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Data-driven value assessment of packaging solutions

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Abstract: Research in Product Service Systems design increasingly focuses on how to develop ‘capabilities’ for assessing the value of solutions already in a design project fuzzy front end. A data-driven approach shall then guide engineers in the process of identifying what to develop, and not merely to verify if a solution meets (or not) performance requirements. This process of frontloading problem identification and solution generation activities with models is of high interest to raise quality and lower risk and cost for the development work. The objective of the paper is to explore the use of a data-driven approach to enable value prediction of packaging material configurations in early design. Its main objective is to present a methodological approach and a framework to connect high-level aspects of customer value with simulations and analysis conducted on the mechanical properties of packaging material.

Keywords: data-driven decision making, value-driven design, model-based engineering, product service systems, simulation, performance evaluation.

1. INTRODUCTION

The ability to fulfill increasingly sophisticated customer needs is a major theme in Product Service Systems (PSS) design research (Baines et al. 2009, Mont 2002). The goal of providing added value to customer and stakeholders makes companies to reconsider traditional one-sale models and to move towards total solutions that combine hardware, software, and services (Haase et al. 2017).

The packaging solutions industry is not immune to this servitization trend (Gassmann et al. 2014). Companies have been observed to apply principles of circular economy in their internal activities and relationships with suppliers (Urbinati et al. 2017), with the aim of improving the recyclability of products, so to include a higher percentage recycled materials in new packaging.

Also, today’s unprecedented opportunity to generate, collect and record data about product usage performances and human-product interactions opens up opportunities for new services. One example in the packaging business is the introduction of RFID technology for electronic tagging, which could help customers, for instance, in the tracking of stocks and checking their status.

In this servitization transition, the development of hardware, software and service components needs to be coordinated within the enterprise since an early phase (Isaksson et al. 2009). Yet, companies struggle with managing the servitization transition from the perspective of how ‘hardware’ is design. In most cases, this activity is still seen as a process of finding solutions to requirements, which means that the evaluation of hardware concepts is often based on a performance vs. cost equation. However, this approach does not align well with the development total solutions and

functional results, which is rather based on the maximization of customer and stakeholder value (e.g., Baines et al. 2009; Cavalieri and Pezzotta 2012).

2. MOTIVATION AND OBJECTIVES

A major gap in PSS design research is how to build a chain of models (from material properties to value) that, since an early design stage, can support decision-makers in predicting the future impact of a packaging design regarding a multitude of lifecycle related aspects.

Models are usually distributed across the organization and heavy simulations are not connected to business case analysis (Panarotto et al. 2017b). The question is then how to connect models together to create an executable view (and not only a visualization view) that displays managerial and technical issues in a way to increase awareness of decision makers on the impact of different hardware configurations on value (both tangible and intangible). The main research question can be described as:

How can data-driven approaches support decision makers in populating value models for products and services, increasing awareness on unspoken needs, estimated performances, and impact of the contextual condition on product operations?

The objective of the paper is to present a methodological approach and a framework to connect high-level aspects of customer value with simulations and analysis conducted on the mechanical properties of the packaging material. These findings aim at contributing to the high-level goal of exploring the use of data-driven approaches to generate (by simulation) the necessary information for early stage PSS design decisions to be taken based on how much consumers value certain capabilities against each other.

3. RESEARCH METHODOLOGY

The study is conducted in collaboration with a global food processing and packaging solutions company based in Sweden. The company offers packaging, filling machines and processing for dairy, beverages, cheese, ice-cream and prepared food, including distribution tools.

The overall research effort can be framed into the Design Research Methodology (DRM) (Blessing and Chakrabarti 2009). DRM consists of four stages: Research Clarification (RC), Descriptive Study I (DS-I), Prescriptive Study (PS) and Descriptive Study II (DS-II). The research presented in this paper covers a review-based RC, a comprehensive DS-I and an initial PS.

Within DRM, the authors adopted a single case study approach (Yin 2013). Following the guidelines for qualitative research proposed by Miles et al. (2013), the research question was iteratively developed from the conceptual framework and guided the sampling plan for the interviews as well as the development of the coding scheme for the analysis of the transcripts. Data collection activities featured mainly semi-structured interviews. Regular multi-day physical co-creation workshops and analysis of internal company documentation served as triangulation method.

Respondents were located mainly using a snowballing technique (Warren 2002). Once the initial respondent (fulfilling the theoretical criteria) was identified, he/she helped to locate others through his/her social network. In the selection, both the 'meatiest' cases and the 'peripheries' were considered (Miles et al. 2013). This means that the sample covers a variety of roles, both at managerial and engineering level. In total, 8 interviews were conducted between May and November 2017.

In the initial phase, the interviewing activity can be described as exploratory and largely descriptive. As suggested by Warren (2002), from the initial research question the interviewers developed a set of 10-12 more specific inquiries: those guiding the conversation, those clarifying answers or requesting further examples, and those pursuing the implications of answers to the main question.

The authors compiled visual representations and demonstrators of the emerging modeling concepts, which were verified with company stakeholders to identify critical topics for modeling. Reflective learning was aided by the participation in regular debriefing activities, in form of both co-located and virtual meetings. Findings were also iteratively discussed and validated with a broader set of industrial practitioners in co-located research workshops.

4. CASE STUDY

The development of a new packaging solution is a costly and time-consuming process, which takes on average 2 months from the earliest idea generation stages to the physical tests for a new packaging configuration. In the book *The packaging value chain*, Sand (2010) shows how the consumer perception of packaging solutions can eventually be traced back to early stage decisions concerning raw materials and paperboard configuration (e.g., Figure 1). Fine-tuning the

latter has a great impact at the system level (i.e., on the behavior of consumers), hence affecting the entire value chain.

Looking at the packaging industry, data-driven simulations is well-established and supports the engineering team in the process of predicting the realistic behavior of the material structure (e.g., Islam et al. 2016). However, existing approaches are not yet at the level to leverage aspects related to consumer value in the early stage decision-making process. The reason is not only to be found in the lack of data to populate models for 'value' in the fuzzy front end of the design process. As shown by Isaksson et al. (2015), the issue has a more general characterization: computational models and tools for value analysis are less developed than cost- and performance-related domain. In a nutshell, 'value assessment' is not yet made available as a model-driven discipline.

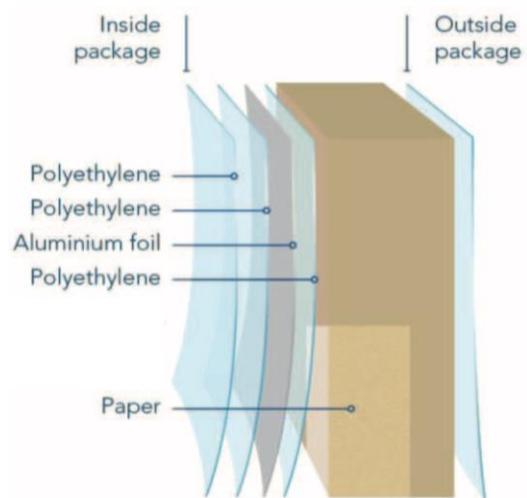


Figure 1. Example of packaging material structure (Andreasson 2015).

The case study deals with the development of a conceptual framework to predict the value of alternative packaging configurations using data-driven simulation, to support early stages concept development. The approach is intended to be used to predict the behavior of the paperboard in the creasing and lamination process and to connect its main value proposition for the company and its customers.

The driving question in the case study can, therefore, be expressed as the following:

What is the best packaging material structure (e.g. aluminum foil, paperboard or polymers) and creasing/lamination technology that gives the improved value for customers at minimum production cost?

5. DATA-DRIVEN VALUE ASSESSMENT IN PSS DESIGN

Bertoni et al. (2016a) have observed how research in Product Service Systems is increasingly focusing on how to develop 'capabilities' for assessing the value of PSS solutions already in a preliminary development phase. The term 'capabilities' refer to the development of skills and knowledge regarding either quantitative simulation techniques (Medini et al. 2015;

Panarotto et al. 2017a) or qualitative models able to provide indication of the multifaceted aspects that plays a role in the final realization of the PSS offers (Bertoni et al. 2017).

A reason for this emphasis on value models lies in the opportunity to exploit them not only as a means for verification but also to actively support the PSS development process (Isaksson et al. 2009). This means that value modeling activities shall guide engineers in the process of identifying ‘what’ to develop, and not merely to verify if a solution complies with (or fails to meet) performance requirements. Emphasis on data-driven development is further sustained by the realization that technology today makes it possible to continuously log data along the entire product/system lifecycle, and to apply data mining algorithms to discover patterns and make predictions (Isaksson et al. 2015).

Methods and tools for PSS value assessment have further been observed to bifurcate into the service and product domain, without the necessary integration (Panarotto et al. 2017b). Some are designed to enable engineers to understand the effect that the provided service would have on customer value (Shimomura and Sakao 2007; Hara et al. 2009). Others focus more on the configuration of the engineering characteristics of a product that creates the highest value during its lifecycle (e.g. Gorissen et al. 2014, Bertoni et al. 2016b), hence stressing the role of the hardware for the provision of functional results.

6. DEVELOPMENT OF THE DATA-DRIVEN VALUE ASSESSMENT ENVIRONMENT

The work in the case study has initially focused on connecting customer value aspects to material properties and board configurations. The preliminary findings from the descriptive study showed that the value creation process includes three main transitions:

- customer experience and value creation is highly influenced by both mechanical and barriers properties of the package ‘system’;
- these, in turn, are determined by the outcome of creasing and lamination activities conducted on the packaging material;
- such activities are influenced, by the atomic properties of the paperboard and by the lamination process.

From these initial results, the authors developed a conceptual framework that links models across the 4 different value creation levels. This means creating a connection between higher-level issue for customer value to lower level concerns about paperboard, polymer and other properties.

The following sub-sections describe the development of the modeling approach at each layer and illustrate a (simplified) map of how statistical and virtual engineering models are connected through the chain up to customer level.

Figure 2 shows a simplified version of the results from the model mapping exercise. The arrows represent major correlations between models as found during the empirical

study, meaning that the output from one model is taken as an input in the following model.

Each model in the framework is treated as a black-box. The concept of black boxes imply that an object is viewed only in terms of its inputs, outputs and transfer characteristics without any knowledge of its internal workings, that is, its implementation is “opaque”. This means that only the inputs of the model the results of the computations are exposed, while its underlying mechanism or logic remains hidden.

6.1 Detailing the customer value drivers

The initial step in the development of the conceptual framework concerned the definition of high-level drivers for customer value. This activity was conducted by means of a literature review and empirical data gathering activities.

The review highlighted the multi-faceted role that packaging has when it comes to customer perceived value (Coles et al. 2003). Rundh, B. (2009), for instance, identifies food safety, shelf life, and printing as major value-adding criteria for consumers. A recent article by Wyrwa and Barska (2017) shows that packaging is not only understood by consumers as a means of protecting a product in the process of distribution, transport or storage but carries more values, mainly with regards to its ability to communicate with the environment.

The empirical investigation that followed, by means of face-to-face semi-structured interviews with packaging experts from the collaboration company (both with engineering and managerial roles) enabled the researchers to shortlist main ‘value drivers’ for packaging solutions: food quality, forming appearance, printing and shelf life.

Even if the proposed value drivers feature different degrees of priorities for the customers (i.e., some are more important than others) and are not linearly independent (e.g., packages with an extended shelf life have a positive direct impact on food quality), they were considered the most representative by the industrial experts to assess the value of packaging solutions during early design. These drivers were further connected to relevant parameters at Package System level and further cascaded down to Packaging Material level.

6.2 Detailing the Package System level

Simulation models at Customer level are built and populated from the results of the experimental tests on the physical board. Data from the real-life investigations are fed into the virtual environment, and models are iteratively refined by comparing simulation results with experimental ones.

The descriptive study brought to the further identification and definition of main modeling areas and parameters that refer to the Package ‘system’ and that have an influence on consumer experience and value. These are: sharpness of creases, board weakness, barrier properties, board integrity.

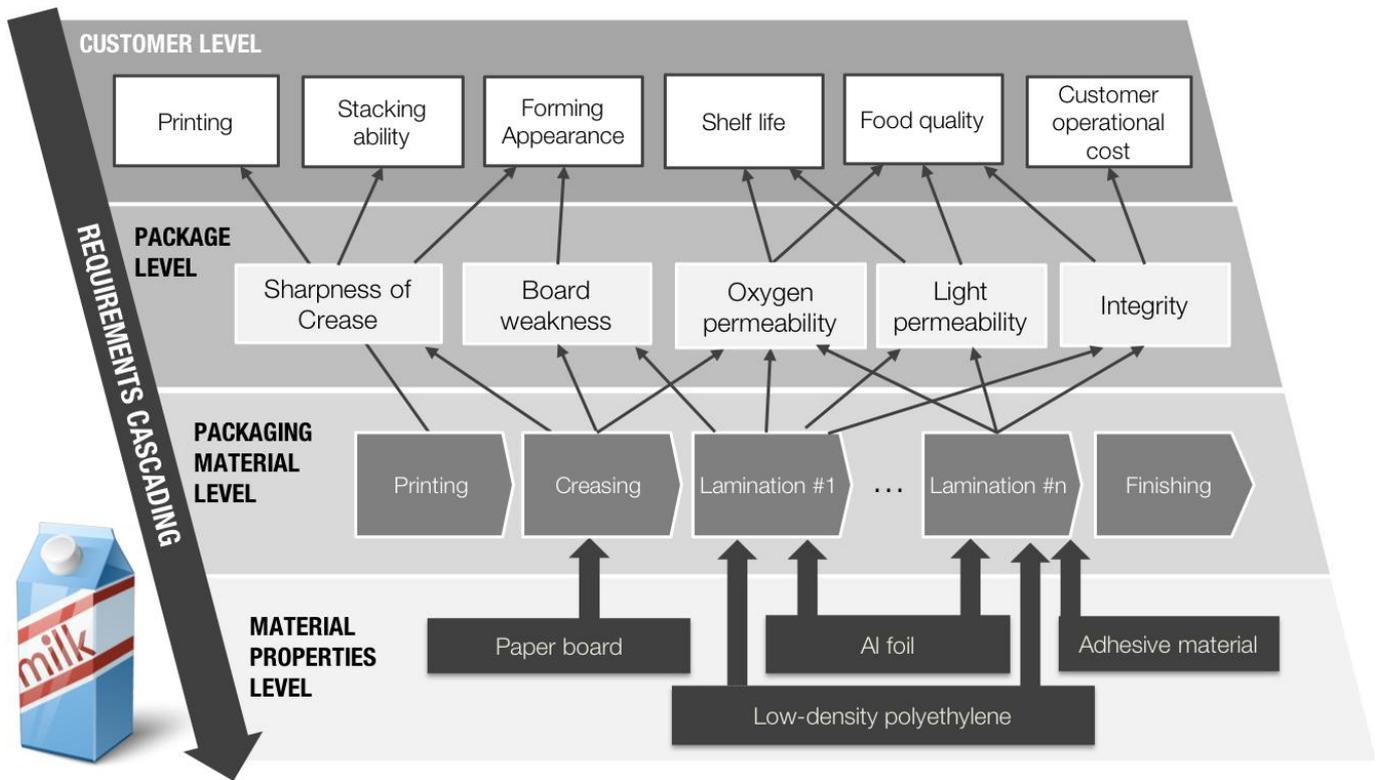


Fig. 2: Mapping of main modeling areas across levels

One example of how models are connected across levels is the modeling domain of ‘board weakness’, which has an impact on ‘forming appearance’ at the customer level. Another example to illustrate how models are connected across levels is related to the issue of assessing ‘shelf life’. In shelf life modeling, chemical reactions, biological degradation, and mechanical properties are all inputs needed to obtain reliable predictions for food degradation. In practical terms, this means that shelf life modeling requires a list on input parameters to be executed, such as the concentration of oxygen or vitamin C (for juice), use of nitrogen in the filling process, as well other characteristics related to the machine.

At Package System level, shelf life is linked with ‘barrier Properties’ of the package, which is also linked to food quality. These depend mainly on Oxygen Permeability (OP) and Light Permeability Rate (LP, representing the intensity of light at different wavelengths). In order to model how shelf life can be extended due to a new packaging configuration, OP values for the flat laminated board, for the board corners and for the creasing lines are needed for the simulation. These values are further obtained by linking the model at the Package System layer to those at Packaging Material layer.

6.3. Detailing the Packaging Material level

The Packaging Material level contains those models that describe the outcome of manufacturing operations (which include printing, creasing, lamination and finishing) on the laminated multi-layered board. Looking, for instance, at ‘forming appearance’, value creation can be cascaded down to the outcome of the application of alternative creasing technologies and to the subsequent folding operations. The

descriptive study showed how alternative configurations of the folding process (which is, inside-inside fold, inside-outside fold, and outside-inside fold.) may have different effects on the board weakness at the micro level (microstructure and fiber orientation), which translates into different barrier properties of the board at the macro level. Eventually, decisions concerning folding operations were found not only to be related to barrier properties issues and food quality, but also to have an influence on package ‘appearance properties’.

Creasing processes may be divided into 2 main families, two-dimensional (2D) (between two panels) and three-dimensional (3D) (three crease lines combined at the corner) creases, which facilitate the 2D and 3D folds. The empirical investigation showed that, once the creasing operation is performed, the properties of the laminated structure changes, affecting board weakness and possibly causing cracks in aluminum-foil. The latter causes issues with ‘board integrity’ at the Package level, eventually affecting the ‘food quality’ and ‘shelf life’ dimensions. Interestingly, while weakness in the board is associated with deterioration of food quality and shelf life, it is a desirable feature to achieve good folding quality.

6.4 Detailing the Material properties level

The Material properties level is the primary input to all the models. Each model at this level deals with the individual mechanical characteristics of the different layers of the board (aluminum foil, paperboard, polymer and adhesive material), including microscopic and macroscopic phenomena.

The intrinsic properties of materials play a significant contribution in terms of performances, and the effect of decisions at this level (e.g., different configurations) climbs up along the entire chain of models, ultimately affecting all customer value criteria. For instance, aluminum foil properties influence the propagation of weaknesses in aluminum foil, which in turn allows the diffusion of oxygen in the package. The dimension of damage in Al-foil (microcracks and pinholes) at the micro level is measured to model the OP. Specific inputs for modeling activities at this level (i.e. young modulus and yield strength for aluminum foil and polymer) are gathered from suppliers and physical tests.

Importantly, in the proposed framework statistical model and physical models are intended to feed on each other when new data (from virtual simulation or empirical testing) are obtained, to increase fidelity and quality of the simulation over time. An example of how results from a paperboard simulation model are correlated with experimental results is presented by Nygård et al. (2009), who performed finite element analysis of creasing and compared the outcome with those from physical tests. This process of creating virtual twins allows reducing the time to execute what-if assessment loops with focus on customer experience and value creation. By moving physical testing into a virtual environment, it becomes possible to evaluate and prove ideas more easily and in a shorter time

7. DISCUSSION

Verification activities with the partner company show that the model map is an effective instrument for cross-disciplinary teams participants to communicate why their work is 'good', and to build arguments on how different hardware configurations may affect consumer perception and behavior. Also, it provides a visual and understandable picture of how different disciplines (from engineering to management) contributes to the creation of value for new products and services. The model map is acknowledged to cover a gap when it comes to stimulating value discussions across functions and organizational roles, as well as to maintain focus on the underlying business case, so that individuals can build arguments for selling their innovative ideas, both externally and internally. It is beneficial not only to explain what the models are doing in the system and how they are interacting with each other. It also serves the purpose of answering questions at the production level, e.g., what changes are necessary to gain the competitive advantages, as well as to explore supplier-related issues (e.g., to understand which combination of suppliers is likely to render superior performances in terms of package quality). Interestingly, practitioners pointed out the use of the proposed model map as a way to educate customers about value generation, supporting co-development activities for hardware, software and services.

Another issue is related to the reliability of the models. It shall be noticed that, while some models are fully developed and have achieved a good level of accuracy and reliability, other models in the chain do not feature the same degree of maturity and are still in a building phase. One example is the

lamination model at Packaging material level, which is not yet fully developed because of the complexity of adhesive bonding, which makes computation time to be significant. Practitioners acknowledge that it is often difficult to trust the model results, in particular when Go-No Go decisions must be taken for a given case study. One mechanism to communicate 'trustworthiness' is to measure by how much the results of a virtual model deviates (in percentage) from the available physical model (i.e., from the results of physical testing). However, such an approach does apply only to models at the bottom layer of Figure 2 and is not feasible when moving towards customer value.

A possible way forward is that of conceptualizing a design support for improving confidence and validity in models, by communicating uncertainties from modeling and simulation to the relevant stakeholder. A feasible approach in this respect is the Knowledge Maturity scale proposed by Johansson et al. (2017). This does not only aim at measuring if and how much the cross-functional team members trust the models, but also provides a mechanism to signal which area in the model needs to be improved to render a more trustable result

8. CONCLUSIONS

Successful consideration of Product Service Systems aspects in design requires the ability to make thoughtful trade-offs between technical aspects (costs, performances), business dimensions and consumer experience. This paper elaborates on this challenge of introducing 'value' as a metrics to guide design decisions when the focus is a shift from designing hardware (i.e., packaging) to total solutions, incorporating software and service dimensions.

Future work will focus on creating an executable map of models (with reliability/maturity assessment) were to demonstrate the capabilities to simulate the value (e.g. shelf life, food quality) for different configurations of the packaging material and its production process. An interesting track for future developments is related to the use of data mining techniques to support decision makers in discovering patterns and making predictions. Developing capabilities to organize such patterns would greatly enhancing the reliability and fidelity of value models at all levels. Nowadays, the challenge is not only to make the virtual model more realistic but also to reduce computation time: value assessment means that more simulations need to be run, some taking days or even weeks to produce the result. The use of response surface methodology or surrogate modeling is therefore highly interesting for future research to enable the effective implementation of the proposed framework.

The presented model map shall be considered a step forward towards a larger research effort, whose purpose is to capture and represent 'value' aspects in models within the engineering design process. The authors will tackle the research question by means of 'few-focused case studies' to overcome the limitations of single-case study approach. Enlarging the number of cases will allow to further build a theory on the topic of data-driven PSS design, identifying key variables, describing their linkages and why relationships exist.

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