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VEHICLE OF THE FUTURE: THE ROLE OF THE NEW GENERATION OF HIGH STRENGTH STEEL GRADES

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Profile of Centro Ricerche Fiat

Centro Ricerche FIAT (CRF) is an industrial organization which has the mission of promoting, developing and transferring innovation in order to provide competitiveness to its clients and partners which include the different companies in the FIAT Group, automotive suppliers, companies from other sectors of industry, SMEs, and national and international research agencies (Figures 1-3).

CRF attains this objective by focusing on: the development of innovative products, the implementation of new processes (manufacturing and organizational), the development of advanced methodologies, consultancy and the training of human resources. Priority areas of R&D at CRF include Energy and the Environment, Safety and Well-Being, and Sustainable Growth.

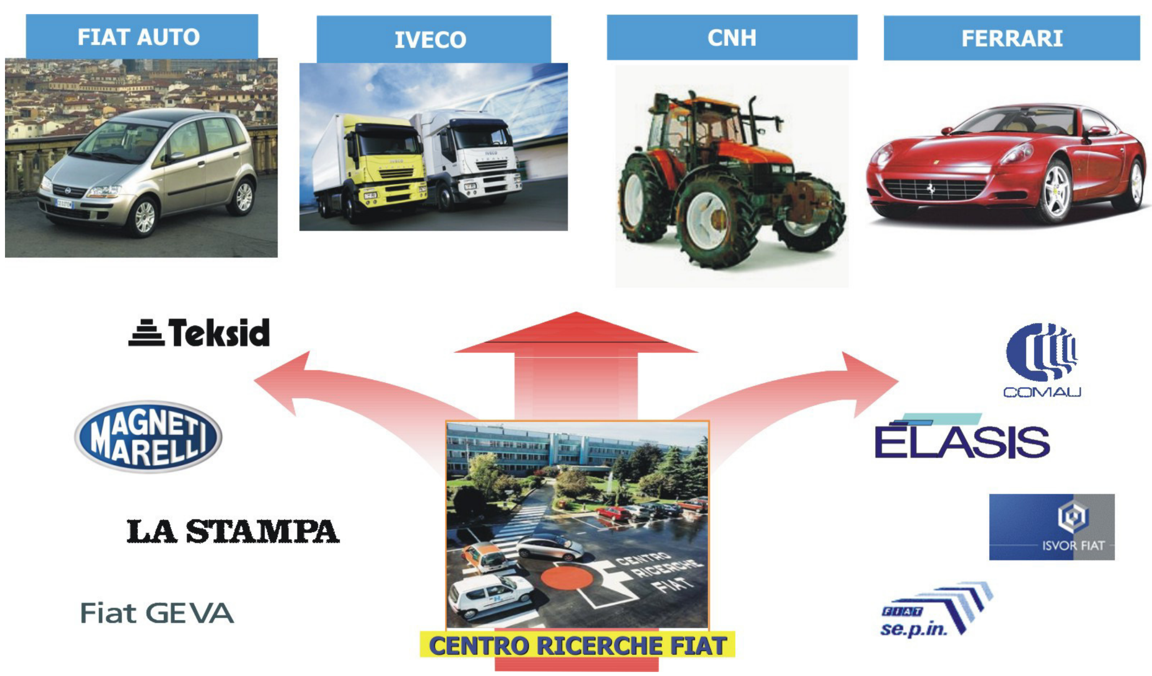


Figure 1. Centro Ricerche FIAT (CRF) customers.

***VEHICLES*: body & suspension architectures, structural analysis, perceived quality, vehicle handling and dynamics, crash and safety, energy-balance**

***POWERTRAINS*: diesel, gasoline, gpl & cng engines, minimal hybrid propulsion system, advanced injection and valve control systems, automatic transmissions**

***ELECTRONICS*: electronics and control systems development, hw for on-board systems**

***TELEMATICS*: telematics, vehicle-environment, communication systems, preventive safety systems**

***MICROTECHNOLOGIES*: micro-optics for headlamps, shape-memory actuators**

***BUSINESS INFORMATION TECHNOLOGIES*: methods for cost/value management, statistical optimisation and robust design**

***PROCESS TECHNOLOGIES*: virtual manufacturing (metal and plastic forming, casting processes), laser-welding applications; advanced machining**

Figure 2. Some areas of CRF's excellence.

The core competence of CRF is centered on land transportation i.e. advanced vehicles and propulsion systems, innovative components with associated manufacturing processes and methodologies for product development. In developing and applying these core competencies, considerable emphasis is placed on the transfer of advanced technologies from automotive applications to other sectors of industry and areas of business. In this context, CRF actively supports the technological growth of SMEs working outside the arena of the automotive industry in fields which range from business process re-engineering, advanced product and process methodologies, to micromechanics and optics, IT methodologies, telematics and others.

CRF currently has approximately 920 employees and is organized in the following principal technical divisions: Engines, Vehicles, Electronic and Electrical Systems, Business Information Technologies, Advanced Product/Process Technologies, Micro- and Nanotechnologies, and Telematic Applications. The state-of-the-art facilities include: electromagnetic-compatibility chambers, anechoic and hemi-anechoic cells, NVH laboratories, optoelectronics and micro-technologies laboratories, engine, fluid dynamics, rapid prototyping, computed tomography, virtual reality, etc.

In order to cover a relatively broad spectrum of technologies, CRF has developed a global network of contacts comprising national and international research institutes, private and public research organizations, universities and companies through the promotion of common research activities, associations, conferences and seminars, mobility and exchanges of researchers, etc. Increasingly over recent years, CRF has been an active participant in national projects (MIUR, CNR, Italian Ministry of the Environment), regional projects, the EUREKA program and in over 220 projects with the R&D programs of the European Union.

Figure 3. Beneficiaries of CRF.

Introduction

In the coming years, the automotive manufactures (OEMs – Original Equipment Manufactures) will face an increasing competition for conservation and acquisition of market share in a more and more global market.

On such a base, in order to meet the customer demands, the OEMs are obliged to introduce more optional equipment in their model, in the basic version, and increase the vehicle dimensions to improve passenger comfort and spaceconfigurability. At the same time, it is possible to observe a continuous implementation of more and more severe norms both for vehicle and pedestrian safety.

These factors mean a consequential incremental increase of the vehicle mass and consequently increased fuel consumptions. For such a reason, the European Commission, in agreement with ACEA, decided to introduce clear regulations for reducing noxious emissions and fuel consumption and at the same time for controlling the dismantling, recycling and reuse procedures of end-of-life vehicles.

Referring to the fuel consumption reduction, the CAFE regulations restrict CO_2 emissions (which are directly linked to the fuel consumption) according to two timetables; 140 and 120 g CO_2 per km for 2008 and 2012, respectively, measured as an average value on the entire OEM fleet.

In order to respect such limits, besides innovation on engines and transmissions, CRF research programs are focused upon improving vehicle structural and aerodynamic efficiency, thereby minimizing the rolling resistance simultaneously.

Focusing on vehicle structural efficiency, the conducted analysis demonstrated that weight saving plays an important role for meeting the CAFE 2008 target and a fundamental issue for meeting the 2012 target.

Product Drivers and Normative

Besides the product drivers that have normally characterized the past vehicle developments such as cost, safety and performances, other new market requests are becoming increasingly important for the development of future vehicles such as personalization, use versatility, frequent and rapid model development, and environmental impact (Figure 4).

These new requests cause a continual increase of different vehicles in terms of architecture (e.g.: the introduction into the market of MPV formulas) and of contents. This trend means that in the near future it is probable that vehicles, manufactured at high volume production rate, will be substituted by various vehicles having different architecture and produced at lower quantity. On such a base, it is probable that the unibody architecture will be not the best solution for the future, but other architectural concepts should be developed, based on the maximization of platform derivability and in the long term, on functional modularity (vehicle concept as integration of standard functional modules) as shown in Figures 5 and 6.

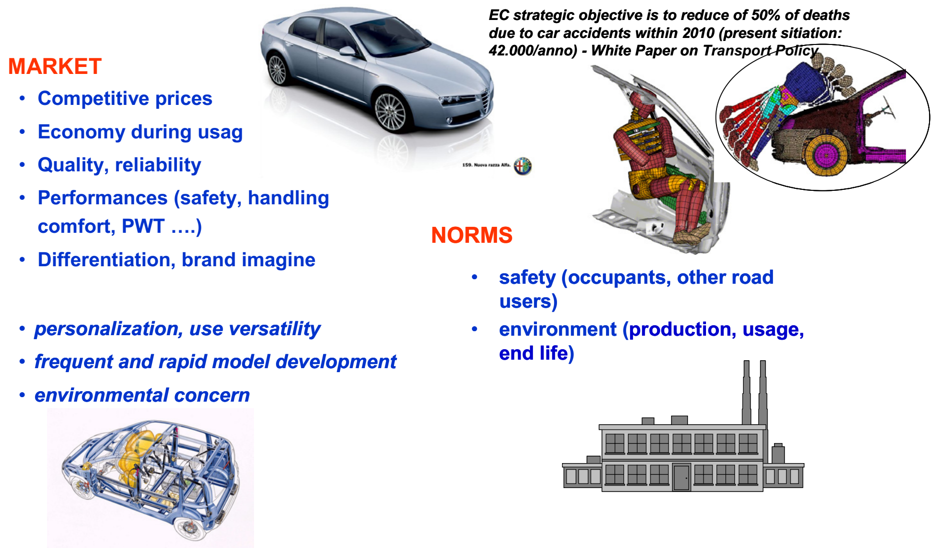


Figure 4. External factors: markets and norms.

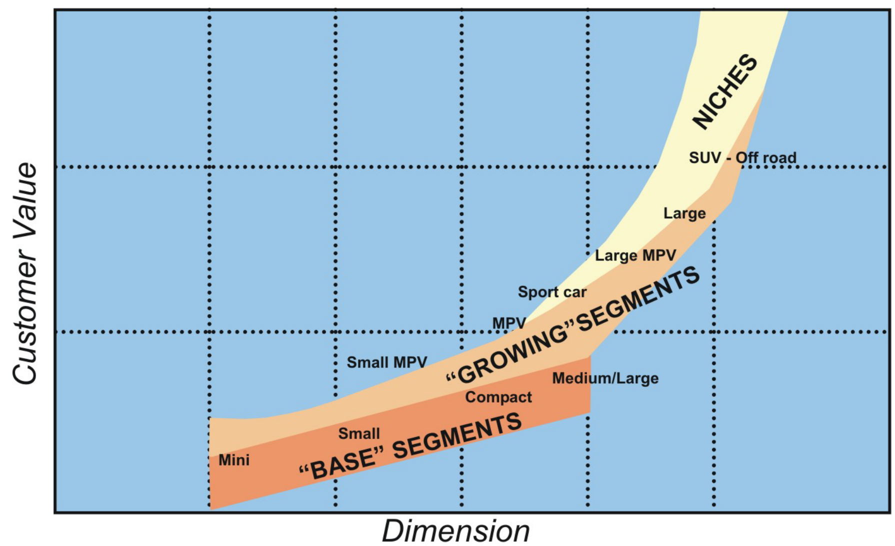


Figure 5. Vehicle segments scenario.

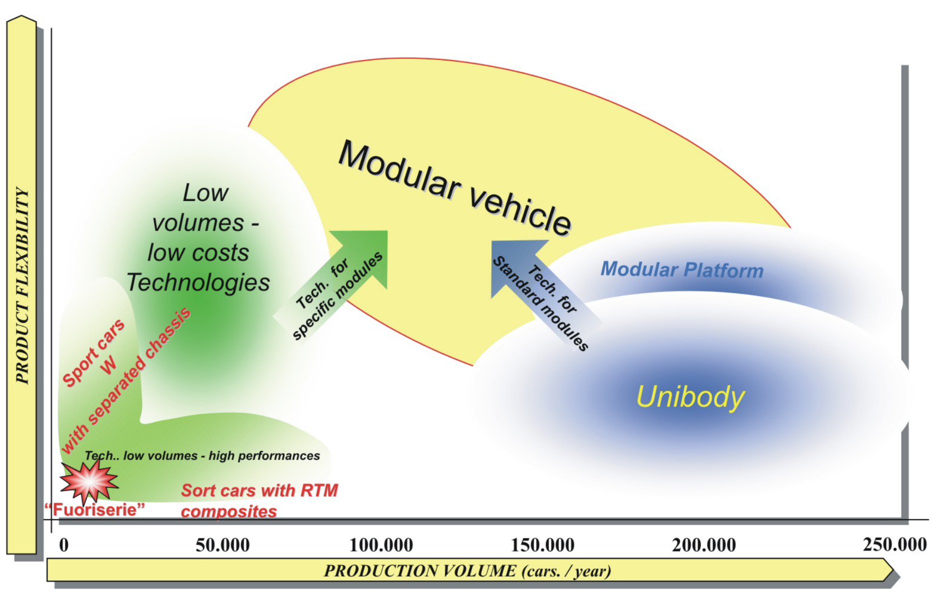


Figure 6. From the integrated unibody to a modular vehicle.

In Figures 7-11 some innovative architectural solutions developed in Centro Ricerche Fiat are shown. In particular, Figures 7 and 8 are based on a platform derivability concept with application of different materials and technologies according to the volume production.

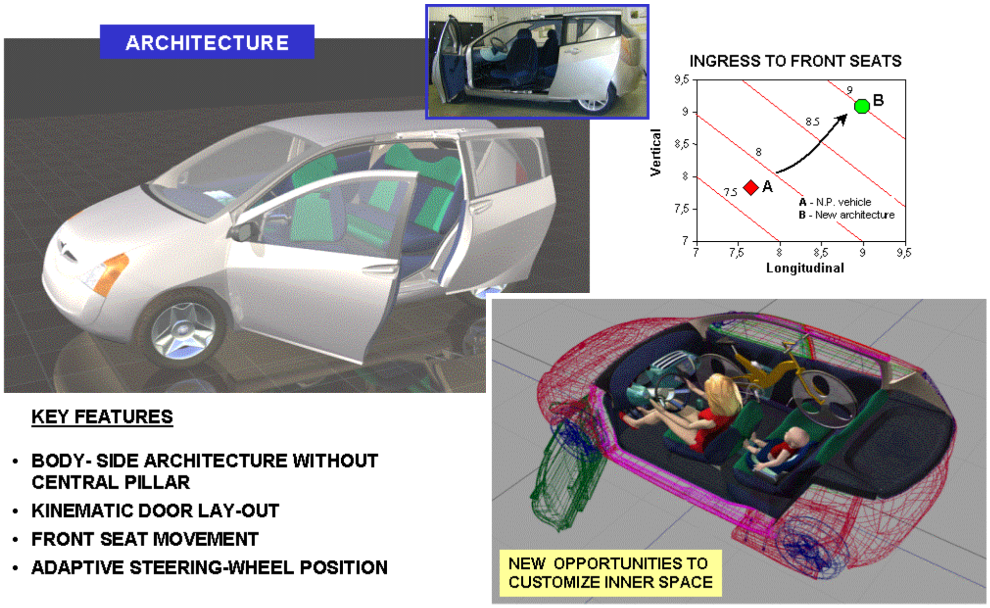


Figure 7. Greenhouse architecture without B-pillar.

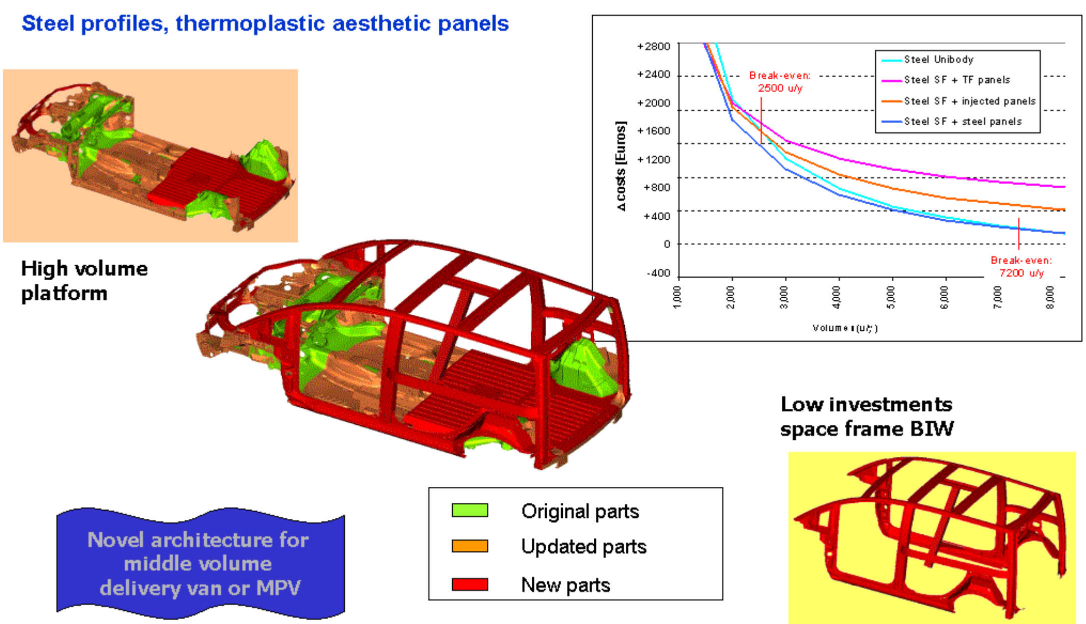
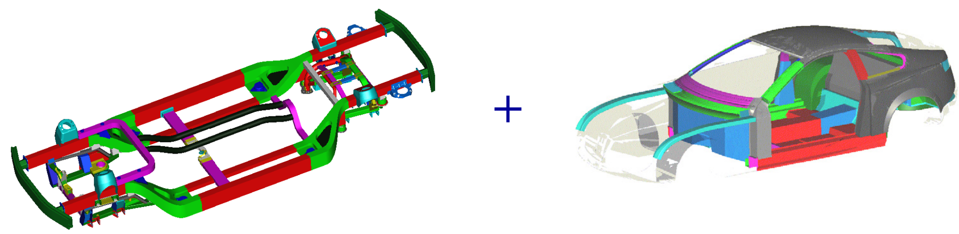


Figure 8. Hybrid space frame architecture.

Figures 9-11 present the split-frame concept for low volume production (functional modularity) where the objective was to maximize the product flexibility, adopting technologies at low investments.

The vehicle frame is divided into two distinct structures: a lower modular frame (rolling chassis) and an upper "space-frame" type body, connected with body mounts (best in class vs. handling & comfort).

"LOWER 3D MODULAR CHASSIS FRAME": ***"UPPER SPACE FRAME":***



Main adopted technologies:
stretch bending, tube hydroforming, sheet stamping, steel profiles, …

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stretch bending, sheet hydroforming, sheet bending, …

Figure 9. Functional modularity – split frame architecture.

Lower Modular Chassis Frame: wheelbase, track, ground clearance and suspensions attachments can be adapted to various vehicle typologies.

Self-standing rolling chassis adopts a 3D structure that includes all force attachments (powertrain and suspensions), to achieve premium performances on noise, vibration,

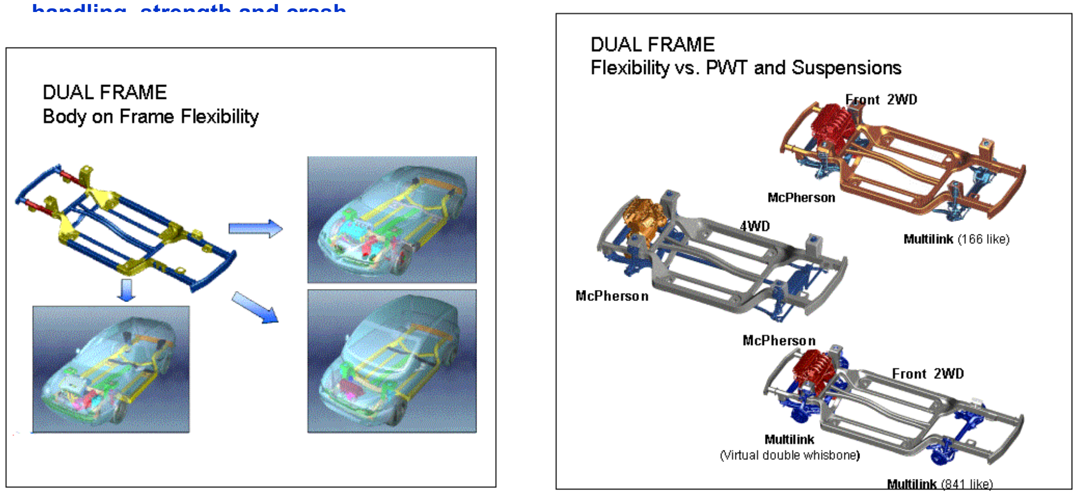


Figure 10. Lower 3D modular chassis frame for low volume vehicles.

From another point of view, the market requirements push the OEMs to develop solutions with increased interior space for comfort or re-configuration. This requirement determines a systematic increase of vehicle dimensions in order to offer more space for comfort, interiors reconfiguration, etc. to the final customer. In Figure 12, a benchmarking for a B-class vehicle is reported where for each automotive company, in a "volume vs. weight" diagram the new B-class model is compared with the previous one. It can be observed that the OEMs had to choose to increase volume and therefore, the weight for meeting the customer expectation with obvious negative influence on environmental impact. In general, the "new" A-class dimensions are moving towards "old" B-class dimensions and simultaneously, the "new" B-class moving toward the "old" C-class dimensions. The risk involved in the class dimension changes may result in superior inertial mass[1], but this will result in increased fuel consumption between 4 and 6%. The end result is particularly crucial as the t various OEMs find themselves now facing a completely

[1] Inertial mass is the mass, representing the vehicle inertia; it is used for evaluating the vehicle fuel consumption on the dynamometer bench rig.

new product mix that can be detrimental with respect to CAFE and noxious emissions regulations (Figure 13).

Figure 11. Split frame architecture for a high performance sport car.

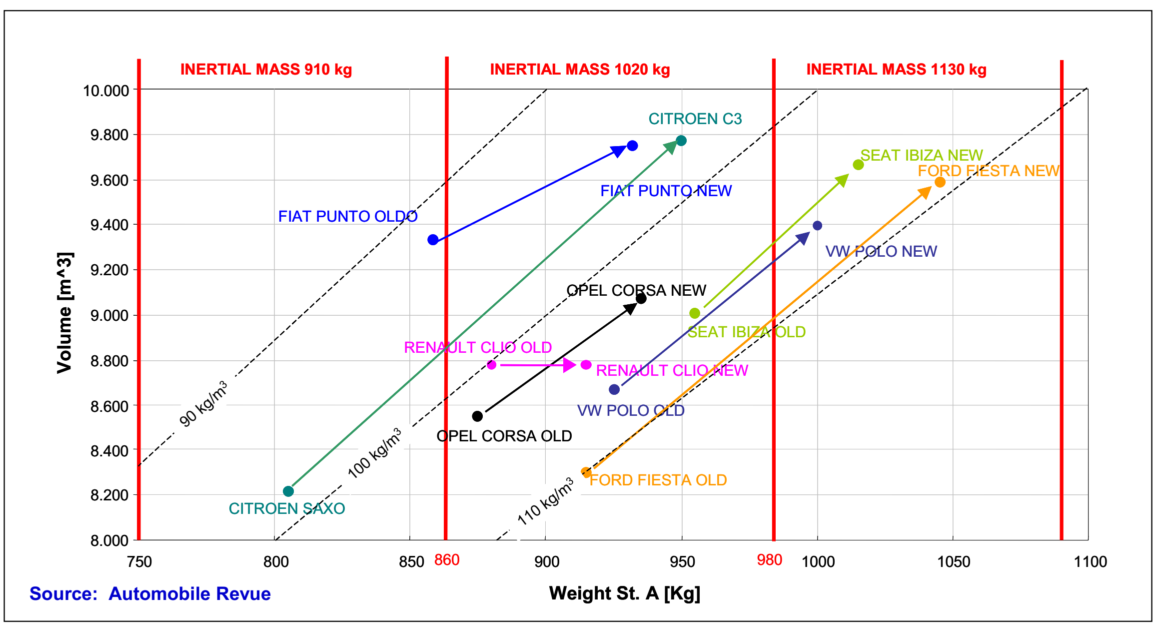


Figure 12. Product scenario "volume vs. weight" for the B-class segment.

A negative influence on the product mix is also supported by the increasing market request of new vehicles formula, such as MPVs, L0 and L1 classes that normally weigh more than traditional architectural solutions.

In addition, given the opportunity of adopting different production lines with the same platform (in order to reduce investments), there is the common necessity to increase platform standardization with additional weight on board.

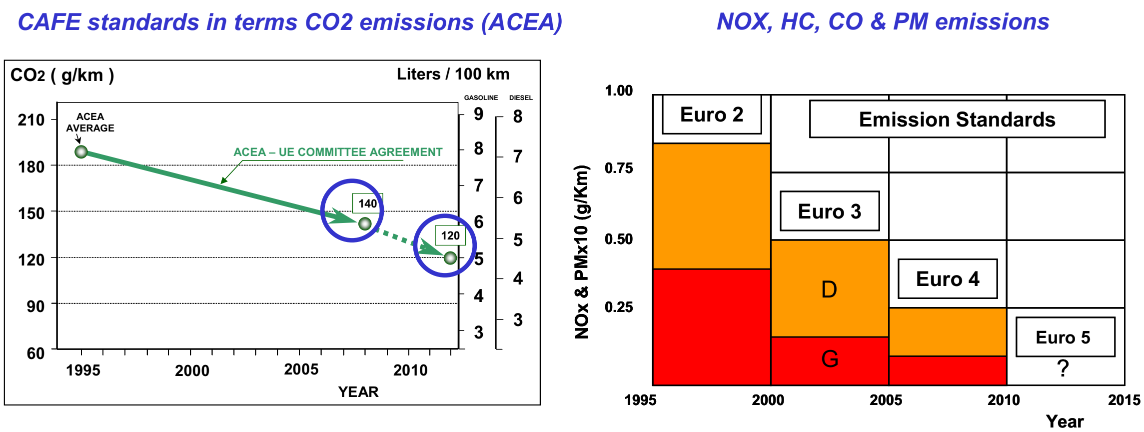


Figure 13. Legal constraints on consumption and emissions.

Moreover, if the normative is taken into consideration, the weight penalty will be the consequence of new safety standards (Figure 14), which are becoming increasingly severe.

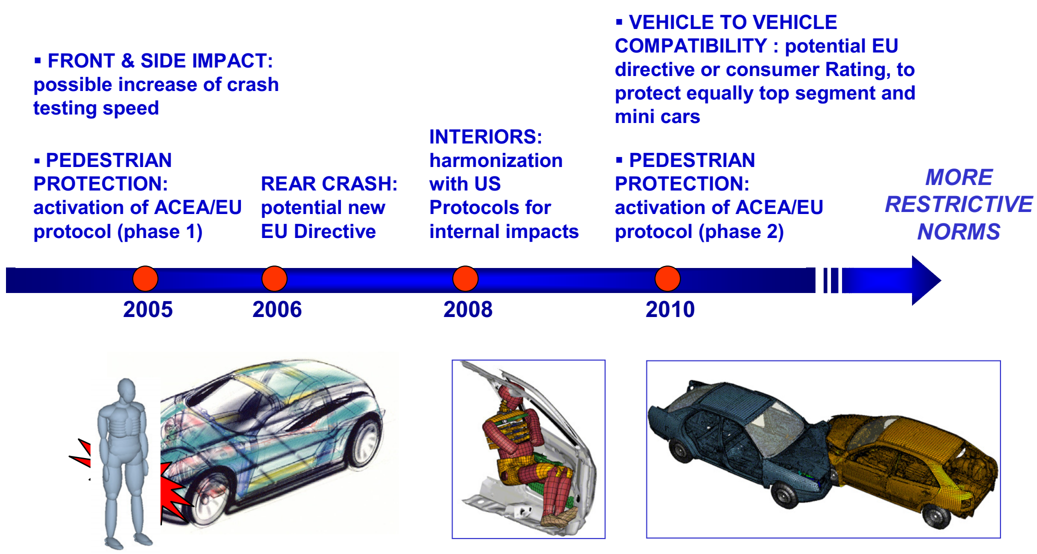


Figure 14. Safety requirement norms.

Another aspect to be taken into consideration is the European end-of-life regulation (Figure 15). Starting in 2006, the recyclability issues will be taken into consideration by the OEMs during the product development stage and therefore, green design methodologies should be adopted for the development of future vehicles (careful selection of materials and assembling technologies).

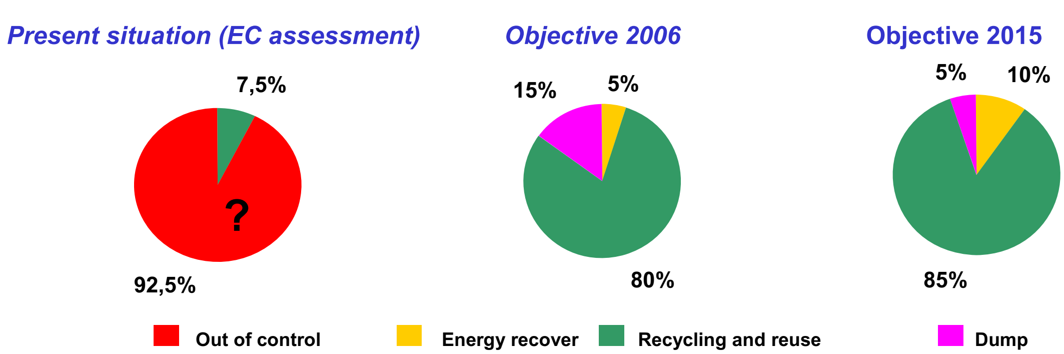


Figure 15. Vehicle end-of-life regulation: the "Extended Producer Responsibility" (EPR) principle.

CRF Approach vs. Fuel Consumption Reduction

With the final objective of the fuel consumption reduction, Centro Ricerche Fiat developed a holistically structured process at the vehicle level, aiming at identifying the optimal mix of various fuel reduction actions/technologies (Figure 16), as the best compromise in terms of performance/cost.

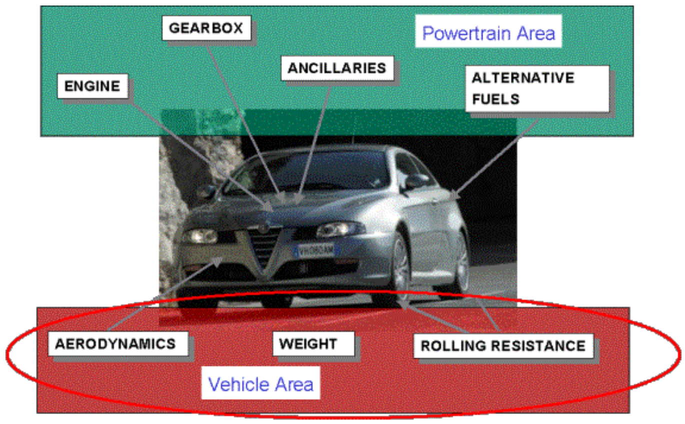


Figure 16. System approach to fuel consumption reduction.

Therefore, all the technologies (available today and those under development) that can contribute effectively to the fuel consumption reduction initiative (and therefore to the CO_2 emissions reduction) were taken into consideration. ISpecific target setting and deployment methodology were designed to identify the potential contributions in reducing CO_2 emissions and the resultant additional cost of the product. The objectives for the various vehicle areas (i.e., engine, drive train, weight, aero, energy management) were set according to the future targets.

Based on this analysis, the role of weight saving is:

- To limit the fuel consumption increase of new vehicle models, due to safety (future safety standard) comfort and versatility/flexibility contents (perceived value for customer) - vs. CAFE 2008 (objective: reduce by 30 - 50 kg).
- To contribute significantly to the fuel saving - vs. CAFE 2012 (objective: reduce by 100 - 150 kg).
- To increase the car performances ("specialties" and "luxury").

The Role of Materials and Technologies

On the basis of the previous considerations, it was possible to define a road map of weight saving and define the contribution of various materials and technologies for the vehicle development along the timeline for meeting the CAFE targets of 2008 and 2012 (Figures 17 and 18).

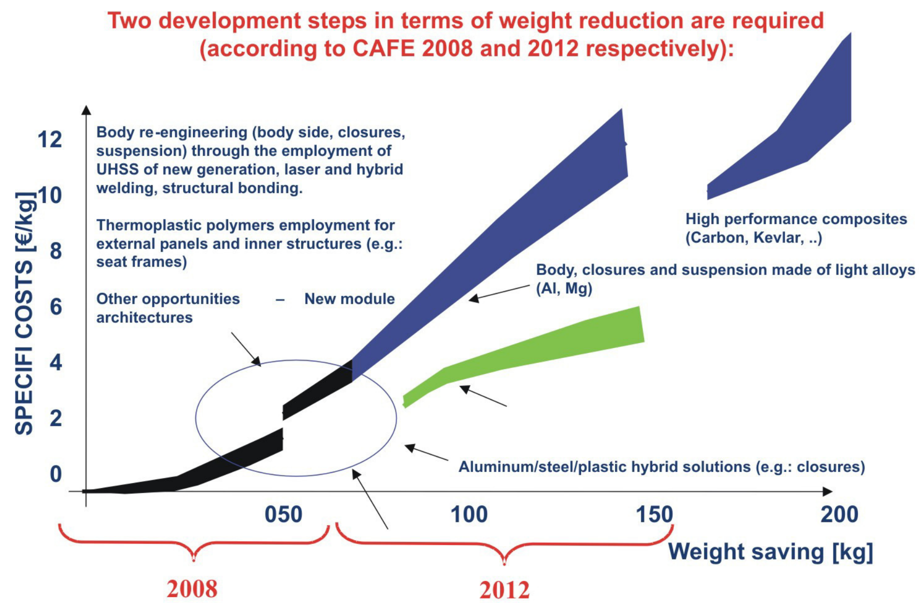


Figure 17. Road map of weight saving (part 1).

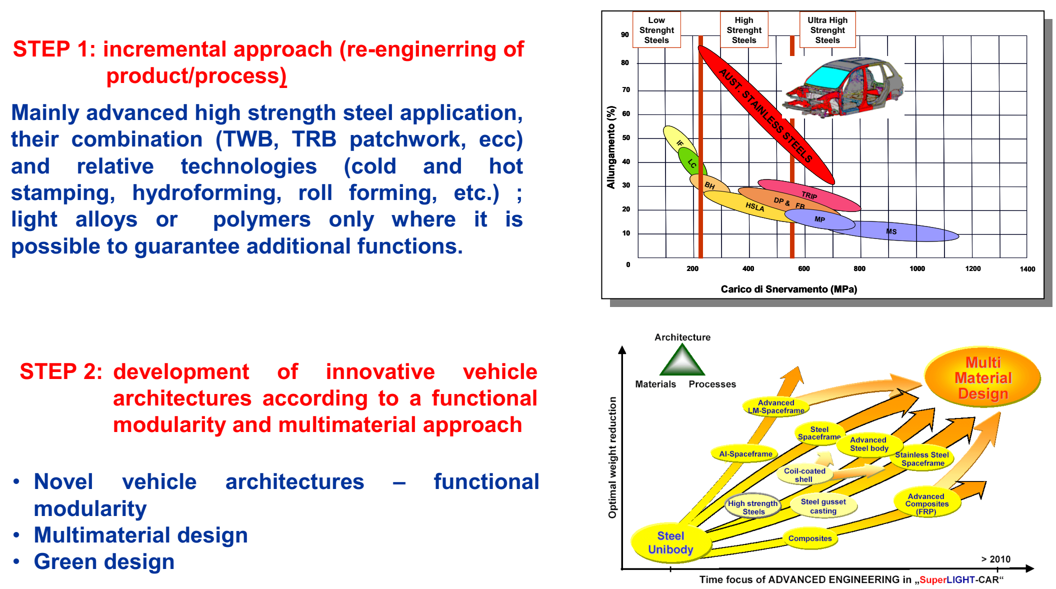


Figure 18. Road map of weight saving (part 2).

<u>Step 1 - weight saving by 2008</u>

The contribution of weight saving for 2008 will be achieved mainly by avoiding a step forward in terms of inertial mass. The objective was defined as 30 - 50 kg weight saving with a maximum delta cost of 2 euro/kg weight saved, to be achieved through:

- Unibody re-engineering (body side, closures, suspension) through the employment of UHSS of new generation, innovative joining technologies, development of methodologies for CAD/CAE integration (Figure19).
- Polymer materials employment for external panels and interior structures.
- Al-alloys application only where the weight saving can offer additional advantages (e.g.: handling referring at suspension components).

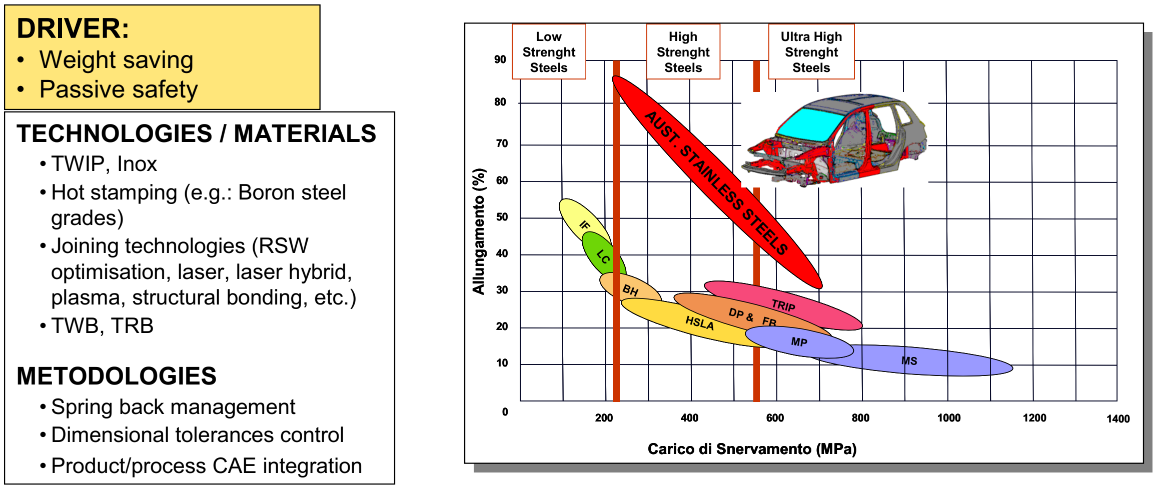


Figure 19. Step 1 (weight saving by 2008) – evolution of UHSS and specific technologies.

As an example of extensive use of steel grades of the new generation, Figure 20 reports the steel typology distribution for the development of the body of the New Fiat Punto. Moreover, the tremendous increase of application of UHS and UHSS can be observed with respect to the previous Fiat models starting with the Fiat UNO in the 1980s.

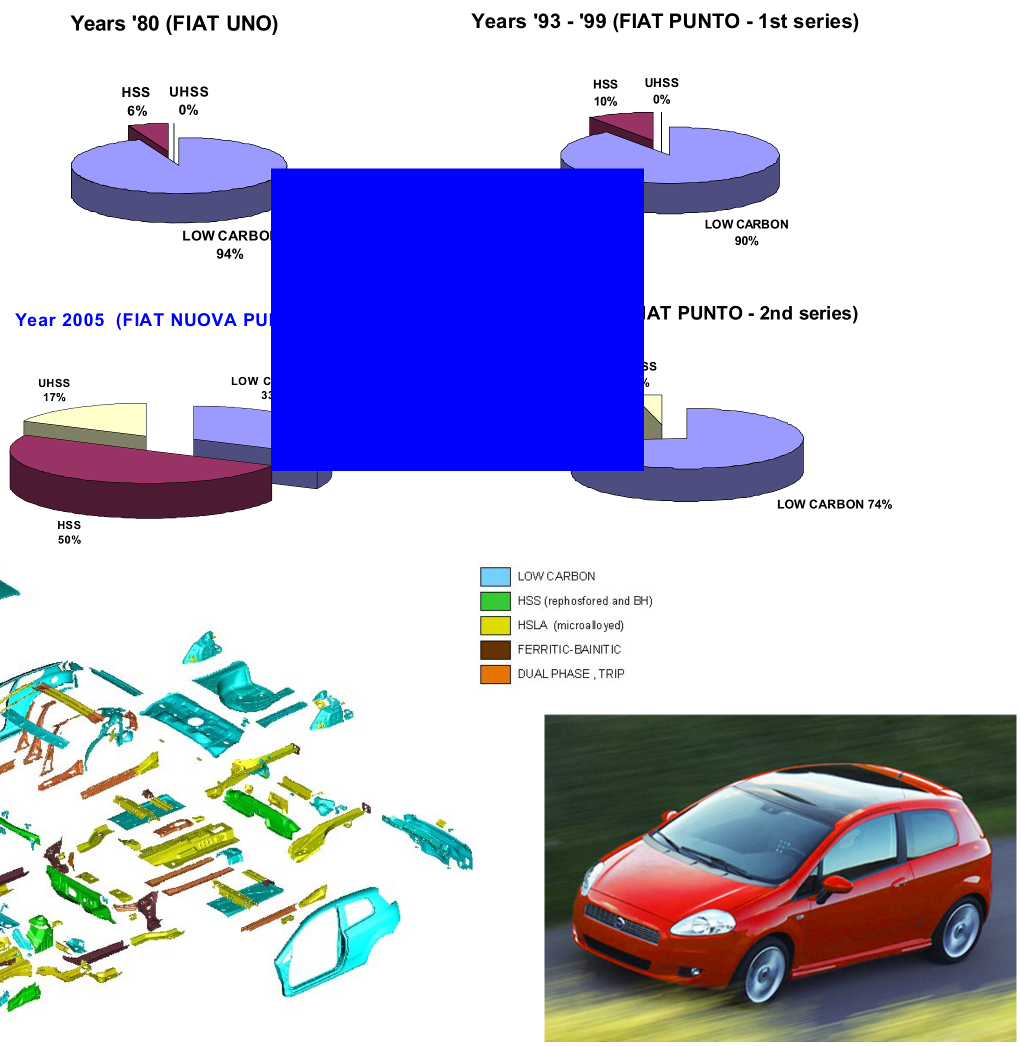


Figure 20. The evolution of high strength steel through the Fiat Punto generations.

For maximizing the exploitation of these new steel materials, Centro Ricerche Fiat in parallel has developed CAE methodologies for:

- Integration of process simulation with product optimization (Figure 21) for taking into consideration the strong work-hardening effect of these materials (Figure 22).
- Multi-disciplinary and multi-objectives optimization for the selecting the right material and thickness as a function of various performances to be fulfilled.
- Spring back management (Figure 23) - the spring back effect is generally increasing with the improvement of the steel strength.

These developments allowed the design of more efficient subsystems archetypes at higher structural efficiency (Figure 24) and enabled by the development of new joining technologies such as the Comau Agilaser (remote laser welding), Figure 25.

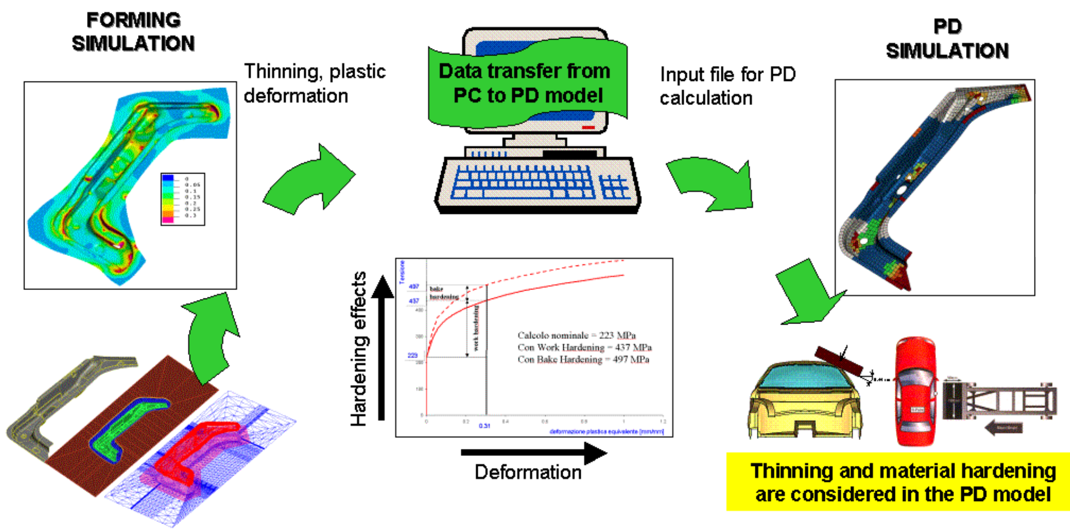


Figure 21. Product / process integration.

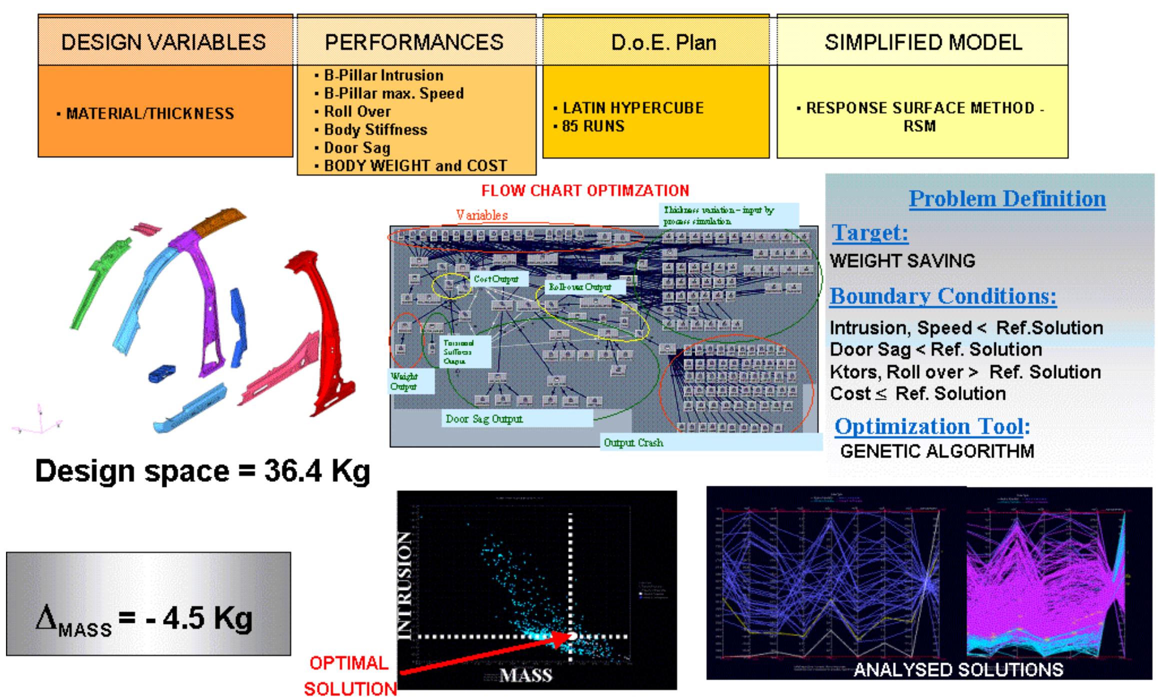


Figure 22. Structural efficiency optimization the body side (multi-disciplinary optimization).

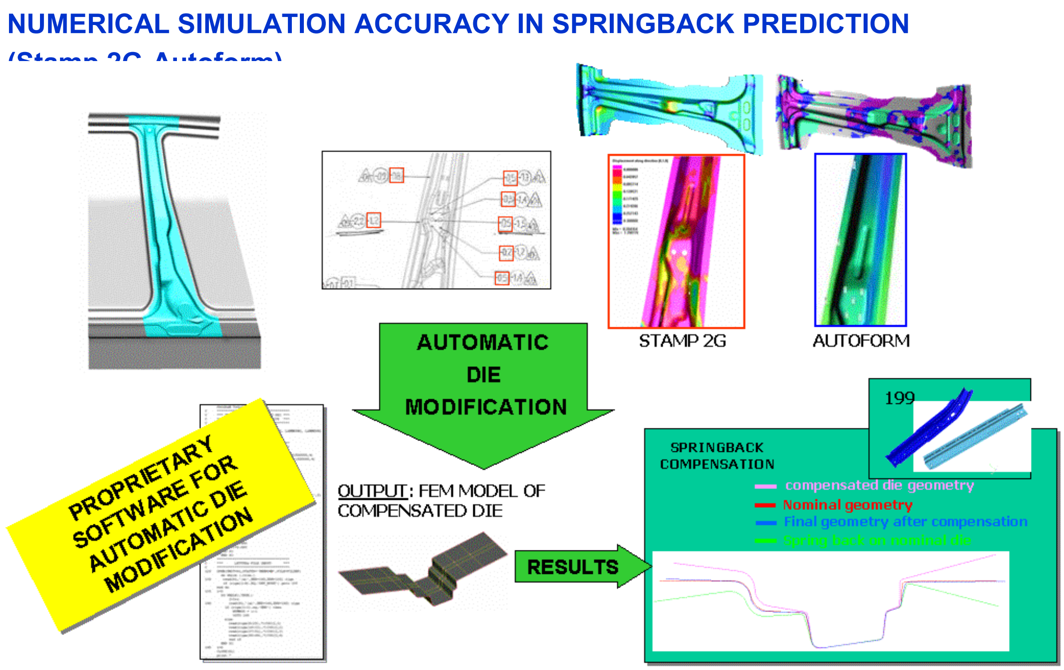


Figure 23. Die compensation by stamping simulation.

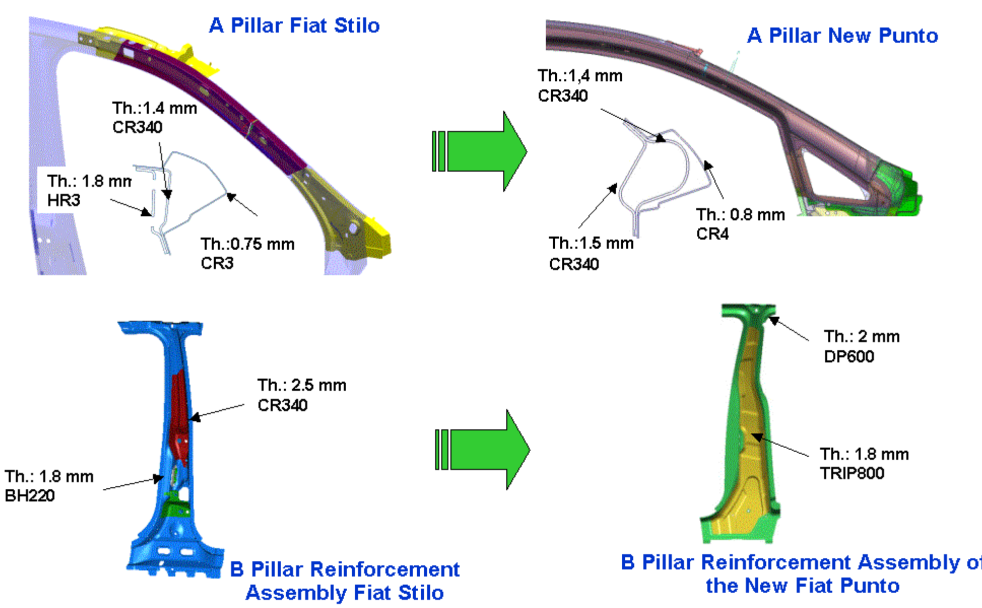


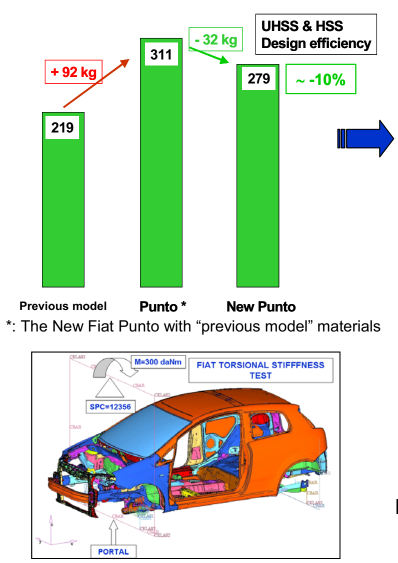
Figure 24. Structural efficiency: architectural evolution of the A- and B-pillar.

Figure 25. Assembly technologies: the Comau Agilaser laser welding solution.

These developments resulted in maximizing the advantages given by the new generation of steel adopted (e.g. DP, MP, TRIP, etc.) for obtaining these excellent final product structural and crash performances (the New Fiat Punto is the best in class of its category, Figures 26-28).

	Previous Punto model	The new Punto	IMPROVEMENT
Torsional stiffness [Nm/deg]:	12850	19500	+ 52%
Bending stiffness [N/mm]:	8700	11200	+ 29%
First torsional frequency [Hz]:	33	39.4	+ 19.3 %
First bending frequency [Hz]:	43.6	50.8	+ 16.5%

Figure 26. Performance evolution by structural efficiency in the new Fiat Punto.



OK for meeting the 2008 CAFE regulations of the FIAT fleet

$$\text{Structure efficiency Index} = \frac{m}{K_t \cdot A}\left[\frac{deg \cdot s^2}{m^4} \cdot 10^3\right]$$

m [kg]:	BIW mass included bolted elements and glued windscreen
K_t [kNm/deg]:	Torsional stiffness of BIW included bolted elements and glued windscreen
A [m²]	projected surface, i.e. length * width

	Previous Fiat Punto model	The new Punto	IMPROVEMENT
Structural Efficiency Index	3.11	2.48	+ 25%

Figure 27. Structural efficiency index – weight saving.

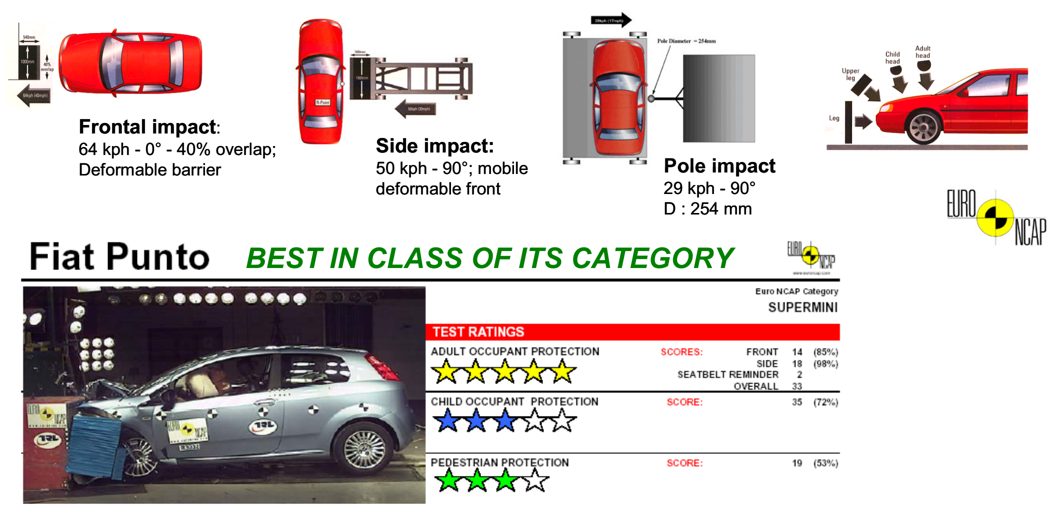


Figure 28. Crash performance of the new Fiat Punto and Euro – NCAP rating.

Step 2 - weight saving by 2012

The 2012 approach is different in that the weight saving will have to contribute effectively to fuel consumption reduction(at least achieving a contribution of 4%.) For meeting this target, a weight reduction objective of higher than 100 kg is necessary (jump into the previous inertial mass) with a target cost in the range of 4 to 6 euro for each kg saved, according to the function performed.

It is clear that in order to achieve this target, other materials beside UHSS should be considered such as light alloys and techno polymers, according to a multi-material approach. This approach will result in the appropriate material selection and appropriate technology to fulfill the specific functionality of the part. In such a way the most efficient solution can be developed (Figure 29). For resolution of managing the material hybrid design, Centro Ricerche Fiat and the main European OEMs are involved in a large-scale European project (sponsored by the EC), named "Super Light Car", whose objective is to reduce 30% of the vehicle body weight at a sustainable cost (Figure 30).

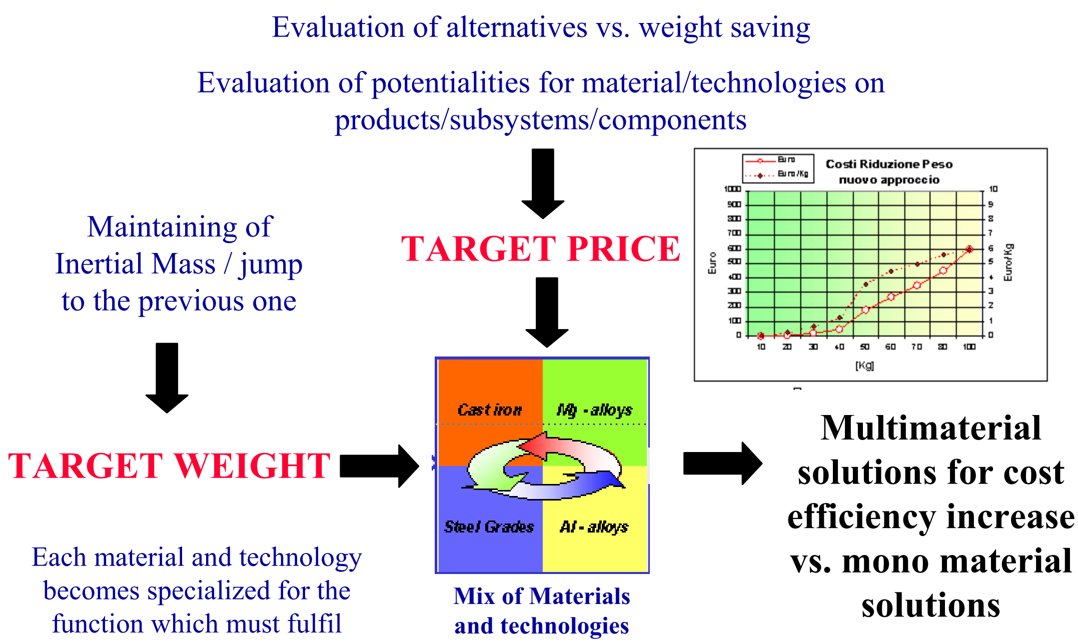


Figure 29. Step 2 (weight saving by 2012) – multi-material approach.

The choice of materials should be defined also taking the recycling issue into consideration (dismantling, recycling and reuse procedures of end of life vehicles, as explained previously). CRF with the support of Universities and Partners is also building innovative methodologies of "green design" to be applied in conjunction with the multi-material selection criteria for the development of vehicles of the future.

In parallel at the hybrid design, as discussed previously, the trend analysis in the vehicle market revealed that in the future, there will be an increase in alternative vehicle architectures. As a consequence, a general reduction of volume rates for an individual model will evolve. Based on these considerations, Centro Ricerche Fiat is promoting the functional modularity approach for the future vehicle architectures (maximizing the product flexibility), integrating standard modules plus specific ones.

A functional module can be defined as a number of components, assembled and installed as single unit, which makes a specific product/process function. It can integrate a certain number of systems and therefore support vehicle specific functions (partial or global), as a standard solution. It can be produced using innovative materials and technologies, minimizing the cost because it can be shared with different vehicles and platforms.

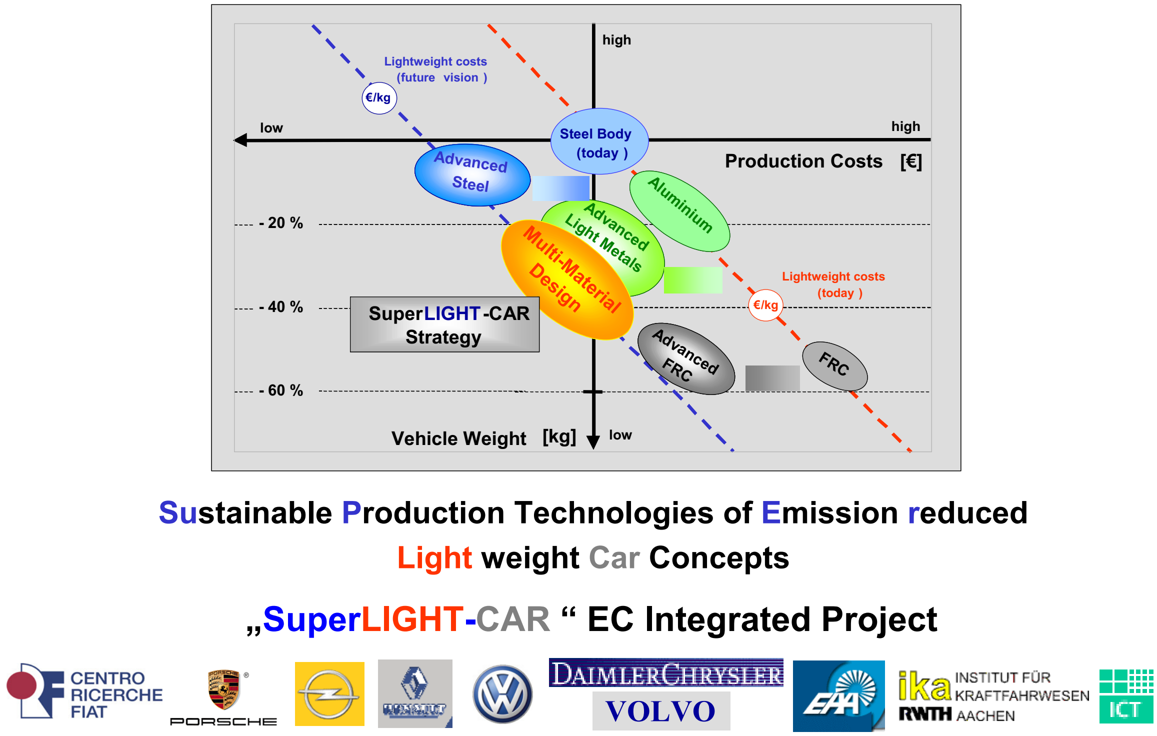


Figure 30. New vehicle architectures by multi-material approach.

Conclusions

The vehicle weight saving strategy is fundamental for meeting the targets of CO_2 emission reduction (2008 & 2012 CAFE objectives: corporate average fuel economy) and for the desired increased performance(structural efficiency, passive safety, performances, etc.).

A few research areas are considered at high priority for the materials of future automotive application:

- New generation of high strength steel grades and specific technologies for weight saving and passive safety increase at sustainable cost (short term application).
- Multi-material and green design approach (medium term application) where each material and technology becomes specialized for the function that it must fulfill, coupled with innovative vehicle architectures.

A program for the strategic development of these research areas involves:

- Universities and research centers of excellence
- Raw materials producers
- Suppliers of components and systems
- The production system producers and users (OEMs and Tier Ones)