

# Packaging Optimization driven by parametric morphing: Development of an Automatic Methodology

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## 1 Abstract

Nowadays product packaging improvement and optimization have become a concern in any market sector. The cost reduction is one of the ways to stand out against the competitors, but this cannot be done at the expense of the product integrity.

This is especially true in the field of home appliances, where the manufacturers have to guarantee the integrity of the product from factory to customer. This means that the product has to be delivered with full functionality but also has to maintain perfect aesthetics. Over the last years due to an increase in product competition and selection, the customers have been paying more attention to the aesthetic quality of the product. Therefore it is important to keep aesthetics in mind, since it has a direct influence on the perceived quality and product performance. Moreover, it will certainly avoid the customer service calls to substitute the damaged products.

Therefore, in this area, the specifications for transportation and handling are becoming more stringent.

Numerical simulation has been used to investigate the impact behaviour of complex product such as home appliances.

LS-DYNA® is a powerful tool for performing repeated analysis of large assembled parts of final product, including the packaging. The main goal of the simulation has been to verify the performance and sustainability of the packaging and its interaction with the structure in case of impact occurring during transportation or delivery. The study has been carried out to guarantee the integrity of the product from factory to customer and therefore to reduce customer service calls, minimizing the overall costs.

The target of the project has been to develop an automatic and integrated approach to study the better shape of a protective system for an home appliance.

## 2 Introduction

The main goal of packaging is to provide protection to the product in case of impact during transportation. But the packaging is a protection system which has no value for the end customer and therefore it must cost as little as possible and must be easy to be disposed of.

To design and build a real packaging can be very expensive due to its long development cycles and experimental testing.

With the aim of cutting down costs and speeding up the packaging development process, the simulation is a strategic solution.

LS-DYNA® is a suitable tool to investigate the performance in the early stage of the design phase due to several reasons:

- Robust contact algorithms.
- MPP scalability (Massively Parallel Processing).
- Several material models implemented (for steel, plastic, foam and glass parts)
- Restart capabilities

Numerical simulations with LS-DYNA® virtually assessed the performance of the designed packaging. Therefore, the confidence in successful tests approval was raised and confirmed by experimental testing.

After virtually testing the original configuration provided by the manufacturer, the packaging design was automatically modified in order to find a more robust and less expensive solution.

The current paper will show the main aspects regarding the development of an automatic approach to execute these tasks.

### 3 Product and packaging description

The product to be protected is made by different materials: steels , plastics , glasses and rubbers. The protective structure (packaging) is mainly made of EPS foams, woods and cardboard, held together by a shrink film.

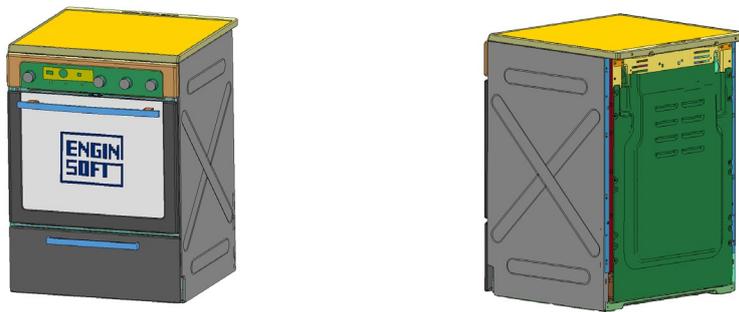


Fig.1: FEM model of the product

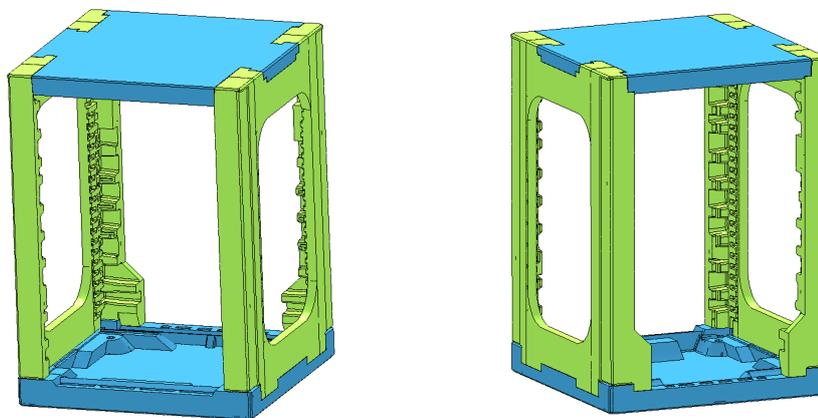


Fig.2: FEM model of the packaging

### 4 Materials characterization

An oven is a mix of materials: steels, thermoplastics, foams and rubber components.

Steel panels and thermoplastic materials were characterized with the \*MAT\_24 (Piecewise linear plasticity) available in LS-DYNA®, while packaging foams were modelled with \*MAT\_083 (Fu Chang Foam). The rubber parts were modelled with \*MAT\_181 (Simplified Rubber Foam).

Experimental laboratory test results were carried out to define all the materials using the modeFRONTIER Integration and Design Optimization software. Tensile tests on steels and compression test on EPS samples were used to calibrate the material models.

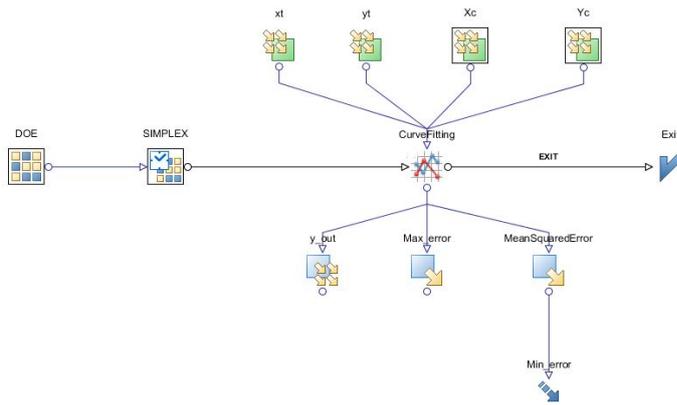


Fig.3: Example of modeFRONTIER workflow used to perform the material calibration

## 5 Packaging Modelling

The packaging shape is crucial to avoid accidental damage during product transportation. Therefore, all packaging components were carefully meshed with special attention to the packaging base, which is the key component driving simulation results on the edges drop tests. The packaging was modelled with 1 point integration tetrahedron elements, which yielded to 0.5 million elements. In order to keep all packaging components together, it was necessary to model the shrink LDPE. For that purpose, 4 node fully integrated membrane shell elements (ELFORM=9) were used.

Once the product and the packaging FEM models were completed, the model was assembled and initial conditions applied. A powerful LS-DYNA® feature is the contact treatment between all parts since most of the interactions were successfully handled with only one contact definition (\*CONTACT\_AUTOMATIC\_GENERAL).

## 6 Test description

The test procedure includes several free fall tests to validate the quality of the packaging. In the current numerical investigation, the four edge impacts have been performed in order to identify the most critical ones to be used in the optimization.

The simulated tests are a free fall edge impacts at 10 degrees with respect to the floor. The falling height is set up to 250 mm, which corresponds to an impact speed of 2.21 m/s.



Fig.4: Impact sequence – right, left, rear and front, respectively.

Preliminary tests showed that the most critical cases were the right and rear edge tests, so they were used in the optimization phase.

## 7 Model parameterization

Traditionally, to find the best geometric shape of packaging, the user has to import the model in the pre-processor and proceed by translating elements, projecting nodes, opening holes, etc. then to regenerate the solid mesh elements and start a new analysis.

After the numerical analysis, the user has to post-process the results and decide a new configuration to be tested, and so on. Thus, it has been a time consuming task due to the multiple "manual" steps involved.

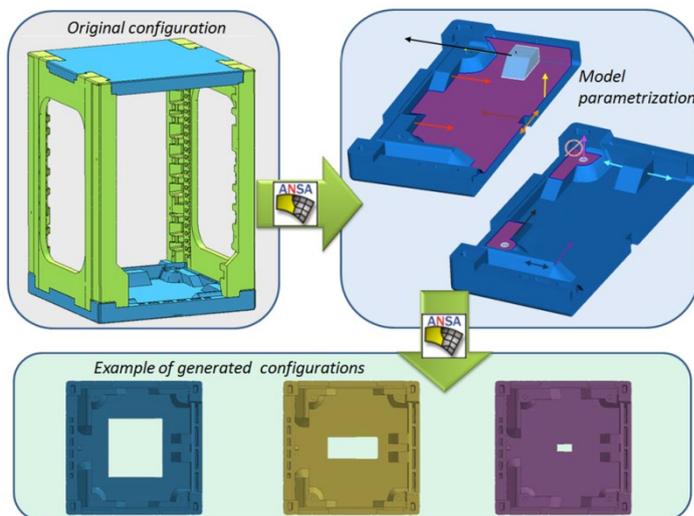


Fig.5: Parametric model of packaging base

In order to change the shape of the packaging in a quick way ANSA's Direct morphing features have been used; it allows the user to create local modifications on the packaging.

Using these features, it is possible to define some mesh modifications such as: translation, surface fitting, opening hole etc, and to link these features to a morph parameter (i.e defining a range of action).

In the figure above, some of the most common morphing operations are summarized; the arrows indicate the translational vectors and the diameter indicates the hole parameterization.

Another powerful tool inside ANSA is the "reconstruct", which allows, at the end of the morphing operations, to perform high quality remeshing on the distorted.

## 8 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.

This is not trivial task because the maximum deformations are very small due to the acceptance criterion, which is related to subjective aesthetic defects; it is required to avoid not only the deformations that could compromise the functionality of the product, but also aesthetic imperfection which is closely related to the perception of the quality by the customer.

To implement this, a virtual product instrumentation system has been used, made of zero stiffness springs that measure the panels displacements during the impact.

To make an analogy with the biomechanics, this method could be compared with the dummies instrumentation of ribs during side impacts.

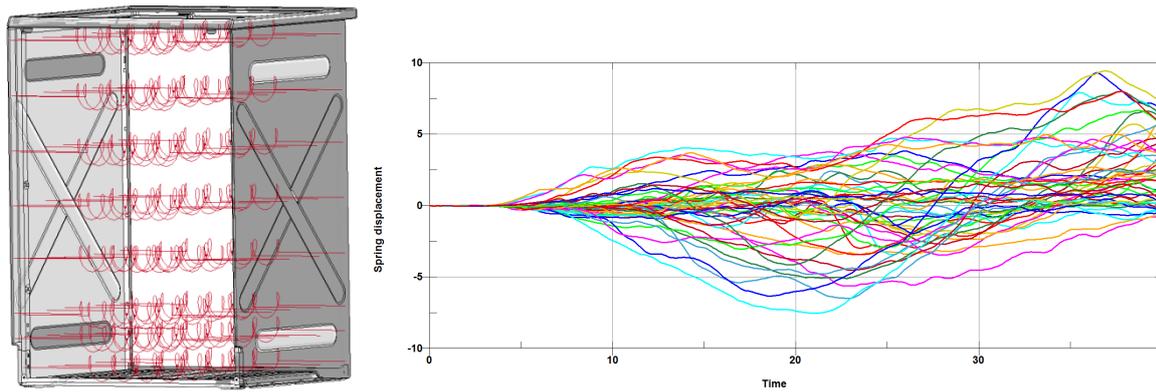


Fig.6: Virtual product instrumentation and spring displacements

Using this trick it is possible to record some macros that automatically post process the results in order to calculate a rating of the current configuration. The software chosen for the post processing has been LS-PrePost, the native LS-DYNA GUI.

## 9 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 packaging. 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, the input variables are the morphing operations, so a change in the value implies a modification of the packaging shape.

After that, using some script (programming language instructions), the packaging is mirrored (in the current case it is symmetrical) and the solid elements are generated, renumbered and exported.

By means of the "sh node" 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 (i.e mass minimization, local stress reduction and spring displacements reduction, etc). Extracted values can be also managed inside a calculator node where further operations can be performed.

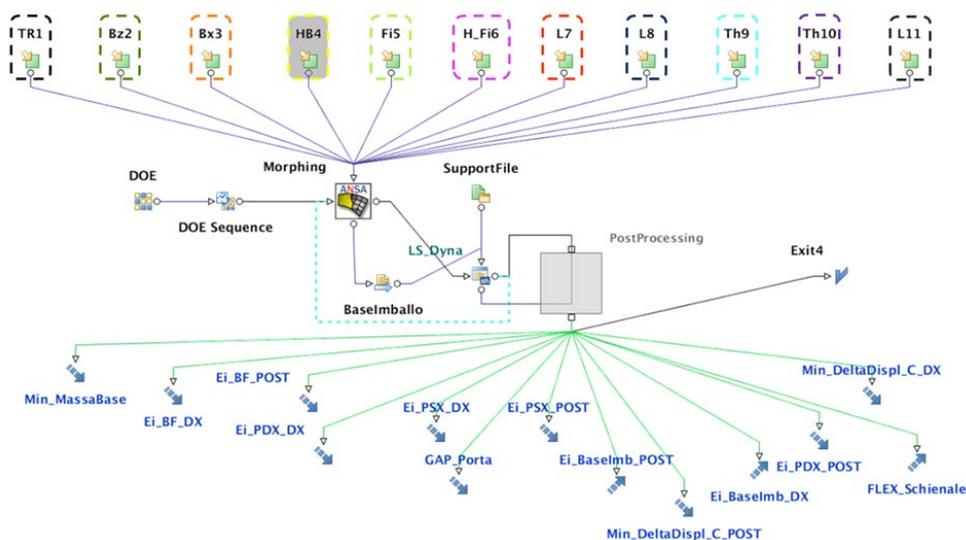


Fig.7: modeFRONTIER workflow

By looking at the workflow in fig 7, 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. Output, the objective functions that have to be minimized or maximized to achieve the target results.

### 10 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 the product integrity after testing and, at the same time, minimize the mass of the packaging. 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:

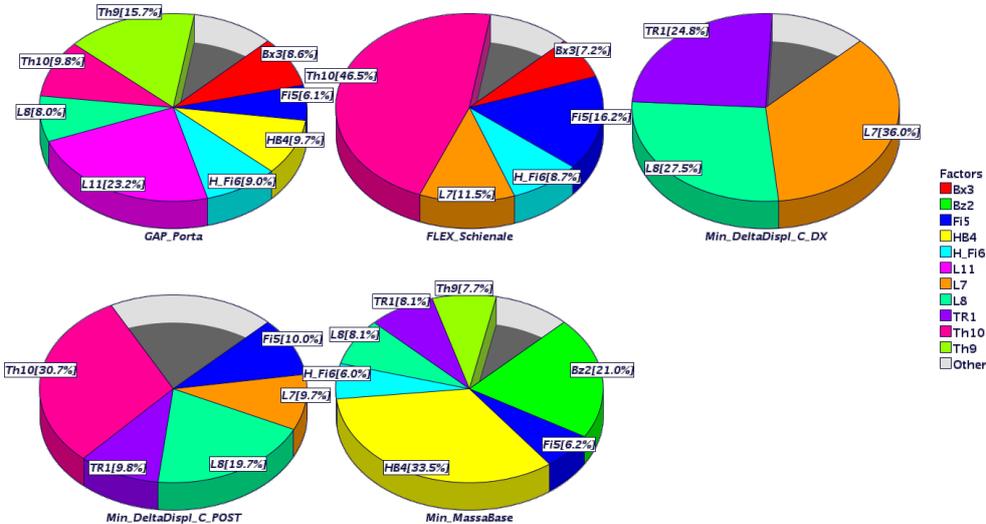


Fig.8: Overall Student Chart

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 mass minimization objective function (pie chart legend Min\_MassaBase), the most influence factors are respectively HB4 and Bz2, while the factor Th10 is very important for the back cover bending and for side panel deformation, measured by product instrumentation (pie chart legend FLEX\_Schienale and Min\_DeltaDispl\_C\_POST).

This output type gives the influence factor, but does not indicate, 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.

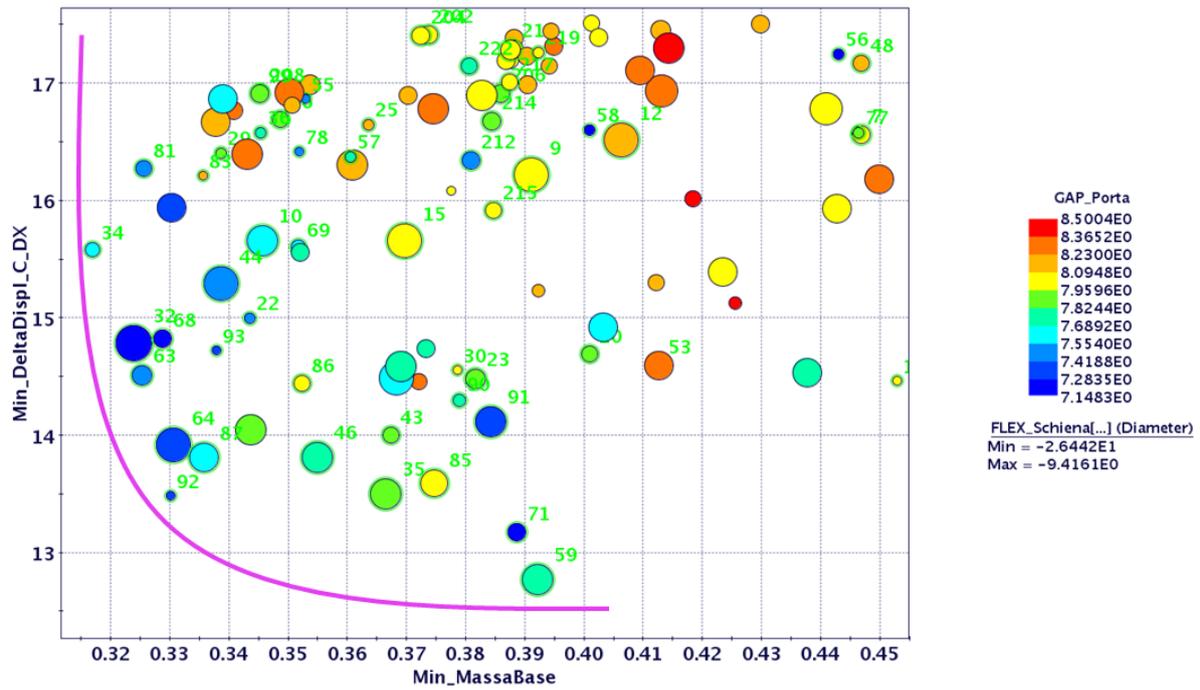


Fig.9: Pareto 4D Chart

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 Mass vs Deformation), with the lower door gap (colour close to blue) and with lower back cover bending (big diameter).

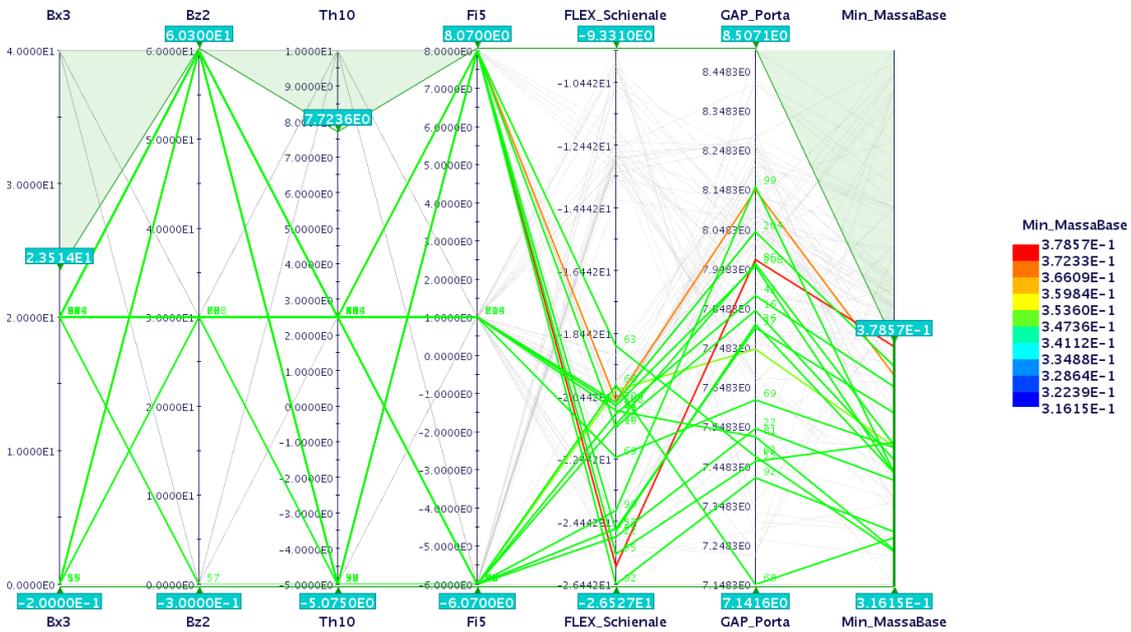


Fig.10: Parallel Chart

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.

## **11 Conclusion**

The goal of the project has been to develop an automatic and integrated approach to define the optimal shape of a protective packaging for an home appliance.

The selected software have 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 packaging.

The reliability of the simulation results have been confirmed by experimental tests. As expected, the product deformations have been strongly reduced compared to the original packaging configuration.

Moreover, the packaging mass reduction led to important cost savings in the order of one euro per piece. Considering a large scale production which is estimated to be close to a million pieces in 3 years, a remarkable saving can be obtained.