# Design concept development for a flexible polymeric packaging

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**Abstract:** Within the economic growth of Bosch Car Multimedia S.A., which is related to the increasing market demands for new and innovative multimedia products, the packaging solution employed for the internal transport and storage of electrostatic sensitive electronic systems generated an issue related to the company area employed for storage sections. It became necessary to introduce a new approach that is suitable for the safe transportation of such a diversity of electronic systems, while saving company space and improving the logistics associated.
The development and optimization of a new concept design for a flexible polymeric packaging, based on structural simulation analysis, is presented in this paper. Preliminary concept designs were developed and refined by performing structural simulations to validate the structural strength when subjected to specific mechanical efforts. Two types of simulations were performed, maximum filling weight and free fall drop impact for the baseline (actual packaging) and the developed concept design for evaluation and comparison. The simulations output made necessary to further reinforce the initial concept by a combination of structural ribs and thicker features. The optimization of the initial design concept showed improved performance and structural suitability for the replacement of the actual packaging. Other design features that improve the handling and maintenance of the packaging were also considered.
Functional prototypes were fabricated in additive manufacturing by means of FDM (Fused Deposition Modelling) process with the refined design concept.
**Keywords:** Product Development, Simulation Analysis, Additive Manufacturing

## Introduction

A company success is dependent on its ability to respond to the market needs by creating products that meet those needs at competitive prices. For the company in question, these products are smart solutions for car multimedia assemblies for applications such as entertainment, navigation, telematics and driving aids functions. These assemblies include electrostatic sensitive electronic systems that vary in design according to the final product. The company is divided in several sections that include workstations, storage areas and production lines where the electronic systems are fabricated, tested and transported between locations until reaching the final assembly workstation, where the functional multimedia product is completed. Therefore, an adequate packaging that protects the sensitive electronic systems from possible damaging during transportation and storage is crucial.
The current solution involves the use of a commercial plastic packaging (plastic container and loose lid) and specially designed thermoformed plastic trays for each configuration of electronic system. A reference number is attributed to each packaging and thermoformed trays considering the

identification code of the product to transport. The reference allows the collaborator to easily identify the packaging necessary for a specific product, improving this way, the process flow by facilitating the task and reducing time spent.

Although this solution is efficacious, with the increasing production rate of diversified products to best correspond market needs, the employment of such a specific packaging generates some complications regarding logistics. For instance, whenever a new product emerges, a specific configuration of the electronic system is defined, becoming necessary to develop unique thermoformed trays. These are fabricated by a supplier company, and require long lead time for development, testing and validation, and finally, fabrication. Also, due to the increasing number of thermoformed trays for the specific transport of electronic sensitive systems, large quantities of plastic containers and loose lids are purchased for the containment of the new thermoformed trays and transportation across company facilities. Consequently, extensive areas are allocated for storage, and the total number of references substantially increases. According to the company's prediction analysis, it is expected that the number of references will duplicate until the year 2020.

Due to this matter, emerged the need for a new packaging solution. A series of main requirements were identified that the new packaging should meet including: flexibility (adjustability to every electronic system configuration); reliable and safe transportation (material should be electrostatic dissipative to assure protection from electrostatic discharges while also avoiding excessive strain efforts over the electronic systems); optimization of the development process for a new packaging regarding lead time and associated cost; reduction of the total storage area; easy cleaning maintenance; and electronic identification and tracking for logistics improvement.

Market available packaging solutions for electrostatic sensitive devices are mainly fabricated with electrostatic conductive materials (e.g. plastic, paper and even integrating metallic parts) being therefore, unsuitable according to company norms. Also, the majority of existent products present outer structural ribs for reinforcement, which creates propitious areas for particles accumulation adding difficulty to the cleaning maintenance. Other solutions include collapsible containers and assembly systems with a series of components (racks, grids and guide rails) that add complexity to the packaging, and consequently to the process, which may lead to mistakes by the collaborator during the performance of tasks. Electronic identification and tracking are very specific features that need to be analysed individually and for each particular application. A flexible solution that would be suitable to every electronic system configuration was not available in the market, even solutions involving foams present some level of rigidity, as they are fabricated with specific cavity geometries.

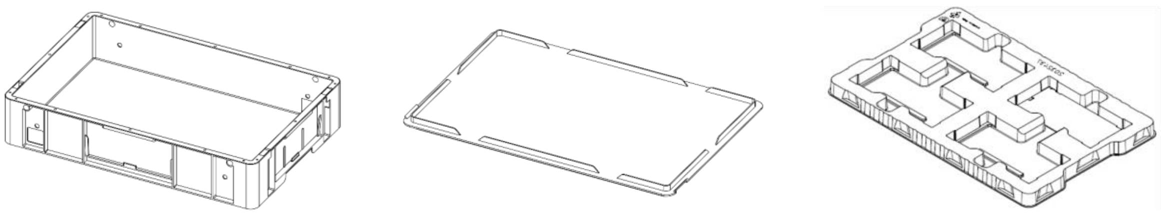
No solution was found in the market analysis that integrates the listed criteria and features for the application purpose. A new solution that combines unique and innovative features, in comparison to existing products, must be developed.

This paper is focused on product development activities until the prototype fabrication for testing and validation. The following sections of this paper present a requirement survey that allowed the perception of the product specifications to be considered for the concept design development. Refining of the design concept is shown by presenting the output results of structural simulation analysis. Finally, the functional prototypes of the optimized design concept are presented followed by the conclusions.

## Requirement Survey

A suitable packaging for the transportation of electrostatic sensitive electronic systems, between workstations, is of major importance, and it presents a series of requirements associated. The current solution employed at the company consists of a packaging system composed by a plastic container, a loose lid, and thermoformed trays (see Figure 1).

The plastic container allows the placement of trays (with and without electronic systems) in its interior guarantying its safe storage and transport, while also allowing an easy carrying, by the operator, through handles located at the width lateral. The base area dimensions are fixed (600 x 400 mm) and three different heights are available according to the requisite, being 120 mm as height, the most commonly employed. The loose lid presents the same base area dimensions as the plastic container, and it assures the closing of the packaging protecting its content from particles and other types of contamination sources. Due to a series of structural ribs, it also allows an easy stacking with security. Finally, the thermoformed trays present cavities that are carefully developed for each electronic system by considering a series of dimensional guidelines.



(a) (b) (c)

Figure 1: 3D CAD representation of the company's packaging system (600x400x120 mm): (a) plastic container; (b) loose lid; and (c) tray.

The concept of flexible packaging considers the suitability of the packaging for the transportation of the total variety of electronic systems. This can be achieved by combining a new and alternative design for the plastic container and loose lid, and, instead of resourcing to trays with specific cavities designs, a flexible intermediate layer that assures protection and safety from possible damages is applied. This paper focuses in the development of the plastic container and loose lid design concept and its structural evaluation based on simulation analysis.

The adequate definition of the specifications for any product is of major importance as they influence its quality and suitability. Design specifications and considerations englobe several fields, that constraint, at some level, the design freedom in order to obtain a good quality product that fulfils the application requirements (Lampman 2013; Cuffaro & Zaksenberg, 2013).

Several specifications were defined considering the analysis of the company packaging, and the new performance expected for the flexible packaging in development. The flexible packaging should be fabricated with a static dissipative material, in accordance to company Norms, for an adequate protection of the electronic systems. Also, it is vital the integration of an electronic identification solution that also allows tracking across company facilities, for improved logistics. Besides these requirements, the new packaging should improve design features for an enhanced performance, while maintaining some aspects of the company packaging.

Regarding ergonomics, the new design should assure an easy handling by means of appropriate handles, and a lid that allows an easy closing and opening of the packaging; adjustable and comfortable solutions for all the components of the packaging system with a balanced weight distribution (≤ 2 kg empty; ≤ 7 kg full, according to the quality requirements), while promoting safety and preventing human errors during the performance of typical tasks. The stacking of packaging systems is a common activity during storage and transportation operations. A proper stacking is essential to avoid possible shifting and damaging. Design features, as for instance structural ribs, can function as guiding and supporting ribs that facilitate the operator task, while creating a connection point between packaging systems.

In terms of dimensions, the base area of the packaging should be maintained (exterior: 600 x 400 mm and interior: 555 x 335 mm) in order to perfectly fit in the storage sections while benefiting the whole useful area. The height may vary between 80 mm - 220 mm.

The company packaging presents a series of structural ribs on the sidewalls for reinforcement, that generate particles concentration, becoming necessary to constantly clean the packaging at the end of each operating cycle. Besides adding an extra step to the operating cycle, the cleaning maintenance requires proper equipment. One of the proposed challenged involves the development of a proper design that avoids particles accumulation reducing, in this way, the cleaning frequency while also facilitating this step.

## Conceptual Design Development

Product development is multidisciplinary and englobes a set of stages from the market need, planning and development, to the product manufacturing (see Figure 2). The development of a product should consider the quality, development time and associated cost.

Initially, a market need appears for a new product solution. Based on the opportunity, a stage named *Planning* begins with the definition of the approach strategy and the project goal. The following stage is the *Development* in which a series of steps are performed for the concept design optimization. First, a requirement survey allows identifying important features to fulfill the defined specifications. A series of alternative product concepts are developed and filtered until only a few are selected for further development and testing. Prototypes of the detailed design that consider the complete specifications and tolerances are manufactured for testing and refinement. Once achieved a robust design, tooling is developed and the *Production* stage begins by manufacturing using the selected production technology and ramp-up (widespread distribution) (Ulrich & Eppinger, 2016; Cuffaro & Zaksenberg, 2013).

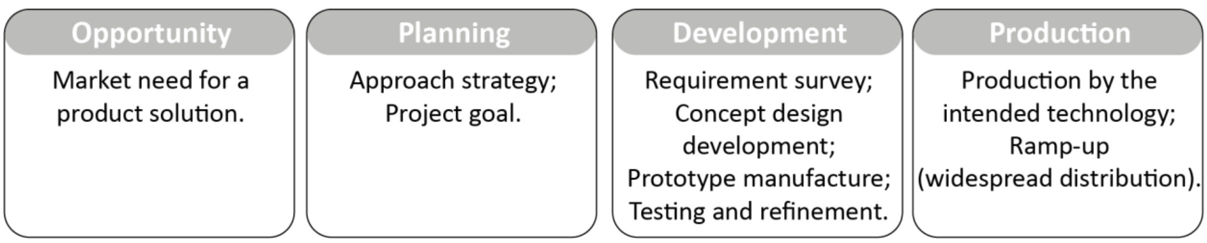



Figure 2: Product development process main stages and activities.

Effective design is important for any product being developed, but when concerning plastic materials, it is absolutely vital. The design is dependent on a series of factors including material, processing technology, working function and conditions, and ergonomic aspects, among others (Cuffaro &

Zaksenberg, 2013). Preliminary conceptual designs without relation to any processing technology were developed as presented in Figure 3. These concepts present a series of features that fulfil the requirements defined in the initial survey. For instance, the smoothness and simplicity of the surface is an important design particularity that can greatly reduce the accumulation of particles. Different approaches were considered for the handling section, an integrated handle and a grip surface to facilitate the handling. Regarding the loose lid, a unique reinforcing rib was designed with a reduced height, comparing to the actual loose lid, and corners with different curvature angles.

(a) (b) (c)

Figure 3: Preliminary conceptual designs: (a) plastic container with smooth surface and integrated handle; (b) plastic container with grip surface; and (c) loose lid concepts.

The preliminary conceptual designs were altered to consider the fabrication technology design guidelines. Injection moulding was the selected technology.

During the most critical stages of the manufacturing process, injection and cooling, several factors must be considered as they directly affect the quality of the product and the process repeatability. Injection moulding has a series of design guidelines although, it is not always possible to follow all the recommendations.

Main design considerations count with: uniform wall thickness to allow the mould cavity to fill more easily and to prevent warpage phenomena from uneven cooling; avoid features such as undercuts that require more complex moulds that are consequently more expensive; avoid sharp corners which increase stress concentration and may not fill properly; structural ribs that assist in alignment with other parts and to increase the bending stiffness of a part without adding thickness (Malloy, 2004; Cuffaro & Zaksenberg, 2013; Goodship, 2004; Rosato & Rosato, 2000; Shi *et al.*, 2003).

Future design considerations will include a draft angle (angle in the part that facilitates part removal from the mould) that can vary between 1 ° - 2 °.

Figure 4 depicts the developed concept designs for the plastic container and loose lid. The new design concept includes a series of structural ribs inside a double sidewall for improved mechanical performance, while maintaining a smooth outer surface for easy cleaning. The integrated handle was developed by avoiding undercut sections and by combining two different approaches that were previously tested, in real context of use, for an ergonomic evaluation in qualitative and quantitative terms for the user satisfaction (Sampaio *et al.*, 2017).

The loose lid presents a total area equal to the plastic container and a single structural rib, on both sides, for: mechanical reinforcement; packaging closing simplicity; and easy stacking. The slight curvature at the edge of the plastic container, in contact with the lid, creates a simple yet effective solution for an easy opening of the packaging system by lifting the loose lid. This feature avoids the need of a handle design over the loose lid.

(a) (b)

Figure 4: Developed conceptual designs: (a) plastic container; (b) loose lid.

## Simulation Analysis and Discussion

Structural simulations are performed in order to validate structural strength of the design concept when subjected to working loads in relatively short time, enabling its optimization prior to building and testing a prototype, thus significantly saving time and costs. Two types of simulation were performed by using ABAQUS™ solver, one representing a test required by standards, namely maximum filling weight and another representing free fall drop impact.

The baseline for the simulation consists in the actual packaging model (RAKO Container 3-201Z-0 EL and loose lid) with the base material PREMIX PRE-ELEC® PP 1380 which consists of a conductive thermoplastic compound based on polypropylene resin. The mechanical properties of the material are shown in Table 1.

Table 1: Material properties.

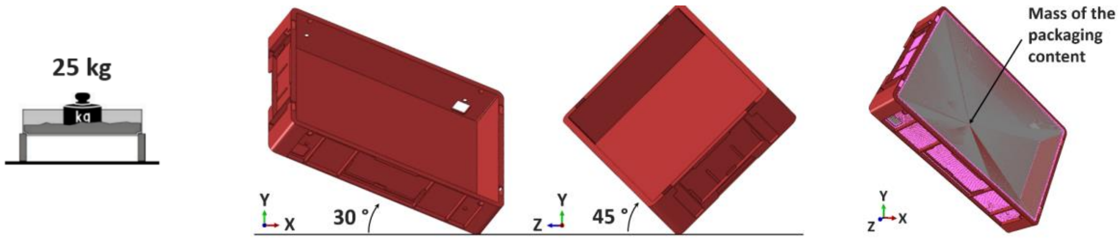
| Elastic Modulus (MPa) | Poisson Ratio | Density (kg/m$^3$) | Tensile strength (MPa) | Elongation at break (%) |
|---|---|---|---|---|
| 1900 | 0.3 | 1060 | 26 | 5 |

The material was modelled using an elastic-plastic formulation. A mesh of finite element model was defined being composed by linear tetrahedral elements C3D4 with an average size of 2 mm for the plastic container and 1.5 mm for the lid.

The maximum filling weight analysis aims to understand the behaviour of a packaging (plastic container and lid) when subjected to a mass of 25 kg of sand, which was represented by applying a correspondent value of pressure (0.00139MPa) on the bottom surface while being supported at its shorter edges (constraint in the nodes on the sides of the bottom surface), leaving approximately 1 cm margin on each side. The reported conditions were defined in accordance to the available data of the company packaging and the simulation was run using a general static procedure.

The free fall drop impact was defined to represent a situation in which, an operator handling the packaging, accidentally drops it. The stablished drop height considered was 1.0 m with a filling weight of 7 kg (maximum weight stablished by the company ergonomic normative). The mass of the packaging content was applied to the master node of the structural distributed coupling connecting all the nodes on the inside surface of the packaging. A smooth inclination angle was considered being 30 ° for the x-axis and 45 ° for z-axis. All the nodes of the packaging have all degrees of freedom and a general contact was defined between the packaging and the floor, which was modelled as a rigid body with all degrees of freedom fixed. The simulation was run considering the packaging close to

the floor surface for time saving. An initial velocity was calculated and applied to all the nodes of the packaging and the mass of its content corresponding to 4.43 m.s$^{-1}$.
Figure 5 depicts a schematic representation of the described simulations conditions.




(a) (b) (c)

Figure 5: Schematic representation for: (a) maximum filling weight; and (b) impact angle; and (c)mass of the packaging content applied to the master node of the structural distributed coupling.

Simulations were carried out to evaluate the structural performance of the baseline model considering the stablished criteria. The obtained results are reported in Figure 6.
For an understanding of the design performance, the Von Mises stress is considered to evaluate if a specific design can withstand a given load condition. This is evaluated by directly comparing this value with the tensile strength of the material. For instance, if the maximum value of Von Mises stress induced in the material is higher than the strength of the material, the design will fail.
Regarding the maximum filling weight analysis, the Von Mises stress value achieved is lower than the tensile strength of the material, and the maximum strain is within the elastic deformation range. For the free fall drop impact analysis, the maximum value of Von Mises stress reaches the tensile strength of the material at the corner of the packaging subjected to the impact, leading to stress accumulation that significantly exceeds the plastic strain causing some level of damaging. During the impact, torsion phenomena occurs, but with no significant proportions.

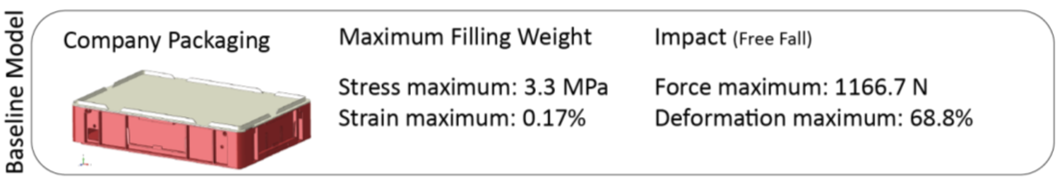



Figure 6: Structural simulation main results for the baseline model.

Simulations were carried out for the developed design concept to structurally analyse and compare with the baseline. An iterative design methodology involving a cyclic process of design development, initial testing and refining the concept design was selected.
The initial concept contains a series of radial and structural ribs on the bottom structure for both mechanical performance and to facilitate the polymer flow during the injection process.
Regarding the maximum filling weight analysis, a large displacement was obtained which made necessary to alter the bottom reinforcing structure. For the impact, the packaging endures high stress, especially in the corner that impacts with the rigid floor and neighbouring ribs. The plastic deformation exceeds the value of elongation at break in the outside wall of the container and neighbouring reinforcement ribs presenting some damaging.

The design concept optimization involved a combination of increasing the number of radial and structural ribs and their thickness, and also the total thickness of the plastic container bottom by 200 %. For the corners of the packaging, it was analysed the reinforcement with addition of one and two structural ribs. The changes for the bottom revealed a performance improvement for maximum filling weigh of 78 % and the use of one extra structural rib in the corner proved to be best for the impact performance. Comparing to the baseline, the developed concept presents a similar performance which indicates that it is suitable to replace the actual packaging.
Figure 7 shows the obtained results for the initial concept and the optimization analysis.

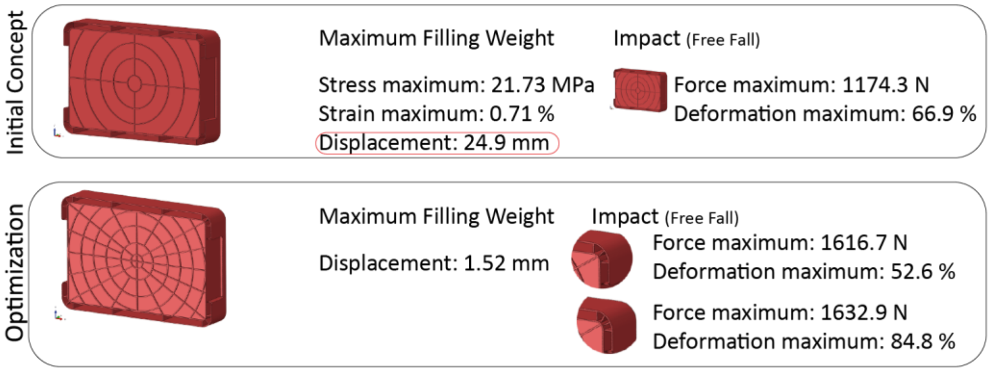



Figure 7: Structural simulations main results for the design concept optimization.

## Functional Prototype Fabrication

Considering the optimized design concept, functional prototypes were fabricated by means of FDM process with a Fortus 900mc equipment and ABS-ESD7 (Acrylonitrile Butadiene Styrene - Electrostatic Discharge) as building material, which is an ABS thermoplastic with static dissipative properties for applications where static charge can damage or impair the performance of a product. The prototype with a 1:1 scale of the original size is functional in terms of the static dissipative specification, and will be employed for dimensional and ergonomic evaluating tests in real context of use.
In the FDM process, a series of steps are required, since pre-processing; production; and post-processing. Initially, in the pre-processing, the 3D CAD file of the product to be fabricated is build-prepared by generating slices and positions while calculating the path to extrude the building material and also, if necessary, the support material. In the production step, the thermoplastic material is heated to a semi-liquid state and deposited in ultra-fine beads along the extrusion path. Once the material is hardened, a new layer is deposited until the build model is complete. In the fabrication of the plastic container and loose lid it was necessary to resource to support material that functions as scaffold for the fabrication of the product. The post-processing is the removal of support material which is usually by a heated bath in dissolvent and water. After the bath, a drying period is required.
Figure 8 shows the manufactured functional prototype and detail.


Figure 8: Functional prototype and details of the structural ribs on the impact corner.

## Conclusion

Company predictions, regarding its own economic growth, generated the need for a new packaging solution for the internal transportation of a wide variety of electronic systems. An initial market analysis for an adequate and viable existing solution, that meets the main requirements for the application purpose, showed the inexistence of such a product. Therefore, the development of a new packaging solution, that is suitable to every electronic system configuration while improving the logistics associated, became mandatory.

This paper reported a series of multidisciplinary steps for product development and prototyping manufacturing, for future testing and refinement, of a new concept for flexible packaging. Product concept design was developed with features and aesthetics aspects that meet the main requirements stablished. The design concept was refined based on results obtained with structural simulation analysis regarding maximum filling weight and impact situations, by comparing with the stablished baseline (actual packaging employed at the company). Thickness increment and more structural ribs in critical locations, for reinforcement, were the main changes required to assure a proper performance.

An optimized packaging, for the internal transport of electronic systems across company facilities, was developed and fabricated by means of additive manufacturing, with an innovative design and adequate performance for the replacement of an existent product.

## Acknowledgements

This work has been supported by the Portugal Incentive System for Research and Technological Development. Project in co-promotion nº 002814/2015 (iFACTORY 2015-2018).

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