

## Increasing passive safety performance using an automatic CAE methodology

Development of an integrated tool able to optimize the geometric features of a door trim and the restraint system setup

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In automotive industry, passive safety requirements are periodically updated becoming, year after year, more stringent.

Moreover, Engineers have to design cars and safety devices appropriately, not just to overcome homologation tests in an optic of "design for testing", but rather with a vision oriented to people's safety, that we could call "design for safety". The market is susceptible to safety aspects and to be the best in class in terms of safety performances is a recognized added value for a car model.

Nowadays, most of car makers work with the traditional trial and error method that means time and resources consumption without approaching the design optimum.

The aim of the presented activity has been to develop an automated and integrated tool capable to optimize the geometric features of a door trim and the restraint system characteristics of a car subjected to a lateral crash, in order to improve the biomechanical performances.



## Introduction

The main goal of door trim is to provide passengers protection in case of lateral impact.

At this step of the project, usually the structural parts of the door are frozen and the design is focused on plastic trim and, if present, foam absorber in the inner door volumes.

The engineers are typically strongly limited by the trim design since every technical solution has to be validated by the style centre. Feasible modifications have to be discussed before to start the activities because they affect the geometrical parameters range of variations.

LS-DYNA® is the most common SW tool for crashworthiness analyses. In the presented methodology it has been coupled with ANSA, a powerful pre-processor with a robust morphing tool; the optimization has been managed by modeFRONTIER, on the edge technology for process automation and design optimization.

The current paper will show the main aspects regarding the development of an automatic approach to lateral crash performances optimization.

## Test description

Some side impacts involve a vehicle travelling sideways into rigid roadside objects such as trees or poles. Often this is the result of a loss of control on the part of the driver, owing to speeding, misjudgement of a corner or because of a skid in slippery conditions. Such accidents are severe and the frequency of death or serious injury is high.

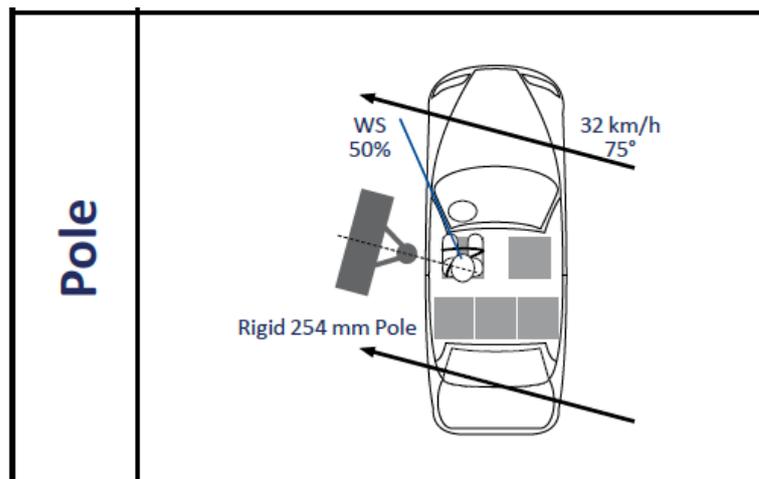


Fig.1 Euro NCAP Side Pole.



In Euro NCAP's test, a car is propelled sideways at 32km/h against a rigid, narrow pole. A single average male side impact dummy is placed in the driver's seat.

This is a very severe test of a car's ability to protect the driver's head. As the loading on the car is so localised, deformation can be very high and the pole can penetrate deeply into the passenger compartment. Without effective protection, the pole would strike the head resulting in serious injuries.

In the analysed model head protection airbag (curtain airbag-CAB) and seat-mounted airbag (SAB) have been used.

### **Model description**

The complete full scale model consist of about 1.8 millions of nodes and 1250 parts.

Multiple material models are used: steel, thermoplastic, foam, rubber and fabric.

The model was managed using several include file in order to be modular and permit to easily change the main assemblies.

The main include files are:

- Car (without door)
- Door
- Seat
- Dummy
- SAB airbag
- CAB airbag.

The door FEM model was maintained as separate file as the goal of this activity is to change the protective foams shape and materials, the geometric features of the door trim, and study the effect on the dummy injury.

Related to the airbags, they were used hybrid inflation models, that give the possibility to manage the porosity and permeability of the fabric materials and the output mass flow though the venting holes.



## Model reduction

In order to save CPU time and provide faster results suitable for an optimization it was created a sub-model that return the same result of a full scale model.

The idea is to record the motion from the full scale model and apply it the to the sub model as prescribed motion.

This method was named "Interface method" and permit to consider mass and inertia of a complete vehicle despite the use of a reduced model.

Some keyword implemented in LS-DYNA® code permit to make it easier, in particular:

- \*INTERFACE\_COMPONENT\_NODE to store the displacement
- \*INTERFACE\_LINKING\_DISCRETE\_NODE\_SET to apply the displacement.

Particular attention have to be paid in choosing the part where extract the motion: to summarize we could say that the motion have to be recorded in the left side body and the interface zone between the under body and the seat attachments.

All other parts are deformable and free to move, but since they are connected to the prescribed motion parts, react as in the full scale simulation.

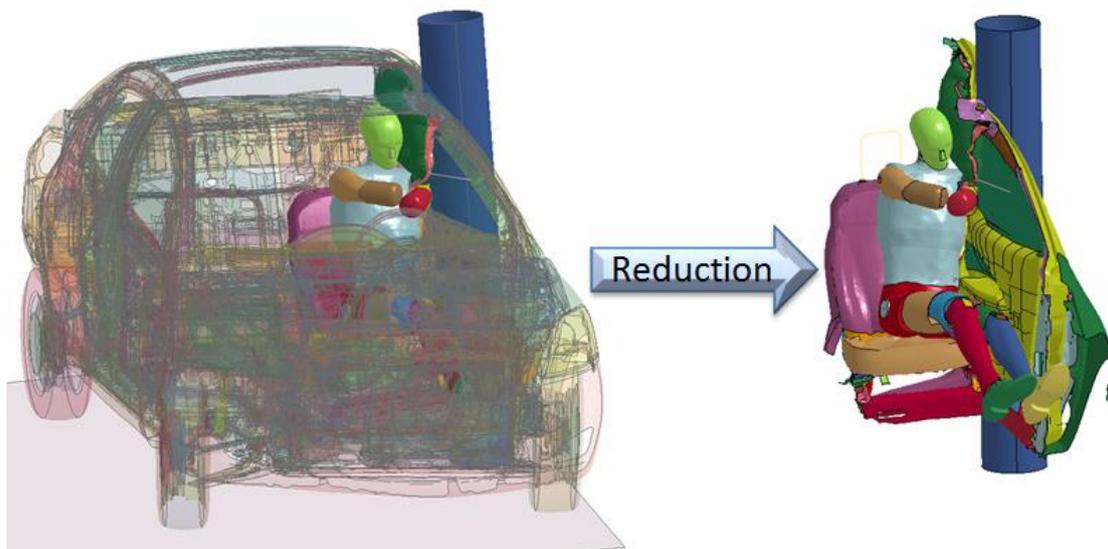


Fig.2 Model reduction



The reduced model consist of 700k nodes and 500 parts, therefore about 2,5 times smaller. In terms of CPU time the full scale model ran in 16 hours @ 16 cores, while the reduced one ran in 10 hours @ 8 cores.

### **Model parameterization**

Traditionally, to find the best geometric shape of door trim, the user has to import the model in the pre-processor and follow a cumbersome procedure made of several manual steps. The latters consists of translating elements, projecting nodes, reshaping parts, regenerating the mesh elements and submitting a new simulation.

After the numerical analysis, the user has to post-process the results and decide the new configuration to be tested, and repeat the procedure again.

In order to optimize the door design, a different approach is used in this study and is based on the parametrization of its geometry.

This step of the whole project has been carried out with **ANSA** pre-processor and, more precisely, the **Morphing Module** coupled with the **Optimization Task** were intensively used. The first one provides the user with two different strategies for the definition of design actions that can affect not only the shape of specific areas and geometrical features but also the associated materials.

Thanks to the options available in this module, it is possible to modify all the parameters that characterize a material such as density, Young modulus, stress vs strain curves and others. One approach consists of using entities called **morphing box** which can be quickly created and easily adapted to the geometry. This way, all the design actions applied to the morphing box, such as extension, translation, offset etc. reflect on everything (faces, shell/solid elements, connections, constrained elements etc.) loaded into it.

The other possible procedure, called **direct morphing**, does not require to apply specific entities and allows the user to directly select what will be affected by the design action. Of course, all the entities that can be loaded into a morphing box can be handled in this case as well.

Both strategies have been applied during this study.

A **morphing parameter** has been created for each previously defined design actions (Figure 3), so that the whole model is eventually parameterized. The coloured areas refer to the portions of the model that will be modified through the direct morphing technique, taking into account a fixed direction (yellow arrows).

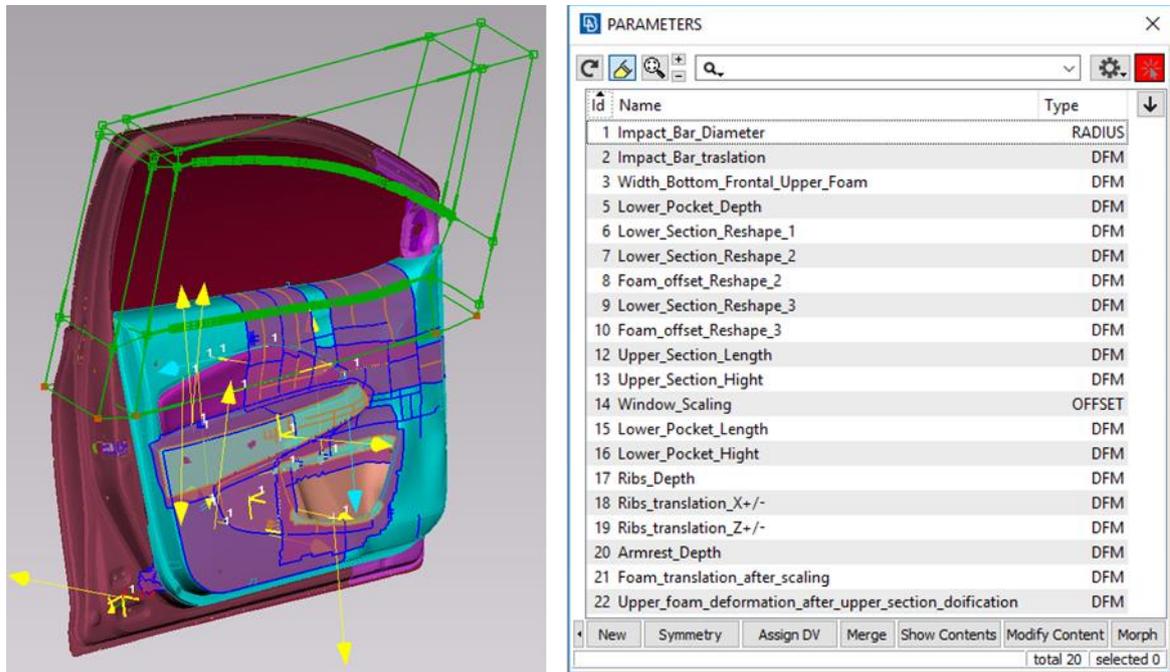


Fig.3 Morphing parameters

The 'Optimization Task' has been used for combining the parameters and defining therefore different DOEs (Figure 4). This tool, indeed, allows the user to set up the design variables and specify for each of them the type (real, integer, string) and the range of values they can assume (bounds, step, list).

Thanks to the 'Optimization Task' it is possible to create different configurations (Figure 5 and 6), to perform the mesh quality check and to export a ready to run file.

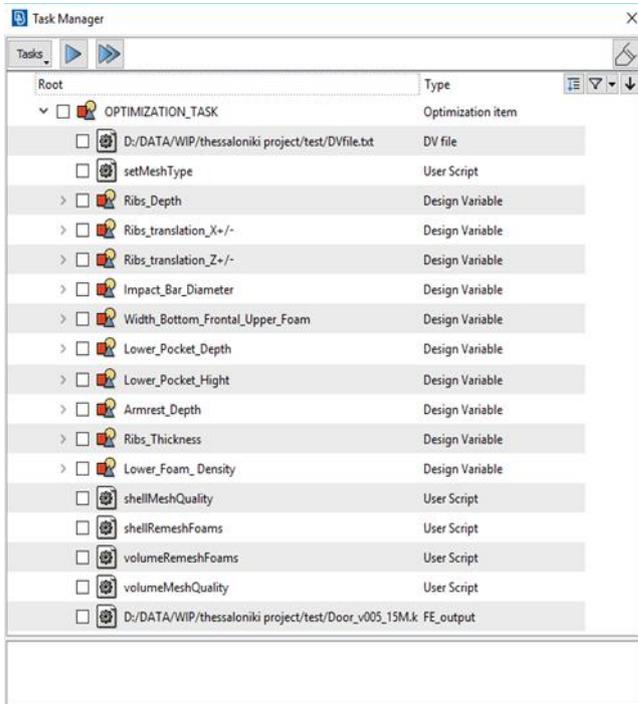


Fig.4 Optimization Task layout

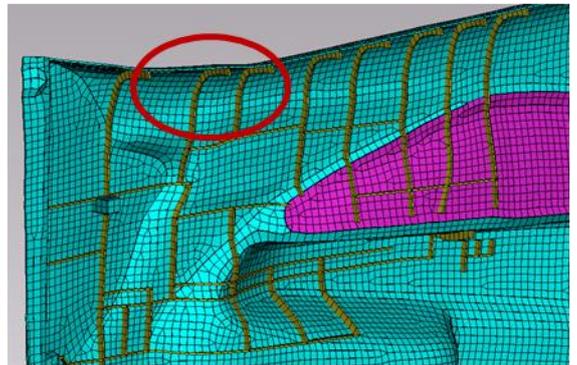
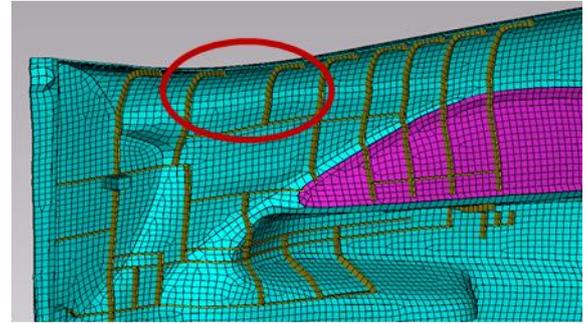


Fig.5 Ribs Translation

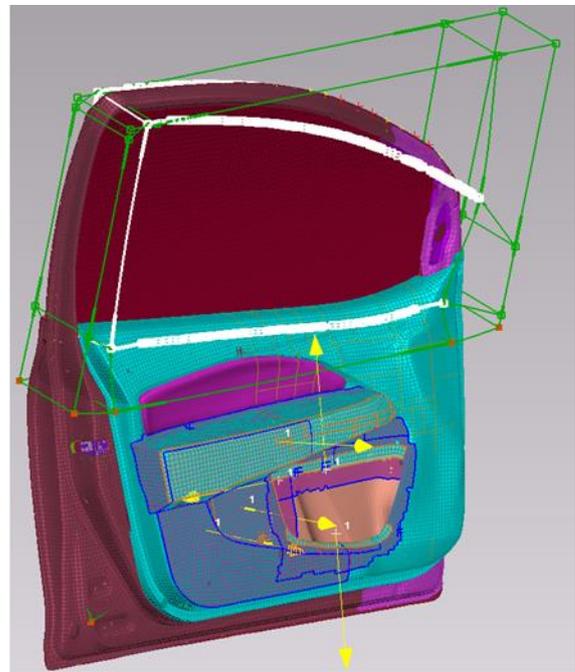
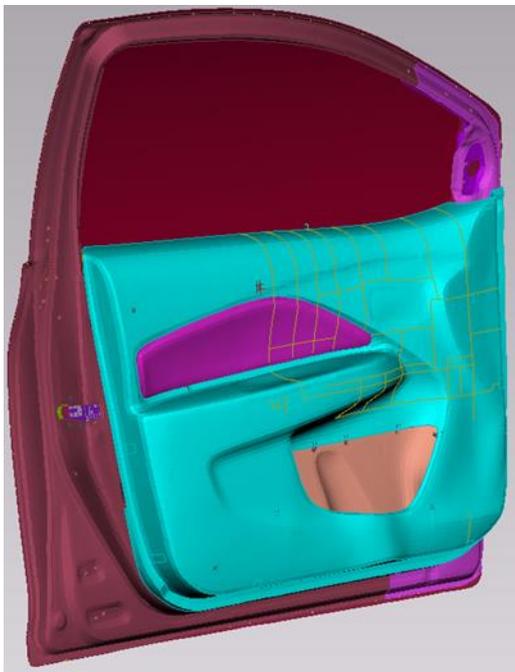


Fig.6 Armrest and lower pocket modification



## Automatic post processing

At the end of each simulation, the user must decide whether the last tested solution is better or worse than the previous one.

The dummy model is provided to accelerometers, beam/discrete elements and load cells to extract the dummy injury criteria.

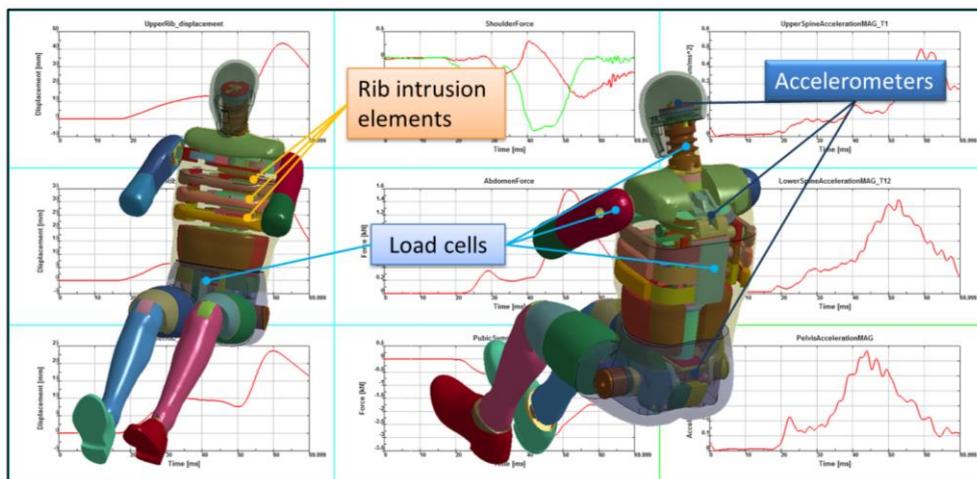


Fig.7 Dummy instrumentation to extract injury criteria

Recording some macros is possible to automatically post process the results in order to calculate the rating of the current configuration.

The software chosen for the post processing has been LS-PrePost, the native LS-DYNA GUI. Going forward on this project is expected to use META to execute these tasks.

## modeFRONTIER integration

In order to perform the DOE/optimization, modeFRONTIER has been used. modeFRONTIER is a state of the art multi-objective and multi-disciplines optimization software.

The ANSA node in the modeFRONTIER workflow allows to import the ANSA files containing the parametric door. As previously mentioned, since the task manager contains all the morphing operations as well as the sequence to be performed, it can be automatically managed by mF.

In the presented work, some of input variables are the morphing operations, so a change in the value implies a modification of the door trim shape.

After that, using some script (programming language instructions), the door elements are generated, renumbered and exported.



By means of the "mynode plugin" it is possible to invoke both LS-DYNA solver that submits the analysis and LS-PrePost that reads the output files and generates further result files suitable for mF interpretation.

Such results are values that mF handles and, after some internal optimization process, modifies as modeFRONTIER input variables to achieve the target outputs. Extracted values can be also managed inside a calculator node where further operations can be performed.

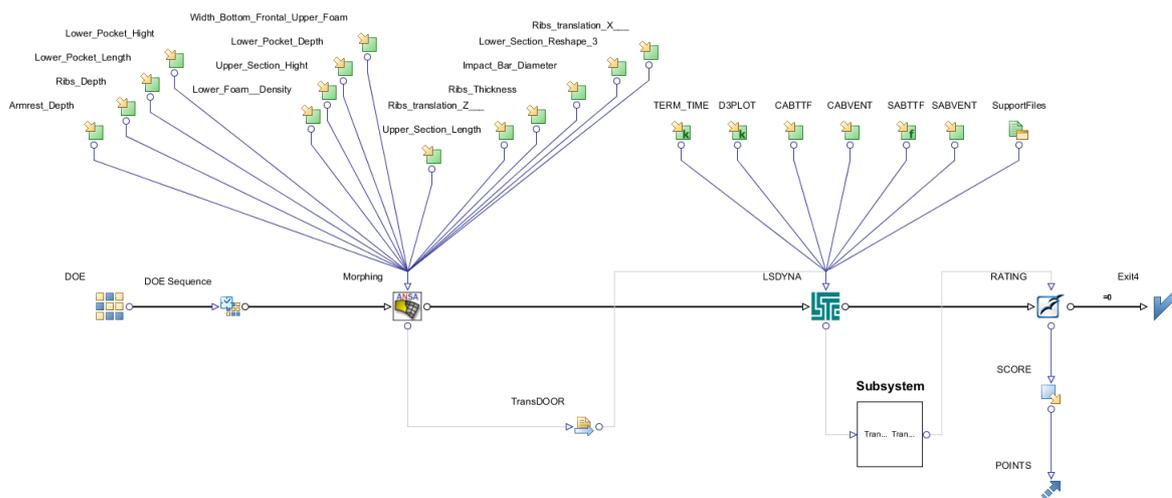


Fig.8 modeFRONTIER workflow

By looking at the workflow in fig 8, it is possible to identify all the processes. Starting from above it is possible to see the input variables that are linked to the ANSA node; a transfer file is created and passed to the LS-DYNA node. The support file folder, containing all files needed for the simulation and for the post processing, also converges at this node. Moving forward in the flowchart, the grey box named "PostProcessing" can be seen, that is a clustering node containing the calculator and output template. The extracted injury criteria are needed to compile the euro-ncap spreadsheet file in order to calculate the point related to that design. Furthermore, this activity was made automatically using the open office node embedded in modeFRONTIER. The extracted values are then copied in the spreadsheet and the resulting score is used.



## Results and Discussion

The optimization task has been mainly divided into two steps: Design space exploration (DOE) and optimization.

DOE is important for mF since it constitutes a basis data group for the subsequent optimization and also provides to the user an understanding of the influence that links input and output parameters.

After the DOE, the optimization task is carried out and mF has to decide which parameters are needed to be increased or decreased to fulfil the targets (objective functions that have to be minimized or maximized).

In the current case, several outputs were studied in order to guarantee a high safety level during testing. It is important to point out that the complexity of the optimization task arises from the fact that objectives usually oppose each other and therefore it is important to find a trade-off.

At the end of the DOE phase, it is possible to plot several graph such as the following pie and bubble charts:

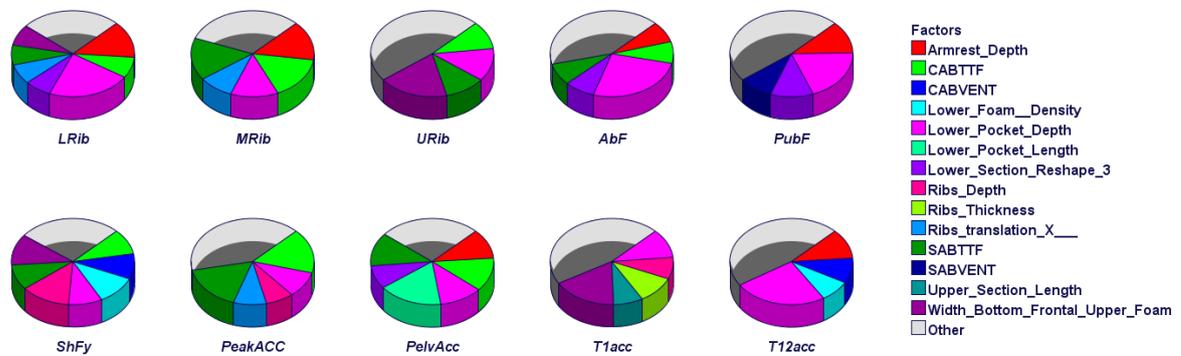


Fig.9 Overall Student Chart

The Overall Student Chart highlights, by means of pie charts, the influence of each input (slice) on each output (pie).

In this case it emerges that for the chest compression objective functions, the most influence factors are lower pocket depth (especially for the bottom rib) and armrest depth (mainly for



bottom and middle). The upper chest compression is very influenced from the upper foam width.

Talking about the head peak acceleration, the most influence factors are the CAB and SAB time to fire settings and following the venting diameters. The lower pocket depth have a medium influence on this response as well.

This output type gives the influence factor, but does not indicate the trend, for example, if the value of an input variable must increase or decrease to minimize an objective function. This can be done by means of a bubble chart and the scatter matrix chart.

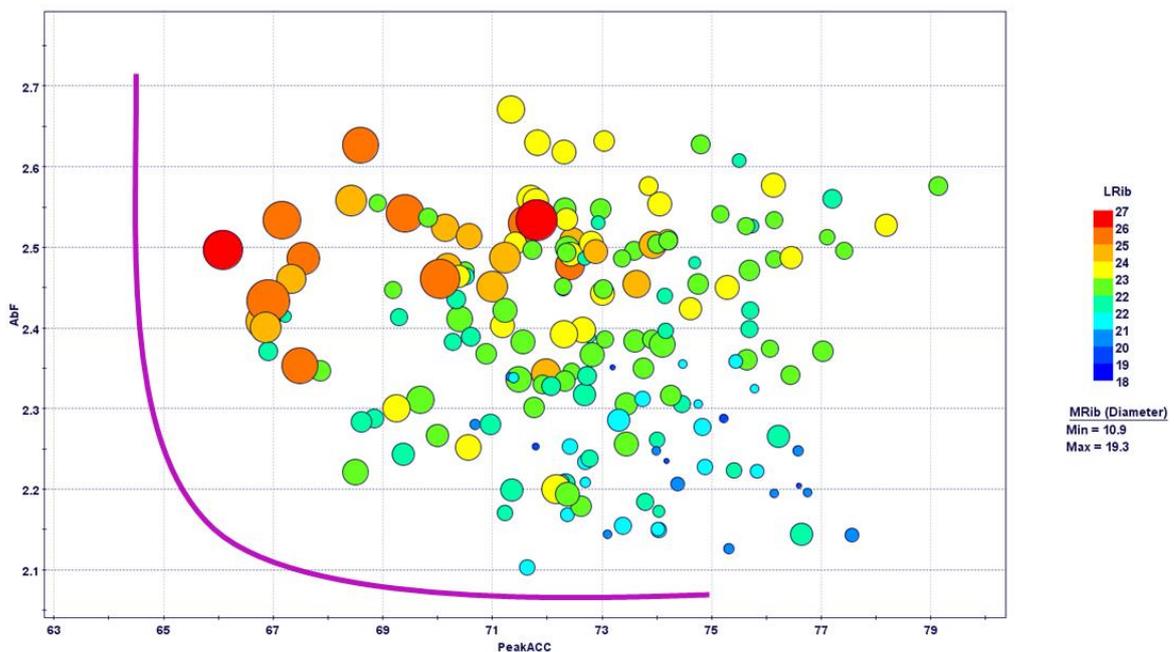


Fig.10 Pareto 4D Chart

This chart allows to represent the data in four dimensions. It can be clearly noticed that the best designs are those close to the Pareto curve (best compromise abdominal force vs head peak acceleration), with the lower bottom chest compression (colour close to blue) and with lower middle chest compression (small diameter).

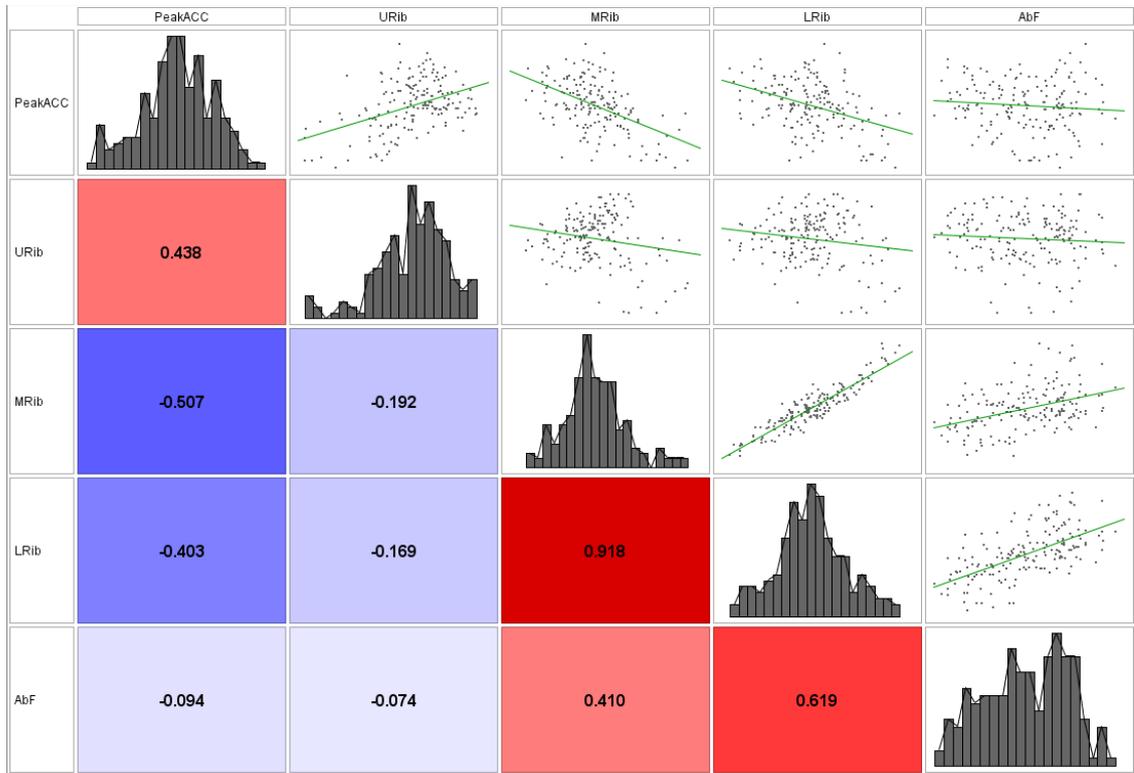


Fig.11 Scatter matrix chart

The scatter matrix allows to understand the correlation among the objective functions. In this case emerges that lower and middle rib are strongly correlated, while peak acceleration and abdominal force have correlation factor close to zero. Thus, in optic of optimization is possible to consider only one the lower rib as objective to minimize, whereas peak acceleration and abdominal force have to be maintained as separate objectives.

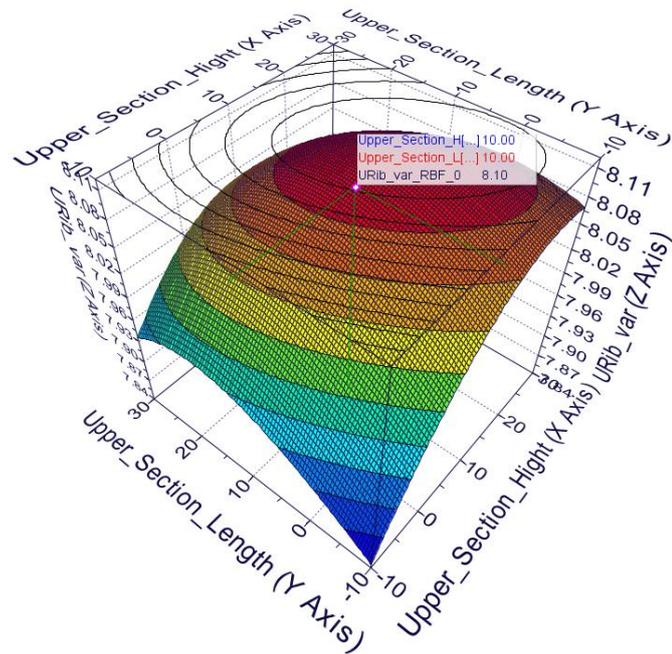


Fig.12 Response surface methodology

Using the DOE data is possible to train a response surface for each output; this meta-models permit to predict the output results without running the real solver and in a faster way. The use of meta-models can be very advantageous and can be applied even when little is known about the problem. Is important to point out that predicted optimum should be validated by a verification run with the original simulation model. The training of rsm will be use in a virtual optimization that we will perform in a following task of this activity.

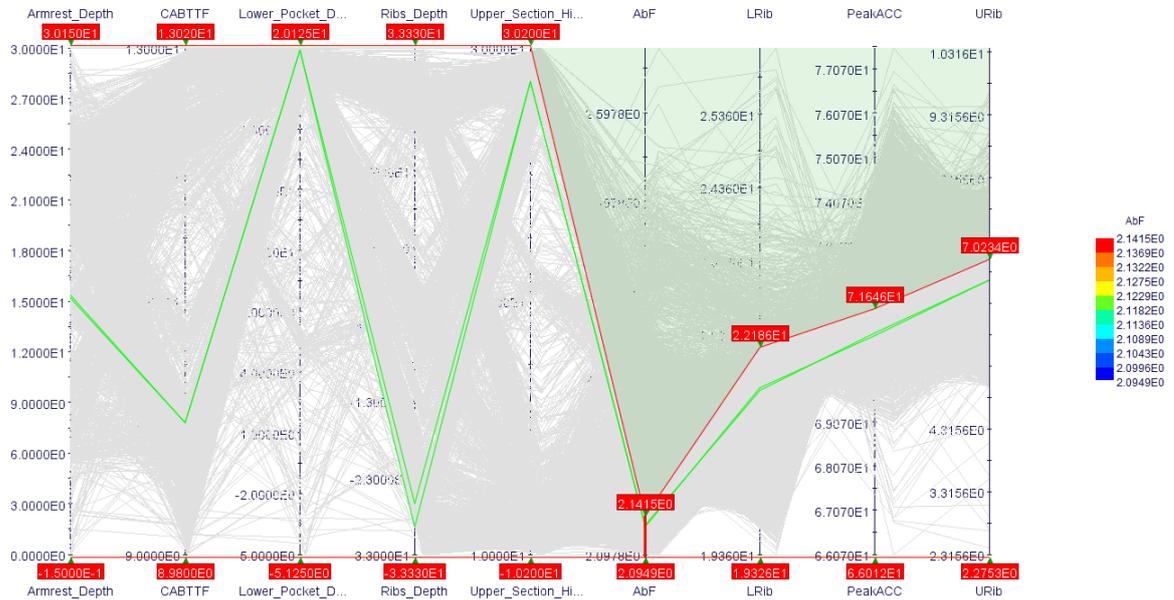


Fig.13 Parallel Chart

Another very important tool for decision-making is the Parallel Coordinate chart, which makes it possible to display multivariable data.

It is a useful tool for visualizing designs in a particular range. For example, if a design variable value is unfeasible for the supplier, the user can filter the value in the feasibility range and see which designs remain. Another use is to look at an output and check out which combinations of the input values fulfil the target.

### Conclusion

The goal of the project has been to develop an automatic and integrated approach to define the optimal shape of a door trim and the airbag setting. The selected software has been proved to be the best-in-class in their field of application and now are part of an innovative automatic methodology suitable both in the concept phase and design phase of a car.

At the moment of writing the article the activity is in progress and what will still be developed will be presented at the CAEconference 2017

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