Bracket	1		0.173			
Lower support (second)	1		0.146			
Anti vibration mass on steering wheel	**1**	**0.258**				

Total Mass	**19.38 kg**

The baseline Venza's Electric Power Steering (EPS) system was considered class competitive and was used for both the Low and High Development models. The benchmarking analysis showed that the steering wheel did not offer a significant mass savings potential. Table 9.5.3.b below shows the Control System masses.

Table 9.5.3.b Control System Mass

Controls	Mass (kg)
Electric Power Steering system	7.45
Steering shaft assembly	3.81
Park Brake Foot Pedal	3.19
Brake pedal	2.42
Steering wheel	1.68
Accelerator pedal	0.35
Anti vibration mass on steering wheel	0.26
Steering wheel cover	0.12
Steering wheel controls	0.11
Total	**19.38**

The park brake, brake pedal and accelerator had the most opportunity for mass reduction. The steering column plastic trim panels and covers were also analyzed for mass reductions. The core structure of the steering column and support were not considered for mass reductions.

Low Development Controls

The park brake pedal system in the Venza weighed 3.2kg and was comprised of a steel stamped pedal mechanism, a mounting bracket and reinforcement and a cable. This system was replaced with an electronic park brake system similar to the current Volkswagen Passat system. The electronic park brake system eliminated the interior mounted park brake mechanisms and replaced cables and brackets in the underbody with wiring and two caliper mounted servos. This system reduced mass in both the interior and chassis systems. This type of system is used on several production vehicles, including the Volkswagen Passat, CC, Tiguan, Audi A4, A5, A6, A8, Q5, Mercedes S-Class, and BMW 7-Series. Volkswagen/Audi is using this park brake system across their entire vehicle lineup; Mercedes and BMW have implemented a similar system on their large cars. There is an initial investment cost associated with switching from mechanical and cable driven systems. The large component reduction should create a piece cost savings once the initial investment is made for the servo motors for the rear brakes. The pedal assembly for the park brake and the cable that connects to the underbody portion of the system could be replaced by a single switch. This switch function was incorporated into the central LCD control screen on both the Low and High Development models, i.e., the need for a separate switch was eliminated. Figure 9.5.3.a illustrates the evolution of the concept.

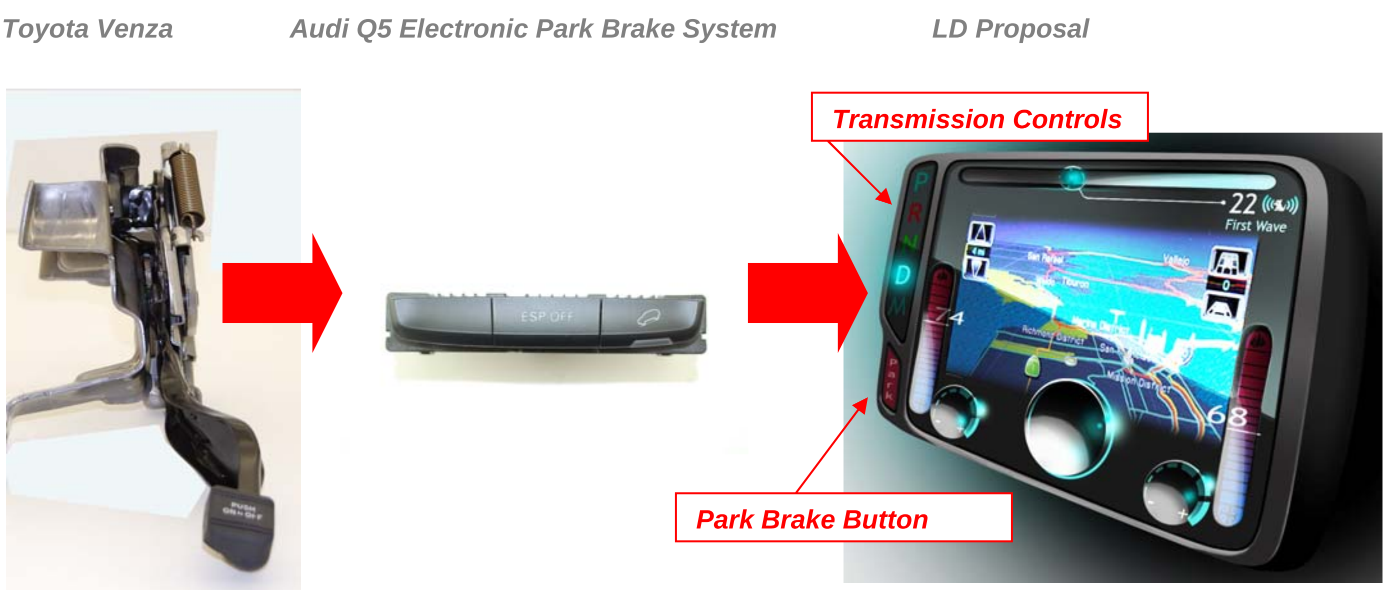


Figure 9.5.3.a Electronic Park Brake Pedal Evolution

The current Venza parking brake system mass could be reduced further by incorporating an aluminum pedal support bracket and a composite accelerator and clutch pedal similar to the Audi Q5. This was not a consideration for either the Low or High Development models as the park brake pedal assembly was eliminated. It could be used for the Venza service brake pedal, i.e., the pedal used to activate the brakes to stop the vehicle when it is in motion.

The steering column trim was another opportunity for mass reduction. The Low Development model used the MuCell foam tooling process to reduce the mass of the trim pieces by 20%. This created a small piece cost increase. Faurecia estimated that the required tool cost increases would be amortized as a 105% increase in piece price. Trexel's experience with several manufacturers was that the foaming process reduced costs for a part designed specifically for the MuCell process.

High Development Controls

The High Development controls model incorporated a small reduction in mass for steering wheel controls due to more integrated voice command interfaces. Other than this reduction, it was identical to the Low Development mass savings. Figure 9.5.3.b detail the mass reduction results and illustrate the high development system results.

Steering Wheel, Cluster, and Pedals

LCD Control Unit – Shifter, Park Brake

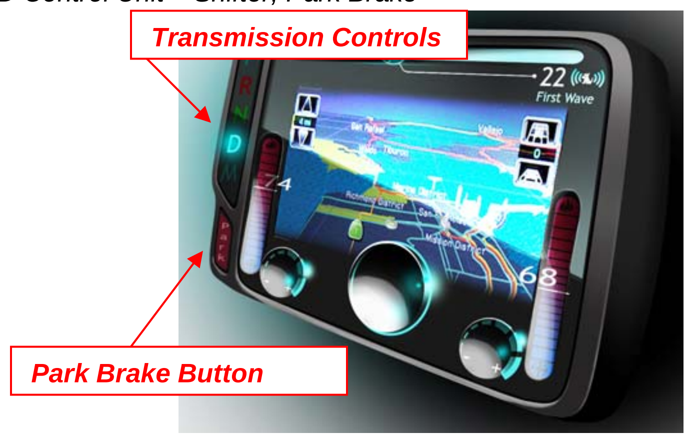


Figure 9.5.3.b High Development Controls System

9.5.4 Control Systems Results

9.5.4.1 Low Development Control Systems

The Low Development control systems have a total mass reduction of 6.68kg and a 110% cost increase. Table 9.5.4.1.a below details the mass reduction results.

Table 9.5.4.1.a Low Development Controls System Mass Reductions

Controls	**LD Mass (kg)**	**% Reduction**	**Mass reduction (kg)**	**%**	Description
	16.017 kg	**-29%**	**-6.68** kg		
Shift lever mechanism	1.134	-68%	-2.43 kg		
Gear selector system	0.000				
Gear selector knob		0.000		0%	
Gear selector base		0.000		0%	
Shift housing assembly	0.000			0%	
Gearshift lever bellows support	0.000			0%	
Mechanism on gearbox	0.081			100%	
Shift rails	0.686				
Shift rails assembly		0.686		100%	
Gears selection control unit	0.137			100%	
Linkage on gearbox support	0.200			100%	
Switch on command	0.030			100%	
Brake pedal	1.936	-20%	-0.48 kg		
Stop light switch	0.022			100%	
Switch		0.022		100%	
Bracket + pedal	1.914			80%	Composite with MuCell
Accelerator pedal	0.282	-20%	-0.07 kg		
Accelerator pedal	0.282			80%	Composite with MuCell
Park Brake Foot Pedal	0.000	-100%	-3.19 kg		
Pedal	0.000			0%	LCD based infotain_Module
Position switch	0.000			0%	
Locking cable	0.000			0%	
Steering shaft assembly	3.126	-18%	-0.68 kg		
Steering column	2.621			100%	
Column covers	0.505				
Steering switch cover		0.239			MuCell
Steering switch covers Upper			0.070	80%	MuCell
Steering switch covers Lower			0.170	80%	MuCell
Cover			0.170	80%	MuCell
Lower parts bezel		0.101		70%	MuCell
Bezel		0.165		70%	MuCell
Ignition switch assembly system	0.023			70%	MuCell
Keys car	0.000	0.000		0%	Keyless GO
Steering adjuster cover	0.034			100%	
Steering adjustment lever	0.174				MuCell
Handle		0.174		70%	MuCell
Angle transmitter	0.134			70%	MuCell
Steering wheel	1.683	0%	0.00 kg	100%	
Steering wheel controls	0.158	50%	0.05 kg		Increase for Extra Controls
Left	0.104			150%	
Right	0.054			150%	
Steering wheel cover	0.012	-90%	-0.10 kg		
Steering wheel rear trim	0.012			10%	Reduced with Designed Molding
Electric Power Steering system	7.454	0%	0.00 kg		
Electric motor system	5.852			100%	
Electric motor		2.555		100%	
Mechanism		3.297		100%	
EPS control box	1.283			100%	
Management Unit Bracket	0.173			100%	
Lower support (second)	0.146			100%	
Anti vibration mass on steering wheel	0.232	-10%	-0.03 kg	90%	Mass reduction through structure

9.5.4.2 High Development Control Systems

The High Development control systems mass reduction was 6.68 kg with a 110% cost delta. Table 9.5.4.2.a details the mass reduction results and illustrate the high development system results.

Table 9.5.4.2.a High Development Controls System Mass Reductions

Controls	HD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	16.017 kg	**-29%**	**-6.68** kg		
Shift lever mechanism	1.134	-68%	-2.43 kg		
Gear selector system	0.000				
Gear selector knob		0.000		0%	
Gear selector base		0.000		0%	
Shift housing assembly	0.000			0%	
Gearshift lever bellows support	0.000			0%	
Machanism on gearbox	0.081			100%	
Shift rails	0.686				
Shift rails assembly		0.686		100%	
Gears selection control unit	0.137			100%	
Linkage on gearbox support	0.200			100%	
Switch on command	0.030			100%	
Brake pedal	1.936	-20%	-0.48 kg		
Stop light switch	0.022			100%	
Switch		0.022		100%	
Bracket + pedal	1.914			80%	Composite with MuCell
Accelerator pedal	0.282	-20%	-0.07 kg		
Accelerator pedal	0.282			80%	Composite with MuCell
Park Brake Foot Pedal	0.000	-100%	-3.19 kg		
Pedal	0.000			0%	LCD based infotain_Module
Position switch	0.000			0%	
Locking cable	0.000			0%	
Steering shaft assembly	3.126	-18%	-0.68 kg		
Steering column	2.621			100%	
Column covers	0.505				
Steering switch cover		0.239			MuCell
Steering switch covers Upper			0.070	80%	MuCell
Steering switch covers Lower			0.170	80%	MuCell
Cover			0.170	80%	MuCell
Lower parts bezel		0.101		70%	MuCell
Bezel		0.165		70%	MuCell
Ignition switch assembly system	0.023			70%	MuCell
Keys car		0.000		0%	Keyless GO
Steering adjuster cover	0.034			100%	
Steering adjustment lever	0.174				MuCell
Handle		0.174		70%	MuCell
Angle transmitter	0.134			70%	MuCell
Steering wheel	1.683	0%	0.00 kg	100%	
Steering wheel controls	0.158	50%	0.05 kg		Increase for Extra Controls
Left	0.104			150%	
Right	0.054			150%	
Steering wheel cover	0.012	-90%	-0.10 kg		
Steering wheel rear trim	0.012			10%	Reduced with Designed Molding
Electric Power Steering system	7.454	0%	0.00 kg		
Electric motor system	5.852			100%	
Electric motor		2.555		100%	
Mechanism		3.297		100%	
EPS control box	1.283			100%	
Management Unit Bracket	0.173			100%	
Lower support (second)	0.146			100%	
Anti vibration mass on steering wheel	0.232	-10%	-0.03 kg	90%	Mass reduction through structure

Safety Systems

The Venza safety systems were not targeted for mass reductions due to the current requirements for safety performance and the potential for NHTSA to impose more stringent regulations for future vehicles.

There are several promising technologies surrounding the direct safety systems that have been recently implemented to save mass. Faurecia's "soft" airbag door packages the airbag closer to the windshield and their "spacer knit" fabric reduces mass compared to the reinforced airbag mounting structure. The spacer knit fabric uses a truss type internal reinforcement that creates a semi-solid structure vs. a solid surface for the Venza IP; this fabric also eliminates the IP seam. This approach reduces mass, improves perceived quality and reduces the cost of implementation. This system was included as a top pad IP feature in the Instrument Panel subsystem; it has been proven with production implementation.

The current core safety system components (airbags, igniters, inflators, etc.) found in modern automobiles have been optimized for performance and mass over decades of development by their suppliers and the OEMs. They are manufactured by a limited number of suppliers and are similar in design and execution. These components are combined and tuned specifically for each vehicle as a system based on each vehicle's particular requirements to meet federal regulations.

Although technological breakthroughs for safety systems could occur within the 2017 – 2020 timeframe, such a breakthrough was not considered for this study. More stringent regulations could drive an increase in safety system mass. No mass reductions were incorporated for safety components in either the Low Development or High Development proposal. Figure 9.5.4.2.a below shows the current Toyota Venza safety system deployment areas. These inflatable restraints are incorporated in addition to the standard seat belts. The mass of these systems was 17.852 kg; the cost factor was 100%.

Figure 9.5.4.2.a: Toyota Venza Safety System Coverage

9.6. HVA/C & Ducting

9.6.1. HVA/C Module & Ducting Trends

HVA/C modules, which contain heat exchangers, a blower or blowers, mode doors and air inlet and exit paths, are well optimized for meeting customer requirements. There were no significant HVA/C module mass differences for vehicles with comparable interior volumes. The Venza heater core, evaporator and blower were maintained for the Low Development model.

The HVA/C effective open duct area is key to HVAC performance; decreasing the duct size was not considered as a mass reduction opportunity. However, the HVA/C duct mass can be reduced using less dense materials such as MuCell processed plastic. The ducting exterior is not a Class A-surface and can use the maximum possible MuCell mass reductions.

The Wemac air vent, a patented rotary design, with the appropriate area for an automotive outlet is typically 90% efficient; most automotive outlets range from 50%-80% efficiency. The Wemac efficiency increase is due to the reduced internal blockage of the Wemac vent (discussed earlier in the IP section). Wemac vents or similar design low restriction vents can reduce mass and are relatively neutral to the IP design. The Faurecia IMPAMO structural duct system also can reduce mass. Those savings were included in the instrument panel mass reduction and are not considered in this section. The thermal losses of the HVAC ducting may be reduced due to the improved insulation properties of MuCell processed plastics.

It was desirable to increase the functionality of the HVA/C module as part of the interior system integration process. It was also appropriate to reduce the mass and cost of the ducting as well as decrease thermal losses. The MuCell technology was selected for molding the ducts because of its low mass, reduced cost and improved thermal performance.

9.6.2. HVA/C Module & Ducting Benchmarking

No benchmarking was done for this system as the Venza components were used for both the Low and High Development models. These components included the heater core, the evaporator, the refrigerant expansion device, and the blower motor. The basic duct work used the Venza geometry; the ducting material incorporated the MuCell foaming process.

9.6.3. HVA/C & Ducting Analysis

The HVA/C air distribution system masses are listed below in Table 9.6.3.a. The total Venza mass was 9.57 kg.

Table 9.6.3.a: Venza HVA/C Ducting Sub-system Mass

	Mass (kg)
Heating system	**9.572**
Covers	1.633
Left	0.791
Right	0.842
Defroster air vent	**0.548**
Left	0.109
Right	0.114
Face Vent Duct	0.037
Right	0.019
Left	0.018
Central	0.288
Side vents	**0.122**
Left	0.061
Right	0.061
Windshield defroster vent ducts	**0.279**
Central	0.279
Windshield defroster grill	**0.662**
Central	0.662
Rear air duct	**0.22**
Central	0.22
Front	0.117
Rear	0.103
Front air duct	**0.988**
Front rear air vent connector	**0.158**
Lower front air vent	**0.36**
Driver	0.219
Passenger	0.141
Front air duct under driver	**0.347**
Front air duct under passenger	**0.396**
Total	**13.652**

Low Development HVA/C Module & Ducting

The Low Development proposal used the MuCell foamed plastic to reduce mass. The projected mass savings was 26%. The estimated cost factor was 99%.

High Development HVA/C & Ducting

The High Development HVA/C module and ducting model integrated the HVA/C ducts into the dash module and upper cowl trim of the IP; the lower HVA/C casing was used as part of the interior trim replacing the front portion of the console. The Venza heater core, evaporator and blower masses were maintained for the High Development model.

The lower floor ducts were integrated into the HVA/C casing trim and the rear floor vents were molded into the center console module. This approach increased the mass of some components, such as the HVA/C case, but reduced the total interior system mass. The ducting mass was reduced by integrating this function into the IP dash module and HVA/C casing. The plastic components used parts molded with the MuCell process. As reported in the Low Development section, the MuCell foamed plastic created a significant mass reduction and a potential thermal performance improvement. WEMAC vents were selected due to their increased efficiency.

The High Development model used the Low Development model and incorporated a higher level of integration and the MuCell technology.

9.6.4 HVA/C & Ducting Results

9.6.4.1 Low Development HVA/C & Ducting

The Low Development proposal used the MuCell foamed plastic to reduce mass. Table 9.6.4.1.a below shows mass reductions for the Low Development HVA/C module and ducting system. The projected mass savings was 24% or 3.34 kg. The estimated cost factor was 99%.

Table 9.6.4.1.a: Low Development HVA/C Ducting System Mass Reductions

HVA/C and Ducting	LD Mass (kg)	% Reduction	Mass reduction (kg)	
	10.311 kg	**-24%**	**-3.34** kg	
Heating system	7.070	-26%	-2.50 kg	%
Covers	1.143			
Left		0.554		*70%*
Right		0.589		*70%*
Motors	0.464			
Lateral air vent flap motor		0.207		
Left/single			0.098	*70%*
Right			0.109	*70%*
Auto Climate control box		0.258		
Right			0.143	*70%*
Right support			0.115	*70%*
Selection flaps	0.542			
Windshield demisting		0.064		*70%*
Lower front part		0.051		
Right			0.031	*70%*
Left			0.020	*70%*
Lateral demisting		0.047		*70%*
Upper front part		0.128		
Left			0.059	*70%*
Right			0.069	*70%*
Support		0.119		*70%*
Hot cold		0.069		*70%*
Central rear		0.064		*70%*
Blowing unit system	1.068			
Air unit		1.005		
Blower motor			0.805	*70%*
Blower motor cover			0.107	*70%*
Blower regulator			0.093	*70%*
Purifier filter		0.062		
Filter			0.039	*70%*
Cover			0.023	*70%*
Radiator system	1.129			
Radiator		0.448		*100%*
Hoses		0.154		
Upper			0.067	*100%*
Lower			0.087	*100%*
Hose connections		0.509		
Left/main			0.275	*100%*
Right			0.234	*100%*
Buffer		0.018		*100%*
Evaporator system	2.013			
Evaporator		0.983		*70%*
Upper housing		0.413		*70%*
Lower housing		0.491		*70%*
Regulating valve		0.121		*70%*
Buffer		0.005		*70%*
Harness	0.058			
Drain Tube - Air Conditioning	0.046			
Right		0.046		*100%*
Air intake Duct	0.608			
Front		0.165		*70%*
Rear		0.267		*70%*
Flap motor		0.091		*70%*
Flap		0.085		*70%*
Defroster air vent	0.384	-30%	-0.16 kg	
Left	0.076			*70%*
Right	0.080			*70%*
Face Vent Duct	0.026			
Right		0.013		*70%*
Left		0.013		*70%*
Central	0.202			*70%*
Side vents	0.122	0%	0.00 kg	
Left	0.046			*75%*
Right	0.046			*75%*
Windshield defroster vent ducts	0.279	0%	0.00 kg	
Central	0.195			*70%*
Windshield defroster grill	0.662	0%	0.00 kg	
Central	0.497			*75%*
Rear air duct	0.220	0%	0.00 kg	
Central	0.154			
Front		0.082		*70%*
Rear		0.072		*70%*
Front air duct	0.692	-30%	-0.30 kg	70%
Front rear air vent connector	0.111	-30%	-0.05 kg	70%
Lower front air vent	0.252	-30%	-0.11 kg	
Driver	0.153			*70%*
Passenger	0.099			*70%*
Front air duct under driver	0.243	-30%	-0.10 kg	70%
Front air duct under passenger	0.277	-30%	-0.12 kg	70%

9.6.4.2 High Development HVA/C & Ducting Results

The mass savings was less than the Low Development model because of the increased functionality of the HVA/C case. Table 9.6.4.2.a below shows mass reductions for the High Development HVA/C and Ducting system. The mass savings was 17%; the estimated cost factor was 81%.

Table 9.6.4.2.a: High Development HVA/C Ducting System Mass Reductions

HVA/C and Ducting	HD Mass (kg)	% Reduction	Mass reduction (kg)	
	11.272 kg	**-17%**	**-2.38** kg	
Heating system	8.377	-12%	-1.20 kg	%
Covers	2.450			
Left		1.187		*150%*
Right		1.263		*150%*
Motors	0.464			
Lateral air vent flap motor		0.207		
Left/single			0.098	*70%*
Right			0.109	*70%*
Auto Climate control box		0.258		
Right			0.143	*70%*
Right support			0.115	*70%*
Selection flaps	0.542			
Windshield demisting		0.064		*70%*
Lower front part		0.051		
Right			0.031	*70%*
Left			0.020	*70%*
Lateral demisting		0.047		*70%*
Upper front part		0.128		
Left			0.059	*70%*
Right			0.069	*70%*
Support		0.119		*70%*
Hot cold		0.069		*70%*
Central rear		0.064		*70%*
Blowing unit system	1.068			
Air unit		1.005		
Blower motor			0.805	*70%*
Blower motor cover			0.107	*70%*
Blower regulator			0.093	*70%*
Purifier filter		0.062		
Filter			0.039	*70%*
Cover			0.023	*70%*
Radiator system	1.129			
Radiator		0.448		*100%*
Hoses		0.154		
Upper			0.067	*100%*
Lower			0.087	*100%*
Hose connections		0.509		
Left/main			0.275	*100%*
Right			0.234	*100%*
Buffer		0.018		*100%*
Evaporator system	2.013			
Evaporator		0.983		*70%*
Upper housing		0.413		*70%*
Lower housing		0.491		*70%*
Regulating valve		0.121		*70%*
Buffer		0.005		*70%*
Harness	0.058			
Drain Tube - Air Conditioning	0.046			
Right		0.046		*100%*
Air intake Duct	0.608			
Front		0.165		*70%*
Rear		0.267		*70%*
Flap motor		0.091		*70%*
Flap		0.085		*70%*
Defroster air vent	0.384	-30%	-0.16 kg	
Left	0.076			*70%*
Right	0.080			*70%*
Face Vent Duct	0.026			
Right		0.013		*70%*
Left		0.013		*70%*
Central	0.202			*70%*
Side vents	0.092	-25%	-0.03 kg	
Left	0.046			*75%*
Right	0.046			*75%*
Windshield defroster vent ducts	0.195	-30%	-0.08 kg	
Central	0.195			*70%*
Windshield defroster grill	0.497	-25%	-0.17 kg	
Central	0.497			*75%*
Rear air duct	0.154	-30%	-0.07 kg	
Central	0.154			
Front		0.082		*70%*
Rear		0.072		*70%*
Front air duct	0.692	-30%	-0.30 kg	70%
Front rear air vent connector	0.111	-30%	-0.05 kg	70%
Lower front air vent	0.252	-30%	-0.11 kg	
Driver	0.153			*70%*
Passenger	0.099			*70%*
Front air duct under driver	0.243	-30%	-0.10 kg	70%
Front air duct under passenger	0.277	-30%	-0.12 kg	70%

9.7 Closure Trim

9.7.1 Closure Trim Trends

The closure trim included the door and the rear lift-gate interior trim components. The Venza closure trim was competitive with vehicles in its current size and content class based on the benchmarking analysis.

Human Area Networking

Human Area Networking is a process by which external devices can transmit signal information through manipulation of the small magnetic field that exists surrounding the human body. Several small companies, such as RedTacton, have started development on the sensors and transmitters necessary for this technology. This process may eliminate switches in the interior by using graphic contact points and basic sensors to transmit signals rather than using electro-mechanical devices. This process can potentially pass consumer data for vehicle preferences by using this data transmission to pass personalized setting information to the vehicle through HAN. This could also be a security and identity feature; a non-approved personalized profile could immobilize a car in case of theft. Below is a summary of the RedTacton technology from a published web article:

NTT Firmo transmits data through skin[41]
24 Apr 2008
RedTacton human area network -- NTT has begun selling a device that transmits data across the surface of the human body and lets users communicate with electronic devices simply by touching them, the company announced on April 23.

The new product, called "Firmo," consists of a card-sized transmitter carried in the user's pocket. The card converts stored data into a weak AC electric field that extends across the body, and when the user touches a device or object embedded with a compatible receiver, the electric field is converted back into a data signal that can be read by the device. For now, Firmo transfers data at 230kbps, but NTT is reportedly working on a low-cost 10Mbps version that can handle audio/video data transfers.

Firmo is based on NTT's RedTacton human area network (HAN) technology, which is designed to allow convenient human-machine data exchange through natural physical contact — even through clothing, gloves and shoes.

NTT initially hopes this human area network technology will appeal to organizations looking to boost convenience and security in the office. Obvious applications include secure entrances and keyless cabinets that recognize employees when they touch the door handle (thus bypassing the need for card-swipers and keys), or secure printers that operate only when you touch them.

For now, a set of 5 card transmitters and 1 receiver goes for around 800,000 yen ($8,000), but NTT expects the price to come down when mass production begins.

MuCell by Trexel

The MuCell foaming process was incorporated to reduce component mass.

Capacitive Switch and Touch Technology

This technology was covered in detail in section 9.3.1. It was applied to the inner trim. Several examples are shown below in Figure 9.7.1.a.

WACOM "touch slider"

iPhone "touch screen"

Motorola RAZR (Capacitive buttons)

Figure 9.7.1.a **WACOM Tablet** (Capacitive Slider Switch)**, iPhone** (touch screen) **and RAZR Phone**
Photos courtesy of www.maximumcpu.net, www.apple.com, www.66modbile.com

Planar Speaker Technology

Planar speaker technology reduces magnet mass for a defined performance level. The speaker can be made of soft material using a printed circuit on the backside and incorporating leads for signal input. The "scrim", or fabric covering of a typical automotive loudspeaker installation becomes the actual speaker. The fabric used to cover and aesthetically trim the loudspeaker is the speaker. Planar speaker technology eliminates the current loudspeaker assembly, it's mounting and sealing requirements and fasteners from the closure trim.

From Wikipedia:
http://en.wikipedia.org/wiki/Loudspeaker
Planar magnetic speakers (having printed or embedded conductors on a flat diaphragm) are sometimes described as "ribbons", but are not truly ribbon speakers. The term planar is generally reserved for speakers which have roughly rectangular shaped flat surfaces that radiate in a bipolar (i.e., front and back) manner. Planar magnetic speakers consist of a flexible membrane with a voice coil printed or mounted on it. The current flowing through the coil interacts with the magnetic field of carefully placed magnets on either side of the diaphragm, causing the membrane to vibrate more or less uniformly and without much bending or wrinkling. The driving force covers a large percentage of the membrane surface and reduces resonance problems inherent in coil-driven flat diaphragms.

Audi A2 Door Module

The Audi A2 uses full upper door production modules (shown below in Figure 9.7.1.b). The A2 composite module encompasses the entire upper door frame and trim. This is similar to the High Development door module and closure trim. This approach can eliminate add-on trim for the upper door frame as well as the belt line section of the door inner trim.

Figure 9.7.1.b Audi A2 Door Module and Upper Trim

Zero Power

Zero power is a concept that uses the kinetic energy of vibration to create energy sources for low power items like switches and displays. Small composite fabric panels convert the compression and tension caused by panel vibration to electrical energy. This technology has the potential to power switch banks, control interfaces, interior lighting and possibly even window lifts for automotive applications without using main battery power or the associated wiring. This technology combined with wireless communication has the potential to eliminate door and closure system wiring. This could eliminate the typical closure wiring mass and reduce the main electrical system energy loads. It could reduce mass by lowering energy transmission and signal processing requirements.

This novel system utilizes a ceramic fiber network embedded in a composite fabric to convert micro vibrations and energy into electrical energy that can be stored for later use[42].

'fibers have the proven the ability to produce 880 mJ of storable energy in a 13 second period…enough to operate a LCD clock that consumes 0.11 mJ/s for over 20 hours. Energy sufficient to power wireless systems for sensing and control of equipment,

appliances, medical devices, buildings, and other infrastructure elements have been demonstrated.'[43]

Constant Current Networked Wiring

Applied Minds, a California based technology company, has proposed a new method of controlling and directing electrical power and signals in a network grid fashion. The system uses a constant current circuit potential for higher voltage electrical systems, mainly 42V, to manage loads and help prevent arcing. Current automotive electrical circuits run essentially in series through multiple individual looped systems. In the Applied Minds proposal, each node in the networked arrangement has the ability to self diagnose, check and send and receive power and input signals. This concept can reduce redundant wiring bundles by allowing components to share networked routes. It provides self healing and diagnosis capabilities. For example, if a component or sub-network quit functioning, or the wiring shorted, power and signals would be re-routed through the system using another path to the component. This is due to the node's ability to process voltage and current deltas. This system, in conjunction with fiber-optic wiring, could offer significant savings in mass over copper/aluminum wired systems, and reduce cost through commonization of the nodes. The system could pinpoint issues between and at nodes directly, target troubleshooting efforts, and leave critical systems on line even in the event of signals processing or power failure at a network path. A high level of simulation accuracy could reduce development time and allow high speed design changes.

9.7.2. Closure Trim Benchmarking

The Venza inner trim mass was competitive with vehicles using trim with similar content. The Venza mass was as light as some vehicles that were significantly smaller, indicating an optimized design. Table 9.7.2.a below shows the benchmarking results for the driver door inner trim. **The Venza rear door and hatch trim masses were also comparable to smaller vehicles.**

Table 9.7.2.a Basic Closure Trim Benchmarking – Driver's Door Inner Trim

											
	Venza 2.7 FWD	Tiguan 1.4 TSi Sport	Qashqai 2.0 Visia	X3 3.0D Sport	Kuga 2.0 TDCi Titanium	XC60 2.4D Basis	RDX 2.3 Technology Package	Q5 2.0 TDi Base	GLK 220 CDi BE	Grand Espace IV 2.2 dCi Expr	7 Series 740i
Weight and Measurements											
Weight	*2.694*	*2.889*	*2.961*	*3.01*	*3.194*	*3.429*	*3.785*	*3.794*	*3.859*	*4.327*	*4.404*

9.7.3. Closure Trim Analysis

The closure trim system was primarily comprised of plastic trim panels; these panels contributed the most mass to the overall system. Table 9.7.3.a below shows the mass sensitivity analysis.

Table 9.7.3.a Closure Trim Sensitivity Analysis

		Total Mass (kg)	Component Mass (kg			
Opening systems		**13.326**				
Front driver	1		3.046			
Inner panel				2.523		
Panel	1				1.392	
Cushioning	1				0.069	
Trim	1				0.074	
Medallion	1				0.296	
Bottom storage	1				0.227	
Upper band	1				0.408	
Inner door handle					0.057	
Handle	1					0.057
Power controls				0.217		
Multi functions control					0.217	
Bezel	1					0.081
Control	1					0.136
Speaker system				0.306		
Speaker	1				0.306	
Front passenger	1		2.969			
Inner panel				2.513		
Panel	1				1.371	
Upper band	1				0.416	
Trim	1				0.077	
Medallion	1				0.292	
Passenger Door Weather Strip	1				0.079	
Door pocket front side	1				0.222	
Inner door handle					0.056	
Handle	1					0.056
Power controls				0.149		
Mirror and window control switch					0.130	
Control	1					0.036
Bezel	1					0.094
Locking System	1				0.019	
Speaker system				0.307		
Speaker	1				0.307	
Rear door left	1		2.644			
Inner panel				2.303		
Panel	1				1.288	
Cushionnng	1				0.034	
Trim	1				0.072	
Medallion	1				0.286	
Upper panel	1				0.372	
Door pocket front side	1				0.179	
Inner door handle					0.072	
Handle	1					0.072
Power controls				0.120		
Window control switch					0.120	
Control	1					0.036
Bezel	1					0.084
Speaker system				0.221		
Speaker	1				0.221	
Rear door right	1		2.644			
Inner panel				2.303		
Panel	1				1.288	
Cushionnng	1				0.034	
Trim	1				0.072	
Medallion	1				0.286	
Upper panel	1				0.372	
Door pocket front side	1				0.179	
Inner door handle					0.072	
Handle	1					0.072
Power controls				0.120		
Window control switch					0.120	
Control	1					0.036
Bezel	1					0.084
Speaker system				0.221		
Speaker	1				0.221	
Tail gate	1		2.023			
Inner panel				2.023		
Lower/main panel	1				1.493	
Upper panel	1				0.270	
Left side	1				0.130	
Right side	1				0.130	

Table 9.7.3.b below indicates that the trim panels were the highest mass components in the closure trim system. The remote handle system and electronic switches also contributed. Switches and switch modules could be integrated with the bolster. Electronic latching allowed the mechanical linkage that connects the remote inner handle to the latch to be eliminated and permitted the latch to be moved to the B-Pillar. This closure trim mass reduction could reduce the hinge size.

Table 9.7.3.b: Closure Trim Sub-System Analysis

			Total mass (kg):	kg
Opening systems			13.326	
	Front driver			**3.046**
		Inner panel		2.523
			Panel	1.392
			Cushioning	0.069
			Trim	0.074
			Medallion	0.296
			Bottom storage	0.227
			Upper band	0.408
			Inner door handle	0.057
			Handle	0.057
		Power controls		0.217
			Multi functions control	0.217
			Bezel	0.081
			Control	0.136
		Speaker system		0.306
			Speaker	0.306
	Front passenger			**2.969**
		Inner panel		2.513
			Panel	1.371
			Upper band	0.416
			Trim	0.077
			Medallion	0.292
			Passenger Door Weather Strip	0.079
			Door pocket front side	0.222
			Inner door handle	0.056
			Handle	0.056
		Power controls		0.149
			Mirror and window control switch	0.130
			Control	0.036
			Bezel	0.094
			Locking System	0.019
		Speaker system		0.307
			Speaker	0.307
	Rear door left			**2.644**
		Inner panel		2.303
			Panel	1.288
			Cushionnng	0.034
			Trim	0.072
			Medallion	0.286
			Upper panel	0.372
			Door pocket front side	0.179
			Inner door handle	0.072
			Handle	0.072
		Power controls		0.120
			Window control switch	0.120
			Control	0.036
			Bezel	0.084
		Speaker system		0.221
			Speaker	0.221
	Rear door right			**2.644**
		Inner panel		2.303
			Panel	1.288
			Cushionnng	0.034
			Trim	0.072
			Medallion	0.286
			Upper panel	0.372
			Door pocket front side	0.179
			Inner door handle	0.072
			Handle	0.072
		Power controls		0.120
			Window control switch	0.120
			Control	0.036
			Bezel	0.084
		Speaker system		0.221
			Speaker	0.221
	Tail gate			**2.023**
		Inner panel		2.023
			Lower/main panel	1.493
			Upper panel	0.270
			Left side	0.130
			Right side	0.130
	Total			**13.326**

Low Development Closures Trim

The Low Development closures trim mass reductions focused on the polypropylene panels. The design, processing of assembly, and feature content was the same as the current production Venza door trim panels. The MuCell process was used for the appropriate panels; the estimated mass reduction was 20%. The same methodology for fasteners and class A surface considerations was used as detailed previously. The Low Development proposal replaced the mechanical remote handle with an electronic push button system similar to the 2009 production Corvette. This eliminated the remote handle and allowed the latch to be located in the B-pillar structure. This eliminated the need for the rod connecting the inner remote handle to the latch. This mass reduction had a compound effect; the latch and mechanism were moved from the door system and the door and hinge structure was reduced due to the smaller swing mass of the door. Only a striker and a small capacitive switch for remote unlocking were carried on the door. An emergency mechanical release cable was located in the B-pillar. Only the mass reduction for the remote handle itself is tracked in the interior closure proposal.

High Development Closure Trim

The High Development model merged the door inner structure and the door inner trim panel into one part. The HD proposal also incorporated emerging automotive electronics technology to eliminate switch banks and door wiring. The long glass fiber polymer door inner panel on the High Development body closure was also the inner surface of the door module. This door module inner would be grained and molded in color and eliminate the hard plastic door inner trim panel. The electronics would be HAN, or Human Area Networked for signals processing, or lightweight capacitive switch panels molded into the door bolster. This eliminated conventional switch banks and trim bezels. The lower map pocket area was made of a MuCell foamed polymer. A digitally knit soft trim part was used to cover the door module. The passenger armrest was formed using a separate wood fiber bolster part and over molding it with low durometer foam and a leather or vinyl covering. This provided soft trim coverage at the human interface points consistent with the current Venza execution. The closure trim system is pictured in Figure 9.7.3.a below.

Figure 9.7.3.a High Development Closure Trim

The mass savings was created by full integration of the door module, the elimination of speakers in the door lower, the speaker wiring and the mechanical remote handle system. Speakers would either be planar or be located in the cowl kick panel location. This eliminated the wiring and the need to protect the speakers from environmental issues such as rain. It also created potential cost savings. The door remote system was replaced with a capacitive switch which communicates with the B-Pillar located latch electronically. An emergency cable was located in the door map pocket was designed as a low mass, occasional use part. Figure 9.7.3.b below shows the entire door trim system as a whole.

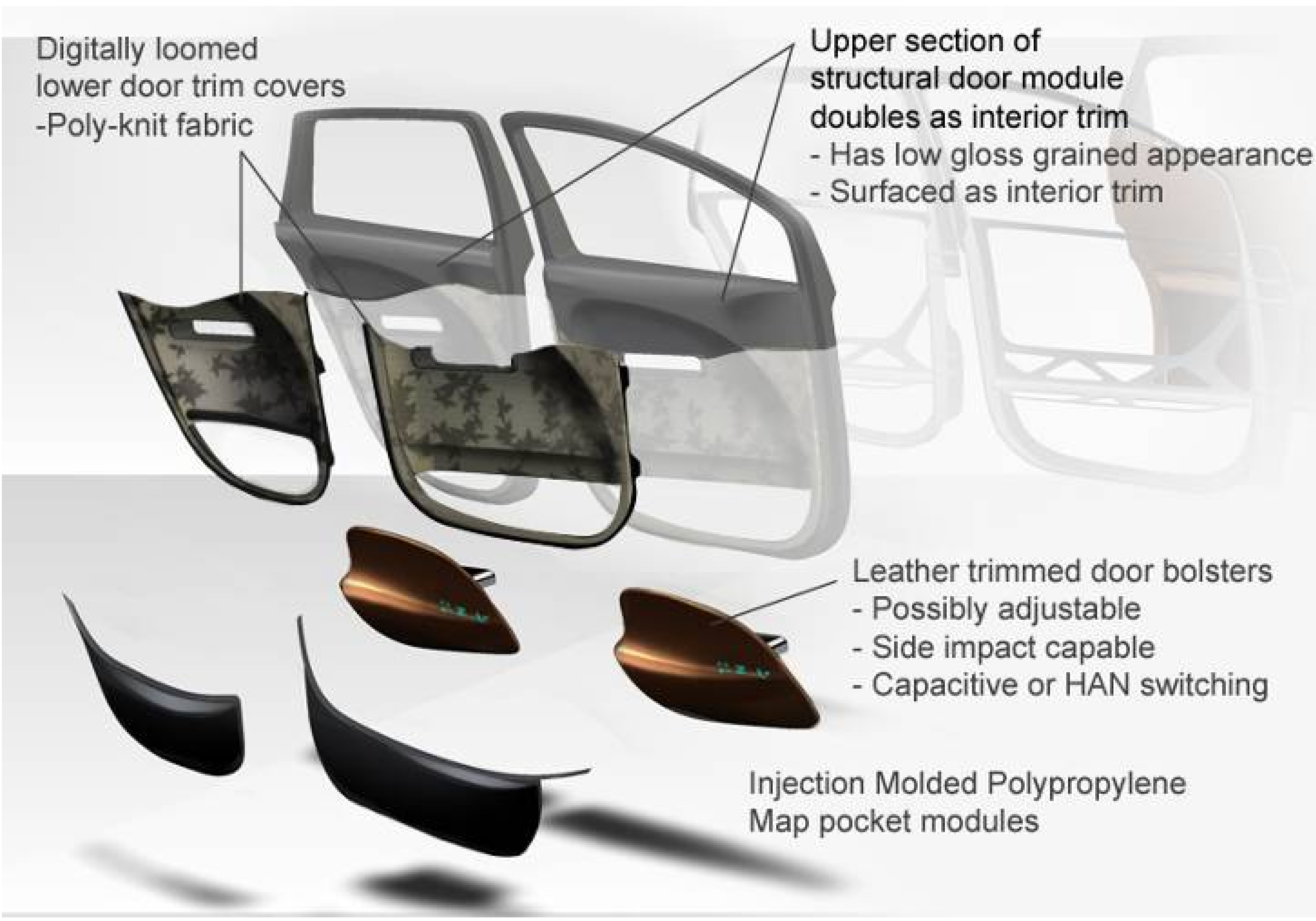


Figure 9.7.3.b High Development Closure Trim Assembly

9.7.4. Closure Trim Results

9.7.4.1. Low Development Closure Trim

Table 9.7.4.1.a below shows the Low Development closure trim system mass reduction was 2.56kg. This represented a 20% mass savings vs. the Venza. The estimated cost factor was 90%.

Table 9.7.4.1.a Low Development Closure Trim Model Mass Reductions

Closures Trim	LD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	10.674 kg	**-20%**	**-2.65 kg**		
Front driver	1.172				
Inner panel		0.649			
Panel			0.055	80%	MuCell
Trim			0.059	80%	MuCell
Medallion			0.296	100%	
Bottom storage			0.182	80%	MuCell
Upper band			0.057	100%	
Inner door handle			0.000	100%	
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.217			
Multi functions control			0.217	100%	
Bezel			0.081	100%	
Control			0.136	100%	
Speaker system		0.306			
Speaker			0.306	100%	
Front passenger	2.403				
Inner panel		1.947			
Panel			1.097	80%	MuCell
Upper band			0.333	80%	MuCell
Trim			0.062	80%	MuCell
Medallion			0.234	80%	MuCell
Door pocket front side			0.222	100%	
Inner door handle			0.000	100%	
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.149			
Mirror and window control switch			0.130		
Control			0.036	100%	
Bezel			0.094	100%	
Locking System			0.019	100%	
Speaker system		0.307			
Speaker			0.307	100%	
Rear door left	2.538				
Inner panel		2.197			
Panel			1.288	100%	
Trim			0.072	100%	
Medallion			0.286	100%	
Upper panel			0.372	100%	
Door pocket front side			0.179	100%	
Inner door handle			0.000	100%	
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.120			
Window control switch			0.120	100%	
Control			0.036	100%	
Bezel			0.084	100%	
Speaker system		0.221			
Speaker			0.221	100%	
Rear door right	2.538			100%	
Inner panel		2.197			
Panel			1.288	100%	
Trim			0.072	100%	
Medallion			0.286	100%	
Upper panel			0.372	100%	
Door pocket front side			0.179	100%	
Inner door handle			0.000	100%	
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.120			
Window control switch			0.120	100%	
Control			0.036	100%	
Bezel			0.084	100%	
Speaker system		0.221			
Speaker			0.221	100%	
Tail gate	2.023			100%	
Inner panel		2.023			
Lower/main panel			1.493	100%	
Upper panel			0.270	100%	
Left side			0.130	100%	
Right side			0.130	100%	

9.7.4.2. High Development Closure Trim

Table 9.7.4.2.a shows the High Development model produced an 82% mass reduction; the cost factor was 75%.

Table 9.7.4.2.a: High Development Closure Trim Mass Reductions

Closures Trim	HD Mass (kg)	% Reduction	Mass reduction (kg)	%	Description
	2.412 kg	**-82%**	**2.41 kg**		
Front driver	0.695				
Inner panel		0.478			
Panel			0.000	0%	Eliminated due to module
Trim			0.000	0%	Eliminated due to module
Medallion			0.296	100%	
Bottom storage			0.182	80%	MuCell
Upper band			0.000	0%	
Inner door handle			0.000		
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.217			
Multi functions control			0.217		
Bezel			0.081	100%	
Control			0.136	100%	
Speaker system		0.000			
Speaker			0.000	0%	
Front passenger	0.619				
Inner panel		0.470			
Panel			0.000	0%	Eliminated due to module
Upper band			0.000	0%	Eliminated due to module
Trim			0.000	0%	Eliminated due to module
Medallion			0.292	100%	
Door pocket front side			0.178	80%	
Inner door handle			0.000		
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.149			
Mirror and window control switch			0.130		
Control			0.036	100%	
Bezel			0.094	100%	
Locking System			0.019	100%	
Speaker system		0.000			
Speaker			0.000	0%	
Rear door left	0.549				
Inner panel		0.429			
Panel			0.000	0%	
Trim			0.000	0%	
Medallion			0.286	100%	
Upper panel			0.000	0%	
Door pocket front side			0.143	80%	
Inner door handle			0.000		
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.120			
Window control switch			0.120		
Control			0.036	100%	
Bezel			0.084	100%	
Speaker system		0.000			
Speaker			0.000	0%	
Rear door right	0.549				
Inner panel		0.429			
Panel			0.000	0%	
Trim			0.000	0%	
Medallion			0.286	100%	
Upper panel			0.000	0%	
Door pocket front side			0.143	80%	
Inner door handle			0.000		
Handle			0.000	0%	Electronic Remote Handle
Power controls		0.120			
Window control switch			0.120		
Control			0.036	100%	
Bezel			0.084	100%	
Speaker system		0.000			
Speaker			0.000	0%	
Tail gate	0.000				
Inner panel		0.000			
Lower/main panel			0.000	0%	
Upper panel			0.000	0%	
Left side			0.000	0%	
Right side			0.000	0%	

9.8 Total Interior System Results Summary

For the overall interior system, the results of the mass reduction for Low and High Development models are summarized below. It is important to note that each sub-system was analyzed individually and prioritized by their order of mass contribution to the overall interior system. The systems were analyzed individually due to their differing functional objectives and processing techniques.

9.8.1. Low Development Interior Summary

For the Low Development Interior, a majority of the mass reduction came due to benchmarking the low mass systems and sub-systems. For certain sub-systems, integration and emerging technologies where utilized due to fact they have already been implemented in production on some models. Table 9.8.1.a below shows the overall mass reduction for the Low Development Interior of 27%, giving a final Low Development mass of 182 kg

Table 9.8.1.a Low Development Interior Mass and Cost Summary

System	Sub-System	Venza Baseline mass	% of Interior	Low Development Mass	Low Development Cost
Interior					
	Seats	97.9 kg	39%	61.6 kg	88%
	Instrument Panel|Console|Insulation	43.4 kg	17%	28.7 kg	105%
	Hard Trim	41.4 kg	17%	36.7 kg	105%
	Controls	22.9 kg	9%	16.0 kg	108%
	Safety	17.9 kg	7%	17.9 kg	100%
	HVA/C and Ducting	13.7 kg	5%	10.3 kg	99%
	Closure Trim	13.3 kg	5%	10.7 kg	90%
Total		**250.6** kg		**181.8** kg	**97%**

9.8.2 High Development Interior Summary

For the High Development Interior, a majority of the mass reduction came from component integration and technologies emerging for use in both automotive and non-automotive applications. Some systems are currently under development by suppliers while others are in production in other markets and industries. Table 9.8.2.a below shows the overall mass reduction for the High Development Interior of 39%, giving a final Low Development mass of 153 kg

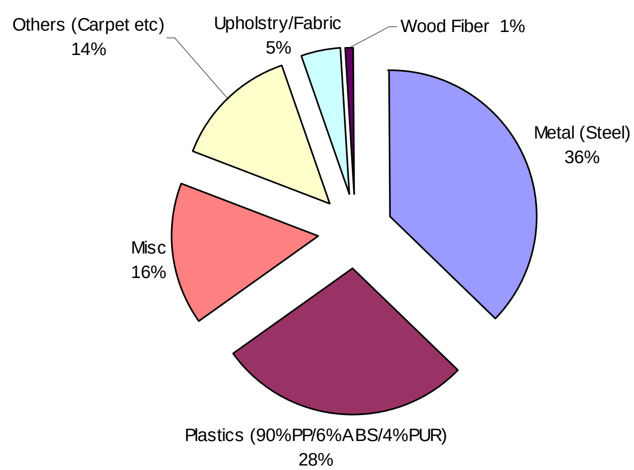
Table 9.8.2.a High Development Interior Mass and cost Summary

System	Sub-System	Venza Baseline mass	% of Interior	High Development Mass	High Development Cost
Interior					
	Seats	97.9 kg	39%	55.2 kg	94%
	Instrument Panel|Console|Insulation	43.4 kg	17%	25.8 kg	105%
	Hard Trim	41.4 kg	17%	24.3 kg	105%
	Controls	22.9 kg	9%	16.0 kg	108%
	Safety	17.9 kg	7%	17.9 kg	100%
	HVA/C and Ducting	13.7 kg	5%	11.3 kg	81%
	Closure Trim	13.3 kg	5%	2.4 kg	75%
Total		**250.6** kg		**152.8** kg	**96%**

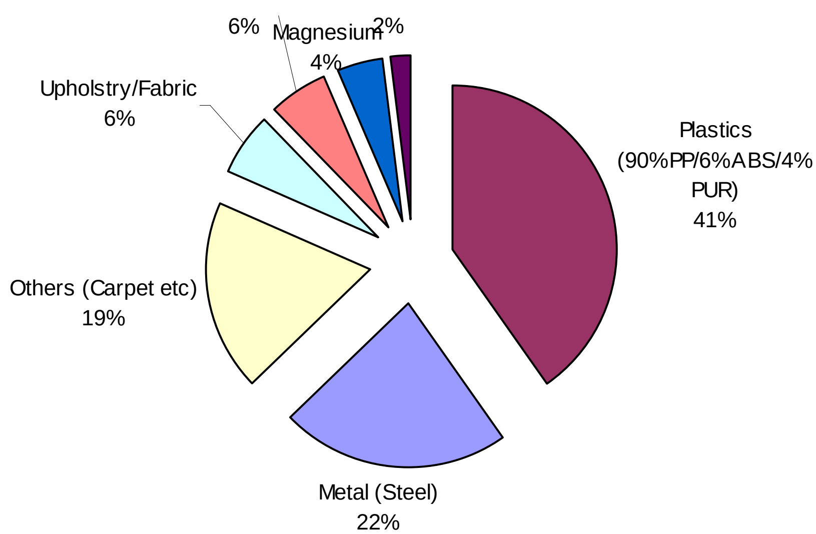
9.8.3 Interior Mass Distribution by Material

The interior materials analyses are shown in the following charts. The steel content decreased significantly for both the Low and High Development and the plastics usage increased. Wood fiber usage increased by a factor of four from the baseline to the High Development model.

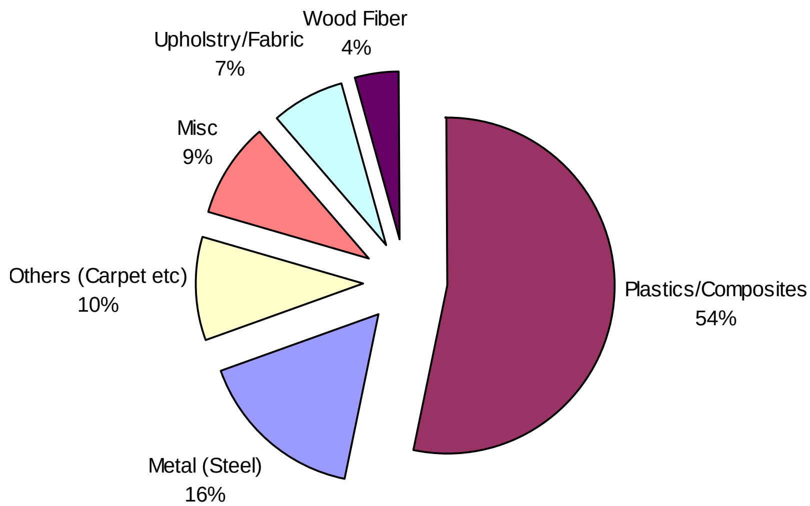
Baseline Interior Materials



Low Development Interior Materials



High Development Interior Materials



10. Chassis

10.1. Chassis Overview

The chassis and suspension systems evaluated for this study include the front and rear suspension, steering, tires and wheels, subframes and brakes. The total of all the chassis components evaluated for this study is 373.1 kg. The 20% reduced low development goal is therefore 298.5 kg and the 40% reduced high development goal is 223.9 kg. The baseline Venza chassis masses were established through a vehicle teardown. The targets for the Low Development (20% mass reduction) and the High Development (40%) mass reductions were based on the measured Venza masses. The measured Venza mass was 1700 kg. Toyota lists the weight for the base FWD four cylinder Venza as 3,760 lbs (1705 kg). The published Toyota value was used as the baseline mass for the chassis study. This 0.3% variation is due to allowable production tolerances and represents a typical deviation.

A common methodology was used for all chassis and suspension systems with the exception of tires and wheels. A different tire and wheel methodology was used because of the requirement to maintain the Venza 19” wheel diameter for styling reasons. The overall tire diameter was allowed to vary slightly from the Venza baseline tire diameter. The tire and wheel methodology is presented at the end of this section.

The powertrain mass reduction study was done independent of this study. The Low and High Development powertrain masses, including powertrain, fuel system and halfshafts, were included in the Low Development and High Development total vehicle masses used for this analysis.

A suspension mass sensitivity analysis was done to evaluate the mass efficiency of a variety of production suspension architectures vs. the Venza front and rear suspension types. This study is detailed in the suspension section.

The Low Development systems utilized lightweight production systems and innovations from suppliers that are expected to be production feasible by the 2017 model year. A 20% cost increase was set as the cost threshold for the Low Development components. The High Development model utilized the selected Low Development mass sub-systems normalized to a 40% mass reduction plus systems integration and innovations in component design and materials that are expected to be production feasible by the 2020 model year. The cost methodology was covered in section 4.

The Low Development analysis investigated current production chassis hardware. The lightest components were selected after scaling to the mass of the Venza. These low mass systems were normalized to the Toyota Venza curb mass by multiplying the selected system mass by the ratio of the Venza curb mass (M_V) to the selected vehicle curb mass (M_S), M_V/M_S. These components were then sorted in mass order. The tires and wheels were not optimized using this methodology due to the requirement that the Venza 19” wheel diameter be maintained.

This methodology yields a linear mass reduction only as a straight proportion to the vehicle mass. A complete design analysis, which was beyond the scope of this study, could provide additional mass savings as a result of section optimization for the given vehicle mass.

The project scope mandated that the Venza styling theme, which utilizes 19” wheels as a key design element, be maintained. This study utilized the Venza 19” wheel diameter to preserve the side view appearance. Tire and wheel width were the variables investigated for mass reduction.

Projected costs were also used as selection criteria for the Low and the High Development components. The most cost effective hardware was selected for the final BOM’s.

The target GVW (Gross Vehicle Weight) and Front and Rear GAWR (Gross Axle Weight Rating) masses were then developed. The GVW was determined by adding the Venza payload rating to the Low and High Development mass targets. The Low and High Development powertrain masses (developed independently) replaced the Venza powertrain mass and created the final Low Development and High Development curb weights. The front and rear GAWR's were then calculated and used as the basis for the lightweight Low Development and High Development chassis systems. The percent of load capacity represented by the GAWR was maintained for all tire/wheel widths investigated. Table 10.1.a. summarizes the vehicle mass analysis.

Table 10.1.a: Vehicle Mass Calculation for Low and High Development

	Venza	Low Development	High Development
		20.9% curb mass reduction on all but powertrain	40.9% curb mass reduction on all but powertrain
Curb Weight	1699.6	1376.05	1118.21
% of change		-19%	-34%
Powertrain (From EPA)	410.41	356.3	356.3
Payload	549	549	549
GVW	2249	1925.05	1667.21
% of change		-14%	-26%
GAWR-Front (kg)	1400	1227.77	1090.52
GAWR-Rear (kg)	1230	1078.68	958.10
GAWR-Front (%)	53%	53%	53%

The cost analysis for this study involved the development of a baseline cost for the Venza components based on Lotus experience and input from suppliers. In the case of advanced design concepts cost estimates were provided by suppliers. In the case of components where the mass was proportionately reduced based on the target vehicle GAWR's, the cost was adjusted based on the cost of the reduced material mass. The estimated component value was based on supplier input[44]; either supplier estimated values or a value calculated using supplier costing methodologies were used for this section. As explained in the introductory remarks, the absolute value of an identical part varies significantly depending on the OEM and the supplier. To eliminate this cost variation, relative costs were developed and normalized to a baseline Venza value of 1.00. The relative cost factors used in this study allow an OEM to do an in-house absolute value analysis and then calculate the cost differential by applying the developed cost factor to the estimated absolute value. The example below explains how the cost factor was determined for a typical chassis component.

The Passat strut mass was adjusted to the target GAWR by multiplying the ratio of the Low Development GAWR to the Passat GAWR ($GAWR_{LD}/GAWR_{Passat}$) which yields a ratio of 1243/1050 or a value of 1.18 times the Passat strut assembly mass of 3.274 kg. The new mass is therefore 1.18 x 3.274 or 3.88 kg. The Venza Baseline strut mass is 5.88 kg; the mass savings is 2.00 kg. This mass reduction was assigned a value of $0.50/kg. This represents a current material cost and was obtained from www.metalprices.com. This value was then applied to the mass removed from the strut (a predominantly steel part). The cost of the baseline strut assembly was estimated at $20.00; the new cost was $20.00 – (2 kg x $0.50/kg or $1.00) = $19.00. The cost factor was arrived at by dividing the estimated new cost by the original estimated cost ($19.00/$20.00) which yields a 0.95 cost factor. This is the strut cost factor value listed in the Low Development BOM.

Tire and Wheel Methodology

Table 10.1.b. below shows tire sizes which meet the GAWR requirements for this vehicle. The same size tire and wheel was used at the front and rear to match the Venza configuration. The tires and wheels selected for this study are shaded. These are currently available sizes with published masses. The 205/65 tire met the GAWR requirement for the high development vehicle but was judged to be too narrow for acceptable vehicle appearance. This tire/wheel combination would have resulted in an additional mass savings of 1.9 kg per corner or a total additional savings of 7.6 kg for the High Development wheel/tire.

Table 10.1.b: Tire Sizing with 19 inch Wheel

Note: All calculations based on 19 inch wheel diameter

	Section Width (mm)	Profile (%)	Sidewall (mm)	Load rating	Max load (lbs)	LC (Load capacity) at 32 psi(lbs)	Front GAWR +10% (lbs)	% of LC used	Rim Width (in)	Tire Mass (kg)	Wheel Mass (kg)
Venza	245	55	134.75	103	1929	1812.56	1697.85	94%	7.5	15	10*
Low Dev	225	60	135	101	1819	1709.20	1488.98	87%	7	13.2	9.75
	215	65	139.75	98	1653	1553.22	1488.98	96%	6.5	11.8	9.5
High Dev	215	60	129	96	1565	1470.53	1322.53	90%	6.5	11.8	9.5
	205	65	133.25	96	1565	1470.53	1322.53	90%	6	10.4	9.25

*Venza wheel mass reflects lighter cast wheel design

The wheel and tire mass could be lighter if the wheel diameter was reduced from 19" using tires that met the GAWR requirement. The potential mass savings from using a smaller tire and wheel that meets the Low Development GAWR is an additional 4.4 kg total vehicle savings. This represents a 5% mass savings vs. the Venza 19" Low Development wheel/tire combination. The potential mass savings from using a smaller tire and wheel that meets the High Development GAWR is 0.8 kg savings per corner or an additional 3.2 kg total vehicle savings. This represents a 4% mass savings vs. the Venza 19" High Development wheel/tire combination. Table 10.1.c. below lists typical tire/wheel combinations for tires ranging in diameter from 15" to 19" that meet the minimum GAWR requirement.

A more detailed system analysis is presented in the Low and High Development Tire and Wheel sections.

Table 10.1.c: Tire Sizing with Varying Wheel Sizes

	Wheel Dia (in)	Section Width (mm)	Profile (%)	Sidewall (mm)	Load rating	Max load (lbs)	LC (Load capacity) at 32 psi(lbs)	Front GAWR +10% (lbs)	% of LC used	Rim Width (in)	Tire Mass (kg)	Wheel Mass (kg)	Total Tire & Wheel Mass (kg)	SUV or Car Tire
Venza	19	245	55	134.75	103	1929	1812.56	1697.85	94%	7.5	15	10*	25.0	SUV
Low Dev BOM	19	225	60	135	101	1819	1709.20	1488.98	87%	7	13.2	9.8	23.0	SUV
LD alternative	17	235	60	141	101	1819	1709.20	1488.98	87%	7	14.1	8.8	22.8	SUV
LD alternative	15	225	75	168.75	102	1874	1760.88	1488.98	85%	6.5	14.1	7.5	21.6	SUV
LD alternative	15	235	70	164.5	102	1874	1760.88	1488.98	85%	7	12.7	7.8	20.4	Car
High Dev BOM	19	215	60	129	96	1565	1470.53	1322.53	90%	6.5	11.8	9.5	21.3	SUV
HD alternative	17	235	55	129.25	96	1565	1470.53	1322.53	90%	7	11.8	8.8	20.5	SUV
HD alternative	16	235	55	129.25	96	1565	1470.53	1322.53	90%	7	10.4	8.3	18.7	Car
HD alternative	15	235	55	129.25	95	1521	1429.19	1322.53	93%	7	10.4	7.8	18.2	Car

*Venza wheel mass reflects lighter cast wheel design

10.2. Chassis Trends

Chassis systems have long had low mass as a goal in order to reduce unsprung mass and improve vehicle dynamics. This has generally been tempered by the desire to produce low cost vehicles. As manufacturing methods, materials and design knowledge improve there is greater usage of low mass components. Any cost disadvantages are increasingly being accepted in the pursuit of lower mass vehicles for performance or fuel economy.

The materials and processes which are already seeing extensive usage are high strength steel and aluminum (cast and sheet). High strength steels are commonly used in all structural elements of the chassis as they are generally a cost effective alternative. Aluminum has been used primarily on higher priced vehicles such as BMW, Audi and Mercedes but is starting to be incorporated on other vehicle classes such as SUV's (GM Acadia/Enclave lower A arms), mini-vans (Chrysler mini-van steering knuckle) and mid-size sedans (VW Passat steering knuckle assembly). Aluminum has also been used for high fuel economy vehicles such as the Toyota Prius and the GM EV1.

There have been a limited number of components using cast magnesium, plastics and foam reinforcements. Magnesium has been used on higher priced vehicles but is starting to be incorporated on other vehicle classes such as the F150 cradle. As an example the Z06 version of the Chevrolet Corvette is using cast magnesium for the front subframe. Plastics have been used for a few components. Foam reinforced stampings have been used primarily as development aids but with increased knowledge about this technique it should start to see more widespread use earlier in the design process.

There has always been a significant effort made to reduce the rotating mass of the chassis with innovations being made in brake rotors and wheels. These again have been primarily used on high price performance vehicles. Brake rotors can be found with partial aluminum content and even made out of carbon. Wheels have historically been made with aluminum and magnesium and there is an increased availability of composite constructions.

Other Investigated Technologies - Suspension and Steering

- **HSLA (High Strength Low Alloy) steel for strut components**
  - Steel strut parts would be optimized for processing and cost and the appropriate grade of HSLA would be employed.
  - ThyssenKrupp has researched this area and believe a 25% strut mass savings is possible at a competitive cost.[45]
- **Titanium for springs**
  - The higher ultimate strength of Titanium allows smaller diameter wire and a smaller diameter spring body to be used to get equivalent spring rate with lower mass.
  - The mass savings possible could be as high as 60% of the spring mass[46]
  - The cost of Titanium kept this source of mass reduction out of the final BOM.
- **Aluminum welded subframe**
  - Benchmarked from the 2008 BMW 318i shown in Figure 10.2.1.a.
  - It is estimated to save 45% of the mass from the Venza front subframe at a cost penalty of 23%.
  - This was not used in the development of the low or high development BOMs due to the greater mass savings available with Magnesium casting.

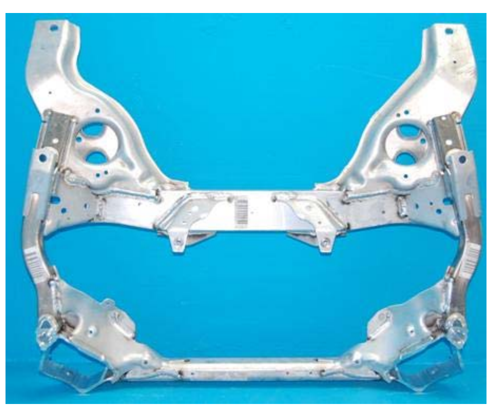


Figure 10.2.1.a.: BMW 318i Subframe

▪ **Carbon Fiber and Glass Fiber Reinforced Composites**
- Could be used for structural components like subframes, control arms, links and leaf springs.
- A special class of GFRP called "Pultrusion" which uses continuous glass fiber has been successfully used on links in the past (Corvette, EV1). A sample link is shown in Figure 10.2.1.b. This offers approximately 50% mass reduction at a 100% cost increase over the tubular steel components used in the Venza. Due to the cost increase these were not included in the BOMs.

Figure 10.2.1.b.: Pultruded Link

- Leaf springs have been produced from continuous fiberglass rovings (reinforcement) that are bound together by an epoxy resin (matrix).and used in various applications (Corvette shown in Figure 10.2.1.c., GM Mid-size vans, 80's GM E/K cars shown in Figure 10.2.1.d.).

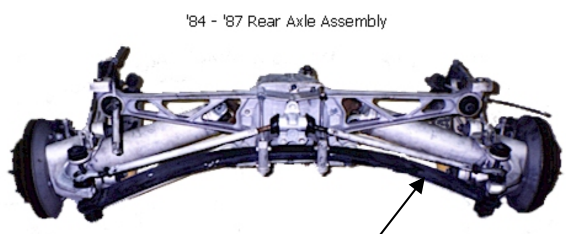


Figure 10.2.1.c.: 1984 Chevrolet Corvette rear composite leaf spring

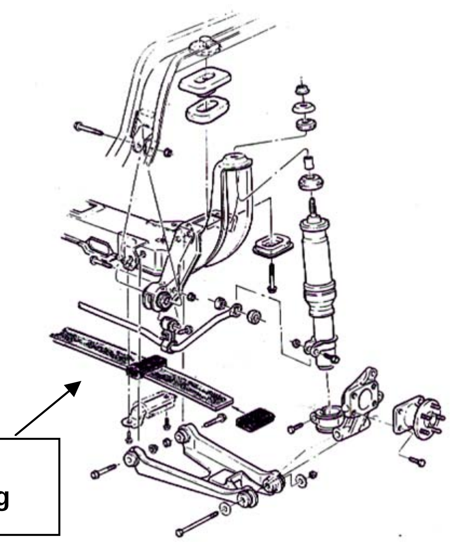


Figure 10.2.1.d.: 1986 Cadillac Eldorado rear composite leaf spring

- A significant redesign of the suspension would be required to integrate these into the vehicle and was beyond the scope of this study.
- Investigated for subframes for this study but due to the many design constraints that would need to be considered, the anticipated high cost of these materials and due to the lack of a benchmark part this material was not considered for any chassis component for this study.

Other investigated Technologies for the Brake System

▪ **MMC rotor**
- Various material variations and manufacturing methods have been used to produce brake rotors using Aluminum MMC. At this point there are technical issues such as noise and high temperature performance that need to be resolved. Additionally the costs to date have been too high to consider for a mass market vehicle. The mass savings are in the 50 - 60% region.
- There has been limited usage of this technology in GM's EV1, Plymouth Prowler, VW Lupo, Toyota RAV-4EV, and the Lotus Elise.

▪

- **Carbon/Ceramic rotor**
  - Requires specific brake pad material.
  - 40-60% mass reduction, currently 20 x's brake corner cost, may be able to get to 10 x's cost in the future per Brembo.
  - Too high a cost for high volume production vehicle at this time.
- **Forged aluminum caliper**
  - Approximately 3% mass savings over cast aluminum with a 10% cost increase
  - Primarily done for packaging or performance.
- **Electric caliper**
  - Several designs have been proposed by different suppliers including Delphi, Continental and Brembo.

Other investigated Technologies for Tires & Wheels

- **New Aluminum alloy from Alcoa for forged wheels**
  - 20% higher strength results in 15% mass savings, no cost impact (i.e. 15% material cost increase per kg)
  - This is a proprietary Alcoa alloy designated C91H which should be available by mid 2010.
- **Carbon Fiber composite wheel.**
  - 20 kg per vehicle mass savings from baseline Venza wheel, approximately 6-10 times the cost of cast aluminum wheels.
  - Dymag produces two piece magnesium/carbon composite wheels for racing and niche vehicles and has developed a one piece carbon composite wheel.
  - Dymag Racing UK LTD is headquartered in Wiltshire, England. More information is available at www.dymag.com."
  - A CF wheel was not included in the BOM due to the projected high cost.
- **Michelin Tweel Design**

Figure 10.2.2.a.: Michelin Tweel

  - According to the Michelin website the benefits of the Michelin TWEEL are:
    - maintenance-free
    - easy mounting and dismounting
    - puncture-proof
    - longer wear resistance
    - better distribution of pavement stress
    - simplified manufacturing process
    - reusable base structure for retreading
    - improved shock and road hazard resistance

- In addition through discussion with Michelin it was found that the Tweel does have reduced rolling resistance over pneumatic tires.
- Because it is non-pneumatic it is not legal for road use in the U.S., this would have to be addressed before serious development was conducted.
- The Tweel is a mass increase over a comparable tire and wheel assembly but if factoring in the ability to eliminate the spare it may be mass neutral.
- It is a cost increase over a current tire & wheel.
- There is still significant development to do on this concept before it is considered for a road vehicle.

- **Michelin Active Wheel**

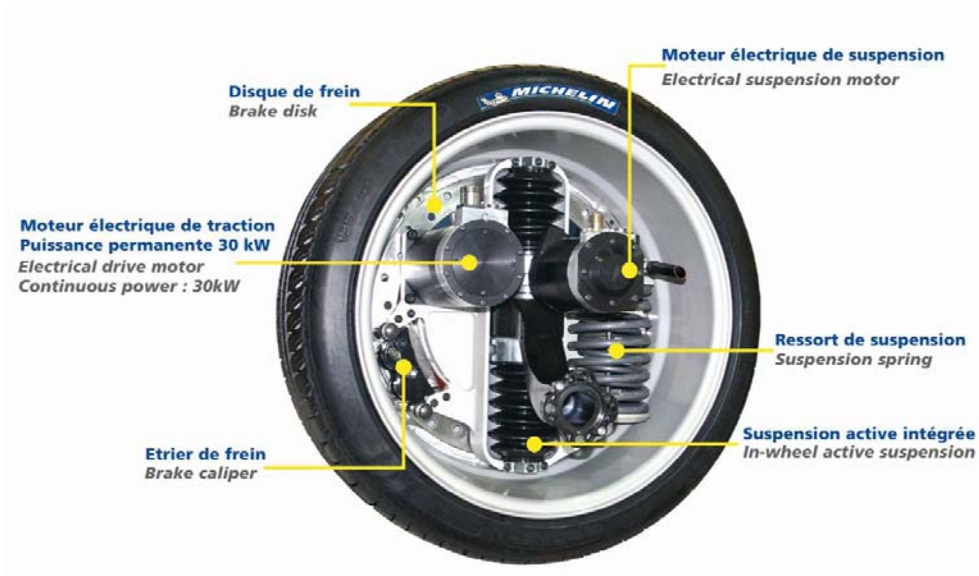


Figure 10.2.2.b.: Michelin Active Wheel

- According to the Michelin press kit from the 2008 Paris Motor Show, “The key to the Michelin Active Wheel’s technological breakthrough is its compact traction motor and integrated suspension system. By reducing the size of these components, Michelin has made it possible to reinvent the wheel.”
- The Active Wheel is still in the early development stage and it is too soon to determine the overall impact to the vehicle in terms of cost and efficiency but it is an intriguing concept and would certainly offer significant packaging advantages.

10.3. Chassis Benchmarking

Tables 10.3.a. and 10.3.b. summarize selected low mass production suspension systems and normalize their system mass relative to the Venza. Based on this analysis, the Volkswagen Passat was selected as the basis for the front suspension and the Alfa Romeo 147 was selected as the basis for the rear suspension.

Table 10.3.a.: Low Mass Front Suspension Systems

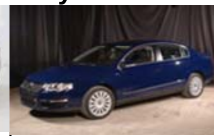
				
	2009 Toyota Venza 2.7 FWD	**2005 Volkswagen Passat 1.9 TDI**	**2004 BMW 5 Series 3.0 i Sport**	**2007 Mercedes C Class 220 CDi Classic**
Suspension Weight (kg)	67.374	34.472	38.804	40.808
Damper Weight (kg)	23.137	13.552	11.436	12.786
Total Front Suspension	90.511	48.024	50.24	53.594
Curb Mass	1705	1560.4	1620.2	1603.7
Normalized to 1700 kg Curb Mass	90.511	52.47	52.87	56.98

Table 10.3.b.: Low Mass Rear Suspension Systems

				
	2009 Toyota Venza 2.7 FWD	**2005 Toyota Sienna V6 3.3 l XLE Blue Sil**	**2005 Alfa Romeo 147 1.9l JTD Multijet**	**2006 Opel Astra III 1.8l**
Suspension Type	Strut with 3 lower links	Twist axle	Strut with 3 lower links	Twist axle
Weight	46.162	44.242	25.348	32.904
Damper Weight (kg)	21.651	13.942	15.472	7.431
Total Front Suspension	67.813	58.184	40.82	40.335
Curb Mass	1705	2091	1298	1257
Normalized to 1700 kg Curb Mass	67.81	47.44	53.62	54.71

Suspension System Architecture Benchmarking

Although a basic assumption for this study was to maintain the suspension architecture of the Venza, an analysis was conducted to determine if there might be low mass alternatives available if this assumption was relaxed.

The Venza incorporates a MacPherson strut with lower A-arm for the front suspension and a MacPherson strut with three lower links for the rear suspension. The Venza architecture is representative of the lightest front suspension; execution on VW Passat is lightest.

An analysis was done to evaluate the relative mass efficiency of the Venza front and rear suspensions relative to other widely used suspension types. Production suspension configurations were selected and normalized to the Venza 1705 kg curb mass. Tables 10.3.c. through 10.3.f. list the results of this analysis.

An explanation of suspension types and terminology is included in the Suspension Architecture Explanation and Nomenclature area in the "Technical Key" section.

Table 10.3.c.: Front Suspension Average Masses

	Venza - MacPherson strut with lower A arm	MacPherson Strut, 2 Lower Links (High Al Content)	Hi A arm, 2 lower links, Coil/Shock (High Al Content)	MacPherson Strut, Lower A arm – Car (Mixed Content)	4 Link, Coil/Shock	MacPherson Strut, Lower A arm - SUV	Hi arm SLA, Coil/Shock
Arms/ Subframe/ Wheel Carrier	67.4	43.2	55.6	45.7	47.4	62.9	74.8
Dampers/ Springs	23.1	13.0	12.8	14.9	18.7	19.2	17.9
Total	90.5	56.2	68.4	60.6	66.1	82.1	92.8
Curb	1705	1644.1	1831.4	1589.7	1638.9	1685.0	1554.0
Normalized	90.5	57.8	63.7	65.1	69.2	83.0	92.6
Vehicles used:		-05 BMW 320i -07 Mercedes C220 -04 BMW 5 Series 3.0i	-08 Mercedes CLS -06 Mercedes S Class	-08 Mazda 5 -04 Ford Tourneo -07 Citroen C4 -05 VW Passat	-08 Audi A4 -07 Audi A5 -05 Audi A6	-07 Toyota Rav4 -08 Suzuki Grand Vitara -07 Hyundai Tucson	-08 Maxda 6 -06 Alfa Romeo 159 -06 Chrysler 300C

Table 10.3.d.: Front Suspension Minimum Masses

	Venza - MacPherson strut with lower A arm	**Low Mass MacPherson Strut, Lower A arm**	MacPherson Strut, 2 Lower Links	Hi A arm, 2 lower links, Coil/Shock	4 Link, Coil/Shock	MacPherson Strut, Lower A arm - Car	MacPherson Strut, Lower A arm - SUV	Hi arm SLA, Coil/Shock
		05 VW Passat 1.9 (High Al Content)	04 BMW 5 Series 3.0i RWD (High Al Content)	08 Merc CLS 350 RWD (High Al Content)	05 Audi A6 AWD (High Al Content)	07 Citroen C4 2.0 FWD (Mostly Fe Alloys)	08 Suzuki Grand Vitara 1.9 AWD (Mostly Fe Alloys)	06 Chrysler 300C AWD
Arms/ Subframe/ Wheel Carrier	67.4	34.5	38.8	53.1	48.1	48.2	60.1	76.577
Dampers/ Springs	23.1	13.6	11.4	11.4	17.9	16.9	20.0	20.426
Total	90.5	48.0	50.2	64.6	66.0	65.0	80.1	97.003
Curb	1705	1560.4	1620.2	1734.0	1753.8	1679.0	1702.0	1871.00
Normalized	90.5	52.5	52.9	63.5	64.2	66.0	80.3	88.4

Table 10.3.e.: Rear Suspension Average Masses

	Venza - MacPherson strut with lower A arm	Twist Axle	Hotchkiss dead axle	**Strut with 3 lower links**	3 link	Lower H arm, 1 upr link, coil/shk	5 link	H arm lwr, 2 link upr	4 link
Arms/ Subframe/ Wheel Carrier	46.2	37.9	34.6	30.4	54.7	53.3	53.7	59.0	56.7
Dampers/ Springs	21.7	10.1	20.1	16.9	10.6	10.1	10.4	10.4	9.6
Total	67.8	48.1	54.7	47.3	65.3	63.3	64.2	69.5	66.3
Curb	1705	1486.2	1624.2	1368.8	1590.1	1498.2	1516.8	1634.2	1521.2
Normalized	67.8	55.1	57.4	58.9	70.0	72.1	72.1	72.5	74.3
Vehicles used:		-06 Opel Astra -04 Peugeot 307 -05 Toyota Sienna -07 Citroen C4 -04 Toyota Corolla	-04 Ford Tourneo	-07 Hyundai Tucson -05 Alfa Romeo 147 -05 Kia Accent	-02 Opel Vectra -04 BMW X3 -06 Alfa Romeo 159	-07 Honda CRV -05 Honda FRV	-05 BMW 320i -07 Mercedes C220	-04 BMW 5 -08 Audi A4 -05 Audi A6 -07 Audi A5	05 Ford Focus C-Max 05 VW Passat 04 Volvo S40 08 Mazda 5

Table 10.3.f.: Rear Suspension Minimum Masses

	Venza - MacPherson strut with lower A arm	Twist Axle	**Strut with 3 lower links**	Hotchkiss dead axle	3 link	H arm lwr, 2 link upr	4 link	5 link	Lower H arm, 1 upr link, coil/shk
		05 Toy Sienna AWD	05 Alfa Romeo 147 1.9l	04 Ford Tourneo 1.8	04 BMW X3 AWD	07 Audi A5 3.0 4WD	05 Volks Passat 1.9	07 Merc C220 RWD	07 Honda CRV 2.0 4WD
Arms/ Subframe/ Wheel Carrier	46.2	44.2	25.3	34.6	59.3	55.4	50.5	53.9	52.6
Dampers/ Springs	21.7	13.9	15.5	20.1	12.5	9.9	9.9	9.8	10.3
Total	67.8	58.2	40.8	54.7	71.9	65.3	60.4	63.6	62.8
Curb	1705	2091.0	1298.0	1624.2	1922.3	1707.3	1560.4	1603.7	1540.0
Normalized	67.8	47.4	53.6	57.4	63.7	65.2	66.0	67.6	69.6

This analysis shows that a front strut suspension and a rear twist axle are the lightest suspensions. The Venza front strut suspension design is competitive for mass. The Venza rear suspension type is lighter than all types except a twist axle. It is possible that a twist axle rear suspension could be developed to meet the requirements of the Venza but it is not a competitive architecture for the Venza's target market segment.

A front strut suspension with two lower links had a significant mass advantage vs. the Venza strut. However, this is a higher cost suspension incorporating significant Aluminum content and is used only on vehicles that are more expensive than the Venza. The Volkswagen Passat uses a strut with a lower "A" arm and has the lowest normalized mass. The Passat front suspension incorporates several Aluminum components and demonstrates the mass efficiency of this suspension type. The Passat MSRP is similar to the Venza's MSRP.

Low Mass Brake Systems

The following Table 10.3.g. summarizes low mass production systems by normalizing brake system mass data. The Toyota Prius was selected as the benchmark system for mass and cost development. The Prius is approximately the same GVW for the 20% reduced curb mass target and incorporates hybrid appropriate braking technologies.

Table 10.3.g.: Low Mass Brake Systems

	2009 Toyota Venza 2.7 FWD	2008 Fiat 500 1.2 Lounge	2005 Toyota Sienna V6 3.3 l XLE Blue Sil	2005 Porsche Cayenne Turbo	2008 Toyota Prius 1.5 Base
	Rear Drum-in-hat	Rear Drum	Rear Drum-in-hat	Rear Drum-in-hat	Rear Drum
System Mass	64.835	30.542	64.577	82.768	43.508
Curb Mass	1705	1001.7	2091	2591.1	1349.1
Normalized to 1700 kg Curb Mass	64.84	51.99	52.66	54.46	54.99

Low Mass Tire & Wheel Systems

The following Table 10.3.h. summarizes low mass production tire & wheel systems. The Prius was selected as the basis for tires and wheels. The mass values were normalized to the Venza mass to define the Low Development baseline.

Table 10.3.h.: Low Mass Tire & Wheel Systems

	2009 Toyota Venza 2.7 FWD	2008 Toyota Prius 1.5 Base	2003 Citroen C5 2.0 HDi Exclusive	2008 Kia Carens 2.0 CRDI Active
	P245/55R19 Al Alloy	P185/65R15 Al Alloy	P195/65R15 Steel	P215/55R16 Al Alloy
Weight	140.165	69.226	70.714	90.13
Curb Mass	1705	1349.1	1342.6	1652.8
Normalized to 1700 kg Curb Mass	140.17	87.49	89.80	92.98

10.4. Chassis Analysis

10.4.1. Low Development Analysis

Suspension and Steering

This section develops a Low Development chassis architecture targeted to be 20% lighter than the Venza with a cost factor less than 120%. As is shown in Tables 12.4.1.a. and 12.4.1.b. the targets were easily achieved with a 32% mass reduction in the front suspension and steering and 33% in the rear suspension. This was accomplished with an 8% cost increase and a 4% cost reduction respectively.

Suspension & Chassis Subsystems

Figure 10.4.1.a. shows the Venza Front Suspension and Steering Systems with all the components considered in this study. Figure 10.4.1.b. shows the Venza Rear Suspension with all of its components.

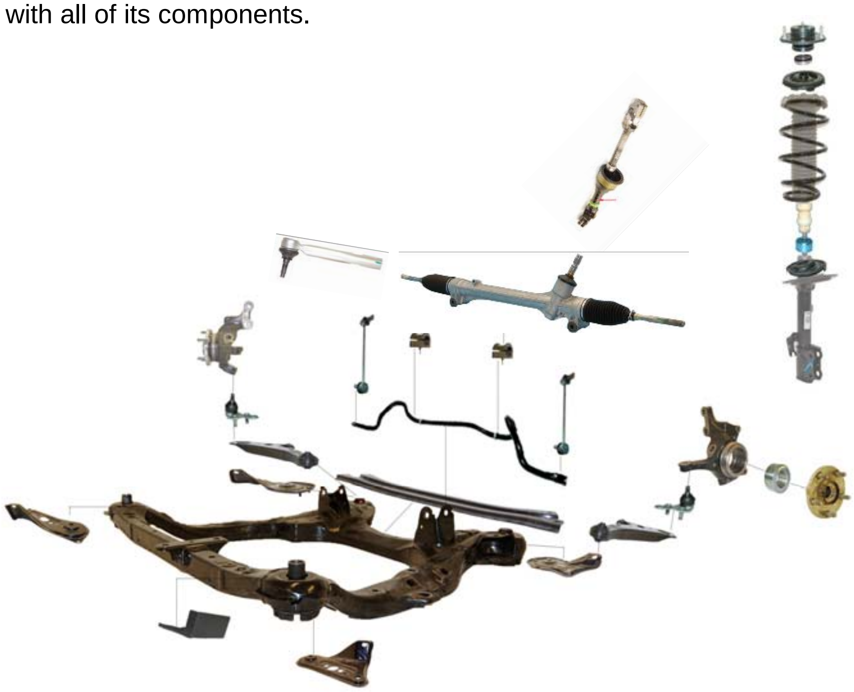


Figure 10.4.1.a.: Front Suspension & Chassis with steering gear

Figure 10.4.1.b.: Rear Suspension & Chassis

Selected Technologies and Materials

- **High strength spring steel for springs**
- There are a variety of spring steels on the market which would allow a mass reduction due to their higher strength. These are used on many vehicles on the market today.
- The Venza springs are basic AISI 5160 spring steel, with the front spring shown in Figure 10.4.1.c.; while the benchmarked low mass springs from the front of the BMW320i shown in Figure 10.4.1.d. and Alfa Romeo 147 use higher strength spring steel.
- For this study the higher stress spring designs resulted in a 1 kg savings per spring for equivalent performance.

Figure 10.4.1.c.: 2009 Toyota Venza Front Spring
3.26 kg

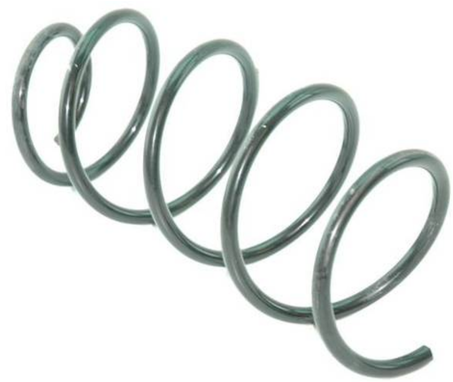


Figure 10.4.1.d.: 2005 BMW 320i Front Spring
1.6 kg/1.90 kg normalized
(High strength steel)
1.3 cost multiplier

<u>Front & Rear Strut Mounts</u> (Included in Low and High Development BOM's) BMW (Figure 10.4.1.f.) uses Aluminum stampings as the structural element of their strut top mounts through their entire range of vehicles. This demonstrates the suitability of this design for use in a Venza level vehicle. The Venza mount is shown in Figure 10.4.1.e. for reference.

Figure 10.4.1.e.: 2009 Toyota Venza Front Mount
1.233 kg (Steel shell)

Figure 10.4.1.f.: 2006 BMW 730i Front Mount
0.468 kg/.393 kg normalized
(Al shell) 1.20 cost multiplier

<u>Front Upper Spring Seat</u> (Included in Low and High Development BOM's)
The Mazda 5 uses a glass filled nylon upper spring seat(Figure 10.4.1.h.) for the front strut. The Mazda 5 is in the range of mass targeted for the low development vehicle so this spring seat

design would work adequately for either the low or high development vehicle. The Venza front spring seat is shown in Figure 10.4.1.g.

Figure 10.4.1.g.: 2009 Toyota Venza Upper Spring Seat
0.535 kg (Steel)

Figure 10.4.1.h.: 2008 Mazda 5 Upper Spring Seat
0.123 kg/0.139 kg normalized
(Nylon 66, 30% glass) 0.5 cost multiplier

- **Cast Magnesium for structural components**
  - As new alloys are developed and processing improvements are made this material will see increased usage in vehicle chassis'.
  - Meridian supplies a cast magnesium subframe for the Corvette ZO6 which is shown in Figure 10.4.1.j[47].. Figure 10.4.1.i. shows the Venza front subframe for reference.
  - Meridian estimates a mass savings of 10 kg (40%) with a 25% cost increase for a magnesium Venza front subframe.
  - Meridian estimates a mass savings of 3 kg (36%) with a 36% cost increase for a magnesium Venza rear subframe.
  - Only the front magnesium subframe is included in the High Development BOM due to the cost tradeoffs.

<u>Front Subframe</u> (Included in Low and High Development BOM)

Figure 10.4.1.i.: 2009 Toyota Venza Subframe
26.992 kg (Steel)

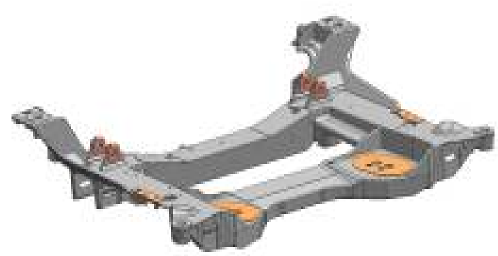


Figure 10.4.1.j.: Cast Magnesium Subframe
15 kg for equivalent part
1.25 cost multiplier

<u>Front Stabilizer Bar from tube stock</u> (Included in Low and High Development BOM's)

Hollow stabilizer bars are frequently used on all types of vehicles for mass savings. The Venza front stabilizer bar is solid and its mass is 6.091 kg. A comparable hollow bar would be 3.66 kg at a cost multiplier of 1.10. The Venza front stabilizer bar is shown in Figure 10.4.1.k.

Figure 10.4.1.k.: Venza Front Stabilizer Bar

<u>Front & Rear Aluminum Knuckle</u> (Included in Low and High Development BOM's)

Aluminum knuckles are used on a variety of vehicles. In this case the Passat has a vehicle mass higher than the target masses in this study. The Passat knuckle (Figure 10.4.1.m.) also includes a pinch bolt strut attachment which matches up with the strut already included in the BOMs. The Venza front knuckle is shown in Figure 10.4.1.l. for reference.

Figure 10.4.1.l.: Venza Front Knuckle
5.945 kg (Cast Iron)

Figure 10.4.1.m.: 2005 Passat Front Knuckle
3.012kg/3.28 kg normalized(Cast Al)

- **Integrated hub, bearing and knuckle module**
  - SKF estimates a 20 – 22% mass savings for a knuckle/bearing/hub assembly[48].
  - SKF estimates a -7% to +26% cost penalty depending on baseline bearing design due to integration assembly steps needed.
  - SKF expects a performance improvement due to the increased stiffness of the assembly.

<u>Rear brake heat shield</u> (Included in Low and High Development BOM's)

Venza uses a drum in hat parking brake which uses drum brakes inside a hat section for the parking brake and an outer flange for disc brakes for the service brakes. The heat shield (Figure 10.4.1.n) has a drum park brake backing plate integrated into it which absorbs the forces from the drum brake shoe assembly. For this study we have selected an integral park brake caliper for the disc brake to provide the park brake function in order to save mass and cost. Therefore the backing plate is no longer needed. The 2005 Alfa Romeo 147 heat shield shown in Figure 10.4.1.o. is typical of a single function heat shield. The integral park brake caliper capacity is adequate for the Low and High Development vehicle masses.

Figure 10.4.1.n.: Toyota Venza Rear Heat shield

1.595 kg

(Multi piece with heavy gage brake backing plate)

Figure 10.4.1.o.: 2005 Alfa Romeo 147 Rear Heat Shield

0.327 kg/0.428 kg normalized

(Light gage steel)

<u>Rear Knuckle</u> (Included in Low and High Development Models)

Alfa Romeo uses a highly compact knuckle design shown in Figure 10.4.1.q. which still allows reasonable suspension geometry. Although the link to knuckle attachments are not as robust as those used on the Venza, they should be sufficient for the low and high development vehicle masses as the Alfa Romeo 147 is close to the target masses. The BOM's also include the mass and cost of using Aluminum for this component. The Venza rear knuckle is shown in Figure 10.4.1.p. for reference.

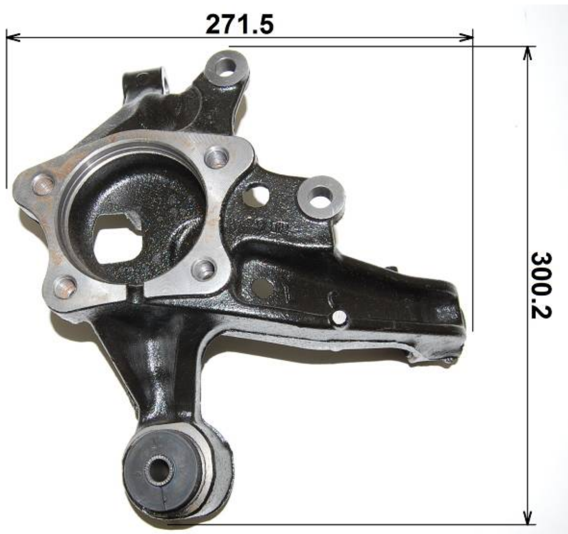


Figure 10.4.1.p.: 2009 Toyota Venza Rear Knuckle
5.58 kg (Cast Iron)

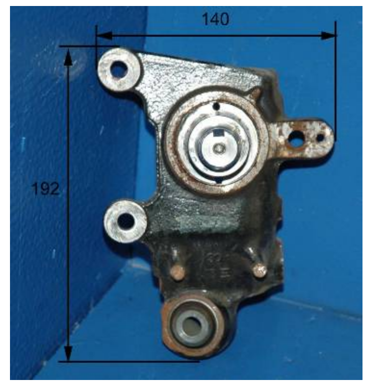


Figure 10.4.1.q.: 2005 Alfa Romeo 147 Knuckle
2.643 kg/3.46 kg normalized (Cast Iron)
0.62 cost multiplier

Brakes

Table 10.4.1.c. shows the low development BOM for the brake system. As can be seen the mass target of a 20% reduction was not able to be achieved with low development technologies or without significant cost increases.

Braking Subsystem

Figure 10.4.1.r. shows the components reviewed in this study for the brake system. (Parking brake cables are not shown)

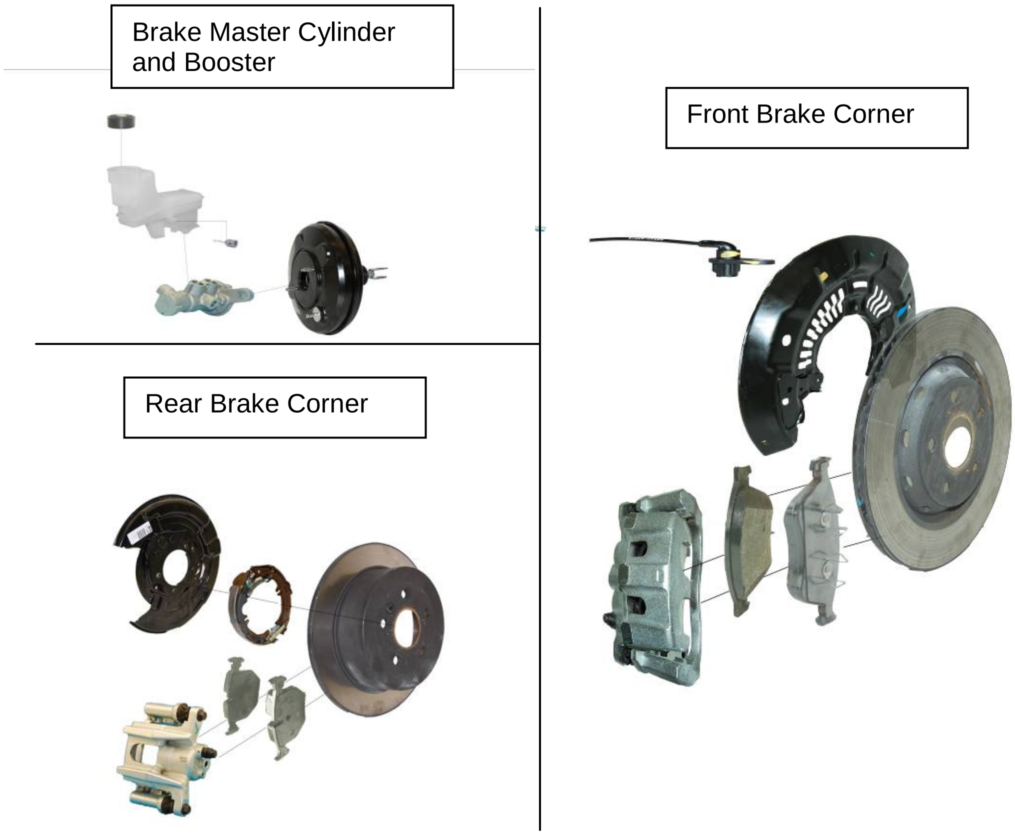


Figure 10.4.1.r.: Brake System Components

Selected Technologies and Materials

Power brake assist

For a hybrid powertrain a hydraulic power assist is expected to be the best choice as used on the Toyota Prius shown in Figure 10.4.1.t. It was expected to be a mass savings but ended up being an even tradeoff for mass and a 35% cost increase but due to the intended powertrain it is a needed system regardless of mass or cost impact. The Venza brake booster is shown in Figure 10.4.1.s. for reference.

Figure 10.4.1.s.: 2009 Toyota Venza
Vacuum booster assy

Figure 10.4.1.t.: 2008 Toyota Prius
Hydraulic pump, plus pipes and bracket
1.854 kg/2.34 kg normalized

- **Electric apply for integral park brake caliper**
  - This design is in production today on several vehicles, including heavier vehicles (Audi A8, Volvo XC60). This is used with an integrated park feature in the rear brake caliper.
  - The electric park apply does not affect the service brake performance.
  - This design is included in the Low and High Development BOM's.
  - This design results in approximately 6 kg/vehicle mass savings and a 46% total system cost savings. The breakouts shown below indicate the total and the chassis only impact since only the chassis content will be presented in the BOM's for this system.

Park brake system

The Venza uses a "drum-in-hat" rear brake system which uses a small drum brake for the park brake function with a disc brake for dynamic braking. This is accommodated by a hat shaped rotor with a small drum on the inside and a flange on the outside diameter for the disc brake to apply. The Venza Park Brake components are shown in Figure 10.4.1.u. and the Passat Park Brake Components are shown in Figure 10.4.1.v.

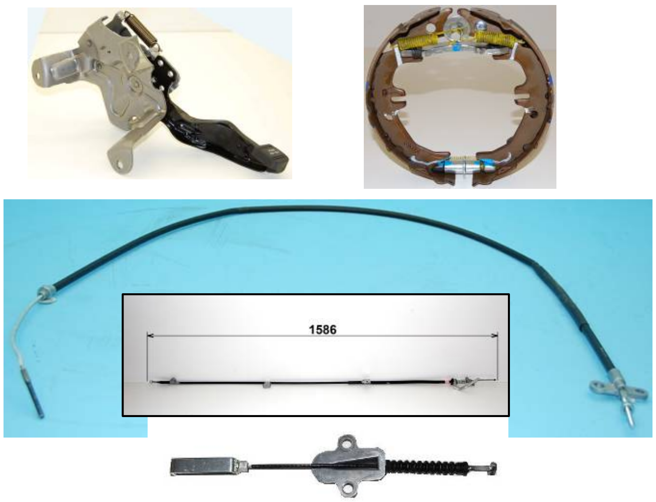


Figure 10.4.1.u.: 2009 Toyota Venza
Pedal, cables, shoes
7.281 kg(total)/4.09 kg(chassis)

Figure 10.4.1.v.: 2005 Volkswagen Passat
Button and actuators
1.041 kg/1.138 kg normalized
0.54 total system/0.8 chassis cost
multiplier (remainder included in

Low Development BOM for Tires & Wheels

Figure 10.4.1.w. shows the Venza Tire & Wheel assembly. Table 10.4.1.d. shows the low development BOM for this system with the impact of the smaller tire and wheel.

Figure 10.4.1.w.: Venza Tire & Wheel

Selected Technologies and Materials

<u>Low mass cast Al wheel</u> (Included in low and high development)

Several vehicles currently in production and several in the Venza price range use lower mass cast aluminum wheel designs. These are shown in Figure 10.4.1.x. along with the Venza wheel. The primary difference was the depth and number of the spokes. The example vehicles indicate the appropriateness of this design for the study vehicle. Applying the ablation casting technique to the Prius wheel would result in an estimated wheel mass of 8.6 kg.

Figure 10.4.1.x.: Venza Wheel shown along with some sample low mass wheel designs.

10.4.2. High Development Analysis

The High Development suspension BOMs in Table 10.4.2.a. and Table 10.4.2.b. used the Low Development BOM as the baseline and introduced more advanced technologies to reduce mass to the 40% target. Additionally, all components were reduced in mass as a result of the lower mass of the vehicle. The advanced technologies used are described below. The cost target was < 150% cost increase vs. the baseline Venza.

Selected Technologies

- **Foam reinforced stamped assemblies**
- This technology could be used for control arms and subframes.
- The application of Henkel's Terocore® foam reinforcement technology to a production stamped lower control arm shown in Figure 10.4.2.b. saved 1.0 kg (25%) by using a nylon insert overmolded with Terocore foam and eliminating the lower half of the stamped control arm. The estimated mass savings for the Venza foam reinforced lower control arm is approximately ~2 kg per vehicle with no change in cost. The Venza control arm is shown in Figure 10.4.2.a. for reference.
- This technology is in production on some underbody rails (Sprinter, Crown Victoria)

<u>Front Lower Control Arm – Foam reinforced, single piece stamping</u>
(Included in High Development BOM)

Figure 10.4.2.a.: 2009 Toyota Venza LCA
8.657 kg (Steel)

Figure 10.4.2.b.: Henkel designed Foam Reinforcement
6.6 kg normalized/ no cost increase

Brakes

Table 10.4.2.c. shows the high development BOM for the brake system. As can be seen the mass target of a 40% reduction was not able to be achieved with anticipated, reasonable cost (less than a 100% increase) technologies.

Selected Technologies

- **Dual cast rotor**
  - Two designs of this concept exist today.
  - A Brembo rotor design (Figure 10.4.2.d.) is in production and combines a cast Aluminum hub with a cast iron ring for the braking surface. (20% mass savings/rotor, +100% cost). The Venza brake rotor is shown in Figure 10.4.2.c. for reference.
  - A second design being investigated incorporates cast iron braking surface cast into a cast Aluminum body. (40% mass savings, at an estimated +50-100% cost)

Dual cast rotors

This is felt to be most applicable to the front rotor due to its size. This technology has not been used on solid rotors as yet. A solid rotor would be the likely choice for the rear brakes.

Figure 10.4.2.c.: 2009 Toyota Venza Front Brake Rotor
8.91 kg
(Single piece cast iron)

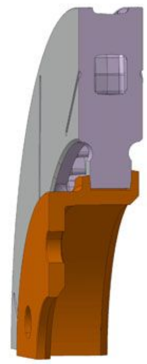


Figure 10.4.2.d.: Brembo Dual Cast Rotor
est. 7.15 kg for equivalent design
(Cast Aluminum hub with cast iron ring)

- **Fixed caliper**
  - Brembo produces a fixed caliper made with cast Aluminum which has opposing pairs of pistons as shown in Figure 10.4.2.f.
  - Aside from a mass savings, the opposing pistons would allow for full retraction of the brake pads from the rotor resulting in reduced drag with these brakes. Typical current brakes have a floating caliper which relies on the high spots of the rotor to “knock” the pads away from the rotor surface which is not as effective. The Venza Front Brake Caliper is shown in Figure 10.4.2.e.
  - A typical fixed Aluminum caliper could save 20% of the mass per caliper vs. a floating Aluminum brake caliper and provide an estimated 40% mass savings over a conventional floating cast iron caliper system. The Aluminum fixed caliper would be a 0 to 10% cost increase over a floating Aluminum caliper and about a 60% cost increase over a cast iron floating caliper.

<u>Fixed Aluminum Front Brake Caliper</u>(Included in high development BOM)

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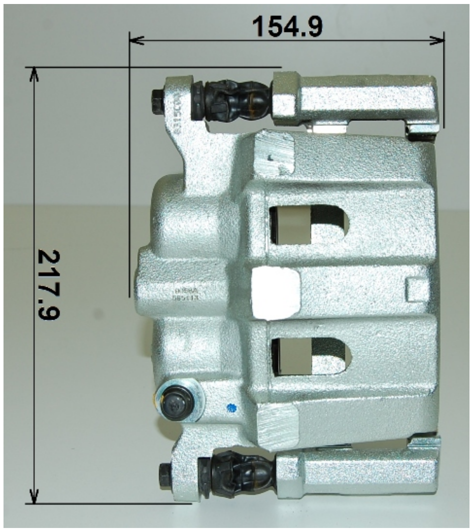


Figure 10.4.2.e.: 2009 Toyota Venza Front Caliper
6.036 kg

Figure 10.4.2.f.: Brembo 4 piston Fixed Aluminum Front Caliper
3.1 kg for equivalent caliper
1.50 cost multiplier

<u>Aluminum Rear Brake Caliper</u> (Included in high development BOM)

The lowest mass rear brake in a comparable mass vehicle was an Aluminum caliper used in the 2004 Toyota Corolla Verso Linea Sol shown in Figure 10.4.2.h. Due to its use in a comparable mass vehicle it should be acceptable for the high development vehicle. The Venza Rear Brake Caliper is shown in Figure 10.4.2.g.

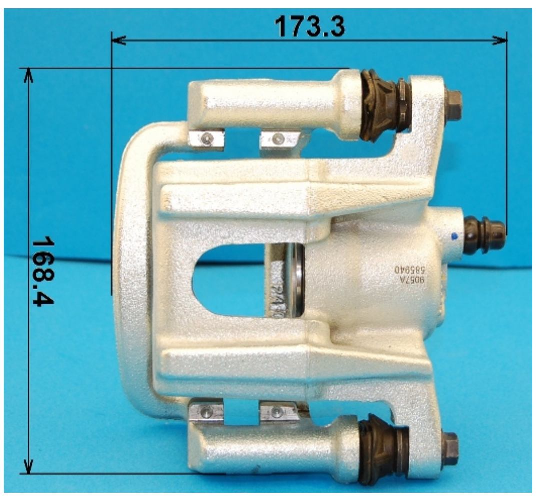


Figure 10.4.2.g.: 2009 Toyota Venza Rear Caliper
3.32 kg

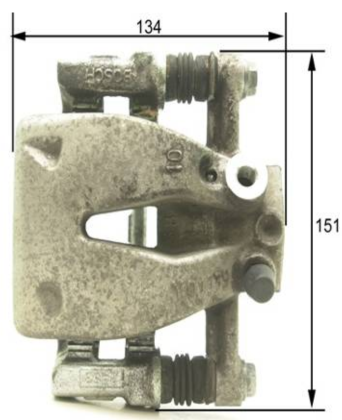


Figure 10.4.2.h.: 2004 Toyota Corolla Verso Linea Sol Rear Caliper
1.80 kg/2.15 kg normalized
1.50 cost multiplier

Selected Technologies and Materials

- **Eliminate spare tire/wheel**
- There are vehicles on the road today that do not have a spare tire.
- They carry a can of tire inflator as a temporary repair, have a run flat member installed inside the tire, or have stiff sidewalls which allow the vehicle to be driven short distances with a flat tire.
- Using the canned tire repair would eliminate an estimated 15 kg**/**vehicle and reduce the total wheel system cost by 10%. The new Dodge Challenger, all Porsches and most Mercedes use a canned tire repair kit. This mass savings technique is included in the high development BOM.
- Eliminating the spare tire/wheel assembly and using run flat tires with stiffer sidewalls would result in a net mass savings of approximately 9 kg for the baseline vehicle with minimal cost impact. The individual tire & wheel mass increases by 8-15%. The cost increase of the run flat tire is typically offset by the savings created by eliminating the spare tire. Run flat tires are used by BMW on all their models.
- Eliminating the spare tire/wheel and using a run flat tire/wheel which incorporates an internal sidewall support member such as the Michelin PAX system adds about 3% to the total vehicle tire & wheel system mass and increases cost by 15%. The Honda Odyssey used the PAX system for several years. Michelin discontinued production in 2008.

- **Ablation cast Aluminum wheels**
  - A relatively new process that rapidly quenches a sand cast alloy part resulting in fine grain structure with minimal voids[49].
  - Results in very good material properties, approaching forged properties.
  - Ablation cast aluminum wheels are being developed for the transportation industry, including motorcycles, Class 8 (heavy truck wheels are currently forged), and automobiles, by Alotech 1. This process has the potential to reduce wheel mass through flexible molding designs (since solidification can occur from thin to thick in regions), improve wheel fatigue characteristics by improved and enhanced microstructures compared with alternative processes, and reduce tooling costs compared to conventional and cast and forged aluminum wheel processes. The Ablation process offers advantages to wheel designs not offered by other processes since hollow sections and wrought based alloys (such as 7075, 2024, 5454 reserved previously only for forging) materials can be cast in Ablation. To achieve optimum results concurrent engineering typically is employed in the prototyping development stage by Alotech with the designer of the product. A two piece or single piece wheel design using an ablation cast beauty face with a ring riser could be produced. The advantage is the wheel face could be hollowed out for mass reductions, improved strength, optimization of rotating mass, and the ring riser spun to make the rim likely using existing tooling at a spinner source. The process is ideally suited for tooling low volumes and development of the product (appropriately funded) is extremely fast. The Ablation process has homogenous properties which is a clear advantage over forge and casting processes existing today. This technology could potentially create low mass cast wheels with fatigue and strength characteristics comparable to or better than a forged aluminum wheels since homogenous microstructures are produced throughout the process and the same alloys used in forging can be deployed at lower cost.
  - This process would be expected to save approximately 1 kg per wheel. Based on what is known about this process at this time it is expected to be a cost savings from the current casting process but for this study it is assumed to be cost neutral.

10.5. Chassis Results

10.5.1 Low Development Front Suspension and Steering

Table 10.5.1.a.: Low Development Front Suspension and Steering

	Qty	Baseline Mass (2009 Toyota Venza)	New Mass (2005 VW Passat)		Cost impact
Total front suspension & Chassis		**101.34**	**68.10**	**33% Lower**	1.07
Front Dampers		23.14	15.62		0.99
Strut Module assy	1	11.56	7.81		1.00
Strut assembly	1	5.88	3.80		0.95
Spring [High Strength Steel]	1	3.26	2.06		1.10
Jounce bumper	1	0.07	0.05		0.99
Bearing	1	0.13	0.30		1.09
Dust cover	1	0.21	0.07		0.71
Upper Spring Seat [Nylon]	1	0.54	0.12		0.31
Dust cover	1	0.09	0.02		0.85
Dust cover support	1		1.05		1.00
Strut top mount [Al metals]	1	1.23	0.33		1.47
Lower coil spring tower	1	0.17			0.94
Front Suspension		67.37	43.13		1.11
Subframe(Cast Magnesium)	1	26.99	14.80		1.14
Subframe reinforcements		2.80	2.44		
Rear reinforcement	1	0.16	0.14		0.98
Front frame member linkages	2	1.43	1.24		0.98
Second rear reinforcement	2	1.21	1.05		0.98
Control arm	2	8.66	7.54		0.98
Stabilizer bar system		7.73	4.56		
Stabilizer bar[Hollow]	1	6.09	3.09		0.82
Bushings	2	0.10	0.10		1.00
Brackets	2	0.68	0.68		1.00
Drop link	2	0.86	0.69		0.96
Balljoint	2	1.97	1.32		0.93
Steering knuckle		17.93	11.72		
Knuckle[Aluminum]	1	5.95	3.50		1.65
Hub	1	1.99			
Front wheel bearing	1	1.04			
Hub + bearing	1		3.82		1.02
Integral Hub/Knuckle/Bearing			-1.46		no cost
Complete Knuckle assy - RH	1	8.94	5.86		
Dust cover	2		0.75		new
Mass damper	1	1.30			deleted
Steering system		10.83	9.35		0.99
Intermediate shaft	1	0.77	0.66		0.98
Column coupling	1	1.030	1.03		1.00
Steering gear	1	7.28	6.19		0.99
Tie rod ends	2	1.74	1.48		0.98

The bold components are revised from the selected basis vehicle and are reviewed in Section below.

10.5.2 Low Development Rear Suspension

Table 10.5.2.a.: Low Development Rear Suspension

	Qty	Baseline Mass (2009 Toyota Venza)		New Mass (2005 Alfa Romeo 147)			Cost Impact
Total rear suspension		**67.813**		**44.641**	**34% Lower**		0.95
Rear Dampers		21.651		15.433			1.07
Spring[Hi Strength Steel]	1	3.343		1.300			1.38
Strut module right	1	10.815		7.716			1.00
Strut assembly	1	6.138		5.760			0.99
Dust cover strut	1	0.308		0.052			0.66
Bump Stop	1	0.093		0.026			0.91
Jounce Bumper	1	0.083		0.044			0.98
Top Mount [Al metals]	1	0.800		0.332			1.47
Tower cover	1	0.013		0.013			1.00
Upper spring insulator	1			0.083			new
Lower spring insulator	1	0.058		0.105			1.06
Rear Suspension		46.162		29.208			0.90
Subframe	1	9.044		6.631			0.93
Subframe reinforcements		0.672		0.672			
Front left	1	0.333		0.333			1.00
Front right	1	0.339		0.339			1.00
Fore/aft Link	2	2.366		2.061			0.99
Lateral links		6.247		4.735			
Front	2	3.128		1.879			0.95
Rear	2	3.119		2.856			0.99
Heat shield	2	3.189		0.715			0.25
Bearing and hub	2	8.478		7.386			0.98
Knuckle[Auminum]	2	11.160		3.820			1.00
Stabilizer bar system		3.743		3.188			
Stabilizer bar	1	2.866		2.344			1.00
Bushings	2	0.074		0.074			1.00
Brackets	2	0.183		0.183			1.00
Drop link	2	0.620		0.586			1.00
Mass damper	1	1.263					deleted

The bold components are revised from the selected basis vehicle and are reviewed in Section below.

10.5.3 Low Development Brake System

Table 10.5.3.c.: Low Development Brake System

	Qty	Baseline Mass (2009 Toyota Venza)	New Mass (2008 Toyota Prius)		Cost impact
Brakes mechanism		**65.214**	**57.480**	**12% Lower**	**1.00**
Master cylinder		2.922	3.911		
Master cylinder	1	0.468	0.985		1.08
Reservoir		0.175	0.662		
Reservoir	1	0.147	0.336		0.85
Support	1		0.296		new
Cap	1	0.028	0.030		0.99
Power booster System		2.272	1.855		1.18
Vacuum Brake Booster	1	2.272	0.000		deleted
Hydraulic pump	1		0.834		new
Hydraulic pump bracket	1		0.214		new
Pipe MC to tank	1		0.438		new
Pipe MC to ABS unit	1		0.369		new
Brake pedal bracket	1		0.400		new
Level sensor	1	0.007	0.009		1.00
Front brakes		33.413	22.556		
Disc	2	17.820	12.811		0.96
Brake caliper	2	12.071	7.413		0.96
Brake pads	2	2.004	1.377		0.98
Speed sensor	2	0.351	0.260		0.97
Hose	2	0.274	0.307		1.01
Backing plate	2	0.893	0.388		0.93
Rear brakes		21.828	18.177		
Speed sensor	1	integral to hub	0.038		new
Hose	1	0.313	0.228		0.97
Drum park brake system		2.517			
Shoes	2	2.517			deleted
Disc system		18.998	17.859		
Disc	2	11.341	10.619		0.99
Brake caliper	2	6.624	6.008		0.99
Brake pads	2	1.033	1.232		1.01
Speed sensor tone ring	1	integral to hub	0.052		new
Park Brake Apply		1.573	1.1745		
Park Brake Actuator	2		**1.174**		new
Cables		1.573	0.000		
Rear cables	2	1.407	0.000		deleted
Center cable	1	0.166	0.000		deleted
ABS system		2.737	9.869		
Bracket	1	0.443	0.202		0.93
ABS pump	1	2.294	7.325		1.25
Bracket	1		2.070		new
Anti-vibration mass	1		0.273		new
Brake line system	1	2.362	0.813		0.34
Distribution block	1		0.601		new
Brake Fluid	1	0.379	0.379		1.00

The bold components are revised from the selected basis vehicle and are reviewed in Section below.

10.5.4 Low Development Tires & Wheels

Table 10.5.4.a.: Low Development Tires & Wheels

	Qty	Baseline Mass (2009 Toyota Venza)		New Mass (2008 Toyota Prius)			Cost Impact
Tires & Wheels	1	**144.541**		**108.896**	**25% Lower**		0.96
Road Tire & Wheel		120.989		87.344			0.95
Front	1	60.249		43.672			0.95
Wheel[19 x 6.5]	1	15.300		8.600			0.93
Tire[P225/60R19]	1	14.880		13.200			0.98
Valves	1	0.036		0.036			1.00
RH Wheel & Tire assy	1	30.010		21.836			0.95
Ball bearing hub cover	1	0.023		0.023			1.00
Rear	2	60.740		43.672			0.95
Spare Tire & Wheel	1	19.176		17.176			0.99
Rim	1	10.731		9.731			1.00
Tires	1	8.435		7.435			0.98
Valves	1	0.010		0.010			1.00
Tool box		4.220		4.220			1.00
Car jack	1	1.791		1.791			1.00
Handle	1	0.312		0.312			1.00
Wheel lock	1	0.479		0.479			1.00
Container	1	0.756		0.756			1.00
Container 2	1	0.882		0.882			1.00
Tire presure system		0.156		0.156			1.00
TPM control unit	1	0.042		0.042			1.00
Control unit bracket	1	0.031		0.031			1.00
Rear wheels receiver	1	0.083		0.083			1.00

The bold components are revised from the selected basis vehicle and are reviewed in Section below.

10.5.5 High Development Suspension and Steering Results

The High Development suspension BOMs in Table 10.5.5.a. and Table 10.5.6.a. used the Low Development BOM as the baseline and introduced more advanced technologies to reduce mass to the 40% target. Additionally, all components were reduced in mass and cost reflecting the lower mass of the vehicle. The advanced technologies used are described below. The cost target was < 150% cost increase vs. the baseline Venza.

Table 10.5.5.a.: High Development BOM Front Suspension and Steering

	Qty	Baseline Mass (2009 Toyota Venza)		New Mass (2005 VW Passat)		Cost impact
Total front suspension & Chassis		**101.340**		**57.296** **43% Lower**		1.01
Front Dampers		23.137		11.682		0.94
Strut Module assy	1	11.559		5.841		1.00
Strut assembly	1	5.880		3.418		0.94
Spring [High Strength Steel]	1	3.262		1.560		0.83
Jounce bumper	1	0.069		0.048		0.99
Bearing	1	0.125		0.269		1.07
Dust cover	1	0.209		0.058		0.70
Upper Spring Seat [Nylon]	1	0.535		0.109		0.27
Dust cover	1	0.092		0.071		0.96
Dust cover support	1			0.015		
Strut top mount [Al metals]	1	1.233		0.293		1.29
Lower coil spring tower	1	0.173				0.94
Front Suspension		67.374		37.304		1.04
Subframe(Cast Magnesium)	1	26.992		13.30		1.05
Subframe reinforcements		2.798		2.191		
Rear reinforcement	1	0.163		0.128		0.97
Front frame member linkages	2	1.426		1.116		0.97
Second rear reinforcement	2	1.209		0.947		0.97
Cntrl arm[Foam Reinforced]	2	8.657		5.083		0.82
Stabilizer bar system		7.726		4.340		
Stabilizer bar[Hollow]	1	6.091		2.542		0.78
Bushings	2	0.098		0.098		1.00
Brackets	2	0.677		0.677		1.00
Drop link	2	0.860		1.023		1.04
Balljoint	2	1.973		1.188		0.92
Steering knuckle		17.925		10.529		
Knuckle[Aluminum]	1	5.945		3.144		1.49
Hub	1	1.992				
Front wheel bearing	1	1.044				
Hub + bearing	1			3.436		1.01
Integral Hub/Knuckle/Bearing				-1.316		no cost inc
Complete Knuckle assy - RH	1	8.944		5.264		
Dust cover	2			0.670		
Mass damper	1	1.303				deleted
Steering system		10.829		8.310		0.98
Intermediate shaft	1	0.773		0.577		0.97
Column coupling	1	1.030		1.000		1.00
Steering gear	1	7.284		5.434		0.98
Tie rod ends	2	1.742		1.299		0.97

The hardware shown in bold is revised from the selected Low Development components and is reviewed in Section below.

10.5.6 High Development Rear Suspension

Table 10.5.6.a.: High Development Rear Suspension

	Qty	Baseline Mass (2009 Toyota Venza)		New Mass (2005 Alfa Romeo 147)			Cost Impact
Total rear suspension		**67.813**		**39.460**	**42% Lower**		0.92
Rear Dampers	1	21.651		13.523			1.02
Spring[Hi Strength Steel]	1	3.343		1.000			1.06
Strut module right	1	10.815		6.762			1.00
Strut assembly	1	6.138		5.176			0.97
Dust cover strut	1	0.308		0.047			0.66
Bump Stop	1	0.093		0.024			0.91
Jounce Bumper	1	0.083		0.039			0.98
Top Mount [Al metals]	1	0.800		0.293			1.29
Tower cover	1	0.013		0.013			1.00
Upper spring insulator	1			0.075			new
Lower spring insulator	1	0.058		0.094			1.05
Rear Suspension		46.162		25.936			0.88
Subframe	1	9.044		5.959			0.91
Subframe reinforcements		0.672		0.672			
Front left	1	0.333		0.333			1.00
Front right	1	0.339		0.339			1.00
Fore/aft Link	2	2.366		1.765			0.97
Lateral links		6.247		4.255			
Front	2	3.128		1.688			1.00
Rear	2	3.119		2.567			1.00
Heat shield	2	3.189		0.643			0.22
Bearing and hub	2	8.478		6.324			0.95
Knuckle[Auminum]	2	11.160		3.428			0.90
Stabilizer bar system		3.743		2.890			
Stabilizer bar	1	2.866		2.107			1.00
Bushings	2	0.074		0.074			1.00
Brackets	2	0.183		0.183			1.00
Drop link	2	0.620		0.527			1.00
Mass damper	1	1.263					deleted

The hardware shown in bold is revised from the selected Low Development components and is reviewed in Section below.

10.5.7 High Development Brakes

Brakes

Table 10.5.7.a. shows the high development BOM for the brake system. As can be seen the mass target of a 40% reduction was not able to be achieved with anticipated, reasonable cost (less than a 100% increase) technologies.

Table 10.5.7.a.: High Development Brakes

	Qty	Baseline Mass (2009 Toyota Venza)		New Mass (2008 Toyota Prius)			Cost impact
Brakes mechanism		**65.214**		**44.254**	**32% Lower**		**1.18**
Master cylinder		2.922		3.435			
Master cylinder	1	0.468		0.866			1.06
Reservoir		0.175		0.581			
Reservoir	1	0.147		0.295			0.88
Support	1			0.260			new
Cap	1	0.028		0.026			1.01
Power booster System		2.272		1.629			1.04
Vacuum Brake Booster	1	2.272		0.000			deleted
Hydraulic pump	1			0.732			new
Hydraulic pump bracket	1			0.188			new
Pipe MC to tank	1			0.385			new
Pipe MC to ABS unit	1			0.324			new
Brake pedal bracket	1			0.352			new
Level sensor	1	0.007		0.008			1.00
Front brakes		33.413		15.011			
Disc (Co-cast)	2	17.820		9.210			1.29
Brake caliper(Fixed Cast Al)	2	12.071		3.997			1.66
Brake pads	2	2.004		1.237			0.98
Speed sensor	2	0.351		0.260			0.97
Hose	2	0.274		0.307			1.01
Backing plate	2	0.893		0.000			
Rear brakes		21.828		14.531			
Speed sensor	1	integral to hub		0.038			new
Hose	1	0.313		0.228			0.97
Drum park brake system		2.517					
Shoes	2	2.517					deleted
Disc system		18.998		14.213			
Disc	2	11.341		9.543			0.98
Caliper(Floating Cast Al)	2	6.624		3.563			0.95
Brake pads	2	1.033		1.107			1.00
Speed sensor tone ring	1	integral to hub		0.052			new
Park Brake Apply		1.573		0.9874			
Park Brake Actuator	2			**0.987**			new
Cables		1.573		0.000			
Rear cables	2	1.407		0.000			deleted
Center cable	1	0.166		0.000			deleted
ABS system		2.737		8.669			
Bracket	1	0.443		0.177			0.93
ABS pump	1	2.294		6.434			1.20
Bracket	1			1.818			new
Anti-vibration mass	1			0.240			new
Brake line system		2.362		0.714			0.30
Distribution block	1			0.528			new
Brake Fluid	1	0.379		0.379			1.00

The hardware shown in bold is revised from the selected Low Development components and is reviewed in Section below .

10.5.8 High Development Brakes

High Development BOM for Tires & Wheels

Table 10.5.8.a. shows the high development BOM for the Tire & Wheel system with the impact of a smaller tire and wheel and the elimination of the spare tire & wheel and tools.

Table 10.5.8.a.: High Development Tire & Wheel BOM (Bill of Material)

	Qty	Baseline Mass (2009 Toyota Venza)			New Mass (2008 Toyota Prius)			Cost Impact
Tires & Wheels	1	**140.165**			**75.992**	**46% Lower**		0.81
Road Tire & Wheel		120.989			75.436			0.94
Front	1		60.249			37.718		0.94
Wheel[19 x 6.5] Ablation cast	1		15.300			7.000		0.91
Tire[P225/60R19]	1		14.880			11.800		0.96
Valves	1		0.036			0.036		1.00
RH Wheel & Tire assy	1		30.010			18.859		0.94
Ball bearing hub cover	1		0.023			0.023		1.00
Rear	2		60.740			37.718		0.94
Spare Tire & Wheel	1	19.176			0.400			0.08
Rim	1		10.731			0.000		deleted
Tires	1		8.435			0.000		deleted
Valves	1		0.010			0.000		deleted
Fix-a-Flat	1					0.400		new
Tool box		4.220			0.000			
Car jack	1		1.791			0.000		deleted
Handle	1		0.312			0.000		deleted
Wheel lock	1		0.479			0.000		deleted
Container	1		0.756			0.000		deleted
Container 2	1		0.882			0.000		deleted
Tire presure system		0.156			0.156			1.00
TPM control unit	1		0.042			0.042		1.00
Control unit bracket	1		0.031			0.031		1.00
Rear wheels receiver	1		0.083			0.083		1.00

The hardware shown in bold is revised from the selected Low Development components and is reviewed in Section below

10.6 Total Chassis System Summary

10.6.1 Low Development Chassis

Summary of Low Development Chassis

As shown in Table 10.6.1.a. the goal of achieving a 20% mass reduction was exceeded by 6% for the chassis in total with no change in cost.

Table 10.6.1.a.: Low Development Chassis Summary

	Mass (kg)			Cost(% of baseline)	
	Baseline	Low Dev		Baseline	Low Dev
Front Chassis Total	101.3	68.1		100%	107%
Rear Chassis Total	67.8	44.6		100%	95%
Tires&Wheels	144.5	108.9		100%	96%
Brakes	65.2	57.5		100%	100%
Total Chassis	378.9	279.1		100%	100%
% Reduction		26%			0%

10.6.2 High Development Chassis

As shown in Table 10.6.2.a. the goal of achieving a 40% mass reduction was exceeded by 3% for the chassis in total with a 5% cost reduction.

Table 10.6.2.a.: High Development Chassis Summary

	Mass (kg)			Cost(% of baseline)	
	Baseline	High Dev		Baseline	High Dev
Front Chassis Total	101.3	57.3		100%	101%
Rear Chassis Total	67.8	39.5		100%	92%
Tires&Wheels	144.5	76.0		100%	81%
Brakes	65.2	44.3		100%	117%
Total Chassis	378.9	217.0		100%	95%
% Reduction		43%			5%

10.6.3 Chassis/Suspension Mass Distribution by Material

The chassis and suspension materials analyses are shown in charts 10.5.3.a through 10.5.3.c. The steel content decreased and the non-ferrous material utilization increased progressively from the baseline through the High Development model. There was not a significant change in materials utilization; steel and aluminum were the primary materials used for all three models.

Baseline Chassis Material Distribution

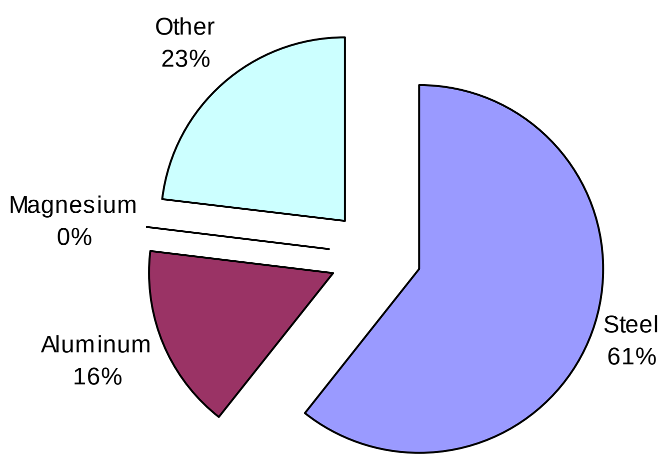


Chart 10.5.3.a

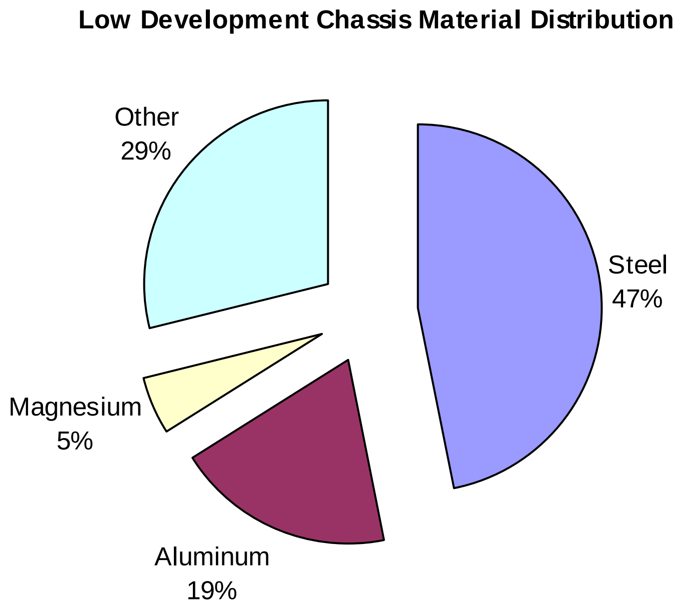


Chart 10.5.3.b

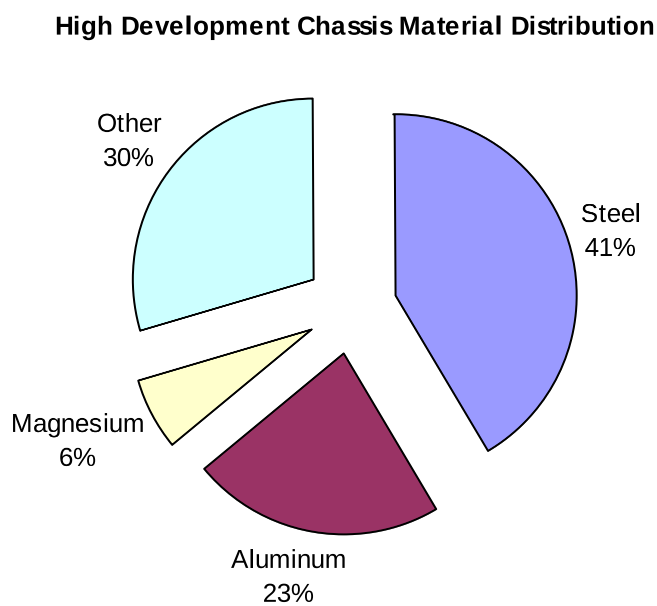


Chart 10.5.3.c

11. Air Conditioning System

11.1 Overview

The air conditioning system was divided into a passenger compartment system and an engine compartment system. This section addressed the under hood components which included the compressor, condenser and related plumbing. The under hood components were investigated for technologies and for mass.

This study indicated that the compressor, condenser and plumbing masses were relatively independent of vehicle mass. Additionally, there was very little mass difference for these components for different interior volumes. Because of these small mass differences and because the existing level of passenger comfort was to be retained, the existing Venza under hood air conditioning components were utilized for both the Low Development and High Development models.

The Interior HVA/C section (section 9.7) of this study included the HVA/C module and the air distribution system; those components were analyzed in Section 9.7.

11.2 Trends

The basic automotive air conditioning system architecture dates back to the 1950's.The HVA/C (heating, ventilation, and air conditioning) system includes a compressor, a condenser mounted in front of the radiator, compressor discharge and inlet lines and a module containing the evaporator, heater core, blower and air distribution systems. The mass, size and efficiency of these components has been refined over many decades by automotive air conditioning suppliers.

Current U.S. automotive air conditioning systems use an R134a refrigerant. The European Union has mandated a phase out of R134a for mobile applications beginning with new models starting in the 2011 timeframe. The mandate bans R134a use on all mobile applications by 2017. The U.S. has not mandated the removal of R134a refrigerants.

Potential replacement refrigerants include R744 (CO_2), R152a and HFO 1234yf. Technical considerations include COP (Coefficient of Performance), flammability, GWP (Global Warming Potential), mass, waste heat utilization, cost and safety.

Although much research has been completed on replacement candidates, OEM's are not unified in their choice of a future refrigerant as of this writing. BMW has publicly stated that they will be using a CO_2 based refrigeration system on their future vehicles[50]. The Society of Automotive Engineers' International Cooperative Research Program has endorsed HFO-1234yf[51].

11.3 Benchmarking

Air conditioning systems are typically sized based on interior volume. Glass area also has a significant impact on the air conditioning load. A Toyota Prius was benchmarked because of its smaller interior volume, similar glass area and common manufacturer. The Toyota Prius had a passenger volume of 96 ft^3 The Toyota Venza had a passenger volume of 108 $ft^{3.}$ These figures were based on published EPA interior volumes[52]. Figure 11.1.3a below compares the Venza under hood air conditioning components to the Toyota Prius under hood components. The air conditioning component mass difference was primarily due to the compressor pulley used on the Venza compressor. The Prius compressor has no pulley; it uses a direct drive electric motor. The Venza compressor mass was 4.650 kg with the pulley removed; the pulley assembly (including pulley, damper, adaptor and fasteners) weighed 1.228 kg. The total Venza under hood air conditioning mass was within 0.67 kg of the Prius system mass after subtracting the compressor clutch mass even though the Venza interior volume is significantly larger than the Prius (see Section 11.4). This mass similarity reflects the highly developed nature of these components. The under hood air conditioning hardware represented 0.5% of the Venza total vehicle mass.

Figure 11.3.a: HVA/C System Benchmarks

11.4 Analysis

The benchmarking study showed a relatively small mass difference for the under hood air conditioning components based on both vehicle mass and interior volume. A Toyota Prius was selected. The Toyota Prius, which weighed 350 kg less than the Venza (1350 kg vs. 1700 kg per A2Mac1 database), and had a smaller total interior volume (110.6 ft^3 vs. 142.4 ft^3per published EPA interior volume data) had under hood air conditioning components that weighed within 0.7 kg of the same Venza hardware, exclusive of the compressor drive source. The total interior volume is the sum of the passenger volume and the storage volume.

11.5 Results

Because of the highly evolved nature of these components, the requirement for equivalent air conditioning performance and the lack of a clear consensus for a future automotive refrigerant, the mass and cost of the Venza compressor, condenser and associated plumbing were left unchanged for both the Low and High Development models. The total system masses for both the Low and High Development models are shown in Table 11.5.a.

Table 11.5.a: HVA/C System Low and High Development Summary

System	**Sub-system**	**Venza Baseline Mass**	Low Development Mass	Low Development Cost	High Development Mass	High Development Cost
Air Conditioning		kg				
	Compressor	5.878	5.878	100%	5.878	100%
	Condenser	2.29	2.29	100%	2.29	100%
	Compressor Out Line	0.256	0.256	100%	0.256	100%
	Liquid line	0.241	0.241	100%	0.241	100%
	Compressor In line	0.587	0.587	100%	0.587	100%
	Refrigerant – R134a	0.500	0.500	100%	0.500	100%
Totals		**9.752**	**9.752**	**100%**	**9.752**	**100%**

12. Electrical

12.1 Overview

This section covers wiring and related hardware including lights. Fuse blocks, fuses, sensors, keyless system hardware and relays were included in the support hardware. Varying vehicle option content and different levels of part integration could create inaccuracies when benchmarking wiring harnesses based on vehicle teardowns.

This study investigated overall architecture choices and material selection. Selected technologies were then applied to the baseline wiring system. Mass and cost were developed based on the selected technologies. The Low and High Development electrical models incorporated the baseline Venza electrical content.

12.2 Trends

Virtually all current automotive wiring systems use copper wire. The Audio industry has started using copper clad aluminum (CCA) wire and it is believed that this trend will soon impact the automotive market. CCA offers the advantages of being nearly 40% lighter and less sensitive to the market price fluctuations of copper. Because CCA cable has approximately 34% more resistance than pure copper wire53, the CCA wire gauge must be increased to provide equivalent resistance. This increases the wire diameter relative to pure copper wire and the wiring harness size. In the Audio market the cost of CCA cables is about half that of copper cables54. The 2011 Toyota Yaris, a subcompact car, will use an aluminum based wiring harness that is nearly 40% lighter and is expected to cost less than a conventional copper wire harness55. Figure 12.2a shows a typical CCA cable and cross section.

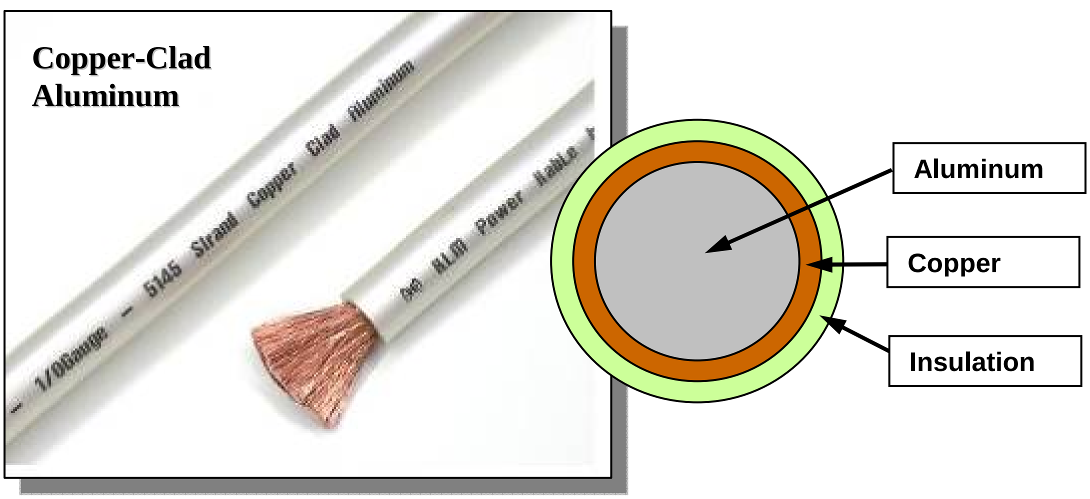


Figure 12.2.a: Aluminum Core wiring

Thinwall coatings are being developed to reduce size, mass and cost. Delphi Packard Electric has collaborated with SABIC Innovative Plastics to develop a wire coating that could provide up to a 25% mass savings compared to conventional coatings[56]. Figure 12.2.b compares a wiring harness using a typical coating vs. the Delphi thinwall coating.

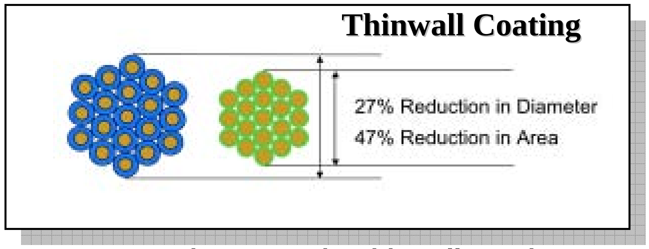


Figure 12.2.b: Thinwall Coating

Increased use of multiplexing, widespread use of digital and wireless technologies, along with copper-clad aluminum wire and ultra thin wall wire coating could reduce the weight of future automotive electrical systems. Other related technologies include optical networks to manage the entire range of vehicle signals, and programmable connectors that will take multiplexing to a higher level. Figure 12.2.c, obtained from the Yazaki[57] website, provides an indication of potential emerging technologies. Yazaki is a Tier 1 automotive wiring supplier.

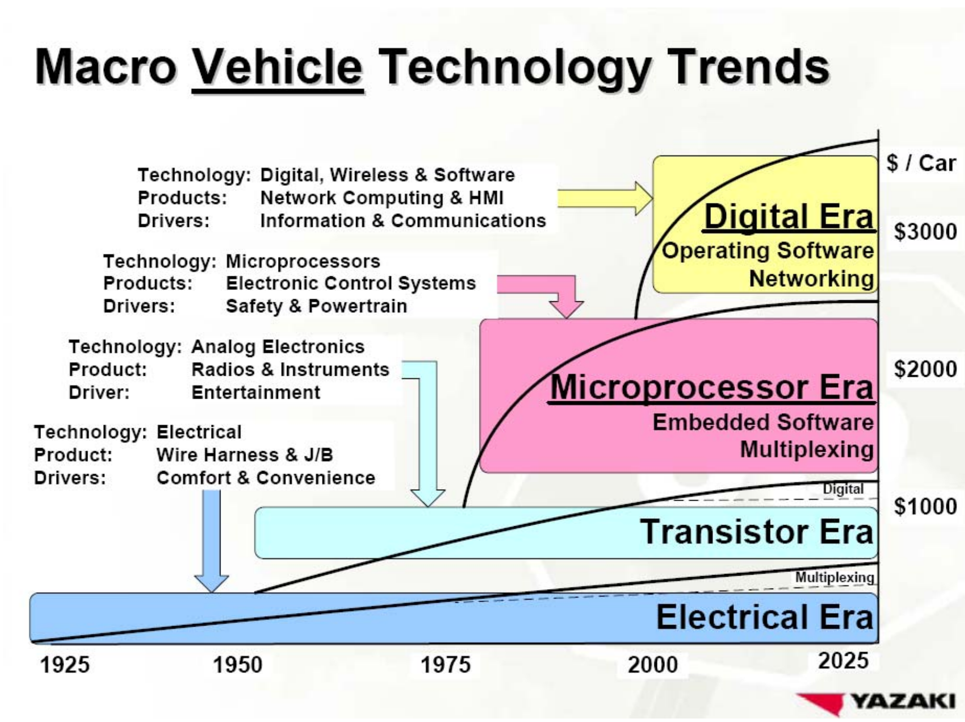


Figure 12.2.c: Macro Yazaki Vehicle Trends

12.3 Benchmarking

The Toyota Venza wiring system mass is shown in Table 12.3.a. The mass included all body related wiring and the support hardware described in the Overview. This mass is vehicle specific depending on the option content and the class of vehicle. Because there can be a wide variation in the electrical content for similar size and class vehicles, the wiring construction was investigated rather than benchmarking vehicles with possibly dissimilar content. The total Venza wiring system mass was 23.68 kg.

Table 12.3.a: Electrical System Benchmarking

	Sub-system	Venza Baseline Mass	Venza Baseline Cost
Wiring		kg	
	Main Body Harness	12.188	100%
	IP Harness	4.532	100%
	LF Door Wiring	0.798	100%
	LF Door Boot	0.152	100%
	RF Door Wiring	0.796	100%
	RF Door Boot	0.150	100%
	Rear Door Harness (2x)	0.456	100%
	Liftgate Wiring Harness	1.030	100%
	Wiring Support Hardware	3.511	100%
Totals		**23.60**	**100%**

The Toyota Venza lighting system mass is shown in Table 12.3.b. The mass included all exterior and interior lamps and fasteners. The total Venza wiring system mass was 9.90 kg.

Table 12.3.b: Lighting System Benchmarking

	Venza Baseline Mass	Venza Baseline Cost
	kg	
Head lamp system	5.578	100%
Light system	3.487	100%
Front fog lamp system	0.617	100%
Third stop light	0.121	100%
License plate light	0.028	100%
Rear reflectors	0.047	100%
Interior lighting system	0.022	100%
Total	9.900	100%

12.4 Analysis

12.4.1. Low Development

The Low Development model reflected the use of CCA (Copper clad Aluminum) for all wiring. A mass savings of 35% was used based on the Toyota Yaris aluminum wiring harness[58]. The cost was assessed by estimating the copper mass percentage in each wire harness, reducing the mass by 35% and calculating the cost for the aluminum. Copper represented 80% of the wiring mass for this analysis. The cost assessment was based on copper at $3.70 lb and aluminum at $1.40 lb[59].

The Venza lighting mass and cost was used for both the Low and High Development models. This eliminated any potential for including a lighting system that was not comparable in performance to the current Venza system and eliminated mass variations caused by styling requirements.

12.4.2. High Development

The High Development model was based on the Low Development model and also incorporated thinwall cladding. Per Sabic Innovative Plastics, the cost of the thinwall cladding for CCA wiring was less than 10% higher. This resulted in an estimated 1% cost increase for the wiring harnesses. The Noryl based coating offered significant environmental advantages and could result in a mass reduction of up to 50% compared to current PVC coatings[60]. The mass savings for the thinwall wire cladding was based on a 50% reduction. The estimated wire coating mass savings was 1.67 kg; this was calculated by multiplying the Low Development total wiring mass by 20% to estimate the coating mass and then multiplying the coating mass by 50% (20% x 16.683 kg = 3.34 kg x 50%). This mass savings of 1.67 kg, combined with the 35% mass savings for the CCA wiring from the Low Development model, resulted in a total mass savings of 36.4%.

12.5 Results

12.5.1. Low Development

Table 12.5.1.a summarizes the Low Development mass and cost. The estimated mass savings was 29% and the estimated cost factor was 95%.

Table 12.5.1.a: Electrical Low Development Results

System	Sub-system	Venza Baseline Mass	Low Development Mass	Low Development % Mass Savings	Low Development Cost
Wiring		kg			
	Main Body Harness	12.188	7.922	35%	90%
	IP Harness	4.532	2.946	35%	90%
	LF Door Wiring	0.798	0.519	35%	90%
	LF Door Boot	0.152	0.152	0%	100%
	RF Door Wiring	0.796	0.517	35%	90%
	RF Door Boot	0.150	0.150	0%	100%
	Rear Door Harness (2x)	0.456	0.296	35%	90%
	Liftgate Wiring Harness	1.030	0.670	35%	90%
	Wiring Support Hardware	3.511	3.511	0%	100%
Totals		**23.60**	**16.683**	**29.3%**	**95%**

12.5.2. High Development

Table 12.5.2.a reflects the estimated cost for the thinwall cladding and the CCA wiring. The estimated mass savings was 36% and the estimated cost factor was 96%.

Table 12.5.2.a: Electrical High Development Results

System	Sub-system	Venza Baseline Mass	High Development Mass	High Development % Mass Savings	Low Development Cost
Wiring		kg			
	Main Body Harness	12.188	7.435	39%	91%
	IP Harness	4.532	2.765	39%	91%
	LF Door Wiring	0.798	0..487	39%	91%
	LF Door Boot	0.152	0.152	0%	100%
	RF Door Wiring	0.796	0.486	39%	91%
	RF Door Boot	0.150	0.150	0%	100%
	Rear Door Harness (2x)	0.456	0.274	39%	91%
	Liftgate Wiring Harness	1.030	0.618	39%	91%
	Wiring Support Hardware	3.511	3.511	0%	100%
Totals		**23.60**	**15.01**	**36.4%**	**96%**

13. Powertrain

13.1 Powertrain Overview

The goal of the powertrain portion of this study was to calculate the powertrain mass, accounting for the mass reduction of the major vehicle systems, by allowing a reduction of the powertrain system horsepower and torque but maintaining similar vehicle performance. The proposed powertrain system should use known technologies and take advantage those probable for vehicle production in the 2017 in terms of feasibly, cost and efficiency gains. Any powertrain mass reduction may allow further mass reduction of the other vehicle systems in the study sometimes referred to as mass-decompounding. Only one powertrain was developed for both Low and High Development vehicles for simplicity but additional technology could be used in the High Development vehicle for further powertrain downsizing and mass reduction. The powertrain developed does not represent a specific powertrain that must be used in this vehicle but instead a single potential solution and placeholder for powertrain mass, accounting for system mass reductions and allowing a downsized powertrain with emerging technologies capable of production in the 2017 timeframe of this study. The overall powertrain and vehicle efficiencies will not be modeled in this study but an estimated system cost will be calculated for appropriateness. Future studies may allow powertrain simulations with the known vehicle parameters such as final vehicle weight, aerodynamics and rolling resistance.

EPA believes that manufacturers are more likely to bundle technologies into “packages” to capture synergistic aspects and reflect progressively larger CO2 reductions with additions or changes to any given package. In addition, we believe that manufacturers would apply new technologies in packages during model redesigns—which occur once roughly every five years—rather than adding new technologies one at a time on an annual or biennial basis. This way, manufacturers can more efficiently make use of their redesign resources and more effectively plan for changes necessary to meet future standards.

In the initial selection of the powertrain for the vehicle in the study, it was considered if the vehicle would use a conventional internal combustion engine or a hybrid powertrain. With current fuel efficiency concerns, the most efficient technology set must be considered to be probable for the time frame of this study, thus a hybrid vehicle was selected. General categories of hybrid vehicles include micro-hybrids, charge sustaining hybrids (IC engine with electric motor assist) and plug-in electric hybrid vehicles (PHEV’s). A charge sustaining hybrid was selected for the powertrain system to match vehicle performance in terms of range and most likely to be adopted by industry and the public. There are several types of hybrid powertrain architectures each with advantages and disadvantages in relationship to fuel economy improvement, cost, complexity, drivability and customer acceptance. Some of the current and proposed hybrid vehicle arrangements include:

1. Single-shift, parallel (Honda)
2. Single-planetary dual-mode (Toyota/Prius)
3. Multiple-planetary, dual-mode (GM)
4. Multiple-shaft, dual-clutch transmission (VW and Borg-Warner)
5. Series - range extended EV (GM Volt).

Documented EPA research[61] along with published papers[62] suggests that the largest fuel economy improvements can be gained by using the hybrid single-planetary dual mode system drive. This arrangement is termed dual mode because it can operate both in parallel and series modes. This system is currently used in the 2007 Toyota Camry and other Toyota hybrids, under license by Ford in the Escape and Fusion and is also used by Nissan in the Altima.

The engine portion of the powertrain was derived from an experimental engine developed by Lotus called project SABRE – “Spark-injection Advanced Baseline Research Engine”[63]. The engine contains an appropriate mix of technologies to increase engine efficiency for the 2017 timeframe. Using the current

Venza vehicle performance metrics as a baseline, including acceleration and vehicle range, a powertrain was developed to meet or exceed these parameters. The powertrain electrical motor/generator and engine size along with the required electrical energy storage capacity of the battery were resized appropriately using anticipated energy and specific power capabilities in the time frame of this study. An overview of the discrete powertrain sub-systems follows explaining the technologies used and anticipated to estimate the final required powertrain mass.

13.2 Powertrain Sizing

The Toyota Venza under review is a 4 cylinder front wheel drive crossover utility vehicle. The vehicle has a curb weight of 1705 kg and 2250 kg fully loaded (GVW) and a peak engine horsepower of 182 hp (135 kW). Considering these simple parameters, the current Venza has a horsepower (HP) to mass ratio of 0.0167 unloaded and 0.0809 at fully loaded conditions (GVW). Maintaining a consistent HP/Mass ratio after vehicle mass reduction and powertrain resizing implies that vehicle performance will remain equivalent. A 20% mass reduction, the Low Development vehicle goal, while maintaining passenger and cargo capacity consistent yields a vehicle mass of 1397 kg unloaded and 1942 kg at the full loaded condition. Using the same ratios from the original Venza to assume similar performance of the lightweighted vehicle, the powertrain must develop a peak horsepower rating for both unloaded and fully loaded conditions. The resultant required powertrain horsepower was calculated at 155 hp (115kW). Using the same electrical motor/generator and engine contribution ratios used by Toyota and Ford yields a conservative peak electrical motor size of 75 hp (90 kW) and peak engine of 120 hp (55kW) for comparable performance. The engine and motor peak power are not directly additive due to the differences in torque verses speed for the discrete components.

13.3 Engine Sizing

The project SABRE engine employs a synergistic combination of engine downsizing, gasoline direct injection and variable valve train to achieve the objectives of increased efficiency using cost effective technology. Although the original engine design uses a single stage turbocharger, further work has been completed by Lotus possibly incorporating a variable geometry turbocharger, two-stage charging unit or cooled EGR[64]. EPA concurs with the feasibility and affordability of these technologies in a 2008 Staff Technical Report[65]. Major enablers for the SABRE engine:

- Variable valve actuation based on switching tappets and twin cam phasers
- Homogeneous air-fuel mixture with direction injection using close–spaced, multi-stream solenoid injectors
- Single-stage, single-entry fixed geometry turbocharger
- Cylinder head with integrated exhaust manifold (IEM)
- Friction reduction concepts
- Limited BMEP levels for durability and reliability

The 3-cylinder, 1.5L turbocharged engine developed in the initial Lotus SABRE report was designed to produce similar performance to a typical 2.2 liter naturally aspirated engine. This engine was further reduced for this study in horsepower, torque, size and mass to adapt to the requirements of the lightweighted Venza vehicle. A target engine peak of 120 hp was determined, in coordination with the powersplit hybrid systems resulting in a required displacement of 1.0 L.

The reduced cylinder arrangement has advantages and disadvantages. The 3-cylinder arrangements limits friction at the expense of creating a primary couple but is addressed by using a counter-rotating balance shaft. Adopting a 3-cyliner configuration also eliminates the inter-cylinder exhaust pulse interaction in the valve overlap period which may occur when the firing interval is less than 240 degrees. An integrated exhaust manifold (IEM) is used; reducing mass, packaging space and complexity along with potential advantages of accelerated engine warm-up and reduce catalyst light-off time. In addition to fuel economy, injection parameters were optimized on the SABRE engine for HC, CO and NOx and PM emissions to ensure low engine-out emissions to achieve EURO V performance. It was assumed for the engine and powertrain developed for this study will have further optimization opportunities fuel economy, criteria pollutants and GHG improvements.

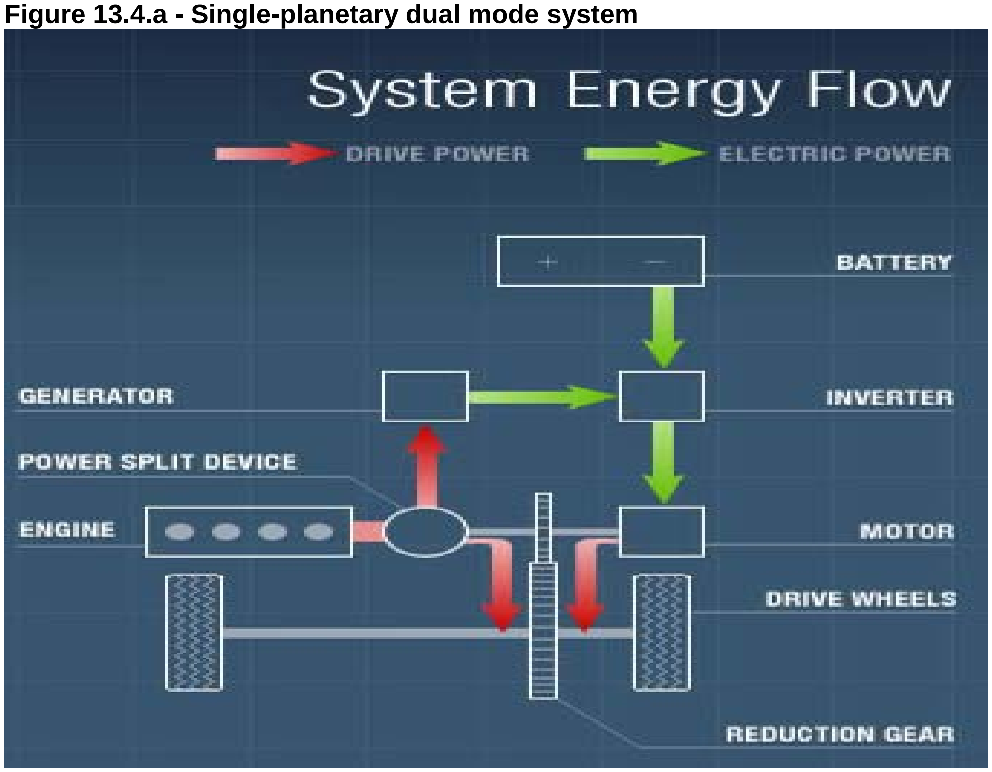
The cylinder head assembly is an aluminum alloy casting which houses the complete valve train as well as the actuators for the twin cam phasing and intake cam switching in a single component for reduced mass. The cylinder bock is split along the crankshaft centerline into upper and lower halves. Both castings are aluminum with cast iron inserts in the lower crankcase. The upper crankcase houses the pistons in aluminum bores for reduced mass and improved heat transfer. The engine cooling system contains a 12 volt electric water pump. The coolant flow is separated into three paths for the cylinder block, cylinder head and oil cooler/turbocharger with the head and block having separate electronic thermostats. This arrangement allows the block to quickly heat up to optimal operating temperature to reduce friction while the cylinder head remains cools to increase charge density and reduce knock.

The engine was also designed for use with an integrated exhaust manifold (IEM) for additional mass savings. The IEM concept has challenges but with additional simulation of engine coolant flow, thermal loads and stresses; the design can be optimized for production capability for cost, mass and durability. The intake manifold, similar to current productions designs are plastic for reduced mass and cost.

13.4 Hybrid System

As previously explained, various alternative hybrid vehicle powertrains are currently being designed and produced by auto companies and many were considered for use in the study. For the powertrain mass calculations of this study, a charge sustaining, single-planetary dual mode system was selected for review as shown in Figure 13.4.a. This system is currently used in the 2007 Toyota Camry and other Toyota hybrids (Hybrid Synergy Drive), under license by Ford in the Escape and Fusion and is also used by Nissan in the Altima. Sufficient data was available on this system for a mass comparison for the scope of this study. The selection of this hybrid does not imply other hybrid types are inferior or not preferred. Other hybrid systems in production or available in this timeframe may be used but it is anticipated the mass, cost and benefits will be similar or improved.

Figure 13.4.a - Single-planetary dual mode system



This system is sometimes called “dual mode” as it can operate both in parallel and series modes. This system consists of an engine and two electric machines; one operating primarily as a traction motor and the other as a generator. The drive system functions as an electromechanical continuously variable transmission (CVT) with no clutches with the effective gear ratio dependent on the torque outputs of the three prime movers. When the engine is operating, its power output is split between the wheels and the generator. This power-split feature of the powertrain arrangement permits the engine to be operated close to maximum efficiency for nearly all vehicle speeds and power demands. Although either motor/generator set (MG) can function as either a motor or generator, the primary drive motor is commonly referred to as MG2 and the generator is referred to as MG1. Both MG1 and MG2 are powered by separate three phase inverters which share the same direct current link. Battery voltage is boosted by a bi-directional boost converter. This allows multiple power flow paths where the IC engine, MG1 or MG2 in combination or alone can supply energy to the battery pack or vice versa.

A hybrid system teardown was preformed on a 2007 Toyota Camry by Oak Ridge National Laboratory[66]. This study evaluated the design, mass dimensions of the individual hybrid drive components in addition to comprehensive testing on the subsystem assembles to fully assess their performance, efficiency, design and packaging characteristics. The report was instrumental for the estimated powertrain mass for the scope of this study. The 2007 version of the Toyota Camry hybrid system includes significant advancements in hybrid technology from the previous Prius version. The electric drive system has higher peak power and more extensive continuous operation capabilities, yet has decreased size and weight of the previous generation. Major advancements include packaging of the inverter/converter system and the design of higher speed and voltage permanent magnet synchronous motors for MG1 and MG2. The power density of the motor inverter and bi-directional boost converter has more that doubled when compared to that of the previous generation. The powertrain calculations for the lightweighted vehicle yielded MG1 and MG2 requirements of 55 kW and 20 kW respectively. The details of the electrical powertrain component sizing are not included in this report.

Additional system improvements are forecasted in the mass estimation summary as shown in table for the lightweighted hybrid system.

13.5 Hybrid Battery

Energy storage is important to the successful operation of any hybrid vehicle. To increase the fuel efficiency of a vehicle, the engine must operate more efficiently than a conventional non-hybrid vehicle in addition to vehicle energy recapture. This is done by utilizing the electric motor to provide the drive torque rather than the engine when the engine would operate less efficiently. The electric driveline is also used to recover energy during braking or deceleration events. In order to provide these functions, the energy storage capacity (kWh) and power capability (kW) of the energy storage unit must be appropriately designed based on the vehicle design, mass and performance targets with the expected use and driving cycle of the vehicle. Currently, most hybrid vehicles in production use nickel metal hydride batteries, but it is expected that in the future most of the hybrid vehicles will use lithium-ion batteries. For the Low Development vehicle with a production date of 2017, a LiMn2O4-spinel or LiFePO4-olivine cathode, laminated cell, power-optimized multi-layered cell construction, power optimized construction was selected based on discussions with battery and vehicle manufacturers. Convergence between energy optimized and cell optimized construction is accomplished by improving the cathode microstructure to increase the rate of charge and discharge of Li ions.

Based on calculations and anticipated battery technology improvements, the final specifications for a battery in a 2017 production vehicle shown in table 13.5.a.

Table 13.5.a – Battery Specifications

Specifications	2017 Low Development Vehicle
Assumptions:	~50% convergence between "energy" and "power" optimized cell construction
Battery Type:	LiMn2O4-Spinel, power optimized construction
Module dimensions (mm):	255 x 140 x 35
Module volume (L)	1.25
Pack volume (L):	26
Pack dimensions (cm)	44 x 40 x 15
Modules/pack	7
Cell energy density (W-hr/kg):	120
Module mass (kg, approximate)	1.7
Module energy (W-hr)	200
Pack mass (kg):	17
Pack energy (kW-hr):	1.4
Sustained max pack power (KW):	55 kW
% cell mass in pack:	68%
% module mass in pack (approximate):	70%
% module volume in pack:	33%

13.6 Hybrid System Cost

EPA has developed a new model to project the feasibility, costs, and environmental and energy benefits of alternative light-duty vehicle greenhouse gas emissions standards. EPA's Optimization Model for Reducing Emissions of Greenhouse Gases from Automobiles (OMEGA) is a free, desktop computer application which estimates the technology cost for automobile manufacturers to achieve variable fleet-wide levels of vehicle greenhouse gas (GHG) emissions (http://www.epa.gov/oms/climate/models.htm).

Based on resizing addition of the hybrid components, the estimated cost of the system is shown in table 13.6.a. No additional cost subtraction or addition was included in this cost assessment for the engine downsizing due to the additional engine technologies required for production would offset decreased displacement.

Table 13.6.a – Hybrid System Cost

Hybrid Components	Cost Basis	Scaling	Cost
Primary Motor ($/kW)	$ 15.00	Mass	$ 825.00
Secondary Motor ($/kW)	$ 15.00	Displacement	$ 300.00
Primary Inverter ($/kW)	$ 7.00	Mass	$ 385.00
Secondary Inverter ($/kW)	$ 7.00	Displacement	$ 140.00
Controls	$ 115.00	1x	$ 115.00
Li-Ion Battery Pack ($/kW-hr)	$ 320.00	Mass	$ 448.00
DC/DC Converter ($/kW)	$ 88.00	Mass	$ 144.09
High Voltage Wiring	$ 200.00	Footprint	$ 207.70
Supplemental heating	$ 42.00	Footprint	$ 43.62
Powersplit transmission change	$ (425.00)	1x	$ (425.00)
Electric AC	$ 450.00	Footprint	$ 467.33
Delete conventional accessories	$ (140.00)	1x	$ (140.00)
Blended Brakes	$ 310.00	1x	$ 310.00
Total			**$ 2,820.74**

13.7 Results:

The individual components added, deleted or resized appropriately for the Low Development lightweighted vehicle target of 20% mass reduction as shown in Table13.7.a The overall powertrain system mass was reduced 13.2% from 410.4 kg to 356.2 kg including fuel mass reduction to maintain equivalent driving range. This hybrid powertrain system is used for both the Low and High Development architectures although other hybrid systems in production or available in this timeframe may be used and anticipated system mass, cost and benefits will be similar or improved.

Table 13.7.a – Powertrain Mass Reduction Results

Component	Current Venza (kg)	LD/HD vehicle (kg)	Comments
Engine			
Engine	131.0	95	Mass: Estimated dry 90 kg – 100 kg Single stage charging, integrated exhaust manifold; Size: 420mm length, 620 height, and 650mm width; Output: 100 Hp (detuned 120 Hp) & 120 Hp.
Engine Components			
Exhaust Manifold	Included in exhaust	Included in engine	
Exhaust system	36.0	18.0	50% mass reduction
Air Induction	3.8	2.9	25% mass reduction
ECM	1.9	1.9	Carryover component
Driveline			
Transmission and flex plate	86.3	Included in hybrid driveline	
Transmission fluid	4.8	Included in hybrid driveline	
Half shafts	19.5	Included in hybrid driveline	
Auxiliary Components			
Starter	3.2	Included in hybrid driveline	
Alternator	6.1	Included in hybrid driveline	
AC bracket (Compressor in separate AC section)	1.1	1.1	Carryover component
Wiring Harness (engine only)	4.1	3.1	25%mass reduction (aluminum)
12 v battery (Required for EPS, lighting)	18.9	9.5	50% mass reduction
Fuel System	25.8	19.3	50% mass reduction (engine size decrease 63%)
Cooling system			
Coolant system (includes below)	10.3	5.2	50% mass reduction (engine size decrease 63%)
Radiator			
Radiator hoses			
Radiator Fan (dual fan)			
Fluids			
Engine Oil	4.2	3.2	5 quarts Venza, 4 qts LD/HD (0.81 kg/qt).
Radiator Coolant	7.3	3.6	50% mass reduction (engine size decrease 63%)
Add EE components			
AC compressor motor		2.0	Motor mass only - component mass separate
Water pump motor		1.0	Motor mass only - component mass separate
Add Hybrid components			
Compete Hybrid driveline (Planetary, MG1, MG2)		108.0	Based on 2007 Toyota Camry ORNL report
Additional Wiring			
Motor Harness assembly		1.0	Based on 2007 Toyota Camry ORNL report
Battery Power cables		4.0	Based on 2007 Toyota Camry ORNL report
Hybrid Battery System			
Pack includes battery management system		17.0	Projected mass of future technology
Battery cooling system (air to air)		2.0	
Inverter/Converter/boost		17.5	Includes boost converter, IPM's, DC link capacitor (11.7 liter volume)
Inverter/Converter cooling system		4.0	Water/glycol system with heat exchanger & fluid
Misc			
Fuel mass (consistent range)	46.2	37.0	Fuel reduction 20% maintaining vehicle range
Total Powertrain Mass (kg)	**364.2**	**319.3**	
Total Powertrain Mass with Fuel (kg)	**410.4**	**356.2**	

14. Discussion of Results

System Mass Distribution

The mass distributions by system are summarized for the baseline, Low Development and High Development models in Charts 14.a through 14.c shown below. The body, interior, suspension/chassis, and closures represented 88% of the total vehicle mass (less powertrain) for each model. The mass contribution of these four systems as a percentage to the total vehicle mass was relatively consistent. The maximum system mass differential was 3% for the baseline, Low Development and High Development models. This analysis indicated that the four major systems contributed uniformly to the overall vehicle mass reduction. There was no single system that generated a disproportionate percentage of the total vehicle mass reduction for either the Low Development or the High Development model. In addition to the mass contribution by system, charts showing the vehicle composition by material are listed as well as the material make-up of the four primary mass systems.

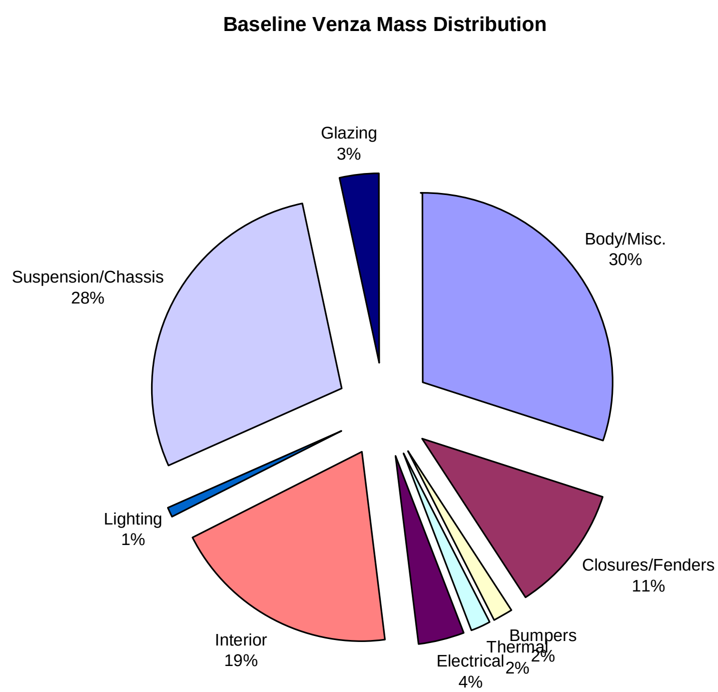


Chart 14.a

Low Development Mass Allocation

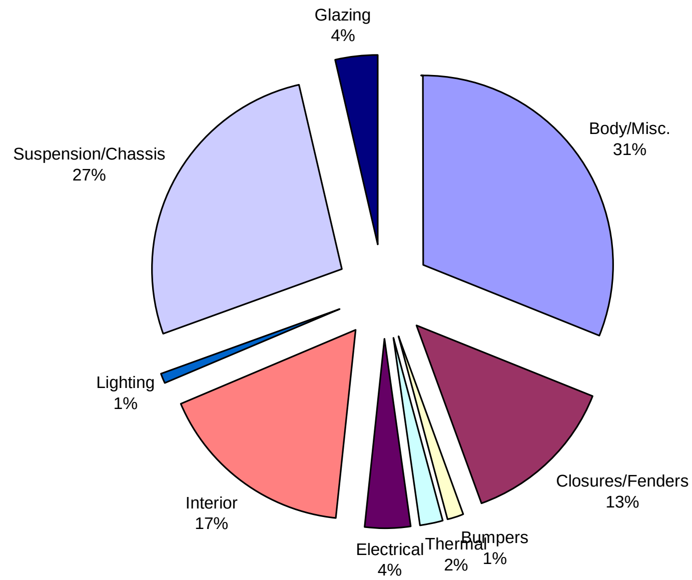


Chart 14.b

High Development Mass Distribution

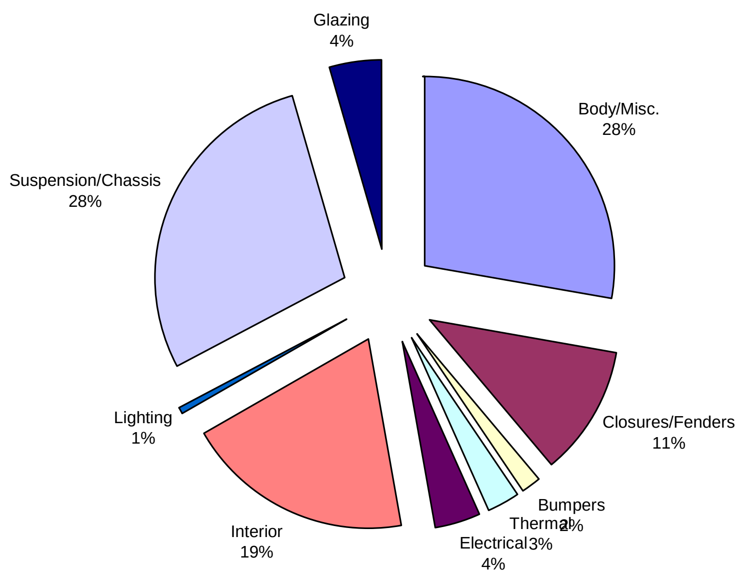


Chart 14.c

Mass Distribution by Material

The shift to low mass materials is reflected in the Low and High Development charts shown below. The baseline Venza materials utilization is shown in Chart 14.d

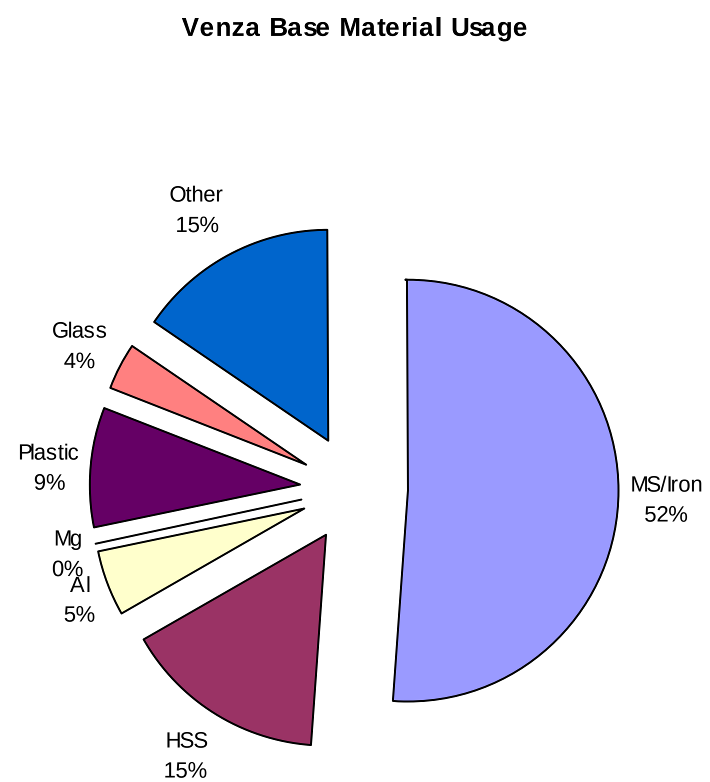


Chart 14.d

The Low Development model incorporated an increased level of high strength steels vs. the baseline. This model is consistent with the industry trend to for increased use of higher strength steels. The Low Development total vehicle materials are shown below in Chart 14.e.

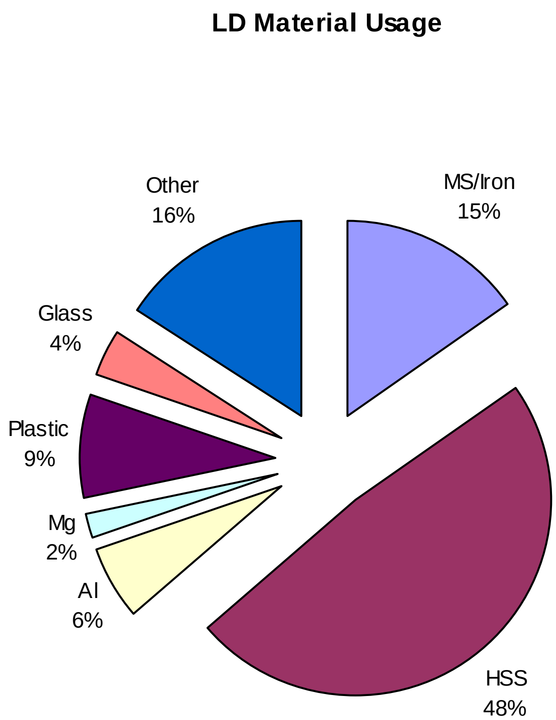


Chart 14.e

The High Development model represented a significant change in vehicle BIW architecture vs. the baseline Venza. It incorporated a high level of non-ferrous materials. The High Development total vehicle materials are shown below in Chart 14.f.

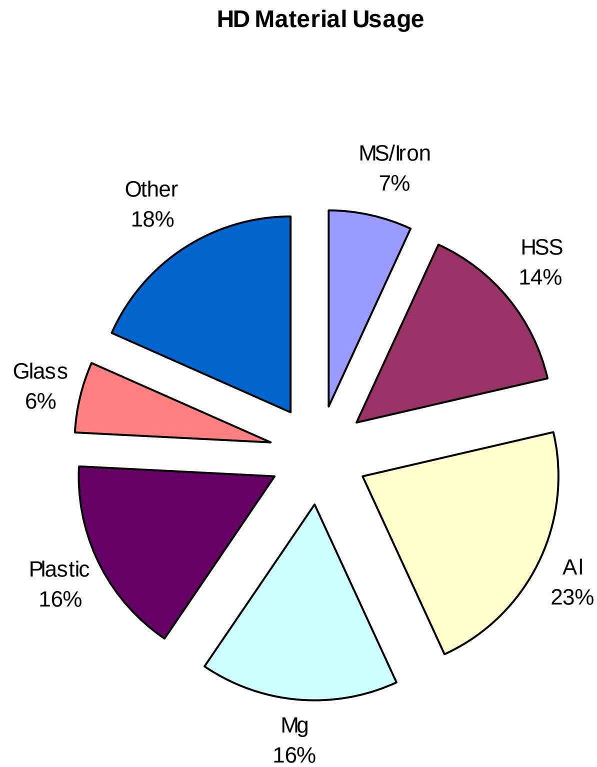


Chart 14.f

Cost

The baseline vehicle system costs were estimated as a percentage of the total vehicle cost. These relative costs were estimated using supplier inputs and Lotus past experience in equivalent systems. These percentages are not absolute and will vary by vehicle class and manufacturer. The intent was to establish a reasonable generic weighting value that could be applied to the cost of each system to establish a total weighted vehicle cost.. The four cylinder, FWD powertrain cost including fuel systems, powertrain electronics and electrical, was estimated at 23% of the manufacturers cost; Chart 14.g. below represented the total vehicle cost allocation by system. The weighted cost for the Low Development vehicle, less powertrain, was 75.36% or 98% of the estimated baseline cost of 77%. The cost breakdown for the non-powertrain parts is shown in Chart 14.h. The weighted cost for the High Development vehicle, less powertrain, was 79.27% or 103% of the estimated baseline value. The High Development cost breakdown, less powertrain, is shown in Chart 14.i. As an example, the baseline body cost was estimated at 18.3% and the weighting factor for the High Development body was 135%; the product of these two values is 24.7%. This number is shown in the High Development cost chart.

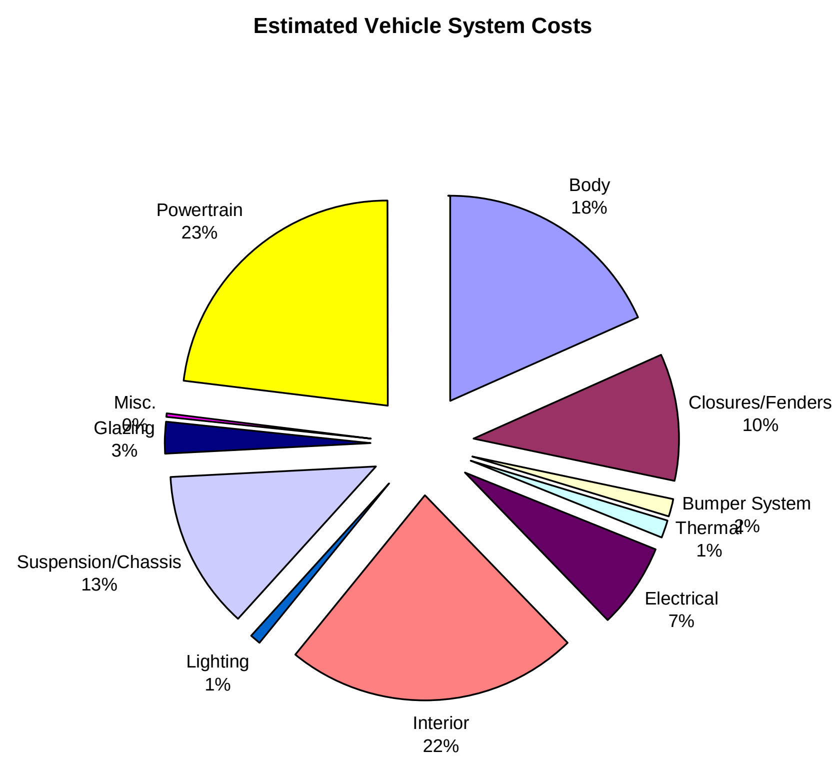


Chart 14.g.

Low Development Vehicle Cost Allocation

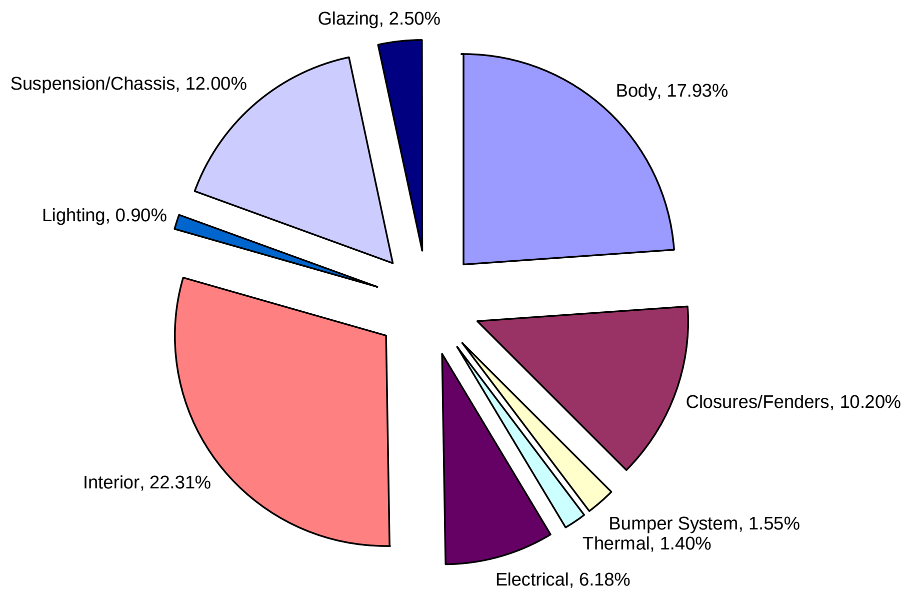


Chart 14.h.

High Development Cost Allocation

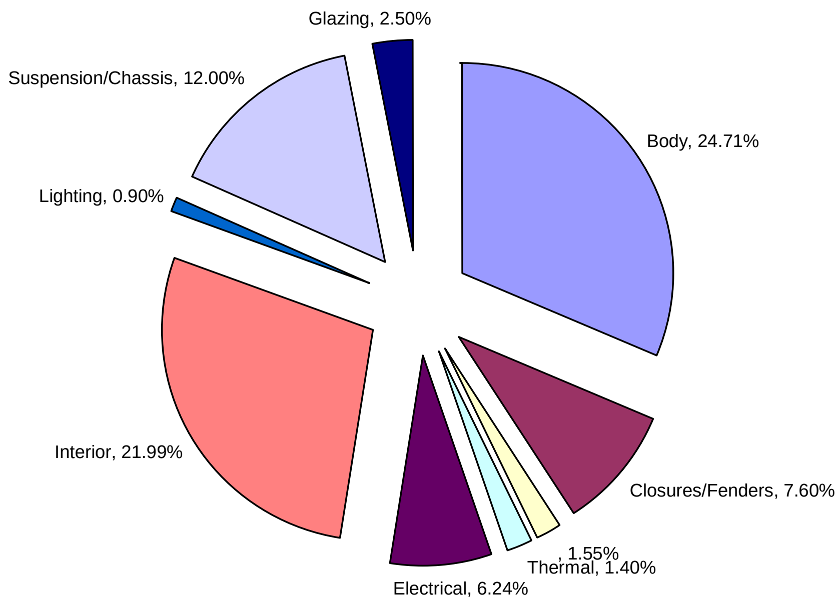


Chart 14.i.

Table 14.a below summarizes the mass and the cost for the Low Development and High Development vehicles. The total vehicle cost is the weighted value.

Table 14.a.

System	Base	LD	LD	HD	HD
		Mass	Cost Factor	Mass	Cost Factor
Body	382.50	324.78	0.98	221.06	1.35
Closures/Fenders	143.02	107.61	1.02	83.98	0.76
Bumpers	17.95	15.95	1.03	17.95	1.03
Thermal	9.25	9.25	1.00	9.25	1.00
Electrical	23.60	16.68	0.95	15.01	0.96
Interior	250.60	182.00	0.97	153.00	0.96
Lighting	9.90	9.90	1.00	9.90	1.00
Suspension/Chassis	378.90	275.50	0.96	217.00	0.95
Glazing	43.71	43.71	1.00	43.71	1.00
Misc.	30.10	22.90	0.99	22.90	0.99
Totals:	1289.53	1012.28		793.76	
Base Venza Powertrain Mass	410.16	Mass	LD Cost	Mass	HD Cost
Base Venza Total Mass	1699.69	78.5%	97.9%	61.6%	103.0%

15. Conclusions

This study indicates that a 21% total vehicle (less powertrain) mass reduction may be achievable for a 2017 production model year vehicle using current and near term technologies with little or no cost impact by using a synergistic, total vehicle approach to reducing mass.

This study also indicates that a 38% total vehicle (less powertrain) mass reduction may be achievable for a 2020 production model year vehicle using current, near term and longer term technologies with a moderate cost impact by using a synergistic, total vehicle approach to reducing mass.

16. Recommendations

Lotus recommends additional follow-up and independent studies to validate the materials, technologies and methods referenced in this report for the High and Low Development vehicles or possibly a combination. Many of the Low Development technologies are already used in production vehicle although not in a substantial manner. Additional studies regarding holistic vehicle mass reduction materials, methods and technologies in collaboration with automotive industry, component suppliers, manufacturing specialists, material experts, government agencies and other professional groups would support efforts of further understanding the feasibility, costs (both piece and manufacturing), limitations of this report.

5. A High and/or Low Development body in white (BIW) should be designed and analyzed for body stiffness, modal characteristics and for impact performance referencing the appropriate safety regulations (FMVSS and NCAP) for the time frame. This study should include mass and cost analysis, including tooling and piece cost.

6. High Development closures should be designed and analyzed further. This additional study should include front, rear and side impact performance as well as mass and cost analysis, including tooling and piece cost.

7. High and Low Development models of the chassis/suspension should be designed and analyzed. This study should include suspension geometry analysis, suspension loads, as well as a mass and cost analysis, including tooling and piece cost.

8. A High and Low Development interior model should be designed and analyzed for occupant packaging and head impact performance. This study should include a mass and cost analysis, including tooling and piece cost.

17. Appendix

17.1. European Trends

ABSTRACT

Vehicle technology in Europe has focused on providing solutions for smaller vehicle sizes than in North America. European automotive manufacturers incorporate a greater percentage of higher strength materials than used in North America to meet the demand for improved fuel economy. Materials with lower densities have also been used to provide mass savings.

Over time, vehicle size and content have increased. Mass reduction techniques have allowed overall vehicle mass gains to be less than they would have been with older materials and technologies. Vehicle components have been re-engineered in lower density materials and/or integrated to maintain or reduce vehicle mass.

OBJECTIVES & DELIVERABLES

The objectives were:

1. To report on trends of mass reduction technologies used in the European Automotive market to date.
2. To report on future mass reduction technologies of automotive systems engineering in European products.

The key deliverable is a technical report that answers the key objectives of the project. The systems included as part of the study are:

Body Structure
Closures
Fenders
Front & Rear Bumpers
Electrical
Interior
Front & Rear Lighting
Suspension/Chassis/Wheels/Tires
Glazing

Powertrain, driveline and transmission systems were not part of the study brief and therefore excluded from consideration in this report.

METHOD

A number of sources inclusive public domain information, publications, conference proceedings, Lotus Engineering technical database and views from Lotus experts as appropriate provided inputs into the study.

The vehicle was divided into systems. The historical trends and developments for these systems were identified. Future trends anticipated for the systems were then identified and forecast.

WORKSCOPE

The approach taken was to compare the Toyota Venza to products of similar masses and footprint(1). This is because the Toyota Venza is a well known product in the USA for which benchmark data is readily available. In addition, the Venza shares a platform with the Toyota Camry in Europe so there is a product common to both markets to allow comparisons to be made.

In addition, vehicle products in other classes are analyzed to provide insights into the evolution of product architectures and vehicle systems technology. The Volkswagen Golf is cited as an example of a product that has evolved over time and has retained competitiveness through the use of contemporary technologies.

The Toyota Venza product was positioned relative to other Toyota products and its competitors, using segmentation analysis. This approach classifies vehicles into categories and types. For example the product portfolio of the Audi brand is depicted in such a classification chart. (Figure 17.1.a)

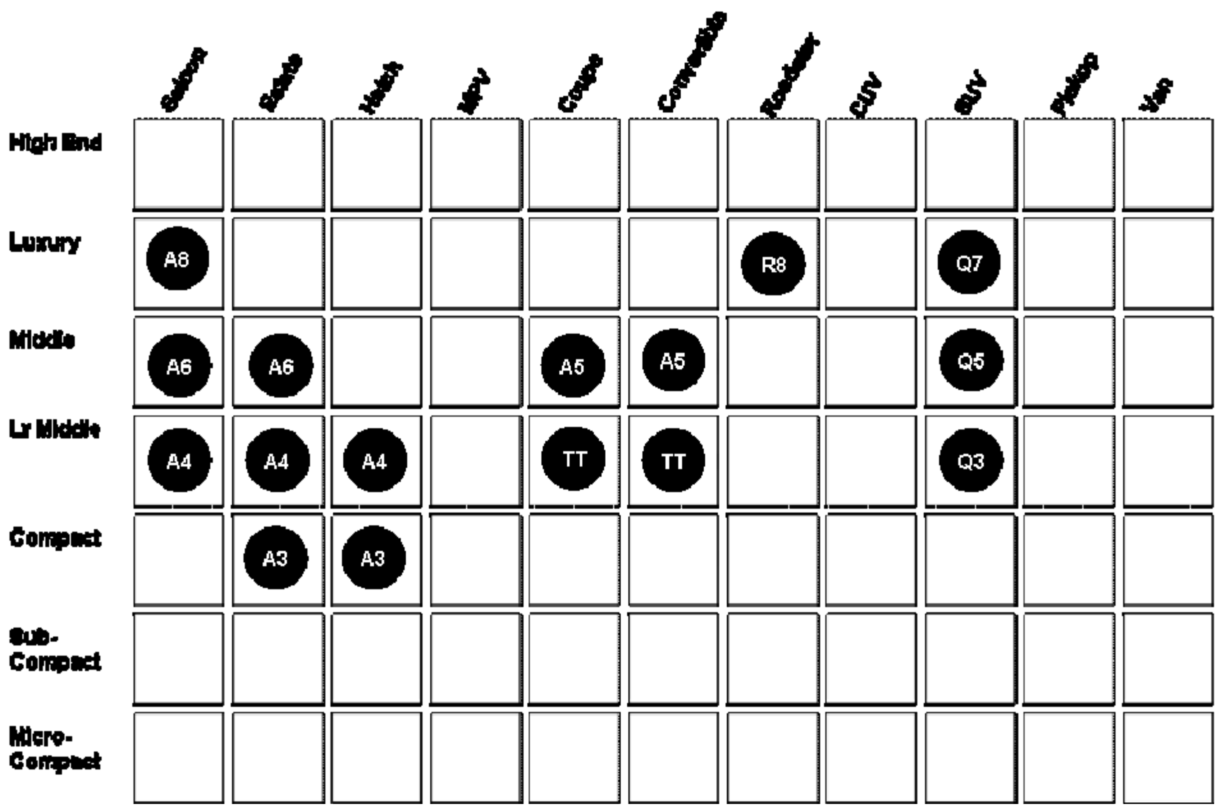


Figure 17.1.a : European automotive manufacturer's portfolio segmentation – e.g. Audi

The positioning of the Toyota Venza is shown in Figure 17.1.b. The positioning is based on a European perspective of the constitution of vehicle classification. Difference of opinions related to the positioning can be explained when the products are reviewed in terms of style or other attributes.

(1) Footprint is defined as: wheelbase length multiplied by front suspension track or width

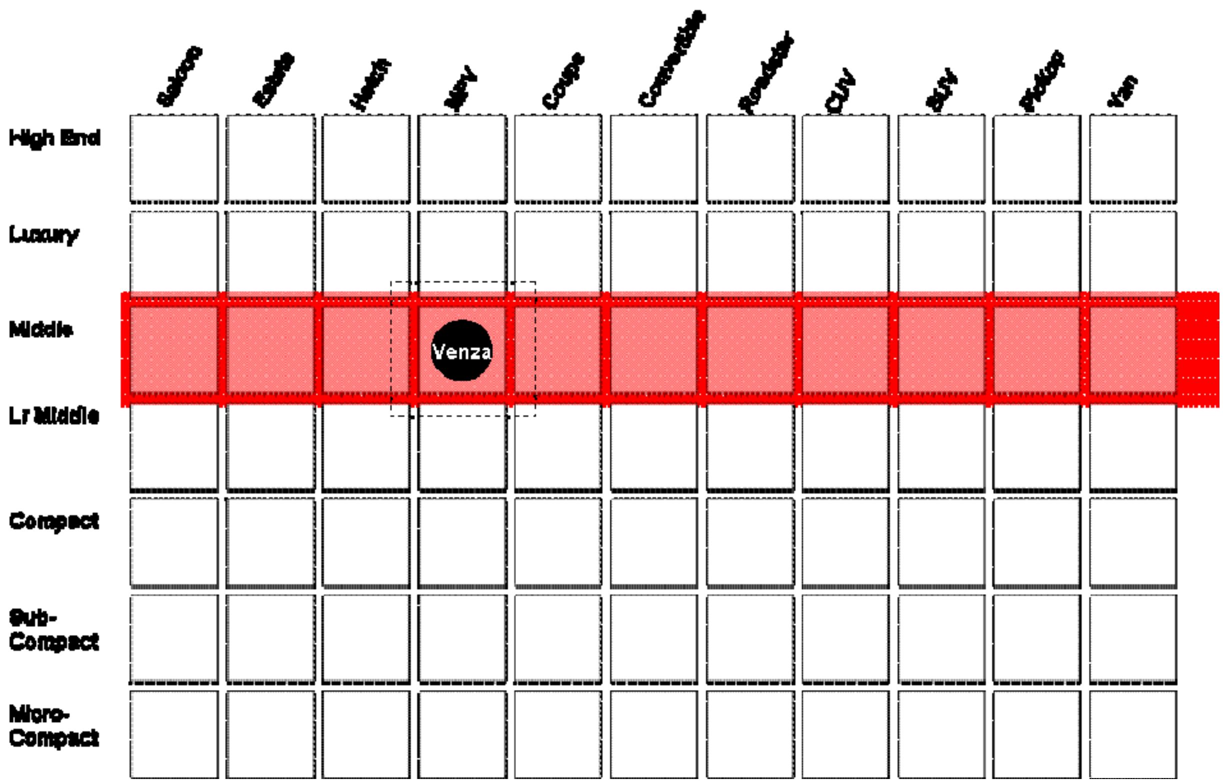


Figure 17.1.b: Positioning of the Toyota Venza according to the segmentation format

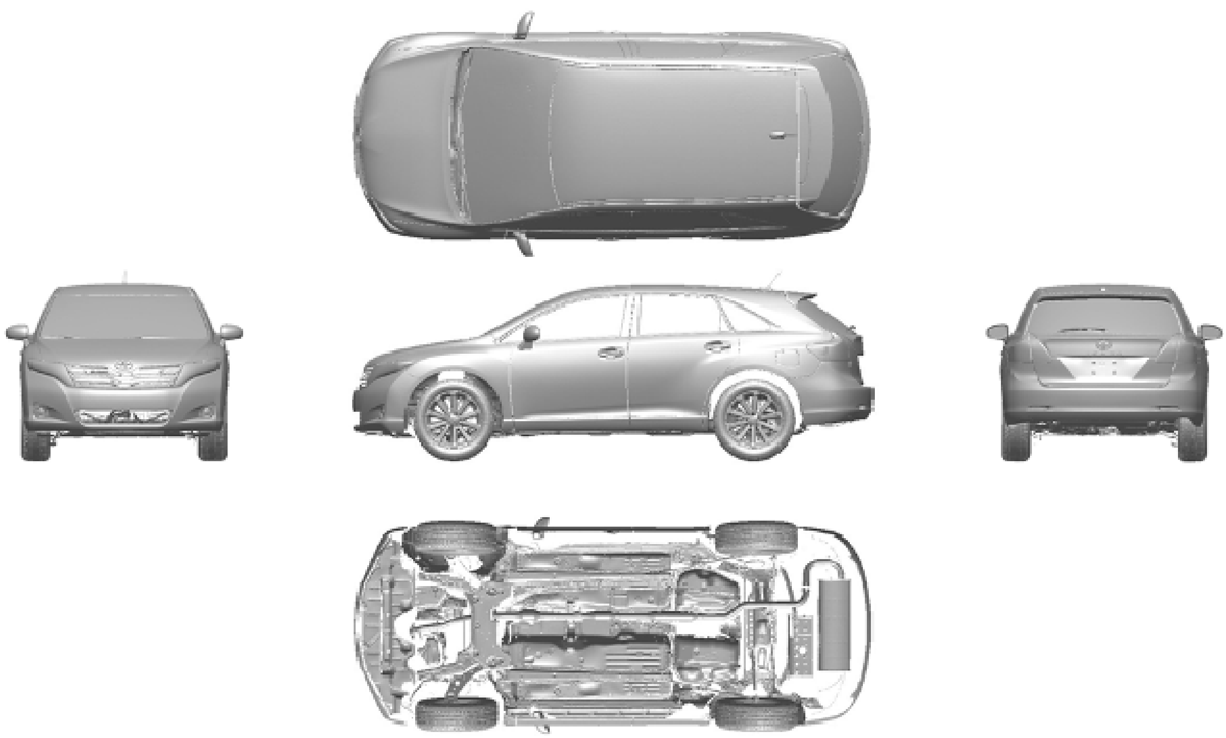


Figure 17.1.c: Views of the Toyota Venza Vehicle

The Toyota Venza (Figure 17.1.c) falls into the ‘middle class’ of vehicle and can be defined as a ‘MPV’ in terms of product type. When compared to European competitors that populate the segmentation matrix, the positioning seems reasonable. (Figure 17.1.d)

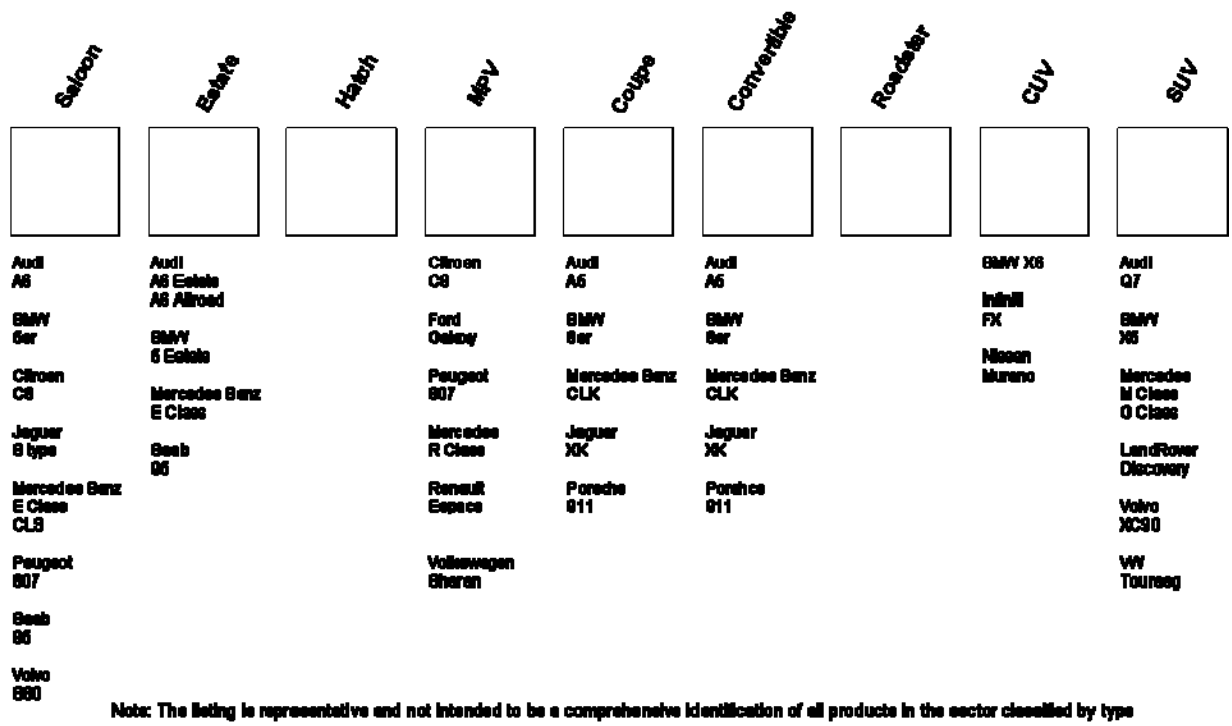


Figure 17.1.d: Products in the ’middle sector’ from European automotive manufacturers

European products in the middle sector have evolved over several model generations. The BMW 5 series, Audi A6, Mercedes Benz E Class Are the key products in the sector. They have been sold for over 20 years in Europe and provide insights into the technological shifts that have occurred over time.

The use of common platforms can offer a variety of products and allow for complimentary technological integration. For example the BMW 5 series saloon & estate have steel fenders, though the BMW 6 series coupe & convertible have composite fenders. The annual production volumes of the 5 series are much higher than that of the 6 series and both products are based on the same base platform.

RESULTS

Vehicles in a variety of classes have shown a continued increase in size and mass. The factors are increased safety, vehicle features and performance. The graph below (Figure 17.1.e) shows the overall trend for European vehicles in the compact class. The trend is typical for vehicles in all classes, driven by increased demand for safety and functionality.

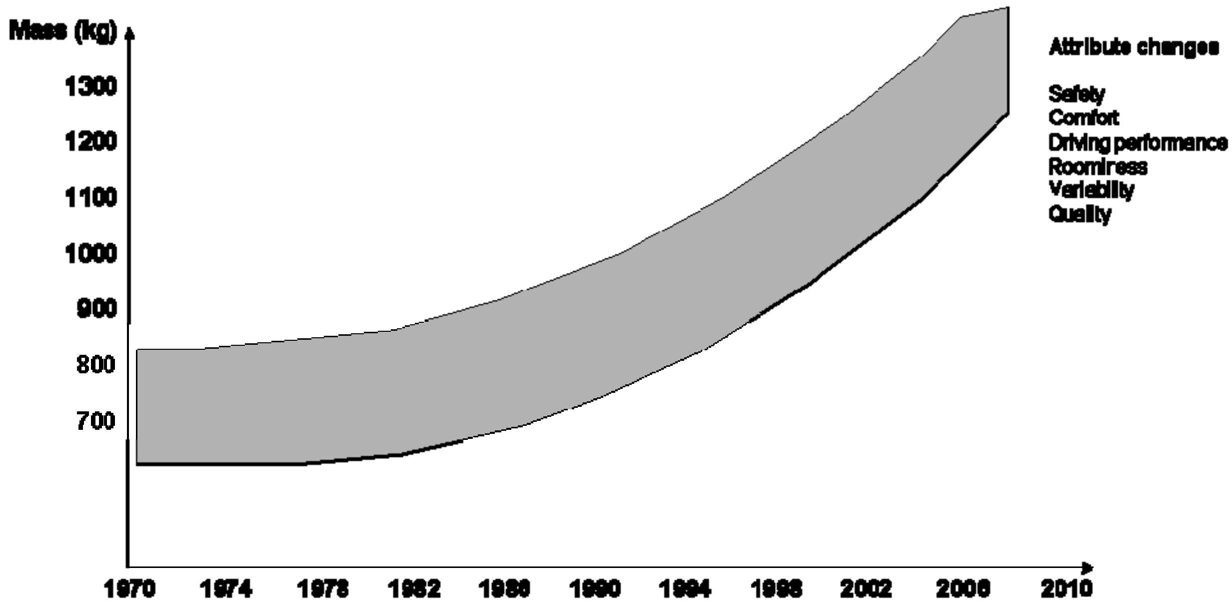


Figure 17.1.e: Trend of Total Vehicle Mass for Vehicles in the 'compact class' [67,68,69]

Mass Drivers

Typical factors in raising vehicle mass are:

i) Safety
Airbags: Driver, passenger, side, thorax, curtain
Seat belts: Load limiters, pretensioners, ISOFIX

ii) Functionality
NVH: Reduced interior noise requires mass damping
Air-conditioning
Stereo systems
Comfortable seats, electric adjustment
Electronic driver aids: ABS, traction control, brake assist, radar, cruise control,

In Figure 17.1.f, the trend for vehicle mass increase has been related to key legislative changes in safety over time. Crash legislation increases over time have resulted in vehicle mass increases. It is expected that market demands for safety will continue to grow with time. Mass reduction measures are making important contributions to limiting these effects on overall vehicle mass.

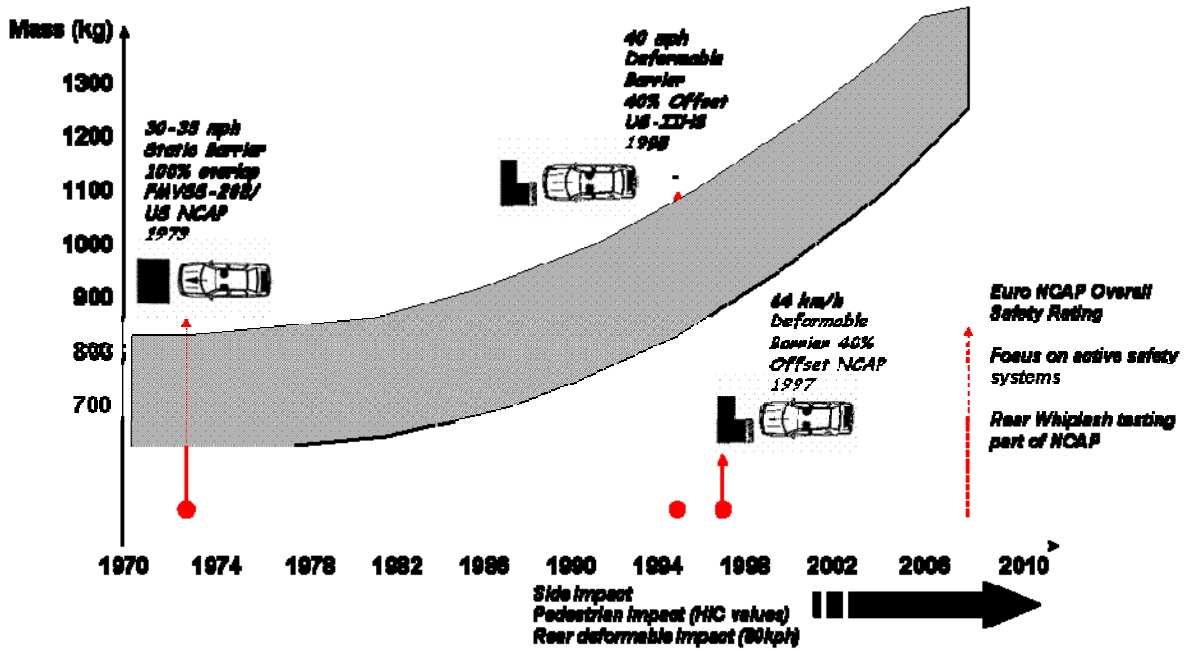


Figure 17.1.f: General Comparison of Vehicle Mass to Safety Features over Time

Body Structure

The body in white is the vehicle system to which the other vehicle systems are attached. For example, engines, gearbox, suspension, interior, electrical harness etc. The body in white provides the form of the vehicle exterior style. Figure 17.1.f below shows a body-in-white.

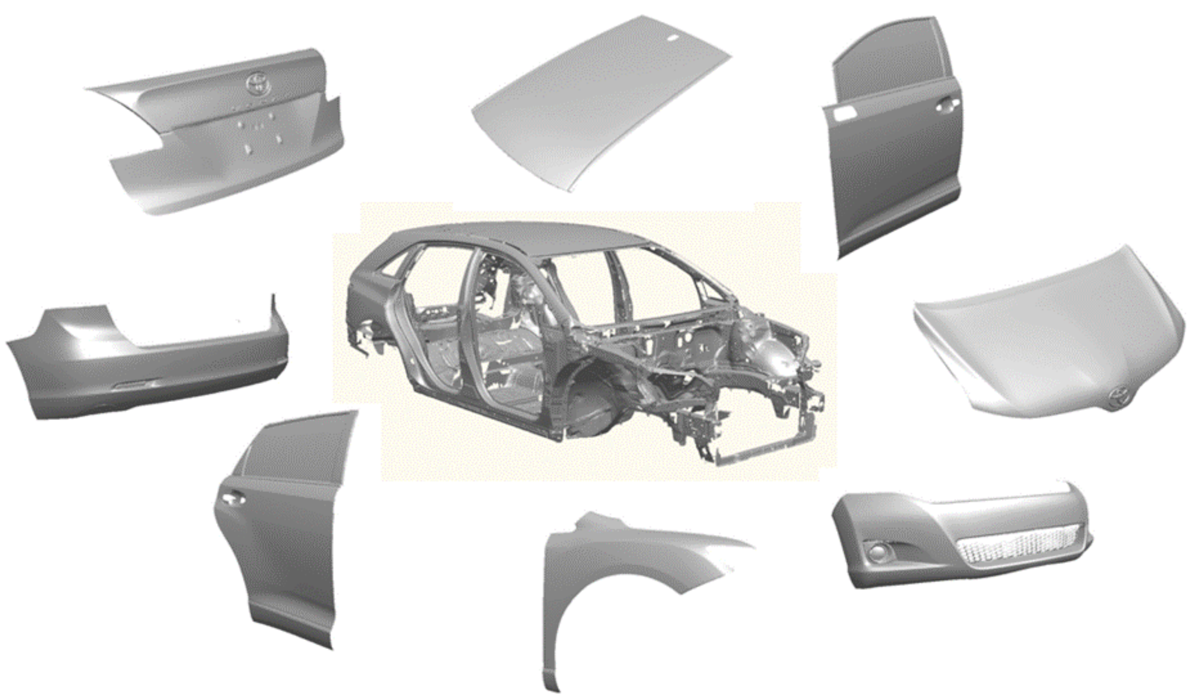


Figure 17.1.g: Sub systems in the body in white: body structure, closures and bolt-ons

The complete body is composed of the body in white, closures, bumper systems, fenders, radiator surrounds and front/rear sub-frames. Other items such as windshield glass can contribute to the body structure for static and dynamic performance.

The body engineering concept has evolved to incorporate ease of vehicle assembly with modular sub systems that attach to the body structure to build into the vehicle (Figure 17.1.h). The focus for modularity has related to the bumper systems, which assists in repairability & cost reduction for relatively low speed impacts. The bumper system in conjunction with the radiator surround becomes a module that allows all the radiator systems, headlights etc to be mounted in a modular manner, facilitating the vehicle build. Other areas of possible modularity that have been used include the front dash panel or firewall which allows insertion of the complete built up dash module into the vehicle.

Body structure material management has limited increases in overall vehicle mass due to legislation, feature and comfort requirement. Body structure material use is likely to be dominated by steel. Types and strengths of steels used have increased over recent years as material technologies have developed.

The percentage of the body structure mass using high strength steels, strengths above 220MPa, has increased from a few percentages from the 1990s to over 50%-60% today. Add definition 80 KSI

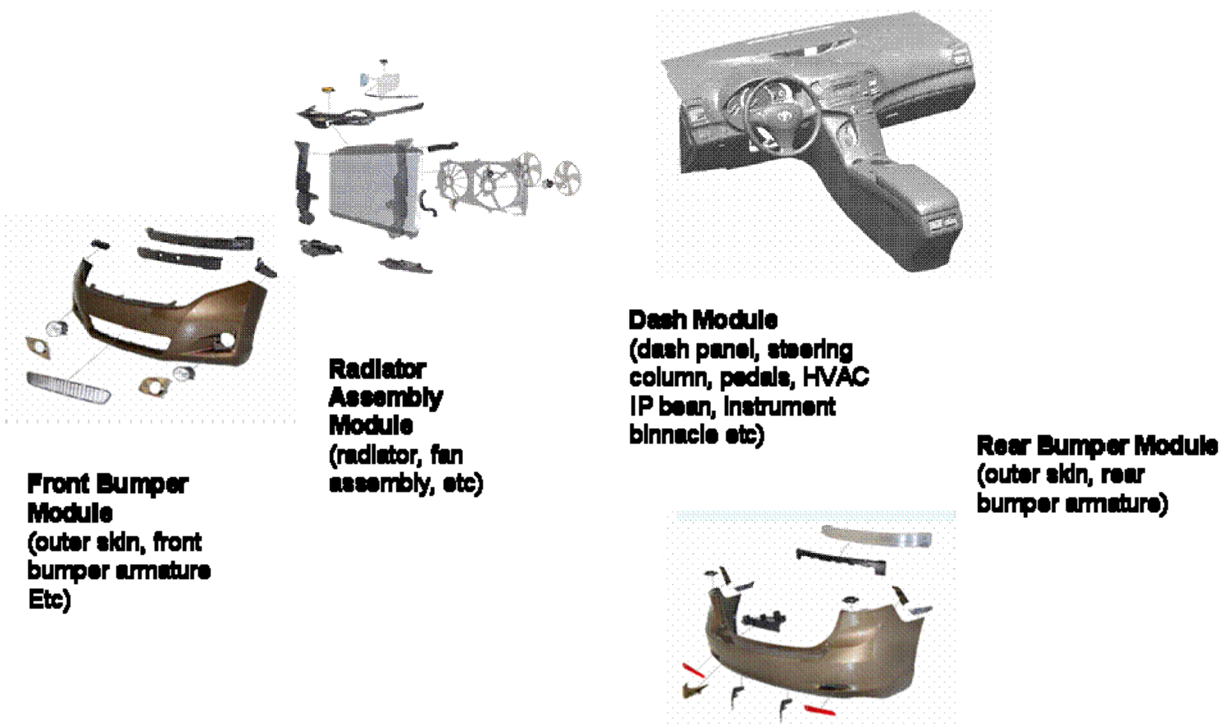


Figure 17.1.h: Sub system modules that assist in ease of assembly

The use of high strength steels in conjunction with other materials has allowed for mass reduction to be realized whilst meeting performance attributes. Figure 17.1.i shows the trend of increased material types use and improvements in the Lightweight Design Index.

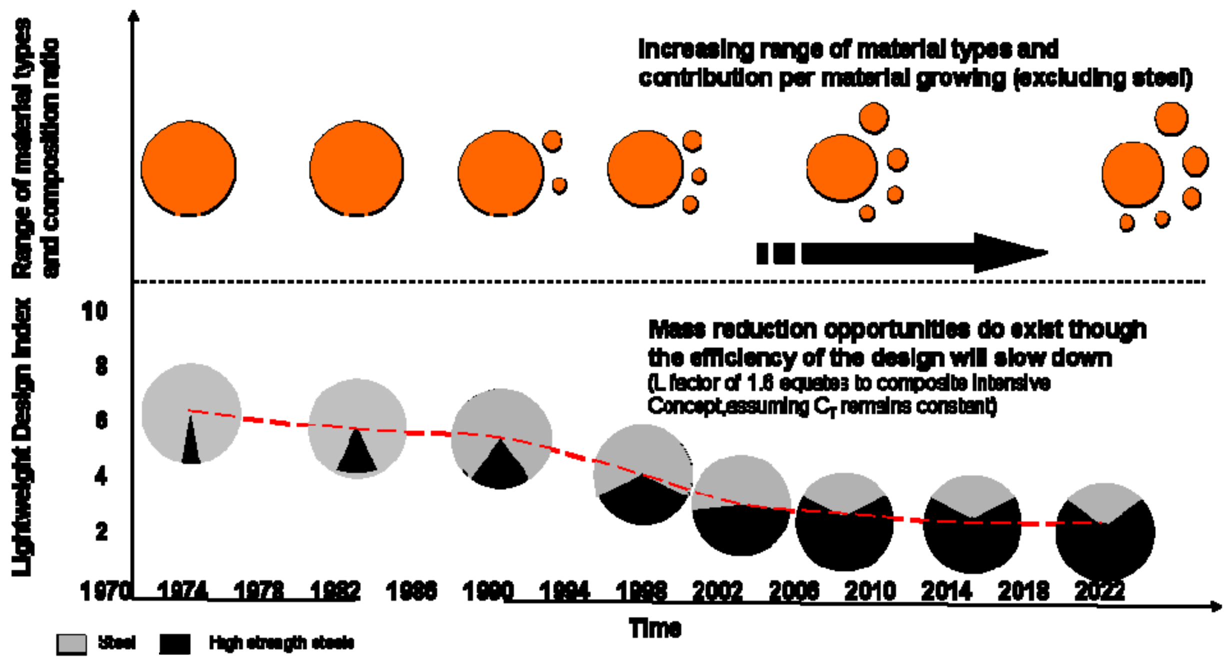


Figure 17.1.i: Progression of strength of steels, and increase in other materials for the body structure in relation to the Lightweight Design Index [70, 71, 72]

The shift of steels from the strength of 140MPa towards higher strengths has caused a re-think and adaptation of material processing to form parts. In general the higher the strength of steel the less formable the material becomes. The use of higher strength materials requires a revised approach including part design, additional forming steps, hot forming or the use of the material in different forms.

Cost effective use of HSS requires design optimization and blank orientation. The use of different forming techniques or additional operations changes the cost of manufacturing parts. Complimentary forming techniques such as tailored blanking, patch blanking, roll forming, tailored roll forming, tubes and hydroforming all assist in the forming of the parts and improved material utilization.

The joining of high strengths steels requires refinement of standard joining techniques such as spot welding or laser welding. The use of a range of material types in the body structure adds to the complexity of structural joining.

Variations in the production volume, number of body variants, quality requirements and product performance attributes all have an impact on the economic assessment of the engineering/manufacturing solutions. (Figure 17.1.j)

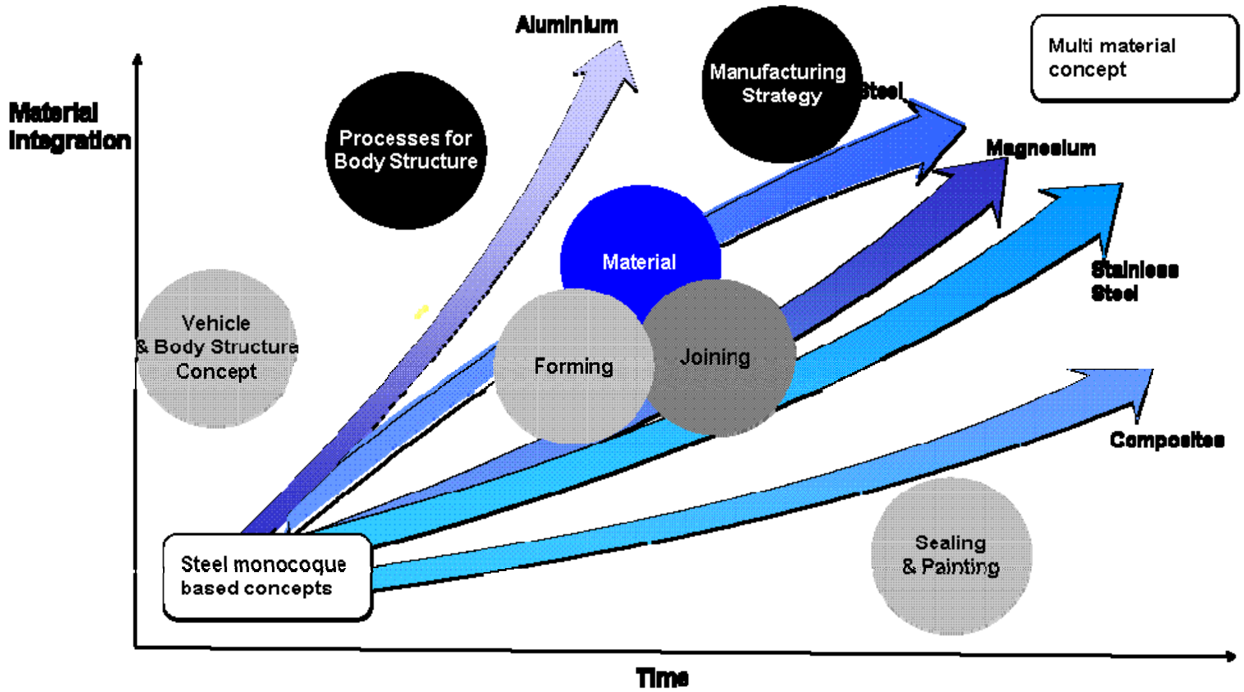
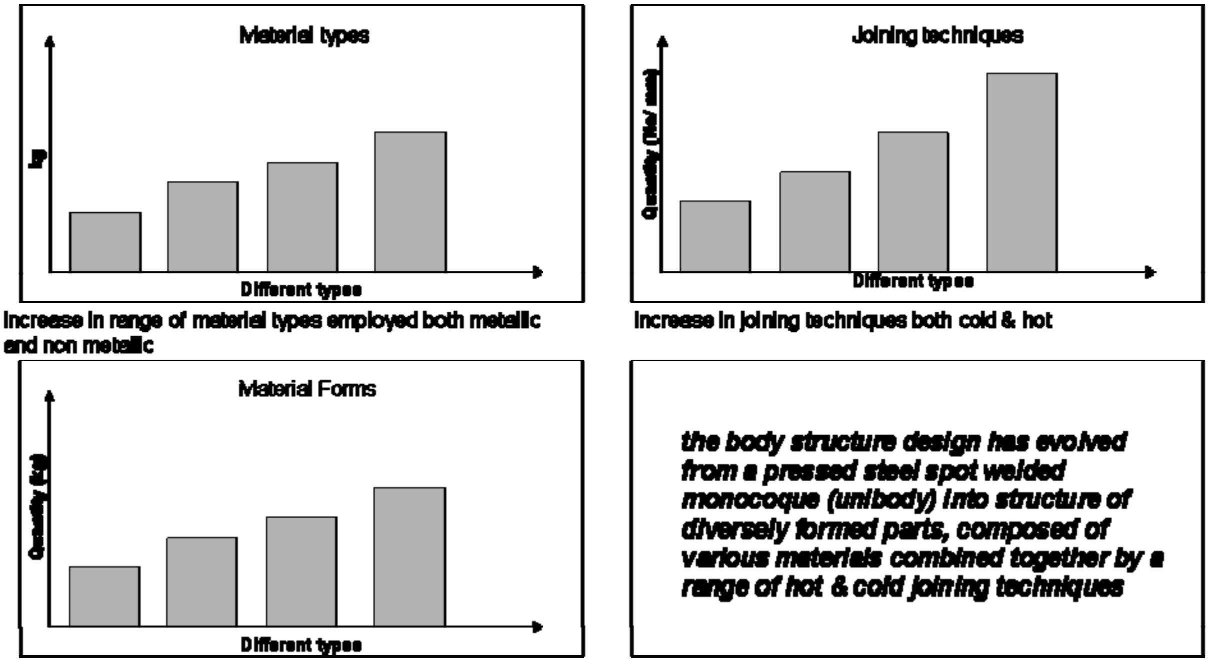


Figure 17.1.j: The shift in the body concept from predominantly steel to multi material

We have seen over time the increase in the use of material types, number of joining techniques and material forming techniques. (Figure 17.1.k) The average European body structure is now a multi material, multi part formed & multi joined entity.



Increase in range of material types employed both metallic and non metallic

Increase in joining techniques both cold & hot

Increase in the use of material material forms, metallic both net shapes (castings etc), formed (press, tube, rolled, extruded) and material optimised (tailored rolled, blanks & patches)

Figure 17.1.k: Increasing type & number of material, joining, forming contributions.

In the 1990s, a variety of vehicle classes incorporated modular aspects into the body structure. This introduced composites or composite hybrids that used metallic reinforcements. Vehicles in early 2000 onwards used lighter alloys in the **shear panels** of the body structure. A front of dash panel is a shear panel. The structural & crash sensitive parts were composed of high strength steels while the main floor & rear parcel shelf shear panels were in aluminum.

During this time a variety of structural concepts for middle class products were adopted by manufacturers. Figure 17.1.l highlights the range of permutations available in finding solutions.
The key shift is the use of aluminum in shear zones while structural load and crash paths remained in steel. The BMW 5 series employs a dual material concept, with the front end of the body structure made in aluminum utilizing pressings, extrusions and castings. The remainder of the structure is produced from steels.

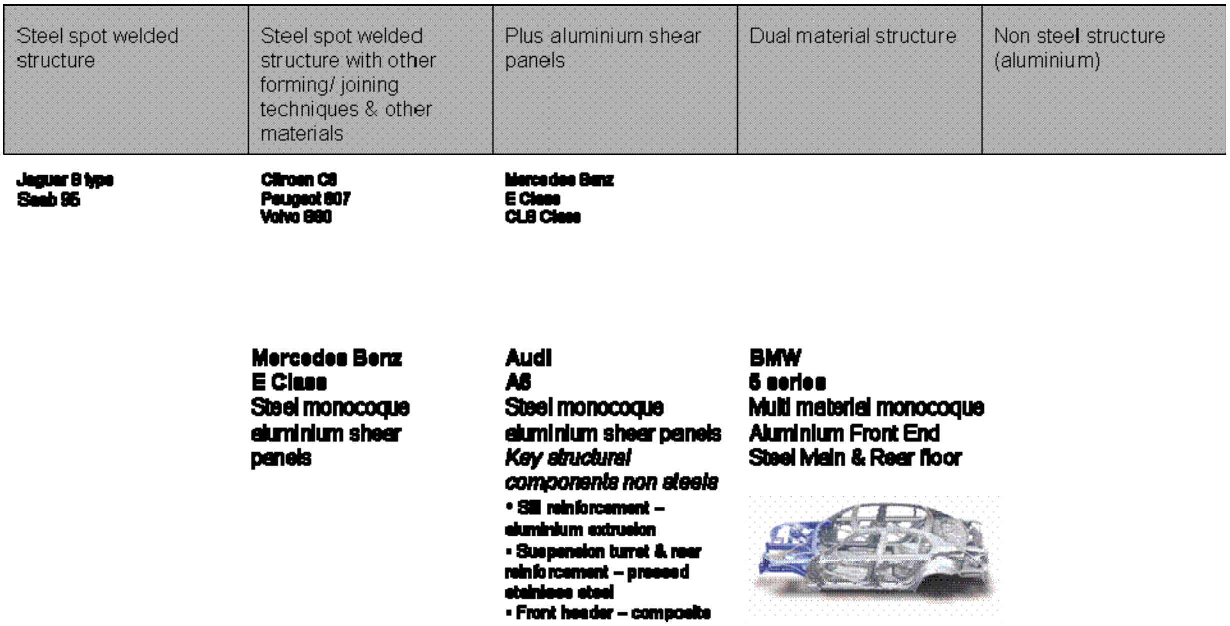


Figure 17.1.l: Comparison of saloon vehicles from within the 'middle class' sector

The current range of vehicles above the 'middle class' have a higher than average use of high strength steel. The average steel strength has risen from 230MPa in the early 2002 to 380MPa in 2009. (Figure 17.1.m) This represents a 60% increase between vehicle generations. The Lightweight Design Index trend shows that future gains in body structure efficiency are likely to be less dramatic.

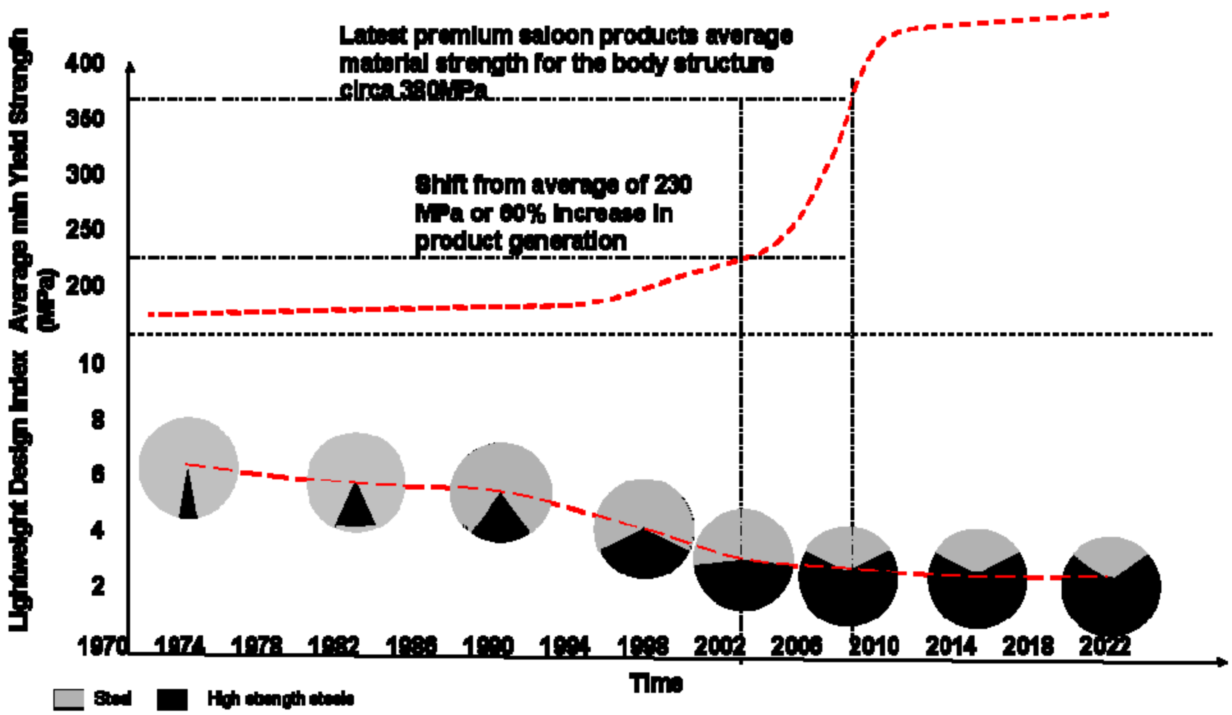


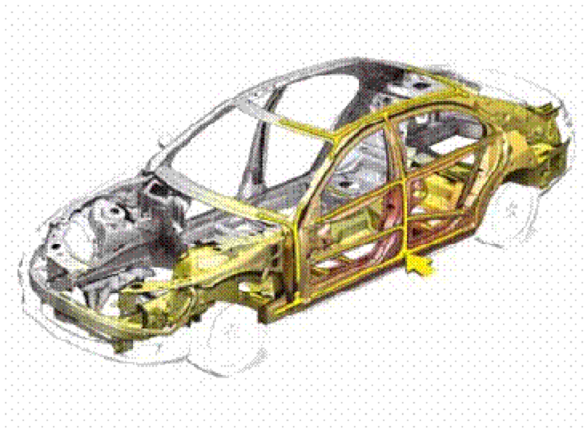
Figure 17.1.m: Increase of the strength of steel in the body in white

Closures

The closures are defined as the hood, doors & tailgate/trunk. See (Figure 17.1.n). Material substitution in the closures can be used to realize significant mass savings. The previous generation of products has shifted from steel towards a greater use of aluminum. This is especially true in the middle sector. Vertical closures were the first to be changed. Horizontal panels such as hoods and boot-lids came later. Some manufacturers have continued to increase the strength of steels used in closures.

Figure 17.1.n: Exploded View of the Closures

The current generation of products in the middle sector and from the class of vehicles above has seen the continued development of new closure concepts. The variety of solutions is increasing with pressed formed, extruded and die cast parts being used in solutions. (Figure 17.1.o) The new BMW 7 series and Porsche Panamera doors in aluminum are examples of this trend.



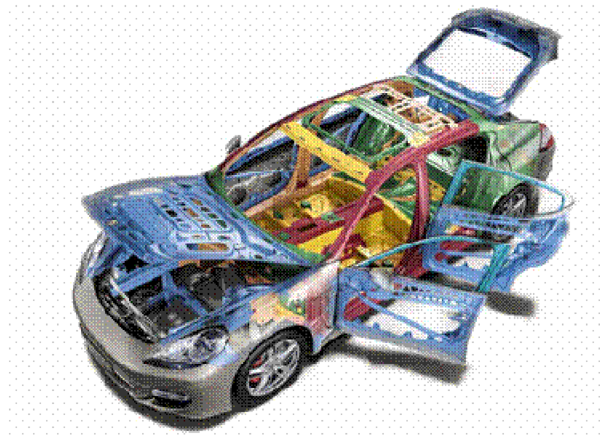


Figure 17.1.o: Development in terms of Closure Material and Engineering Concept [73]

The hood has been an area of challenge due to pedestrian legislation changes. New limits on the collapse load characteristic of the hood place demands on the design and package of the hood and the components beneath it. To achieve efficient solutions the reinforcement panel has been developed through a variety of form designs. Solutions have been developed by various manufacturers to achieve the best balance between mass, function and cost.

In recent years, the material for hoods has moved towards aluminum. Japanese manufacturers[74] demonstrate that aluminum hoods can be a contributor towards achieving pedestrian safety and overall mass efficiency.

Vehicle closures are likely to continue to evolve in terms of material use and technological developments. The ability to use materials in cast form will enable multi-material designs. Figure 17.1.p shows the key materials being utilized for closures. The evolution for the more mature materials, e.g., steel, are displayed as trends.

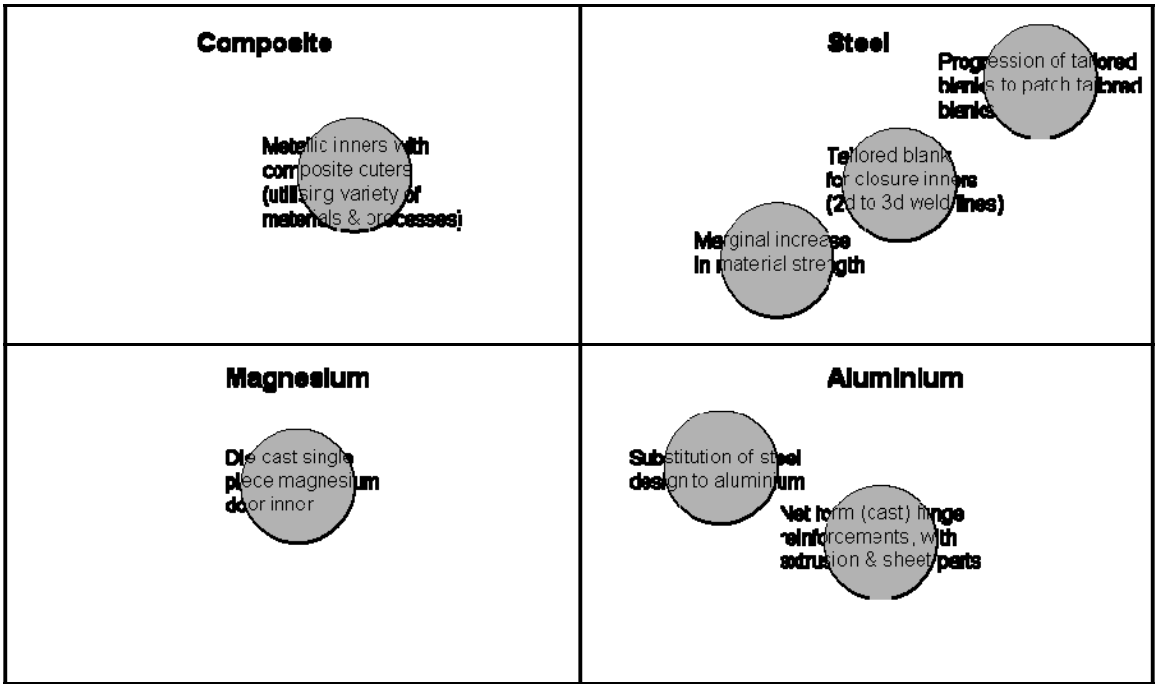


Figure 17.1.p: Closure Materials with the Evolution of Steel and Aluminum Technologies

Fenders

Fenders (Figure 17.1.q) along with other major outer panels represent the face of the vehicle design form. They interface with the front lights, bumpers and provide encasement for the front wheel/tire envelope. The material of choice has been steel with niche volumes using a variety of materials notably composites.

The early 1990s saw vehicles launched where the front fenders were produced using polypropylene. The Renault Clio was the first high volume application in Europe.

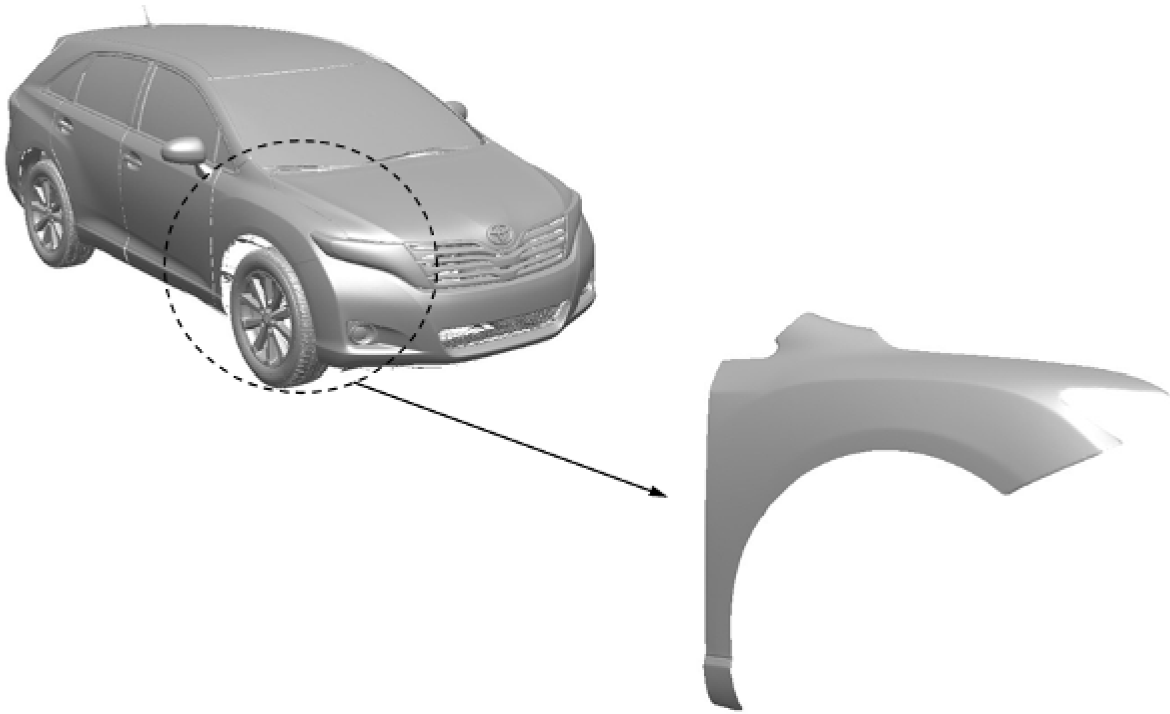


Figure 17.1.q: Exploded View Showing the Fender

The first applications for fenders produced from composites were in the sub compact class of vehicle. Other notable applications were with the Smart, Mercedes A class And Land Rover Freelander.

The next advancement saw application on a large high end saloon vehicle. (Mercedes Benz S Class 500) Today, vehicles like the BMW 6 series coupe & convertible use composite fenders.

The predominant fender material in the future is expected to be steel, with more examples in aluminum and composites being introduced.

Front & Rear Bumpers

The bumper systems provide the primary front and rear end impact structure of the vehicle. They are sub systems in terms of assembly for the majority of cars. Their ability to be easily detached assists with repairability. The engineering effort needed for designing efficient bumper systems has increased due to more demanding crash legislation.

The key structural element in the bumper system is the bumper armature. (Figure 17.1.r) Automotive manufacturers have used a range of material solutions for the bumper armatures.

Figure 17.1.r: Exploded View of front & rear bumper systems with armatures highlighted

In the 1990s, the choice of material for bumper armatures was predominantly high strength steel. Today, the range of steels and strength levels available has increased resulting in the use of dual phase and TRIP steels. Aluminum extruded armatures are a common engineering solution today. There is also the potential for stainless steel.

Automotive manufacturers are pursuing different solutions. The choice of material between the front and rear armatures can vary. (Figure 17.1.s) A variety of forming processes are used to engineer the armatures and low speed crush cans that can range from extrusions to hydro-formed steel parts. The end material selection depends on a variety of factors.

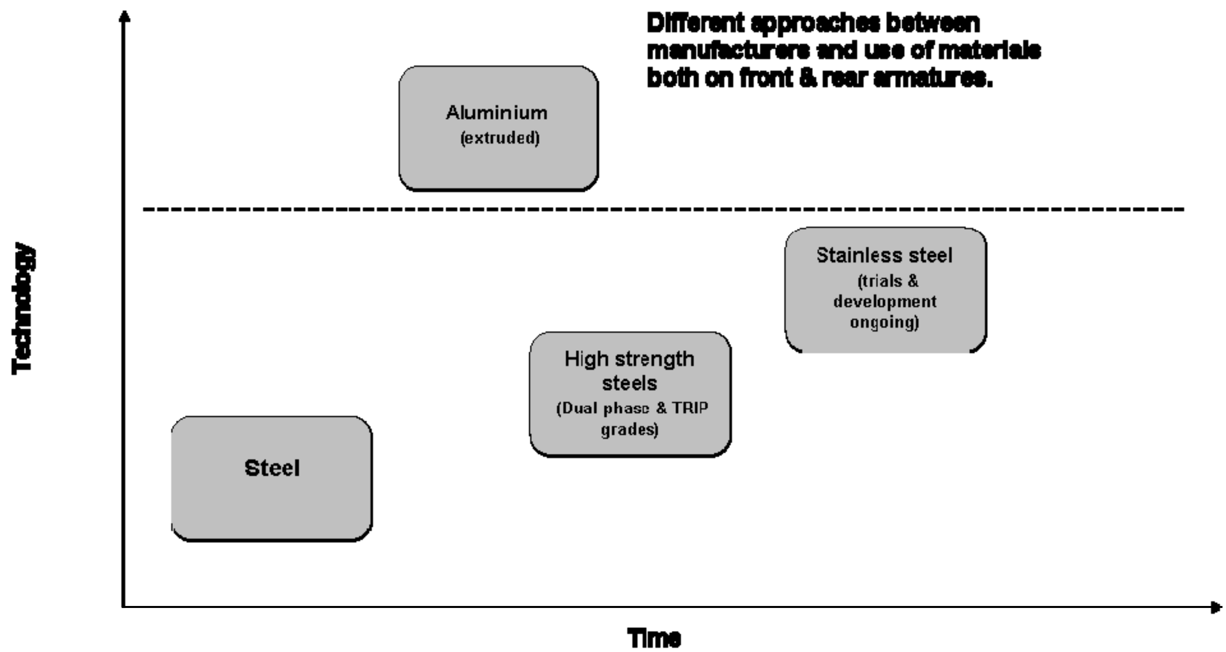


Figure 17.1.s: Roadmap of materials used in bumper armature systems

Studies[75,76,77] indicate stainless steel with its higher strengths and improved formability over high strength steels (e.g. dual phase or TRIP) provides more efficient bumper armature solutions. The improved formability enables more geometric complex shapes enabling additional performance gains and style objectives to be achieved.

Bumper armatures additionally play an important role with regard to vehicle crash compatibility i.e. bumper to bumper contact. Automotive manufacturers have focused on vehicle crash compatibility for products within their product ranges, ensuring good crashworthiness. Figure 17.1.t shows the bumper height differences for a variety of vehicles. The selection of the appropriate material solution enables requirements to be met in conjunction with vehicle engineering for different models in the range.

Figure 17.1.t: Vehicle compatibility an important engineering aspect for bumper systems

Electrical

The growth of vehicle features has focused on comfort related items like electric seats, electric windows; safety related airbags, anti lock brakes and parking aids. (Figure 17.1.u) The linking of features has added complexity to the control systems. This has placed more demands on the electrical/control systems resulting in higher specification & sophistication of electrical systems. The increased content typically impacts mass and cost.

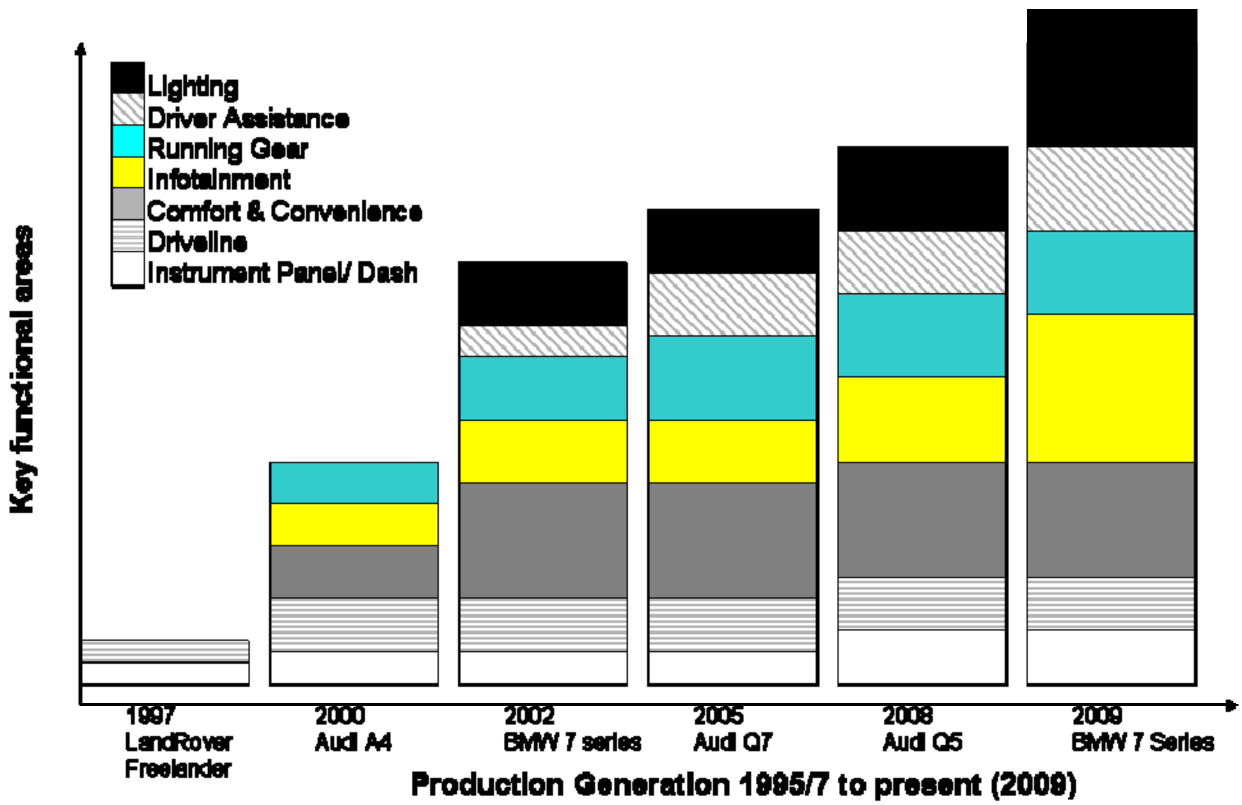
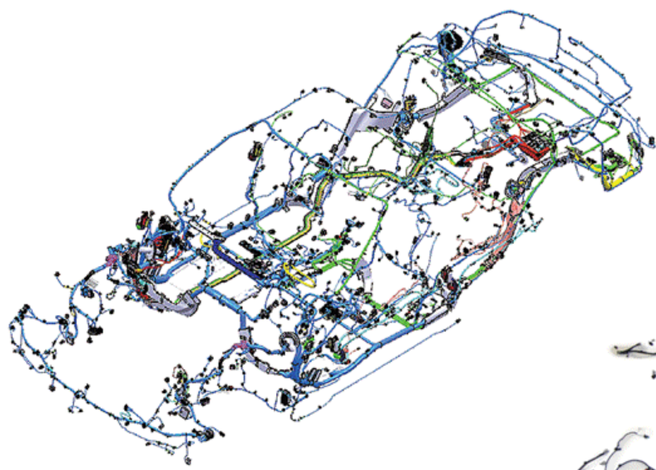


Figure 17.1.u: Roadmap of feature content increase [78, 79]

ICE or 'In car entertainment' has evolved from simple radios to entertainment systems with interactivity, telecommunication and GPS devices, demonstrating the complexity trend. In Figure 7.5-1, the electrical system in vehicles is represented. The visual provides an example into the complexity of the harness that provides the connectivity between all the vehicle devices.

A mid- sized passenger car wiring harness typically has a mass of 45 kg. For reference the length of a wiring harness can vary. If you compared a basic specification vehicle with that of a high specification middle class vehicle, the unwound harness length would be circa 2 km's versus 8 km's. Figure 17.1.v shows a typical wiring harness and a portion of the Venza wiring.

The movement to multiplexing to replace individual wires has progressed in certain vehicle areas, examples being dashboards, though in limited applications. A trend that was forecast though not realized was the progression towards a 42 volt electrical architecture from the current 12 volt.



Example of full vehicle harness

Photograph of Toyota Venza
Sub system body harness (not complete)

Figure 17.1.v: Exploded View of the Electrical System [80]

As with other component systems the trend is reduced mass. For electrical harnesses the focus becomes the optimization of shielding & wire performance. The other technological shift is towards junction boxes.

Different approaches are being taken for the optimization of harnesses either through copper clad aluminum or copper clad steel cables. Typical standard wire has an outer diameter or OD of 1.3mm, cross sectional area or CSA of 0.35mm^2 and mass of 4.5 grams/meter. Compressed cable has an OD of 1.1mm, CSA 0.35mm^2 and a mass of 3.9 grams/meter. The difference is 15 % reduction in size/mass. Currently available in sizes from 0.13 to 1.5mm^2 (most common cable sizes used in vehicle harnesses are 0.35mm^2 - 1.5mm^2). This technology is forecast to become common in the next cycle of new vehicles.

Circuit protection is shifting away from fuses boxes and toward electronic control, thereby reducing component size and mass. The benefit of no customer interface means packaging does not require access functions, thus allowing increased packaging flexibility.

The Human machine interface (HMI) and ICE systems trend is for integration, with the use of touch screens. The use of fiber optic cables in the infotainment systems provides mass saving potential.

Battery technology is being evaluated as part of propulsion studies. This is providing the benefit for the re-evaluation of battery technology for low voltage applications.

Brakes (discs, calipers, lines & booster)

The development of the braking system has followed the path of supporting the growth in vehicle size with increased brake disc sizes and wheel/tire sizes. (Figure 17.1.w) Technology in the form of anti-lock brakes has provided improvements in terms of reduced braking distances or improved braking performance. Figure 17.1.x shows the evolution of brake rotors.

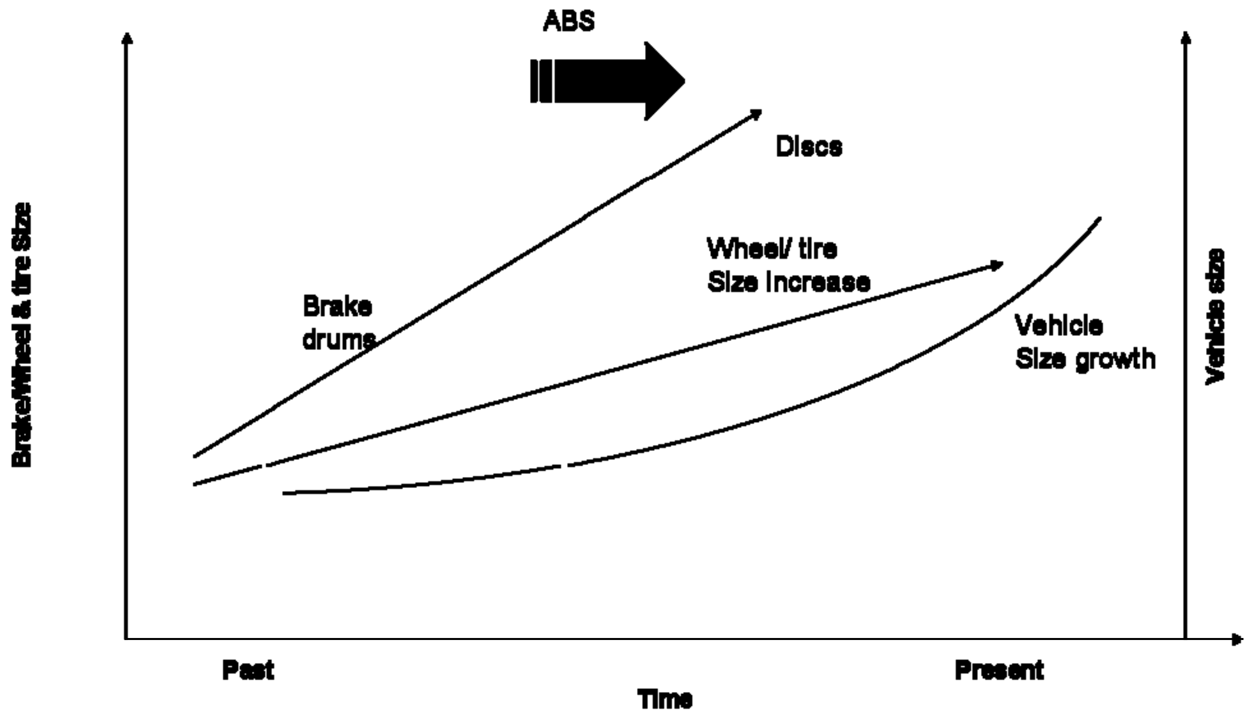


Figure 17.1.w: Trend of increased vehicle, wheel & tire sizes on braking systems

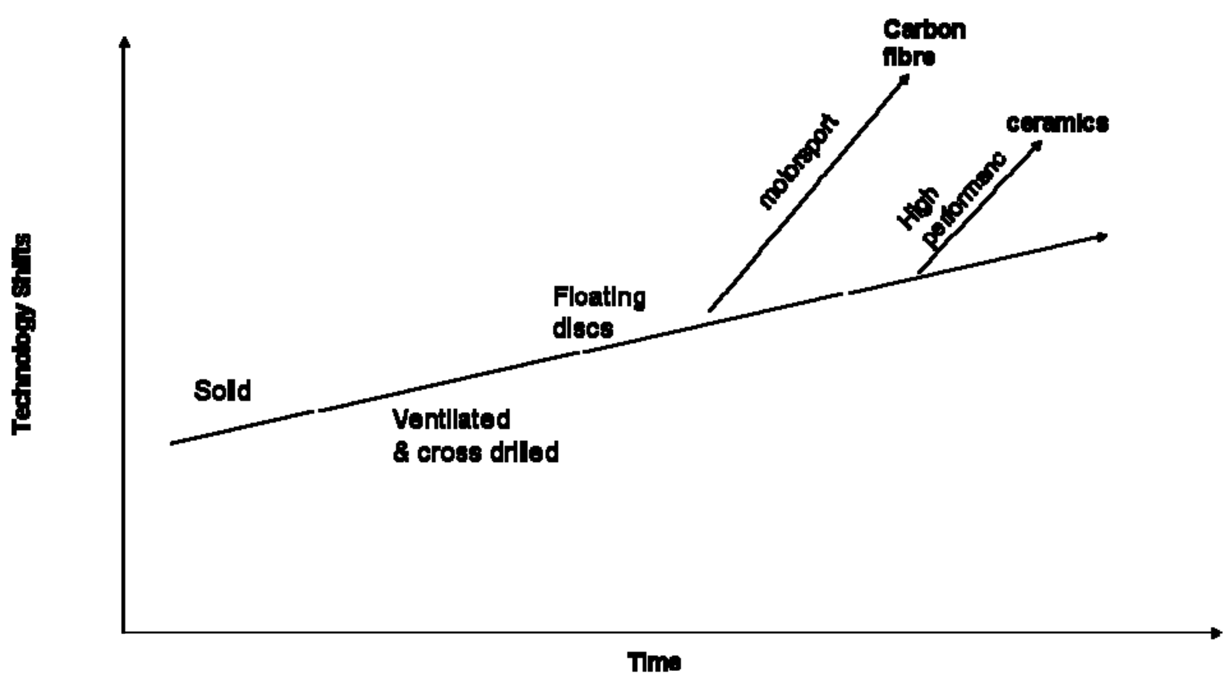


Figure 17.1.x: Brake Rotor Evolution

Other developments are automated parking brake systems and the move from drums to discs (rotors). In terms of performance/premium vehicles the increases in power have lead to the development of ceramic brake discs. Carbon fiber discs are used in motor sport applications. Ceramic versions are found in luxury classes of vehicle, especially in high performance derivatives of supercars. Both are expensive options compared to standard steel versions. As an example, the 2010 Porsche Panamera, a car with a base cost of $89,800, offers a ceramic composite brake (PCCB) option at a cost of $8,150.

Interiors

The development of interiors (seats, dashes, carpets, headliners) (Figure 17.1.y) has focused on features such as cup holders, folding seats, multi use space, integration of support devices (e.g. satellite navigation, HMI controls), refinement of surfaces/textures to improve the usability, comfort and quality of the interiors.

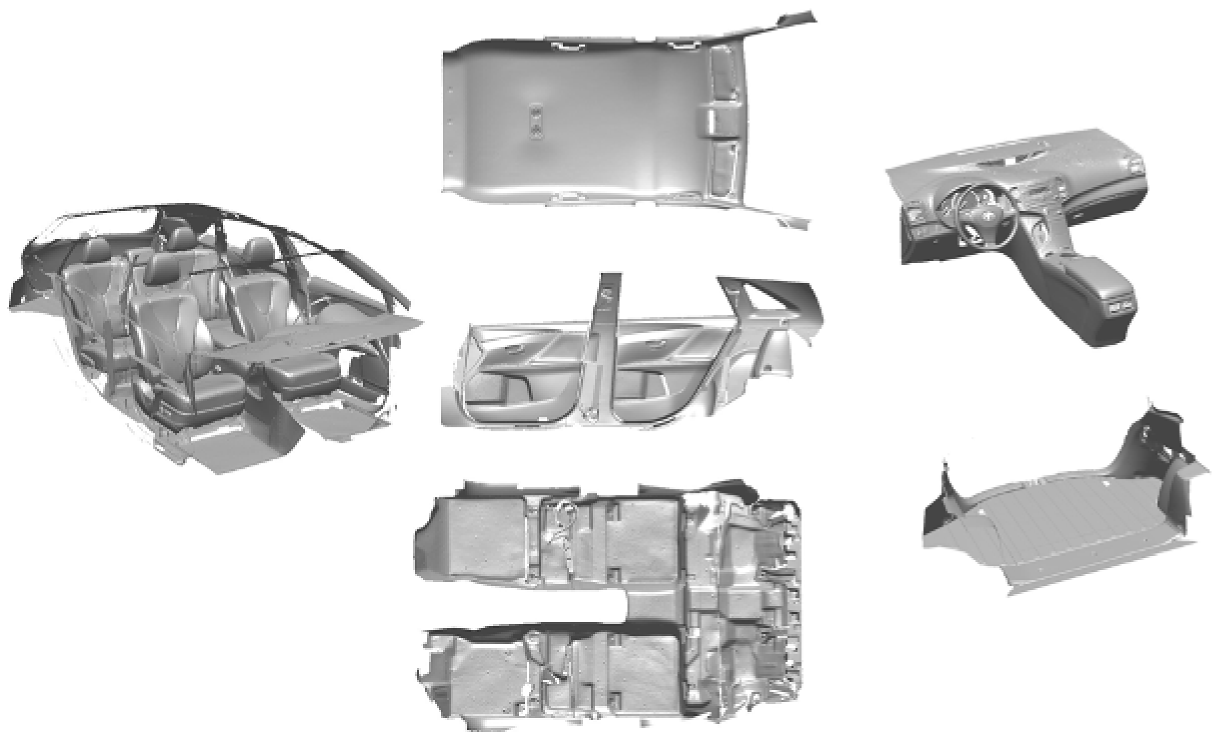


Figure 17.1.y: Visualization of the Interior System

The increased variety of vehicles, the flexibility of use, and inclusion of additional safety features have resulted in growing complexity, a challenge for the engineering and design. Though efforts have gone towards mass reduction the increase in vehicle size and feature content has resulted in mass gain.

Front & Rear Lighting

Lighting technology has progressed from bulbs to LEDs (Light Emitting Diodes). The developments in material technology for glass and polycarbonate have allowed greater freedom of integrating light design into the vehicle form (Figure 17.1.z & 17.1.aa).

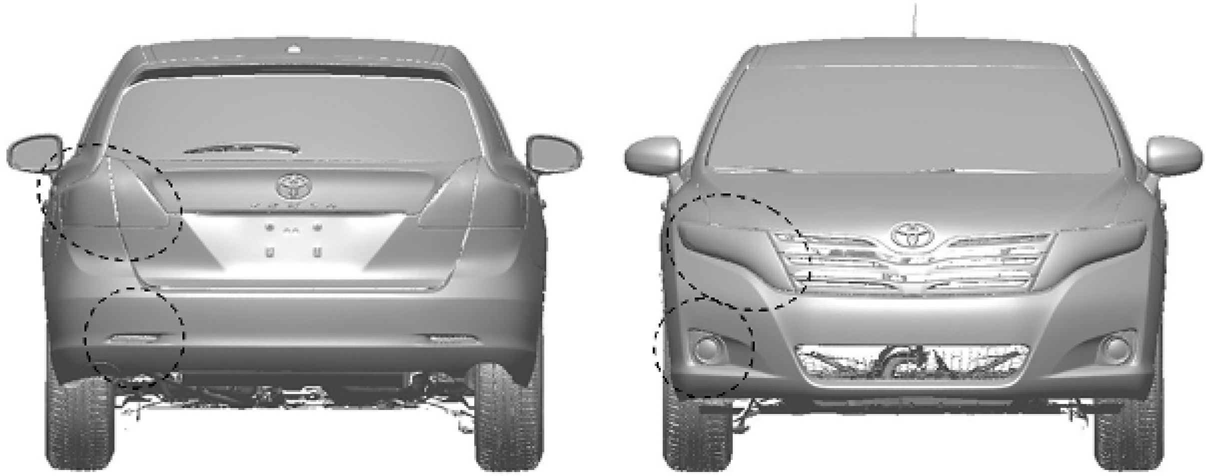


Figure 17.1.z: Example of Front & Rear Lights

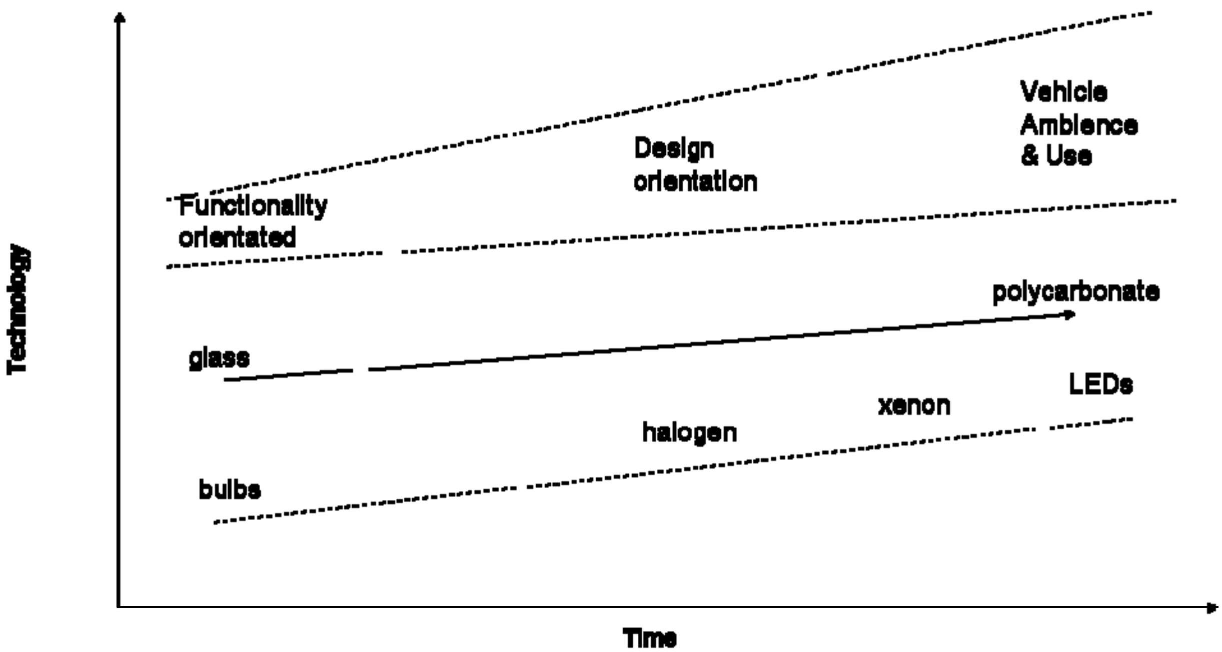


Figure 17.1.aa: Roadmap for Lighting Technology

The use of lights in interiors and doors has provided for design ambience, more illumination of occupants and improving safety during ingress/egress. The integration of lighting functions in visual confirmation of vehicle commands has grown. For example, opening or locking the doors, safety alarm setting and remote opening of the vehicle. Other functions, such as illuminating the vehicle environment have all added to increased complexity with other vehicle systems.

Features have been made of daylight running lights, a legislative requirement and by the use of lighting technology (e.g. LED's). When illuminated they provide for differentiation of the vehicle face. The use of lights requires electrical power and therefore impacts the fuel efficiency of the vehicle.

Chassis/Steering

The steering system (Figure 17.1.ab) technological shift has been in the material utilized, increased functionality and the system assistance strategy, e.g. electrically assisted power steering.

Figure 17.1.ab: Exploded View of the Chassis/ Steering

The steering rack has progressed from a direct steering system to that of assisted which has gone from hydraulic power assistance (HPAs) to electric power assistance (EPAs). The steering wheel has incorporated a driver airbag and the integration of HMI interfaces for various vehicle operational functions. In certain cases transmissions have paddle shifters behind the steering wheel.

Suspension, Wheels & Tires

The trends for wheels/tire and suspension components (figure 17.1.ac) have seen progression towards material substitution from steel to aluminum. Examples are wheels, suspension uprights or hubs and suspension arms etc. Certain vehicle classes have air suspension as options to the standard metal spring designs.

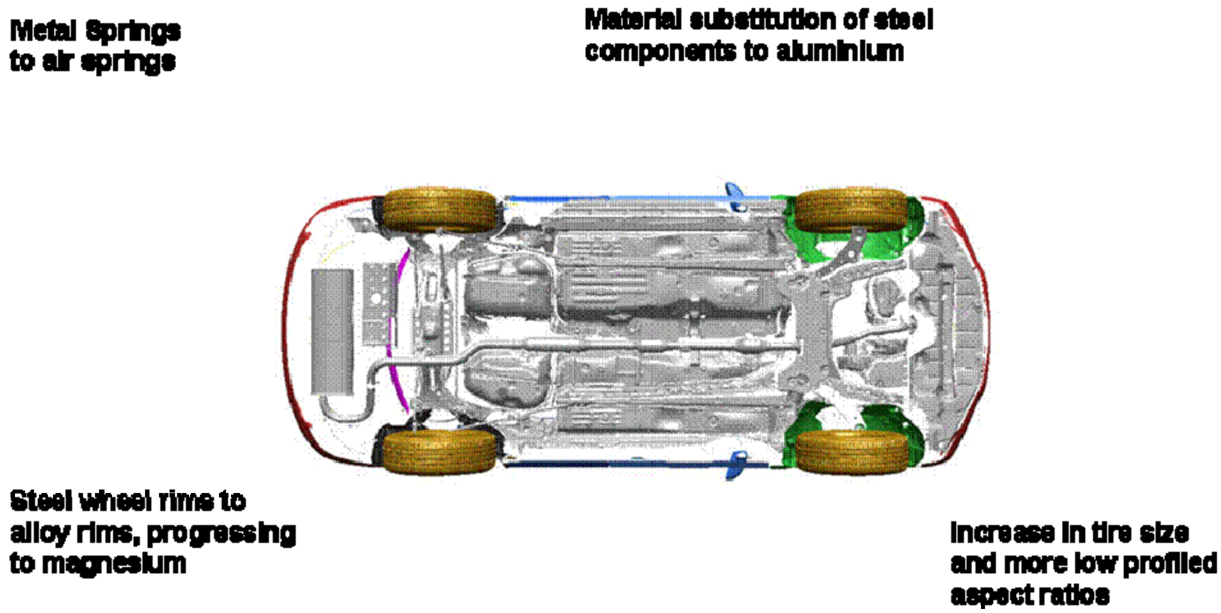


Figure 17.1.ac: Trends for Suspension, Wheels & Tires

The vehicle trend of increased size has resulted in the wheel/tire sizes increasing. The market has seen a shift towards low aspect ratio solutions (height of the tire side wall reducing).

Refinements to vehicle handling come from sophisticated suspension kinematics, bushes and suspension concepts. Vehicles with rear wheel drive solutions have moved to front wheel drive concepts being the norm, especially for the compact size of cars. Four wheel drive systems have become common across all vehicle classes and are not confined to SUVs.

Glazing

The increase in size of vehicles and styling direction has had an effect on vehicle glazing. (Figure 17.1.ad) The improvements in glazing technology have allowed for improved solutions to assist with vehicle design. The increase of features, such as heated front windscreen has progressed from the application being found on the rear.

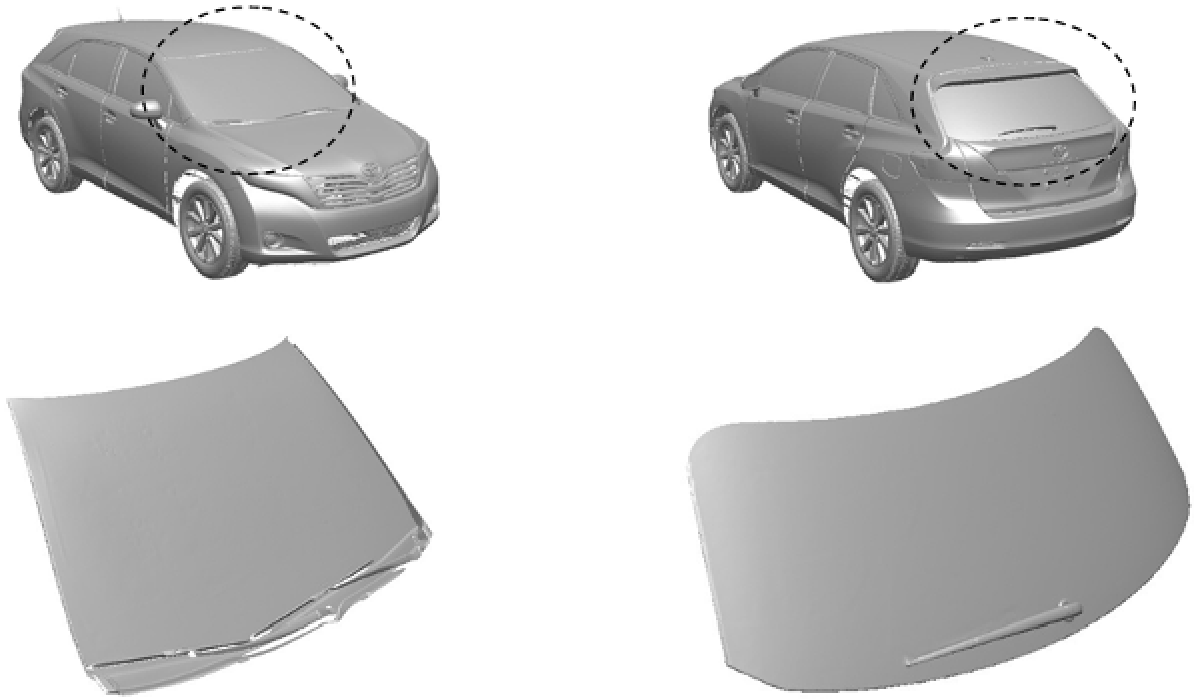


Figure 17.1.ad: Visualization of the Glazing (Front & Rear Windscreens)

The overall material performance of glass/glazing products has improved; new technologies have typically been incorporated on fixed glass applications first.

DISCUSSION OF RESULTS

The availability to consumers of more types of vehicle has changed from the 1970s. The vehicle types will continue to evolve in response to societal needs and the manner of our use. Legislative requirements for safety and emissions will lead automotive manufacturers to provide vehicles that meet market needs and demands whilst providing the performance/feature content we have come to expect.

The transition in the market saw the Golf in the compact segment, superseded by the vehicle class from below, the sub compact class. The Volkswagen Polo (typical sub compact class vehicle) in global terms represents the most popular sized vehicle.

The European trends will see further fragmentation of vehicle types. The leading technology developers and adopters for vehicles will continue to be premium manufacturers. The cascade of technology into the lower vehicle classes will occur at a faster rate than in the past although the transition rate for adoption between manufacturers will remain constant.

Key themes (Figure 17.1.ae), will be the development of new vehicle architectures to accommodate the trend of hybridization of engines and electric propulsion. The opportunity to redefine the vehicle package arises from the manner of future vehicle use, occupant needs and integration of technologies. The next generation of vehicles will see continuing demand for improved performance and specification, set against the challenges of minimal mass increase and maximum fuel economy.

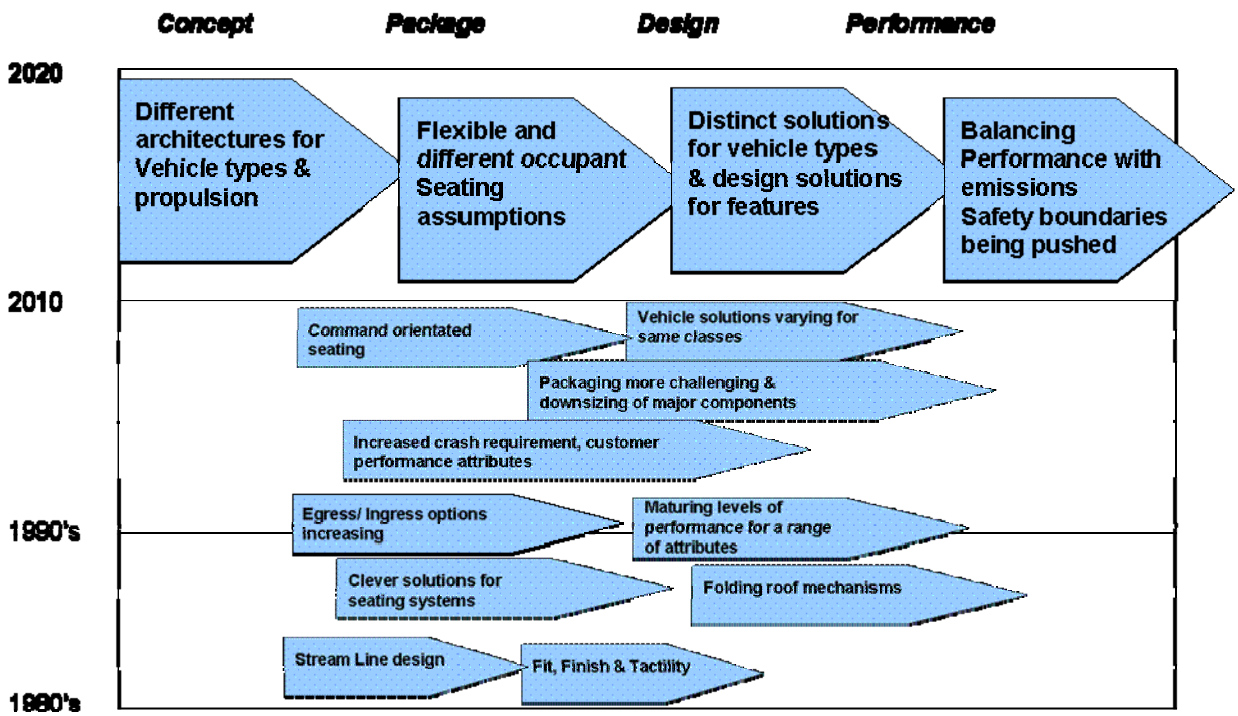


Figure 17.1.ae: Vehicle Forecast Through 2020

The methods and techniques used to develop vehicles in the future are important. (Figure 17.1.af) The further optimization of mass reduction will occur due to the continuing improvements to the techniques of simulation for CAE analysis. Further optimization will utilize material properties from predicted work hardening, thinning of materials during forming operations.

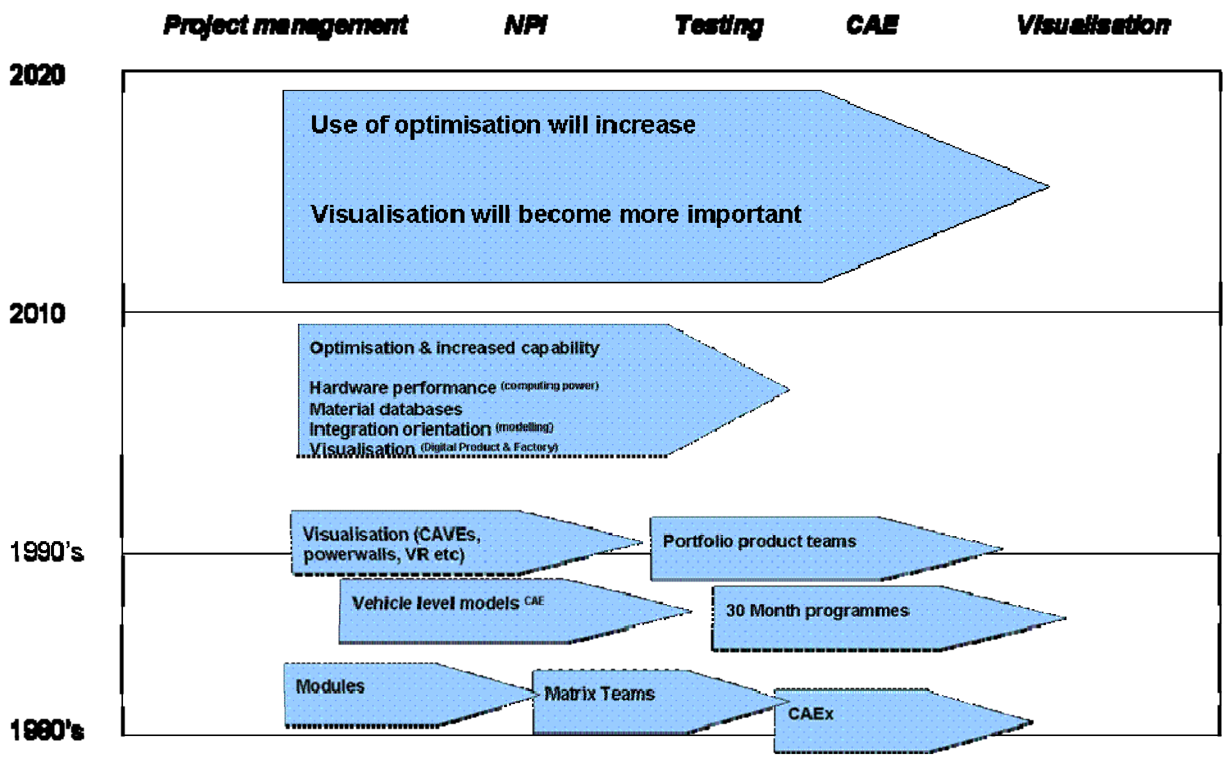


Figure 17.1.af: Forecast 2015-2020 – Techniques

The techniques for correlating test information, whether aerodynamic, crash, NVH, with CAE findings will allow improved interpretation and understanding through the use of Exploded View techniques. This enables further gains in overall efficient engineering solutions.

The body-in-white will remain a focus for mass reduction. (Figure 17.1.ag) The increased number of part forms, joining techniques, material types and material strengths enables a variety of solutions. The future will continue to see more solutions from automotive manufacturers as opposed to convergence. In the main, leading edge technology development and application will continue to come from the premium manufacturers. Solutions will be incorporated into premium vehicles and then follow into the vehicle classes below in subsequent product generations.

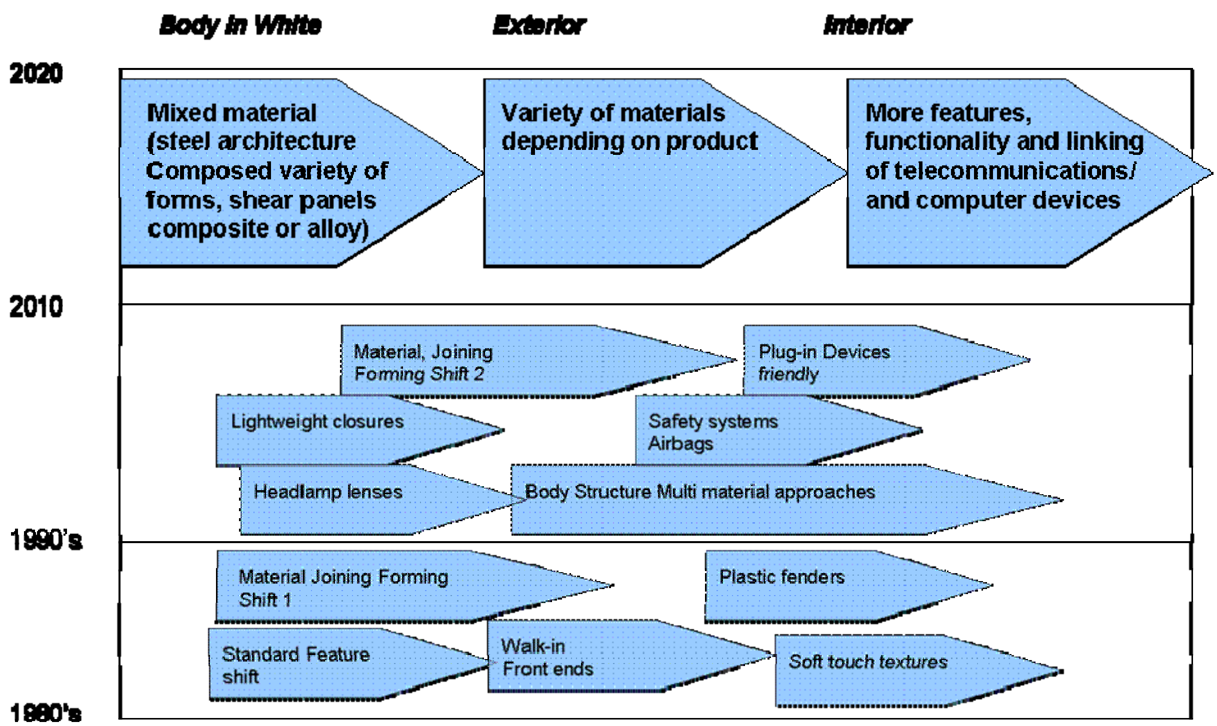


Figure 17.1.ag: Forecast 2015-2020 – Body

Exteriors will utilize different materials depending on the volume range and will become independent of platform strategies. The key trend on interiors will be functionality orientated, the integration of telecommunication devices and safety enhancements.

The early adopters and integrators of electrical or control system orientated technology have been premium automotive manufacturers. In the near future, these manufacturers will continue to be the introducers of new technology in this field. The added cost of the newer systems becomes easier to integrate on products with relative high selling prices. (Figure 17.1.ah)

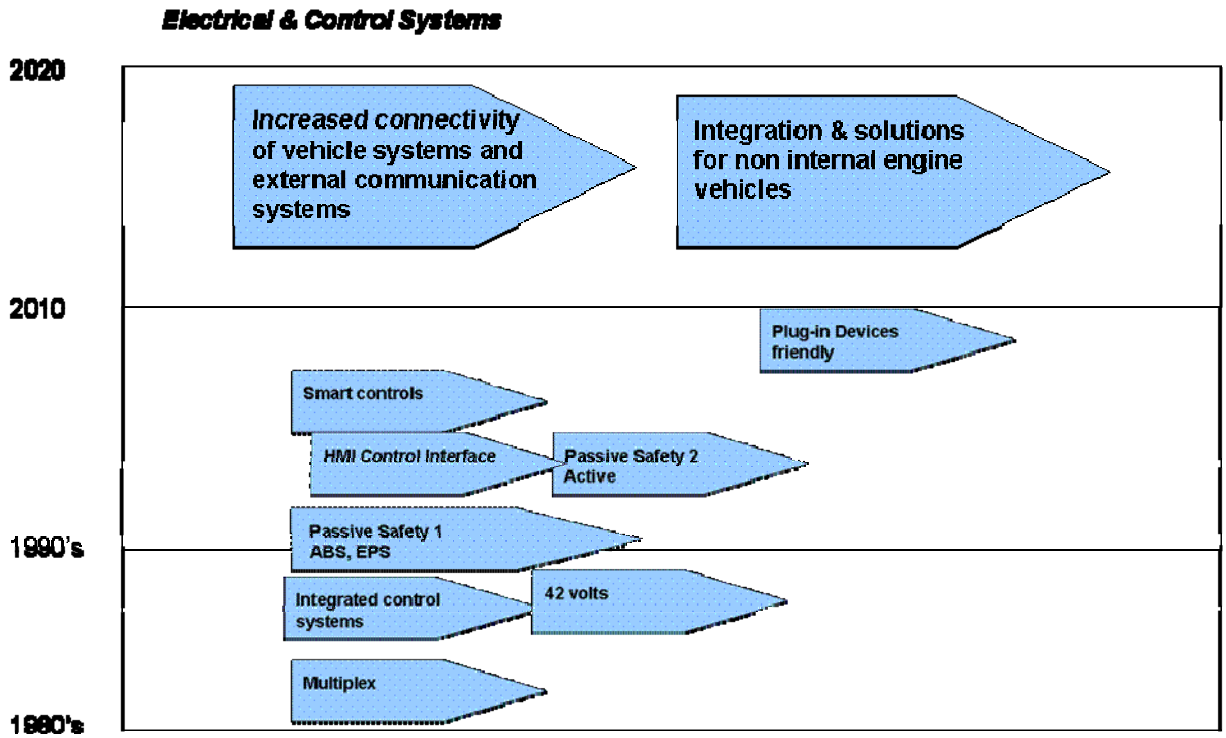


Figure 17.1.ah: Forecast 2015-2020 – Electrical

The issue for electrical orientated technology becomes the integration and control strategies between components systems. Integrating control modules and allowing multiple systems to be managed will be the focus for automotive manufacturers. This leads to mass efficient systems. The introduction of new propulsion technologies and the need for both high and low voltage current systems provides for additional opportunity and challenges.

Further development of the internal combustion engine through either stop start technologies/mild hybridization has impacts on the vehicle architecture/package and interactivity with other vehicle systems. (Figure 17.1.ai) The gearbox housing for the electric drive can be integrated with the electric motor casing. The key theme will be to identify and focus on such components for integration & optimization.

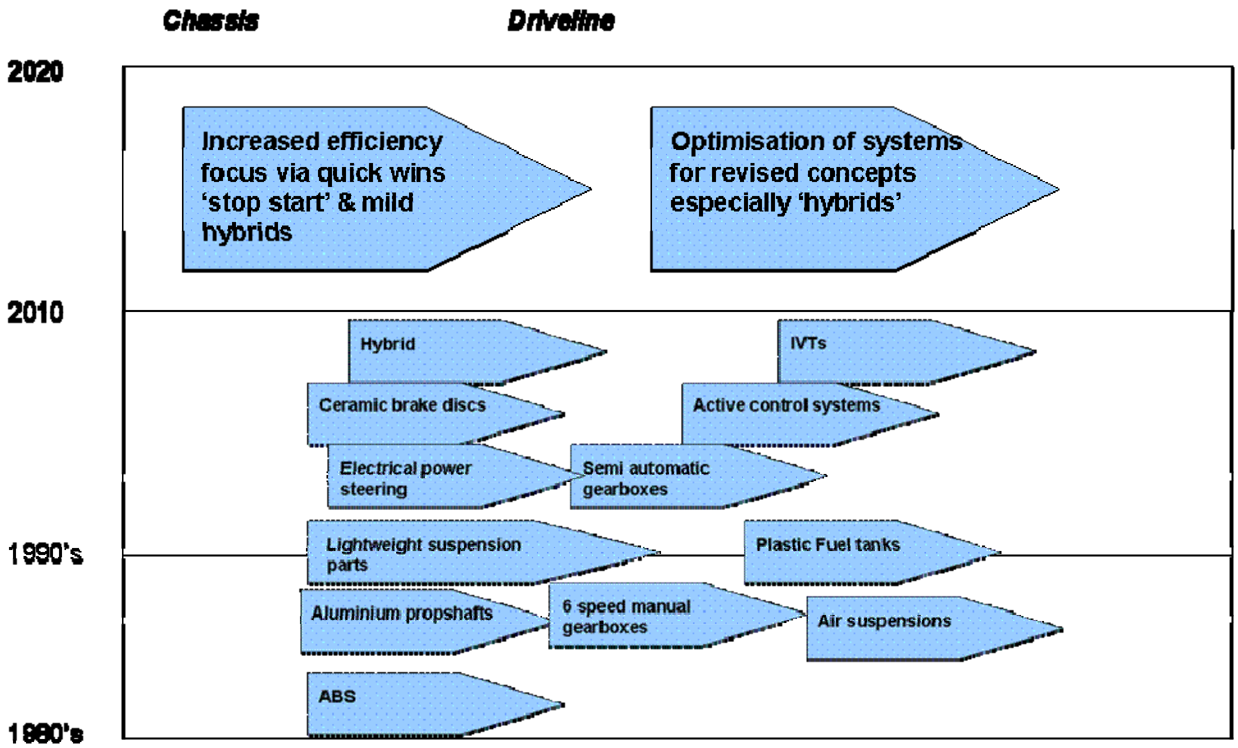


Figure 17.1.ai: Forecast 2015-2020 – Chassis

The standard propulsion system has been the internal combustion engine, either petrol or diesel fueled. The future will see engine size, defined as capacity, decrease. Due to combustion technology such as turbo-charging and other auxiliary engine systems like stop start providing further efficiency gains. In addition, the movement towards electric vehicles, the hybridization of existing powertrain solutions means the future orientated vehicle solutions are in the early phase of adoption and development. We will continue to see developments, refinements and integration of energy retention systems into the propulsion mechanism of vehicles. The focus will be mild hybridization and for niche vehicles full electric offerings. (Figure 17.1.aj)

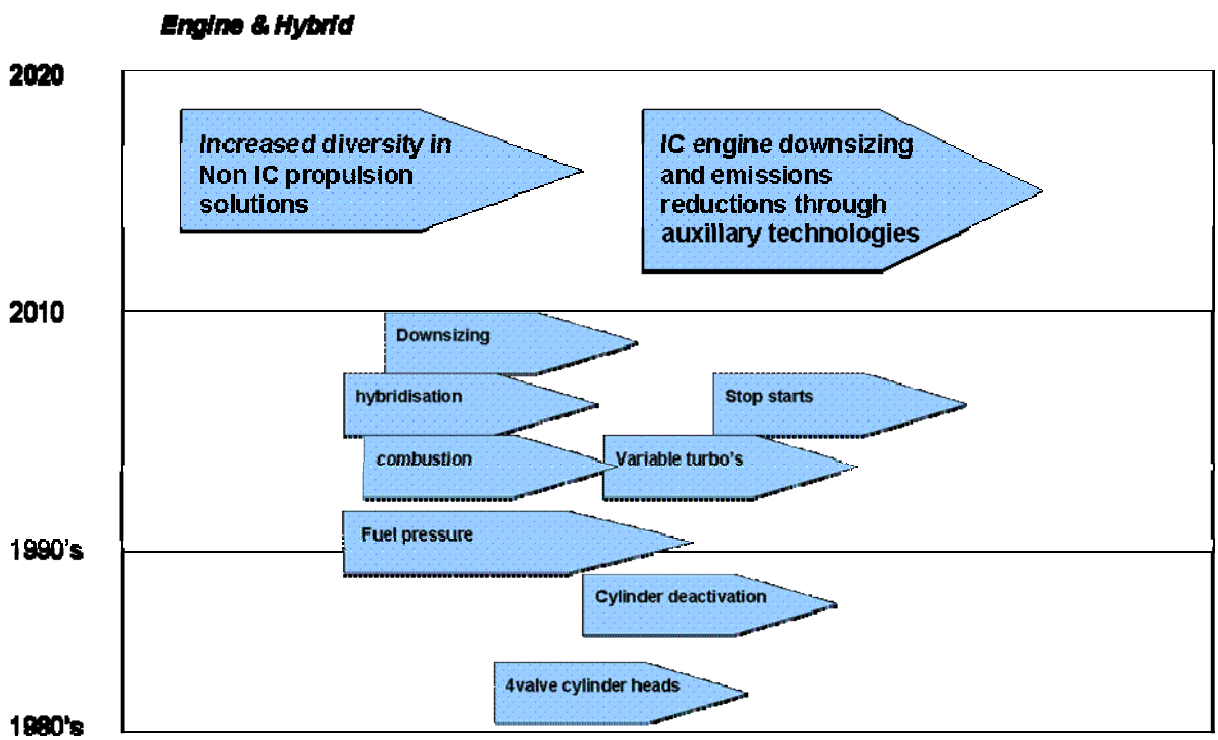


Figure 17.1.aj: Forecast 2015-2020 – Propulsion

CONCLUSIONS

The saloon, estate, coupe or SUV type vehicle has evolved to a multitude of types. This trend will continue to tailor in the future towards lifestyle. An important aspect will be the location/environment where the vehicles are used, urban, city center or rural areas. Location will factor in the selection of the propulsion system vehicle types, vehicle range and vehicle architecture.

Automotive manufacturers require platforms from which a range of vehicle models are produced to achieve volumes of scale. This supports the economics of the business and provides for sustainable cost competitive vehicle offerings. Future platforms need to cater for a wide range of complexity, in particular for the shift in propulsion technology. They need to provide the opportunity for additional mass reduction for specific vehicle models that are derived from the platforms. For example, additional mass reductions maybe required to compensate for the mass of batteries in an electric propulsion version.

The use of a greater variety of materials will increase and play an important role in the future for mass efficient vehicles.

In summary, future vehicle architectures will determine the combination of material, part processes and manufacturing strategies. General trends we are likely to see:

- Continual change in the vehicle form, size and shape from today's conventions
- More raised seats or 'command seating' (the rise of the 'H' point) making ease of ingress and egress easier
- The proportion in terms of the overhangs becoming shorter and vehicle height increases
- Lighting technology in conjunction with design will provide innovative solutions and opportunity for differentiation
- The body-in-white will use of more material types, with a greater variety of processes for forming & joining being standard

- Vehicle package concepts will have an impact on the interior design, closures and use of the interior for either storage or lifestyle functions
- Telecommunications will further impact on the HMI of the vehicle, with increased interaction with various vehicle systems and how the vehicle is utilized

Figure 17.1.ak below shows possible evolutionary paths for future vehicles.

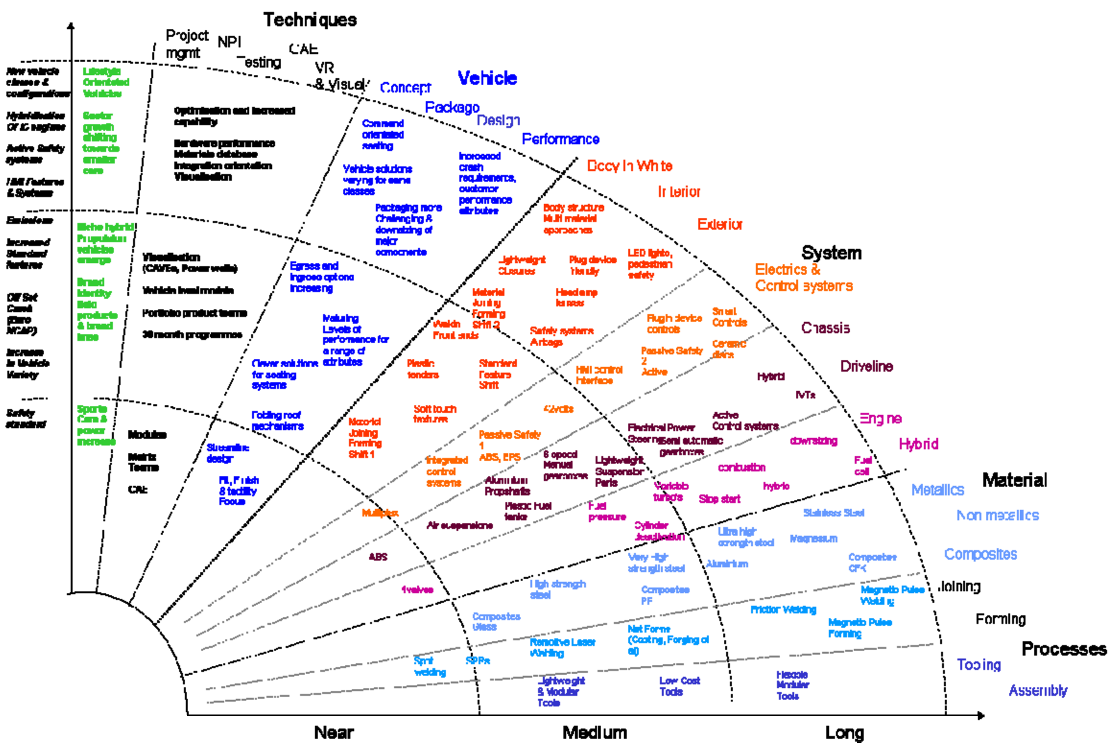


Figure 17.1.ak: Road Map to the Future: 2015-2020

The direction of technologies will be dependent on the rate of adoption and acceptance. This will be driven by either legislative or consumer demands. In reality, both will become more connected than at present. The end vehicle solutions will vary and be driven by the automotive manufacturers market positioning of the vehicle.

The direction for component system development is understood by industry. In certain instances, the state of the technology for cost effective mass reduction remains the final barrier for adoption, e.g., carbon fiber components. Historical projections for technological adoptions have proven inaccurate for the rate of adoption or predicting step changes. When new legislation has been introduced automotive manufacturers have, in many instances, found solutions within the existing technological & manufacturing infra-structure. Meeting the new roof crush standards is an example.

RECOMMENDATIONS (FURTHER WORK)

The establishment of a reference scenario based on vehicle definition enables the exploring of different technology permutations with respect to performance and cost analysis. This understanding for future vehicle concepts incorporating new technologies becomes critical for enabling technological assessments.

Future vehicle definitions should be based on a virtual engineered vehicle (inclusive CAD & CAE). This enables comparison of different permutations of technology at vehicle level or system level for functionality, performance and cost trade-offs. Such a tool would provide the ability to model scenarios and understand the issues from the automotive manufacturer's perspective and end user experience. This provides an enabler to determine options for the future.

Further work could involve understanding the automotive manufacturer's viewpoints/projections of vehicle technologies for the stated period. Such a study would involve direct support & participation from CA-ARB to facilitate dialogue with the automotive manufacturers.

In combination, the further work provides for a comprehensive view of the future horizon. The work would provide a real world scenario of the projected composition of vehicles for sale later in the decade and further.

APPENDIX

Case Study: Volkswagen Golf

The Volkswagen Golf is a compact sized vehicle, launched in the 1970s and still in production today. It has evolved through a number of models from the Mark 1 in 1974 to the Mark 6 in 2009.

The mass and sizes of these models is illustrated in diagrams Figure 17.1.ak and 17.1.al. These show significant increases in these properties over time. The vehicle mass growth in the initial generations was on average 10%-15%, though this slowed down to below 10%. The vehicle footprint grew at a rate of 3.5%-5% and then stabilized. (See Appendix 1)

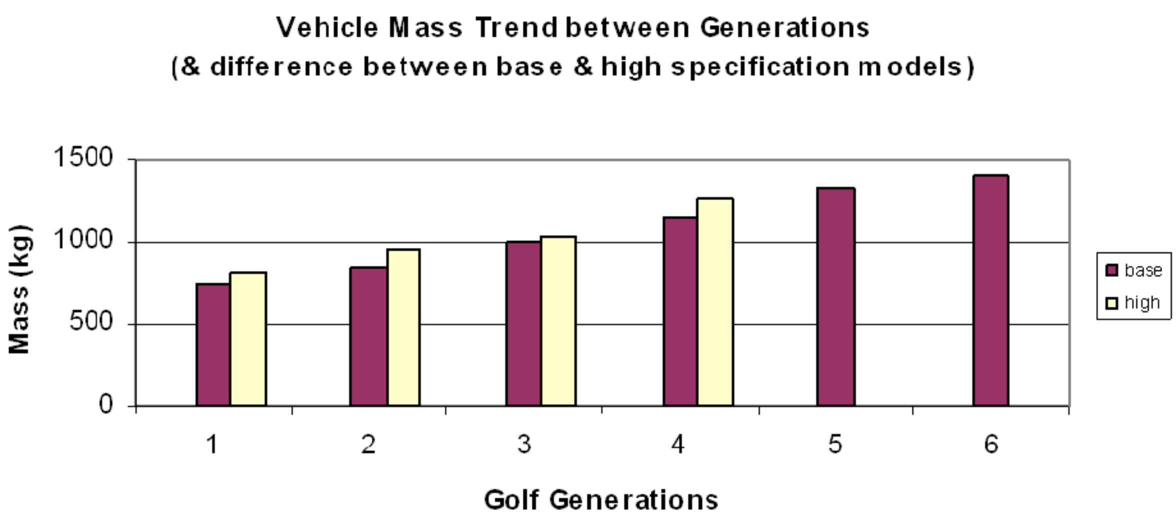


Figure 17.1.ak: Volkswagen Golf Mass Trend

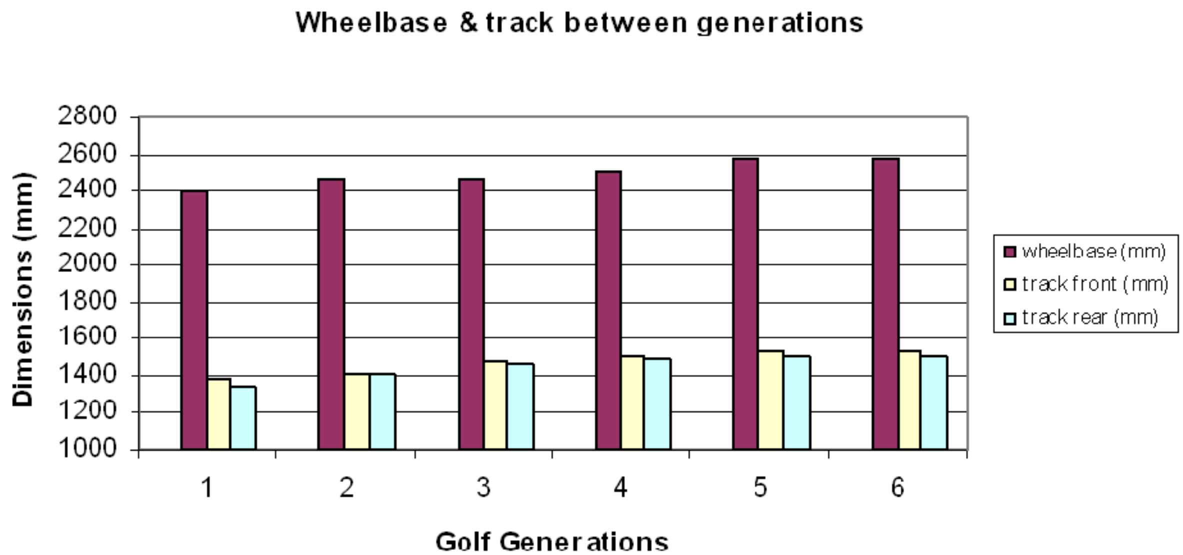


Figure 17.1.al: Volkswagen Golf Footprint Trend

Figure 17.1.am shows how the vehicle mass has increased over time for the Volkswagen Golf, though the Lightweight Design Index has improved. (See Appendix 2)

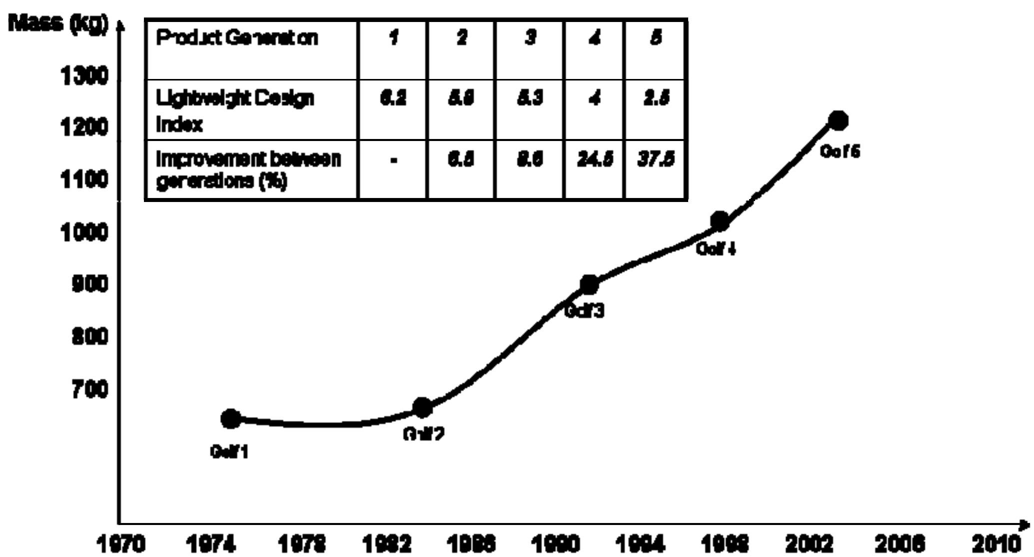


Figure 17.1.am: Comparison of Vehicle Mass & Lightweight Design Efficiency for the Volkswagen Golf over Time

As the body-in-white constitutes a large percentage of the overall vehicle mass, the Lightweight Design Index is therefore relevant in assessing the overall vehicle design.

The trend of mass growth is projected to continue for future generations of product. This will be driven by future legislative requirements and further increase of vehicle comfort features. The rate of mass increase is expected to slow down if the vehicle size remains constant. The mass projection for future Volkswagen Golf generations is shown in Figure 17.1.an.

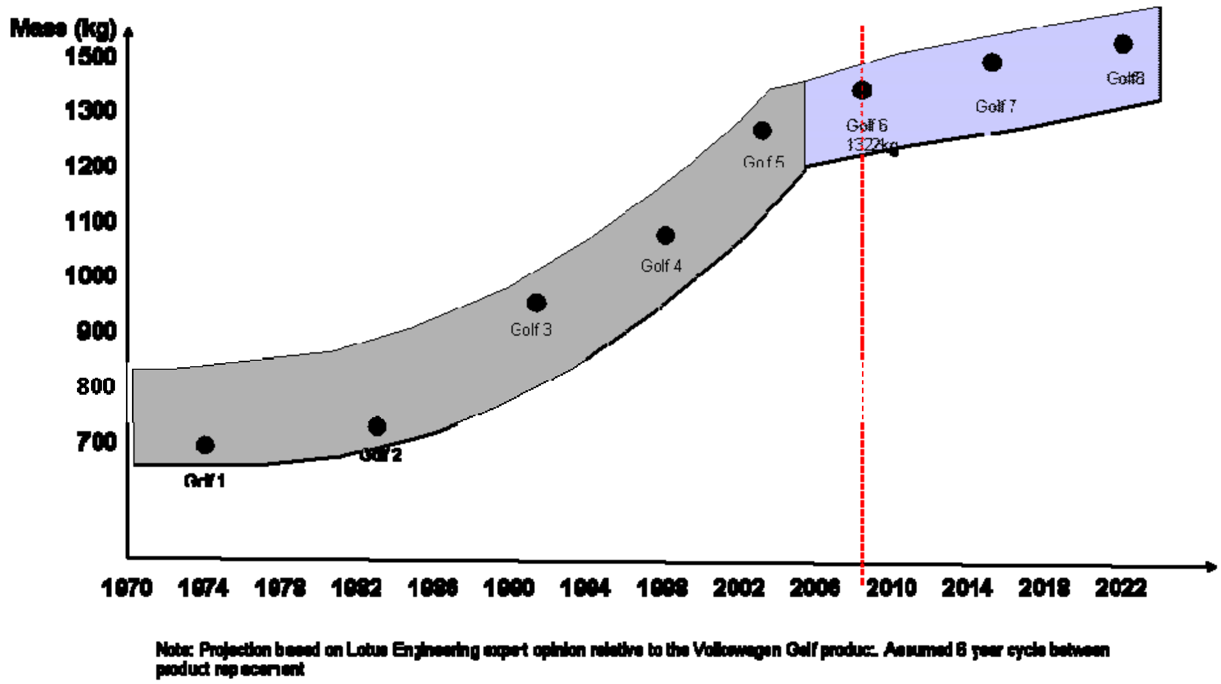


Figure 17.1.an: Projection: Vehicle mass slows in terms of growth

The historical trend has seen increases in vehicle size, defined as height, width and length. Other key dimensions such as wheel base and track though have grown as the vehicle size grew. The recent change from the Golf 5 to the Golf 6 has seen certain key dimensions remain constant for example, wheelbase and track. (Figure 17.1.ao)

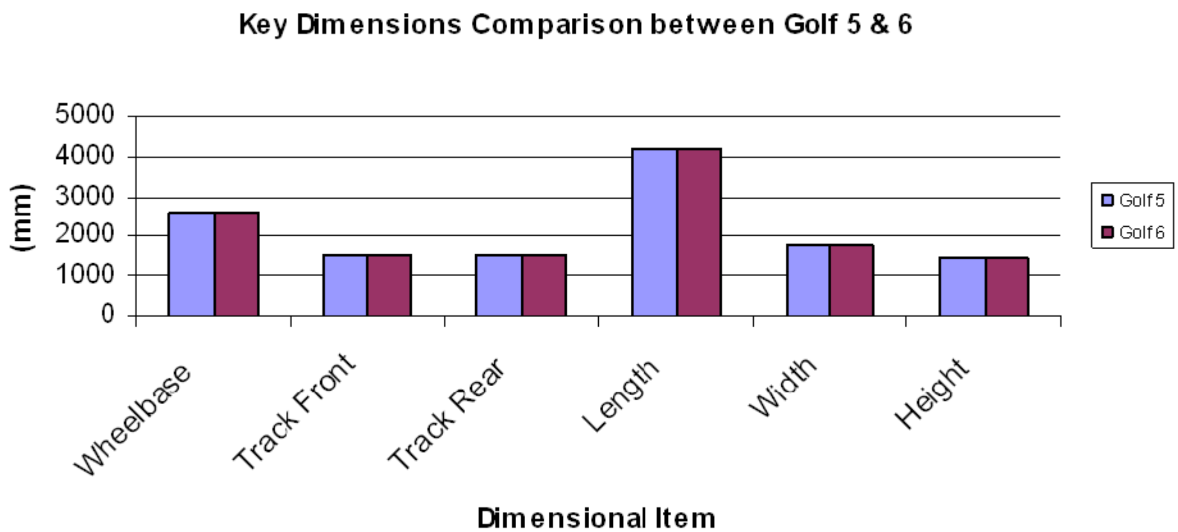


Figure 17.1.ao: Example of Vehicle Dimensions Stabilizing – Volkswagen Golf

In Figure 17.1.ap, we compare the prices of the earlier Volkswagen Golf models in base specification and high specification. We see the price increases between Golf generations and the increase of differences between base & high specification versions. This can account for the greater choice of interior options and permutations of engine, gearbox and suspension available to the consumer.

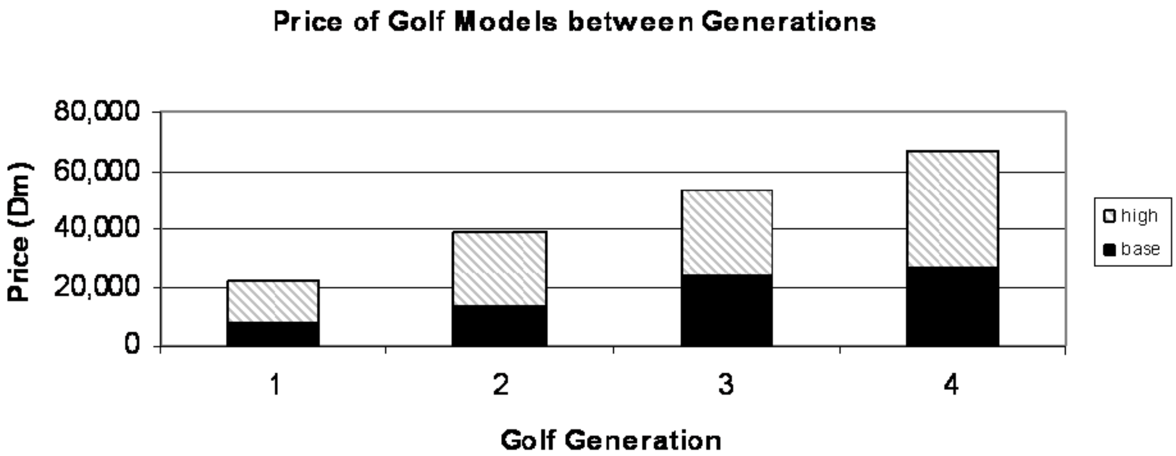


Figure 17.1.ap: The price differences between generations & between base & high specification models [81]

Forecast of Future Trends:

Future drivers for vehicle design are likely to be:

Pedestrian safety
Why? Ergonomics, entry, egress, safety, visibility, heel position,
Footprint – makes things smaller.

Result: Vehicle proportion and shape is likely to change in the future

Taller vehicle, higher hood line, smaller, narrower.

The increase in occupant space will be a result of efficient design. The use of higher strength materials and more predictive techniques will enable more interior space to be found within existing vehicle footprints, thus reducing the vehicle growth trend.

The feature content of vehicles will continue to grow and add mass. Optimization strategies of material substitution and component integration will allow for vehicle mass growth to be minimized.

Figures 17.1.aq, 17.1.ar & 17.1.as show how key dimensions of example vehicles in different classes follow similar trends to the Volkswagen Golf, though over fewer product generations.[82] We see the same slowdown in growth and the stabilization of the vehicle size. The same factors have been the influencers.

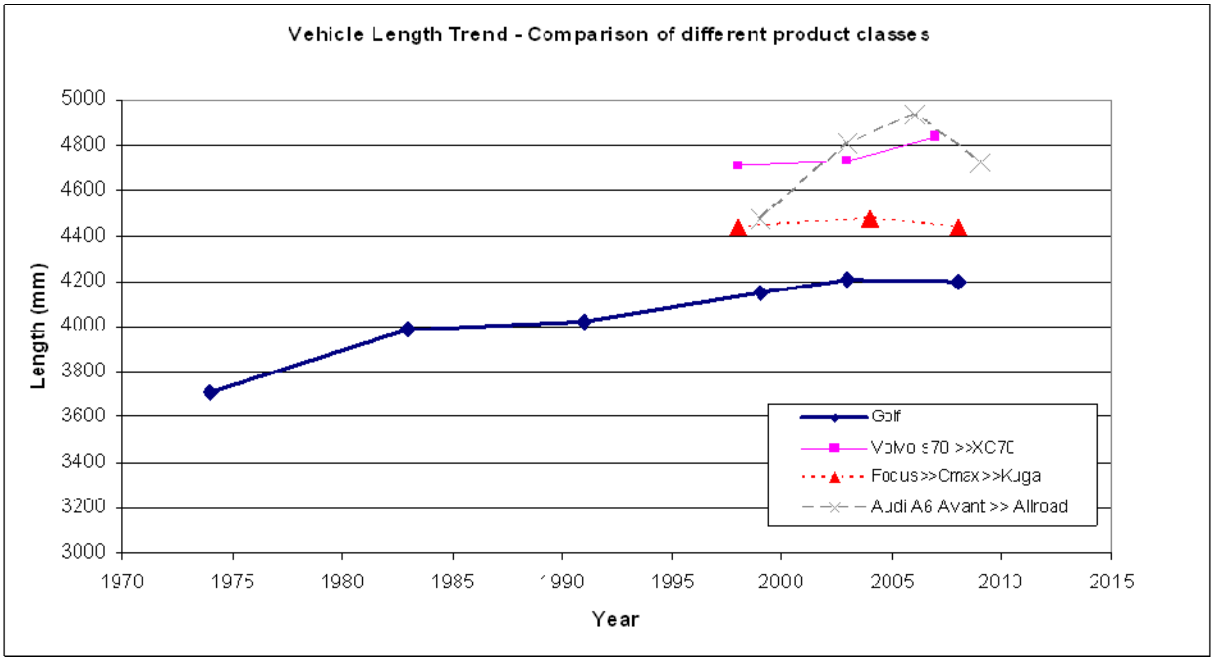


Figure 17.1.aq: Relationship of Vehicle Dimensions (length) between different vehicle classes

Figure 17.1.ar shows the trend of vehicle heights increasing. This is different to the Volkswagen Golf trend. Volkswagen introduced a model derivative of the Golf that was taller than the standard Golf and named it the Golf Plus. The flexibility of the Golf platform/architecture enabled this response to market direction and consumer demands.

Figures 17.1.as through 17.1.av show the mass and dimensional increases for the Golf as it evolved to meet the European market demands.

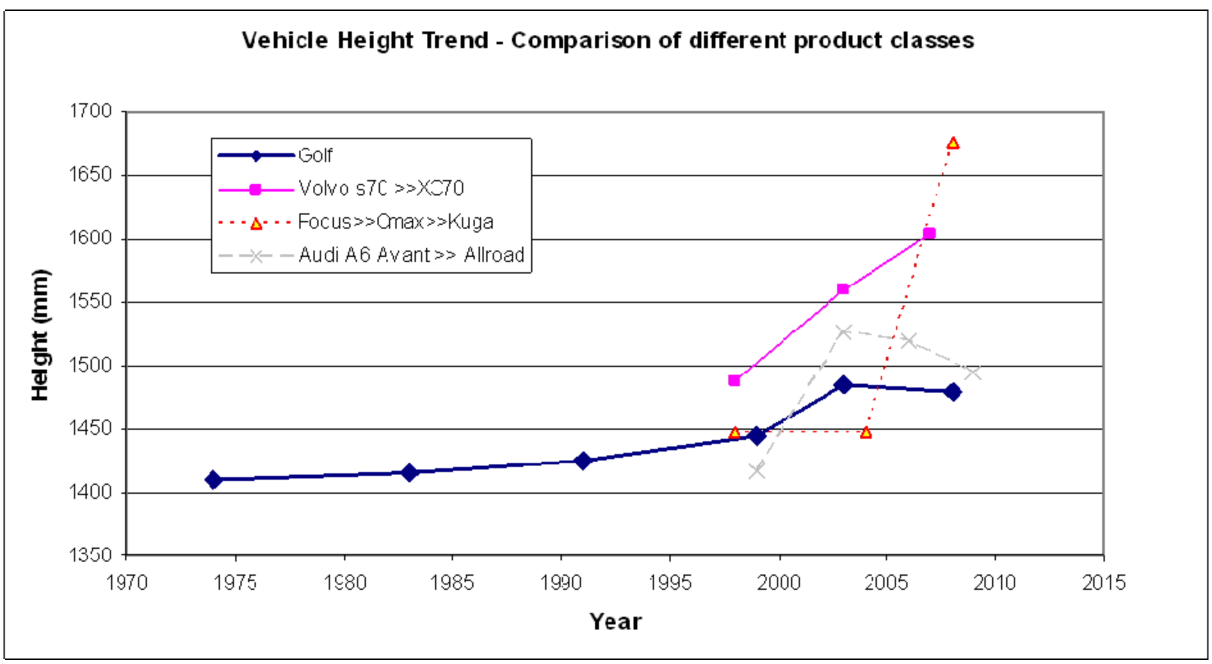


Figure 17.1.ar: Relationship of Vehicle Dimensions (height) between different vehicle classes

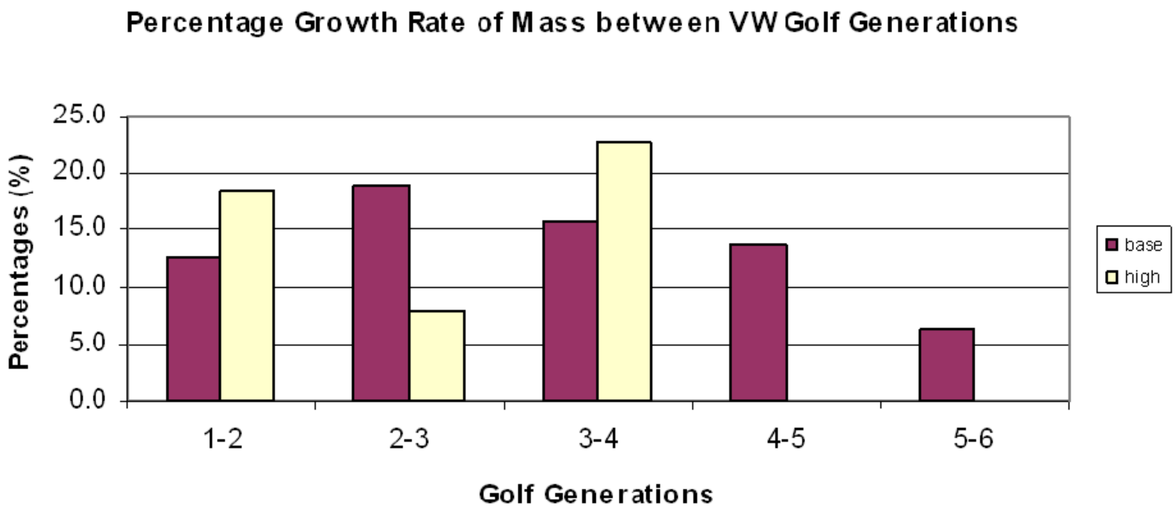


Figure 17.1.as: Trend of Mass Growth for Volkswagen Golf

Figure 17.1.at: Trend of Footprint Growth for the Volkswagen Golf

Figure 17.1.au Trend of Vehicle Dimensions for the Volkswagen Golf

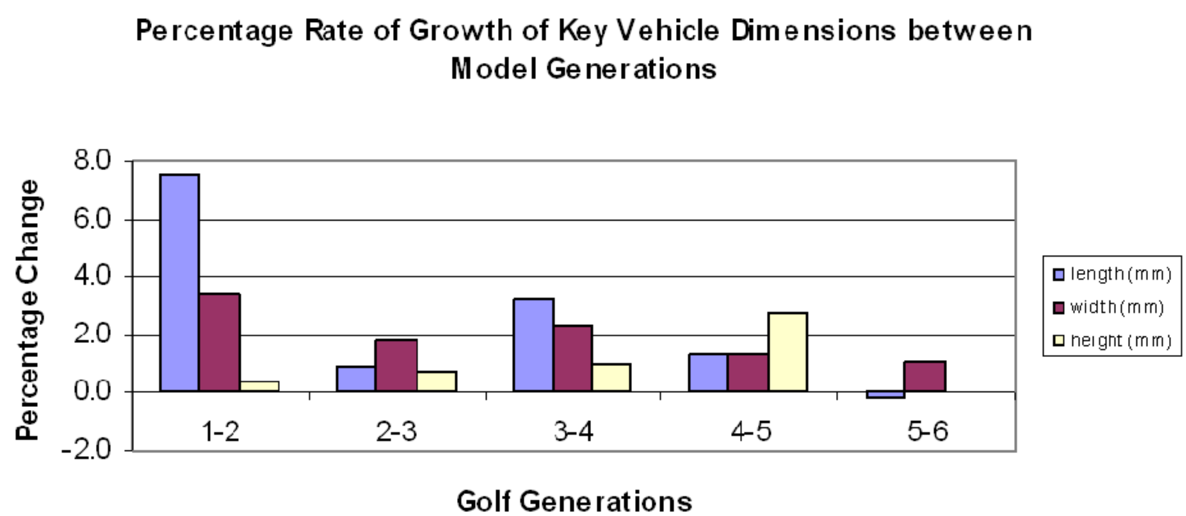


Figure 17.1.av: Trend of Vehicle Dimension Growth for the Volkswagen Golf

Lightweight Design Index

The Lightweight Design Index represents the efficiency of the body structure. It is calculated by the following equation:

$$L = \frac{M_{BIW}}{C^{T} A}$$

L - Lightweight Design Index
M_{BIW} - Body-In-White mass (kg)
A - Area defined by wheelbase and track (m^2)
C^T - Torsional Stiffness of the Body Structure (Nm/Grad)

The numeric value provides a numeric reference of the efficiency of the body-in-white solution that is independent of material(s) used in the body-in-white.

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17.2. Body Structure Backup Material

Steel Mechanical Properties

Table 17.2.a lists typical material properties for steel.

Table 17.2.a Mechanical Properties of Steel Grades

Steel Grade	YS* (MPa)	UTS* (MPa)	Total EL(%)	n-value (5-15%)	r-bar	Application Code
Mild 140/270	140	270	38-44	0.23	1.8	A,C,F
BH 210/340	210	340	34-39	0.18	1.8	B
BH 260/370	260	370	29-34	0.13	1.6	B
IF 260/410	260	410	34-38	0.20	1.7	C
DP 280/600	280	600	30-34	0.21	1.0	B
IF 300/420	300	420	29-36	0.20	1.6	B
DP 300/500	300	500	30-34	0.16	1.0	B
HSLA 350/450	350	450	23-27	0.22	1.0	A,B,S
DP 350/600	350	600	24-30	0.14	1.1	A,B,C,W,S
DP 400/700	400	700	19-25	0.14	1.0	A,B
TRIP 450/800	450	800	26-32	0.24	0.9	A,B
HSLA 490/600	490	600	21-26	0.13	1.0	W
DP 500/800	500	800	14-20	0.14	1.0	A,B,C,W
SF 570/640	570	640	20-24	0.08	1.0	S
CP 700/800	700	800	10-15	0.13	1.0	B
DP 700/1000	700	1000	12-17	0.09	0.9	B
Mart 950/1200	950	1200	5-7	0.07	0.9	A,B
MnB**	1200	1600	4-5	n/a	n/a	S
Mart 1250/1520	1250	1520	4-6	0.07	0.9	A

Application Code: A=Ancillary Parts, B=Body Structure, C=Closures, F=Fuel Tank, S=Suspension/Chassis, W=Wheels

Note: Flat sheet, as shipped properties

* *YS and UTS are minimum values, others are typical values*

** *Properties in heat-treated condition; YS/UTS = 280/450, EL=21% before hardening*

The above table was reprinted from the World Auto Steel web site, October , 2009.

Low Development Mass Reduction Details

Table 17.2.b details the mass reductions for the Low Development body side assembly.

Table 17.2.b Mass Reduction for Low Development Body Side Assembly

Description	QTY	Panel size	Thickness	Part weight MS	HSS grade	Rev. thickness	Part weight HSS
			mm	kg		mm	kg
PANEL-BODY SIDE OTR	2	3270x1300x250	1.00	30.39	DP300	0.75	22.79
PANEL-A PILLAR INNER UPPER	2	878x220x80	1.50	5.81	DP350	1.25	4.85
PANEL-A PILLAR INNER LOWER	2	703x423x35	1.00	4.08	DP350	0.90	3.67
REINFORCEMENT-A PILLAR	2	878x220x80	2.00	8.17	DP500	1.75	7.15
PANEL-B PILLAR INNER	2	1312x467x75	1.50	14.84	DP500	1.25	12.36
REINFORCEMENT-B PILLAR	2	1312x467x75	2.00	19.78	DP500	1.75	17.31
REINFORCEMENT-HINGE MTG REAR DOOR	2		1.50	2.18	DP350	1.25	1.82
REINFORCEMENT-STRIKER FRONT DOOR	2		2.00	0.39	DP350	1.75	0.34
PANEL-C PILLAR INNER UPPER	2	890x550x200	0.75	6.12	MLD140	0.7	6.12
PANEL-C PILLAR INNER LOWER	2	770x416x210	1.00	6.43	DP300	0.8	5.14
REINFORCEMENT-STRIKER REAR DOOR	2		2.00	0.39	DP350	1.75	0.34
HOUSING-REAR LAMP	2	344x155x128	0.75	1.82	MLD140	0.75	1.82
BRACKET- FUEL FILLER REINF.	1	240x185x150	1.00	1.07	MLD140	1.00	1.07
PANEL-REAR QTR UPPER	2	660x425x350	1.00	4.90	DP350	0.8	3.92
PANEL-REAR WHSE INNER	2	870x327x155	1.25	6.64	DP350	0.9	4.78
PANEL-REAR WHSE OTR	2	930x440x220	1.00	7.12	DP350	0.8	5.70
PANEL -REAR WHSE FRNT CLOSEOUT	2	230x156x200	1.00	1.46	DP350	0.90	1.31
RR SHOCK URP REINF.	2	176x135x20	2.00	3.60	DP350	1.75	3.15
REINFORCEMENT-RR DOOR HEADER	2	722x130x60	1.75	5.25	DP350	1.4	4.20
Total				**130.43**			**107.84**

Note: Cells shaded in light blue make up the total for the high strength steel option and includes some parts that are made from mild steel.

The reduction in thickness for the selected items results in a 15.1% weight reduction.

Table 17.2.c details the mass reductions for the Low development front structure.

Table 17.2.c Mass Reduction for Low Development Front Structure

Description	QTY	Panel size	Thickness	Part weight MS	HSS Grade	Rev. thickness	Part weight HSS
			mm	kg		mm	kg
SHOTGUN OTR RR	2	205x176x80	1.50	1.47	DP350	1.1	1.08
SHOTGUN OTR	2	470x110x57	1.00	0.85	DP350	0.90	0.68
FRONT WHEELHOUSE FRNT	2	430x320x170	1.00	1.53	DP350	0.8	1.22
FRONT WHEELHOUSE RR	2	440x360x150	1.00	3.06	DP350	0.8	2.75
FRONT SHOCK TOWER	2	360x320x290		2.88	MLD140		2.88
UPPER HLAMP REINF.	2	520x40x20	1.00	1.07	MLD140	1.00	1.07
FRNT SHOCK UPPER REINF.	2	215x190x15	2.50	2.30	MLD140	2.50	2.30
FRONT CRUSH RAIL INNER	2	550x148x90	1.75	4.33	DP350	1.50	3.71
FRONT CRUSH RAIL OUTER	2	310x165x20	1.50	2.65	DP350	1.25	2.21
LWR RAD SUPPORT UPPER	1	1000x200x115	1.75	2.95			
LWR RAD SUPPORT LOWER	1	840x80x30	1.00	0.77			
Front upper crossmember	1			0.983			
Vertical reinf	1			0.315			
Front end module	1				Cast Mg		5.00
Total				**25.15**			**22.90**

Note: Cells shaded in light blue make up the total for the high strength steel option and includes some parts that are made from mild steel.

The reduction in thickness for the selected items and the use of a cast magnesium front end module results in an 8.9% weight reduction

Table 17.2.d details the mass reduction for the Low Development underbody.

Table 17.2.d Mass Reduction for Low Development Underbody

Description	QTY	Panel size	Thickness	Part weight MS	HSS Grade	Rev thickness	Part weight HSS
			mm	Kg		mm	Kg
MEMBER-RAIL	2	1600x125x 75	1.50	9.68	DP350	1.25	8.07
MEMBER KICK-UP-FRONT	2	650x250x1 25	1.50	5.08	DP350	1.25	4.23
SILL-SIDE INNER	2	1700x240x 40	1.00	8.25	DP350	0.9	8.25
EXTENSION RAIL TO SILL FRONT	2	360X300X2 50	1.50	4.55	DP350	1.1	3.34
CROSSMEMBER-TOE BOARD	1	900X200X1 50	1.70	3.53	DP500	1.4	2.91
REINFORCEMENT-TOE BOARD CROSSMEMBER	2	840x230x1 25	1.50	6.29	DP500	1.25	5.24
REINFORCEMENT - TUNNEL UPPER	1	1100x320x 135	1.50	6.00	DP500	1.25	5.00
CROSSMEMBER-FRONT SEAT FRONT	2	600x180x5 0	1.50	5.06	DP500	1.25	4.22
CROSSMEMBER-FRONT SEAT REAR	2	600x100x1 00	2.00	6.47	DP500	1.50	4.85
CROSSMEMBER-REAR SEAT	1	1400x120x 80	1.50	4.20	DP500	1.25	3.50
CROSSMEMBER-REAR TORQUE BOX	1	1000x100x 160	2.00	3.38	DP500	1.50	2.54
FLOOR-FRONT	1	1470x1300 x160	1.00	11.72	DP280	0.7	8.21
FLOOR-REAR SEAT	1	1500x760x 160	0.75	6.12	DP280	0.7	5.72
EXTENSION-SIDE SILL REAR	2	300x250x8 0	1.20	3.44	DP500	0.9	2.58
MEMBER-RAIL REAR	2	1100x125x 100	1.50	9.22	DP500	1.2	7.38
CROSSMEMBER-TRUNK FLOOR	1	1000x100x 80	1.50	2.64	DP500	1.2	2.11
PANEL-TRUNK SIDE RAIL	2	700x120x2 5	1.00	1.64	DP500	0.8	1.31
PANEL- SHOCK TOWER CLOSEOUT RR	2	150x120x8 5	1.00	1.22	DP500	0.8	0.98
PANEL-TRUNK FLOOR	1	1200x700x100	1.00	7.14	DP280	0.75	5.36
PANEL-REAR END OUTER	1	1800x300x 200	0.85	5.07	MLD140	0.8	5.07
PANEL-REAR END INNER	1	1000x120x 80	0.75	1.26	DP700	0.7	1.26
REINFORCEMENT- LIFT GATE STRIKER	1		1.25	0.00			0.00
SUPPORT-CRASH LOW SPEED FRONT	2		1.20	0.89			0.00
SUPPORT-CRASH LOW SPEED REAR	2	165x110x8 0	1.20	0.77			0.89
Total				**113.65**			**93.78**

Note: Cells shaded in light blue make up the total for the high strength steel option and includes some parts that are made from mild steel.

The reduction in thickness for the selected items results in a 17.5% weight reduction.

High Development Mass Reduction

Table 17.2.e details the mass reduction for the High Development body side assembly.

Table 17.2.e Mass Reduction for High Development Body Side Assembly

Description	QTY	Panel size	Thickness	Part weight MS	Material	Part weight
			mm	kg		kg
PANEL-BODY SIDE OTR	2	3270x1300x250	1.00	30.39	PP G30 overmold	13.93
PANEL-A PILLAR INNER UPPER	2	878x220x80	1.50	5.81	Aluminum stamping	4.36
PANEL-A PILLAR INNER LOWER	2	703x423x35	1.00	4.08	Part of Dash panel casting	
REINFORCEMENT-A PILLAR	2	878x220x80	2.00	8.17	Magnesium Casting	8.4
PANEL-B PILLAR INNER	2	1312x467x75	1.50	14.84	Aluminum stamping	11.13
REINFORCEMENT-B PILLAR	2	1312x467x75	2.00	19.78	Magnesium Casting	6
REINFORCEMENT-HINGE MTG REAR DOOR	2		1.50	2.18	Part of B pillar reinf casting	
REINFORCEMENT-STRIKER FRONT DOOR	2		2.00	0.39	Part of B pillar reinf casting	
PANEL-C PILLAR INNER UPPER	2	890x550x200	0.75	6.12	Magnesium Casting	10.2
PANEL-C PILLAR INNER LOWER	2	770x416x210	1.00	6.43		
REINFORCEMENT-STRIKER REAR DOOR	2		2.00	0.39	Part of C pillar inner casting	
HOUSING-REAR LAMP	2	344x155x128	0.75	1.82	Aluminum stamping	1.37
BRACKET- FUEL FILLER REINF.	1	240x185x150	1.00	1.07	Aluminum stamping	0.80
PANEL-REAR QTR UPPER	2	660x425x350	1.00	4.90	Aluminum stamping	3.67
PANEL-REAR WHSE INNER	2	870x327x155	1.25	6.64	Aluminum stamping	4.98
PANEL-REAR WHSE OTR	2	930x440x220	1.00	7.12	Aluminum stamping	5.34
PANEL -REAR WHSE FRNT CLOSEOUT	2	230x156x200	1.00	1.46	Aluminum stamping	1.09
RR SHOCK URP REINF.	2	176x135x20	2.00	3.60	Aluminum stamping	2.70
REINFORCEMENT-RR DOOR HEADER	2	722x130x60	1.75	5.25	Aluminum stamping	3.94
Total				**130.43**		**77.91**

The modified design and use of alternative materials resulted in a 40.27% weight reduction.

Table 17.2.f details the mass reduction for the High Development front structure.

Table 17.2.f Mass Reduction for High Development Front Structure

Description	QTY	Panel size	Thickness	Part weight MS	Material	Part weight
			mm	kg		kg
SHOTGUN OTR RR	2	205x176x80	1.50	1.47	Aluminum stamping	1.10
SHOTGUN OTR	2	470x110x57	1.00	0.85	Aluminum stamping	0.64
FRONT WHEELHOUSE FRNT	2	430x320x170	1.00	1.53	Aluminum stamping	1.15
FRONT WHEELHOUSE RR	2	440x360x150	1.00	3.06	Part of dash panel	
FRONT SHOCK TOWER	2	360x320x290		2.88	Magnesium casting	6.00
UPPER HLAMP REINF.	2	520x40x20	1.00	1.07	Part of cast Mg FEM	
FRNT SHOCK UPPER REINF.	2	215x190x15	2.50	2.30	Part of shock tower casting	
FRONT CRUSH RAIL INNER	2	550x148x90	1.75	4.33	Aluminum extrusion	4.67
FRONT CRUSH RAIL OUTER	2	310x165x20	1.50	2.65		
LWR RAD SUPPORT UPPER	1	1000x200x115	1.75	2.95	Part of cast Mg FEM	
LWR RAD SUPPORT LOWER	1	840x80x30	1.00	0.77	Part of cast Mg FEM	
Front upper crossmember	1			0.983	Part of cast Mg FEM	
Vertical reinf	1			0.315	Part of cast Mg FEM	
FEM	1				Magnesium	5.00
Total				**25.15**		**18.56**

The reduction in thickness for the selected items and the transfer of parts to a different assembly results in a 28.4% weight reduction

Table 17.2.g details the mass reduction for the High Development underbody**.**

Table 17.2.g Mass reduction for High Development Underbody

Description	QTY	Panel size	Thickness	Part weight MS	Material	Part weight HSS
			mm	Kg		Kg
MEMBER-RAIL	2	1600x125x 75	1.50	9.68	Part of floor molding	
MEMBER KICK-UP-FRONT	2	650x250x1 25	1.50	5.08	Magnesium Casting	6.00
SILL-SIDE INNER	2	1700x240x 40	1.00	8.25	Aluminum extrusion	7.8
EXTENSION RAIL TO SILL FRONT	2	360X300X2 50	1.50	4.55	Part of kick up casting	
CROSSMEMBER-TOE BOARD	1	900X200X1 50	1.70	3.53	DP500	2.91
REINFORCEMENT-TOE BOARD CROSSMEMBER	2	840x230x1 25	1.50	6.29	DP500	5.24
REINFORCEMENT - TUNNEL UPPER	1	1100x320x 135	1.50	6.00	Part of floor molding	
CROSSMEMBER-FRONT SEAT FRONT	2	600x180x5 0	1.50	5.06	Part of floor molding	
CROSSMEMBER-FRONT SEAT REAR	2	600x100x1 00	2.00	6.47	Part of floor molding	
CROSSMEMBER-REAR SEAT	1	1400x120x 80	1.50	4.20	Part of floor molding	3.15
CROSSMEMBER-REAR TORQUE BOX	1	1000x100x 160	2.00	3.38	DP500	2.54
FLOOR-FRONT	1	1470x1300 x160	1.00	11.72	Long fiber reinforced PU molding	26
FLOOR-REAR SEAT	1	1500x760x 160	0.75	6.12	PPG30 Molding	6.42
EXTENSION-SIDE SILL REAR	2	300x250x8 0	1.20	3.44	Magnesium Casting	6.4
MEMBER-RAIL REAR	2	1100x125x 100	1.50	9.22	Aluminum extrusion	5.18
CROSSMEMBER-TRUNK FLOOR	1	1000x100x 80	1.50	2.64	Aluminum stamping	1.98
PANEL-TRUNK SIDE RAIL	2	700x120x2 5	1.00	1.64	DP500	1.23
PANEL- SHOCK TOWER CLOSEOUT RR	2	150x120x8 5	1.00	1.22	DP500	0.92
PANEL-TRUNK FLOOR	1	1200x700x100	1.00	7.14	Part of seat floor molding	
PANEL-REAR END OUTER	1	1800x300x 200	0.85	5.07	MLD140	5.07
PANEL-REAR END INNER	1	1000x120x 80	0.75	1.26	DP700	1.26
REINFORCEMENT- LIFT GATE STRIKER	1		1.25	0.00		0.00
SUPPORT-CRASH LOW SPEED FRONT	2		1.20	0.89		0.89
SUPPORT-CRASH LOW SPEED REAR	2	165x110x8 0	1.20	0.77		0.77
Total				**113.65**		**83.77**

The reduction in thickness for the selected items results in a 26.3% weight reduction

Table 17.2.h below shows a comparison of Venza closures in MS & HSS

Table 17.2.h Comparison of Venza closures in MS & HSS

System	Sub system	Standard Venza	Revised mass	Mass saving	
		kg	kg	kg	
Side door front					
	Front Door Outer LH & RH	11.30	9.89	1.41	
	Front Door Inner LH & RH	8.48	7.53	.95	
	Glass run channel front LH & RH	4.91	4.91	0	
	Door reinforcements LH & RH	11.19	9.92	1.27	
	Side intrusion beam LH & RH	2.36	2.36	0	
	Door Hardware LH & RH	13.76	10.86	2.9	
Side door rear					
	Rear Door Outer LH & RH	9.04	7.91	1.13	
	Rear Door Inner LH & RH	4.71	4.40	.31	
	Glass run channel rear LH & RH	4.91	4.91	0	
	Door reinforcements LH & RH	8.50	7.67	.83	
	Side intrusion beam LH & RH	2.00	2.00	0	
	Door Hardware LH & RH	12.24	10.14	2.1	
Tailgate					
	Tailgate Outer	5.41	4.74	.67	
	Tailgate Inner	5.86	5.21	.65	
	Reinforcements	3.21	3.21	0	
	Tailgate Hardware	8.77	8.77	0	
Hood					
	Hood Outer	8.34	7.29	1.05	
	Hood Inner	6.82	6.37	.45	
	Hood Reinforcements	1.64	1.64	0	
	Hood Hardware	1.68	1.68	0	
Total		**135.13**	**121.41**	**13.72**	**10.2%**

17.3. ThyssenKrupp Steel Body Structure

NSB cutaway

The NSB NewSteelBody is a concept for a lightweight steel auto body developed by ThyssenKrupp Steel. The benchmark for the NSB was the body-in-white of a real volume-produced vehicle. The NSB body performs just as well as the production benchmark but is 24 percent lighter and only three percent more expensive. The reasons for this are the use of high-strength steels, weight-optimized tailored products and a tube-intensive design which makes full use of the weight reduction potential of modern steels. Traditional stamped and welded parts are replaced by tubular components which are stiffer than conventional parts and better utilize existing space.

key words: steel, ThyssenKrupp Steel AG

ThyssenKrupp New Steel Body

NSB® NewSteelBody
For a lighter automotive future.

Thinking the future of steel

A company of ThyssenKrupp Steel

ThyssenKrupp Stahl

ThyssenKrupp

Material properties for a variety of plastics are shown in the tables below. These properties are used as a guideline in selecting a plastic type for a specific application. Table 1 and Figure 2 tabulated by Ticona.

Table 1 Performance of Classes of Plastics[1]

	Representative Properties			
	Specific Gravity	Flexural Modulus ($x10^3$ psi)	Notched Izod Impact Strength (ft-lb/in)	Deflection Temperature @ 264 psi (°F)
Thermosets				
Alkyd polyester	1.2	2	0.3	80
Epoxy, general purpose	1.25	16	0.6	350
Phenolic, general purpose	1.5	10	0.3	370
Urea formaldehyde, black	1.5	10	0.3	270
Thermoplastics				
Commodity				
ABS, injection, medium impact	1.05	320	3	170
Polyethylene (LDPE), injection, general purpose	0.92		No break	<100
Polypropylene homopolymer	0.90	250	0.8	131
Polystyrene, crystal	1.05	475	0.4	180
PVC, general purpose	1.3	13	1.0	155
Engineering				
Acetal copolymer	1.41	300	1.4	230
Nylon 6/6	1.14	493/247[2]	0.7/1.2	220
Polybutylene terephthalate, 30% glass fiber	1.52	1,200	2	410
Polycarbonate, injection, general purpose	1.2	360	18	289
High Performance				
Liquid crystal polymer, 30% glass fiber	1.62	2,100	4.4	445
Polyetheretherketone	1.32	700	1.6	600
Polyetherimide, 30% glass fiber	1.51	1,200	2	405
Polyphenylene sulfide, 40% glass fiber	1.67	1,700	1.3	500

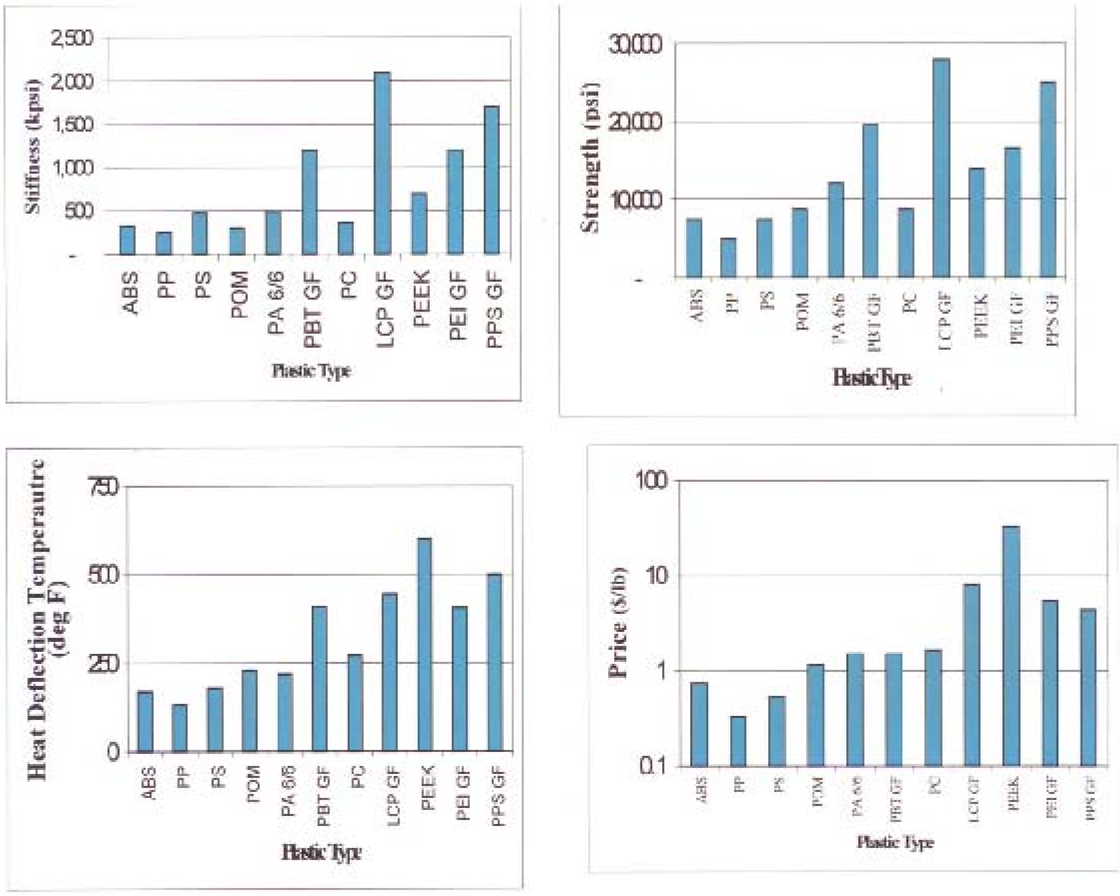
Resin Selection

- **Maximize performance at lowest possible price**
- **Consider processing, fabrication, installation and end-use requirements**
- **Identify all required code and agency approvals**
- **Consider "worst case scenarios"**
- **Evaluate several plastic candidates**

Plastics Cover a Broad Range of Property Performance

[1] Adapted from: **Handbook of Plastic Materials and Technology,** Irvin I. Rubin (1990).
[2] Dry-as-Molded/Moisturized

10



ABS - Acrylonitrile Butadiene Styrene
PS – Polystyrene
PA 6/6 - Nylon 6/6
PC – Polycarbonate
PEEK – Polyetheretherketone
PPS GF - Glass Reinforced Polyphenylene Sulfide
PP - Polypropylene
POM - Acetal Copolymer
PBT GF - Glass Reinforced Polybutylene Terephthalate
LCP GF - Glass Reinforced Liquid Crystal Polymer
PEI GF - Glass Reinforced Polyetherimide

Figure 2 Plastics Cover a Broad Range of Property Performance

18. Footnotes

18.1. Cincinnati Machine, LLC, Mag Corporation, Hebron, KY

Continuous fiber line with linear, transverse and vertical material thickness control

MAG-INDUSTRIAL AUTOMATED SYSTEMS
CONTINUOUS FIBER PREPREG LAMINATING LINE

- **CONTINUOUS LAMINATING LINE W/ INTEGRATED CHARGE CUTTING**

Options:
-Module to introduce Core Materials for Sandwich Structures

18.2. The 2010 Mercedes-Benz E-Class: Passive Safety Features

Posted August 19, 2009 At 7:55 AM CST by T. Philips
http://www.emercedesbenz.com/Mar09/11_001614_The_2010_Mercedes_Benz_E_Class_Passive_Safety_Features.html

Excerpt From above article:

Materials: around 72 percent of all body parts made from high-strength steel

Key aspects of the safety concept at the heart of the new E-Class include intelligent design and meticulous material selection. More so than ever before, Mercedes-Benz has given preference to ultra-high-strength steel alloys because they offer maximum strength whilst minimizing weight and, therefore, are essential for meeting the strict safety and durability requirements.

Around 72 percent of all the body shell panels for the new E-Class Are made from these grades of steel – a new record in passenger-car development. These ultra-high-strength, high-tech alloys, which boast three to four times the tensile strength of conventional high-strength steel grades, account for around eight percent of the weight. They are used at points where the material can be exposed to exceptionally high stresses during an accident – as a material for the B-pillars and the side roof frames to provide side impact protection, for example, or at the rear to produce a robust crossmember.

If these sophisticated alloys were not used, far more material would be required in order to meet the stringent safety requirements. The B-pillar is a perfect case in point: the body components which have to absorb high forces and transfer these into the body structure in the event of a side impact consist of sheet-metal shells and an extensive reinforcement which reaches as far as the upper edge of the belt deflector. One of the shells and the reinforcement are made from ultra-high-strength, hot-formed steel. Were they made using conventional sheet steel, however, the B-pillars would be more than a third heavier. In other words, the ultra-high-strength, high-tech alloy enhances safety whilst also reducing weight.

18.3. Interior Suppliers

NuBax

- **TAG largest investor**
- www.nubax.com
- Contact:
    - Donna Jackson– Director of Product Development
    - John Hall – Head of Division - Automotive

NuBax Study Results

True Textiles

- **Division of Guilford of Maine**
- www.truetextiles.com
- Contact:
    - Rob Harper – Vice President of Sales and Marketing
      Rob.Harper@truetextiles.com
      (616) 554-2256
    - Adiran Meir – Technical Designer – Environmental Coordinator
      Adrian.Meir@truetextiles.com
      (616) 656-5110

Faurecia

- **Tier 1 Automotive supplier, global footprint**
- www.faurecia.com
- Contact:
    - Michael Miner – Product Planning Manager - Seating
      michael.miner@faurecia.com
      (248) 655-1559
    - Jay Hutchins – Product Planning Manager
      jay.hutchins@faurecia.com
      (248) 409-3599

Faurecia “Light Attitude” Study

Faurecia Partial List of Production Interiors

Audi A4 - Seats / Hybrid Steel/Plastic front fascia/bumper tech
Audi A5/S5 - Door Trim, Seats
Audi A4 Cabrio - Door Trim
Audi A6 - IP, Seats, Front end (fascia/bumper)
Audi A8 - Seats
Audi Q7 - IP, Seats
BMW 1, - IP, Front End
BMW 1 Convertible - IP, seats
BMW 3, - Seats, Front End
BMW 5, - Seats
BMW 7 - Seats
BMW X5 - IP, Seats, Door Trim
BMW X6 - IP, Seats, Door Trim
BMW Z4 - IP
Cadillac CTS - Seats, Door Trim
Chevrolet Malibu - IP. Seats
Citroen C5 - IP, Seats, Door Trim
Citroen C6 - IP, Seats, Door Trim
Mercedes Benz E Class - IP, Seats
Mercedes Benz S Class - IP, Door Trim
Range Rover Sport - IP
Renault Laguna - IP, Seast, Door Trim
Renault Clio - IP, Seats
Renault Megane Sedan - IP, Seats
Volkswagen Passat - IP, Seats
Volkswagen Passat CC - IP, Seats
Volkswagen Eos - IP, Seats, Door Trim
Volkswagen Touareg - IP, Seats
Volvo C30 - IP, Door Trim (Floating translucent center stack)
Volvo S40 - IP, Door Trim (Floating translucent center stack)

TREXEL STUDY

Back-up information supplied by Trexel for this study

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1. *The HVAC components are not necessarily better opportunities than the others that we have already reviewed. They are just “no brainers” because they usually do not require any additional attention because of cosmetics. In fact, they represent overall only an additional 2 KG in weight reduction because they tend to be small to begin with. So, it is nice to have them on the list but they are not the highest impact addition.*
2. *Other high impact parts not addressed in the study are cooling systems, under the hood and electronics…not that this is necessary for now.*
3. *I have refrained from putting an economic analysis section in our report because we have only been able to identify 53 KG of solid components specifically identified whereas you have extrapolated this to around 76 KG. I don’t have a problem with that, but our economic analysis would be different based specifically on what we have listed in the report.*
4. *Notwithstanding the preceding paragraph, we have adjusted the original economic study that I did based on your numbers (75.6 KG of mass and 15.6KG of savings) in order to be a little more conservative on cycle time savings and to assume two cavity rather than single cavity tools for smaller Parts (which requires less MuCell investment).*

Economic Analysis

We have tried to develop a broad brush economic analysis to describe the cost savings associated with a global adoption of the "Design for MuCell" option yielding17.2 KG of mass reduction.

What makes the analysis challenging is that a 60,000 annual vehicle volume is not an efficient volume. For example, assuming a 35 second cycle time and a two cavity mold, it would take only 250 hours to produce any single part. Therefore, we have aggregated the production of the parts based on a limited number of assumptions.

Assumptions

1. *Two different size molding machines are assumed.*
    a. *Larger machines (1,000 tons)*
        i. *We understand that two of the larger components may need a larger machine, but this analysis is a simplified and the first cut and is conservative*
    b. *Medium machines (500 tons)*

2. *For the larger machines all molds are single cavity; for the smaller machines, molds are two cavity. If molds were single cavity, the savings from the use of the MuCell Process would rise.*
    a. *Note that for these low volumes the tools could be aluminum because of the low pressure process associated with MuCell. The cost savings associated with aluminum are not included in this analysis.*
3. *Larger machines have 60 second solid cycle times for the applicable products*
4. *Medium machines have 35 second solid cycle times for the applicable products*
5. *The assumed hourly rate of a large machine is $100 per hour*
6. *The assumed hourly rate of a medium machine is $70 per hour*
7. *Material costs will average $1.50 per Kilo over the next 3 years.*
8. *20% of the components will run on larger machines representing 40% of the mass*
9. *80% of the components will run on medium machines representing 60% of the mass.*
10. *The universe of components that are targeted for MuCell has a mass of 75.6 KG and numbers approximately 80 different components.*

With these assumptions we conclude the following:

Components	*Larger*	*Medium*	*Totals*
Gross Cost Savings per Part	*23.3 %*	*24.58 %*	
Cost Savings after Amortization of MuCell Investment (5 Year)	*19.83 %*	*20.92 %*	
Annual Cost Savings Total	*$ 994,000*	*$ 761,258*	*$$1,755,258*
Number of MuCell Systems Required	*3*	*3*	*6*
Cost of MuCell Investment	*$750,000*	*$573,000*	*$ $1,323,000*
Annual Savings Per Vehicle (60,000 vehicles)	*$ 16.57*	*$ 12.69*	*$ 29.25*

David P. Bernstein, President, Trexel

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