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Development of a guideline for the engineering of a coherent, optimized packaging system based on the holistic systemic analysis

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Short abstract

During its life cycle a product experiences transformations in shape, consistency, place, and composition. The stresses which impact the product are various. The packaging as the interface of a product to its surroundings protects the product and covers the expectation of diverse stakeholders in the product supply chain, such as high protection, robustness, light weight, zero waste, low costs, attractiveness to customers and scalability. Science and Industry try to cope with these requirements' complexity by developing specific packaging manuals accordingly. However, quickly changing social and governmental conditions limit the applicability of such straightforward guidelines. A balanced scorecard model attempts to support packaging design considering a variety of influencing factors. The isolated measure of every factor however fails to consider the interconnections and dynamics in this complex field and thus remains one sided. A recent European Union bill towards Packaging and Packaging Waste Regulation (PPWR) aims for the reduction of packaging waste for example by minimizing the packaging size. It has triggered heated debates on feasibility and logic of the requirements. Packaging companies' associations as well as producers are concerned of being unable to meet a packaging's functionalities such as product protection with the proposed threshold. The question arose whether there can be a proper methodology on developing "efficient packaging" which ensures packaging to meet its purpose with minimal environmental impact. This paper describes a new approach to the analysis of packaging design which considers the complex environment and requirements towards packaging. It utilizes the "Malik Sensitivity Modell®Prof.Vester"– a methodology for the holistic consideration of complex systems. This first approach confirms the necessity of a holistic system theoretic analysis of the packaging design requirements.

Keywords: holistic analysis of packaging systems, sensitivity model, systems thinking

1. Introduction and background

Packaging systems are complex systems. This statement is founded in the variety of different packaging elements interdependent on each other (Schoeneberg, 2014). A complex system is characterized by variety, connectivity, and dynamics (Klabunde, 2003). The stakeholders of packaging make various, partially conflicting demands for the packaging which creates a field of tension. Packaging solutions fulfill some requirements better than others. There is however no instrument measuring the overall performance of a packaging system under consideration of all relevant variables which represent the complex packaging system and its environment. According to Bleisch, Majschak and Weiß (2011) and the German standard DIN 55405:2014-12 (Deutsche Institut für Normung, 2014) a multilayered packaging system consists of primary packaging which encases the product followed by several subsequent packaging layers. Those layers mutually influence the entire packaging system (Pfohl, 2018). The requirements of the different stakeholders are represented by a number of functions which a packaging system needs to fulfill, namely the product function, marketing function, usage function, handling function, protection function, storage function, transportation function, manipulation function and information function (Pfohl, 2018). The specifics of the product which needs to be packaged influence the packaging system strongly as well (Pfohl, 2018). Packaged goods' sensitivity towards stresses in the supply chain can be very different. The sensitivity of the packaged goods in combination with their shape and weight can lead to very specific packaging requirements. Packaging solutions differ with respect to the applied packaging materials. But not only the protective features, the production processes, the handling function, and the packaging costs are also influenced by the packaging material (Verghese, Lewis and Fitzpatrick, 2012). Companies are interested in applying economically efficient packaging systems, which means fulfilling maximal functional requirements using minimal material and personnel resources (Bleisch, Majschak and Weiß, 2011). The environmental impact of packaging is mainly driven by the packaging material, but it cannot be considered in isolation. The amount of packaging waste generated by different layers at different points in the supply chain (Pålsson, 2018) may or may not be increased by the selection of the wrong packaging material, the causes for the rising amount of packaging waste are various.

The Commission's proposal for a Packaging and Packaging Waste Regulation (PPWR), amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/64/EC, was published on 2022/11/30, is the inducement of the present analysis. The PPWR proposal stipulates that all packaging placed on the European market must be reusable or recyclable by 2030 and proposes specific measurement criteria (Karamfilova, 2022). The industry apprehends possible disproportionate effort for complying with the new regulation while insufficient overall environmental protection is achieved as a result. Consequently, a comprehensive holistic analysis was initiated.

Currently several regulations for the design and analysis of optimized packaging systems exist. The aim for the optimization varies, however. The EU Commission's PPWR contains requirements for packaging reuse, recyclability, recycled plastic content as well as packaging minimization and a maximum threshold of the proportion of empty volume between packing goods and packaging (Proposal /EC, 2022). Next to addressing barriers to circularity, the aim is to reduce the amount of packaging waste. Companies on the other hand require robust packaging which can protect the packaged goods and being handled along the supply chain until reaching the final customer. Amazon for example has implemented the so-called Frustration-Free Packaging Program and requires special ISTA test certificates. OEMs and suppliers in the automotive industry implement packaging manuals with specific requirements not only for their own packaging but also for the packaging of their suppliers with regard to part protection and handling optimization (Schaeffler Technologies AG & Co. KG, 2020). Logistics service providers, especially, focus on packaging requirements aiming for rapid and effective handling (Wackler Spedition & Logistik, 2022). Those examples underlay the problem at hand – despite the requirements' variety, the involved party implements specific packaging guidelines with partial view on the packaging design only. The Packaging Scorecard method from Olsmats and Dominic (2003) aims for the first time at a systematic evaluation of the measurement of packaging performance. The method takes under consideration all involved in the supply chain and their specific expectations toward the packaging (Olsmats and Dominic, 2003). This method aims a complex consideration of the problem at hand which plays out only partially. Although the analysis respects the *variety* of the problem, the subsequent analysis views the specific requirements only isolated with no regard to the *interdependence* among them and ignoring the *dynamic* changes within the packaging system as well as between the system and its surroundings.

The present paper will therefore for the first time apply a sensitivity model for the analysis of the overall packaging system performance – a method which considers the characteristics of *variety*, *connectivity*, and *dynamics* of complex systems.

2. Materials and methods

The sensitivity model is a system theoretical methodology which takes into consideration the specifics of complex systems: they consist of various elements which are dynamically interconnected and represent a causal loop structure. The intervention in a complex system implies the understanding of its holistic behavior (Vester, 1999). The system theory and the methodology of the so called “systems thinking” postulated by Vester, Senge and other scientists emphasizes the danger of simplifying complex problems and inducing actions based on isolated and one-sided views of the system (Senge, 2017; Vester, 1999). The aim of system thinking is to capture the key components of a system (the so-called system variables) and their interactions and to develop an abstract model representing the system (Vester, 1999). This way, the system can be simulated, and its behavior can be examined.

The Sensitivity Model Prof. Vester® (since 2006 Malik Sensitivity Model®Prof.Vester) supports the systematic extraction and validation of the systems variables as well as the systems modeling and subsequent simulation of the systems response to different actions (Vester, 1999). The sensitivity modeling is executed in three main steps. Initially, the impact variables need to be extracted which represent the highest relevance to the system. In the second step the interaction between the variables as well as their characteristics are analyzed which implies the analysis of the system behavior. Ultimately, a cybernetic approach based on simulation of different impact scenarios is conducted which enhances the system understanding and helps in deriving appropriate controlling strategies (Vester, 1999).

3. Results and discussion

Relevant systems variables were collected. A first summary initially based on results of preliminary investigation of the industry partner with regard to influencing factors towards efficient packaging was enriched in several workshops with the involved experts. The resulting variables were then further examined regarding their interdependencies using a Cross-Impact-Matrix (Table 1). In order to underline the different influences from one variable towards the other, the relations were additionally subdivided depending on the strength of the impact (from 0 to 3) and the direction of the impact (proportional “+” and inversely proportional “−“). When one variable impacts one other variable and the connection is positive (or proportional), this would mean that the increase of the impact variable will trigger an increase of the affected variable. If the connection between the variables is negative (inverse proportional), then the increase of the impact variable will trigger a decrease of the second variable. The numbers 0 to 3 mark how strong the positive or negative impact might be in the complex system.

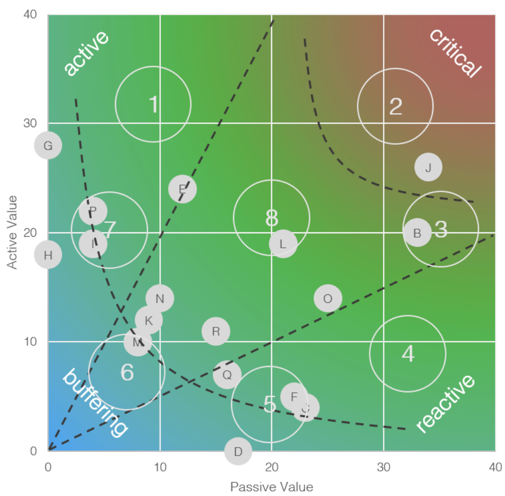
Table 1: Cross-Impact-Matrix developed together with the industry partner

Effect of ↓ on →		B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	**AV sum**	**P Product**
Material selection	B		+/-3	+/-3	0	0	0	0	0	+/-3	0	+/-3	0	0	+/-3	0	2	+/-3	20	660
Demand of resources	C	+/-2		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	92
Emissions	D	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Packaging applicable for re-use	E	-3	-2	+/-1		-3	0	0	0	-3	0	2	2	3	-2	0	2	+/-1	24	288
Amount of packaging waste	F	0	0	2	0		0	0	0	0	0	0	0	0	0	0	0	-3	5	110
Product dimensions	G	-3	3	3	-2	-3		0	2	-3	0	3	1	0	-2	-2	1	0	28	0
Product shape	H	-2	0	0	0	3	0		2	-3	0	3	0	-2	-3	0	0	0	18	0
Fragility of the packaged product	I	-3	3	0	1	3	0	0		-3	0	2	1	0	-3	0	0	0	19	76
Structural packaging design	J	-3	-3	0	-2	-3	0	0	0		-3	-2	1	-3	3	0	0	3	26	884
Complaint rate	K	-1	3	0	0	0	0	0	0	-3		0	0	0	0	0	2	-3	12	108
Packaging dimensions	L	-2	3	0	-1	3	0	0	0	-3	0		1	0	-2	-2	-2	0	19	399
Information and communication	M	-1	0	0	0	1	0	0	0	-1	0	3		0	+/-2	0	0	+/-2	10	80
Standardization and modularization	N	-2	1	0	1	0	0	0	0	-2	-2	1	0		3	0	-2	0	14	140
Manufacturing process	O	-3	-2	-3	0	-1	0	0	0	+/-3	0	0	0	0		0	-2	0	14	350
Mode of transportation	P	-3	0	3	-3	1	0	0	0	-3	2	2	0	-2	0		3	0	22	88
Number of handling stages	Q	-3	0	0	0	1	0	0	0	-1	0	0	2	0	0	0		0	7	112
User experience	R	-2	0	0	+/-2	0	0	0	0	-3	2	0	0	0	-2	0	0		11	165
PV sum		33	23	17	12	22	0	0	4	34	9	21	8	10	25	4	16	15		
Q Quotient		0.61	0.17	0.00	2.00	0.23	-	-	4.75	0.76	1.33	0.90	1.25	1.40	0.56	5.50	0.44	0.73		

The in-depth investigation of the Cross-Impact-Matrix shows besides interferences between the variables, the main character of the relevant variables within the complex system – some variables impact many other variables directly or indirectly and thus their behavior influences the whole system strongly (active variables), and other variables are impacted by many others in the system while providing limited or no impact themselves (passive variables). In the present system for example there is the variable of “Product dimension” – an active variable which impacts almost every other relevant variable. Through the further influence of the impacted variables “Product dimension” shows not only direct but also indirect (belated or long range) influence on the whole system. A further variable “Amount of packaging waste” occurs passively as it does not have any impact on the rest of the variables besides on “Emissions” and “User experience”. Such variables react sensibly to the behavior of the system and cannot be controlled easily and quickly simply by inducing one action because they are impacted by more than one impact variable. One action (e.g. reduction of “Packaging dimensions”) might lead to a short reaction in the desirable direction (reduction of “Packaging waste”), through belated and long range effects in the system (reduction of “Material selection”, increase of “Number of handling stages”, decrease of “Mode of transportation” etc.), the desired holistic result will not last long and thus the one-sides action will not be sustainable.

In extreme cases variables can have an impact on the system that is so strong that they can be indicated as “critical”, and on the other hand, other variables can be impacted by multiple other variables by giving no further impact back to the system. Such variables indicate a “buffer” attitude. An overview in Figure 1 shows the intensity of the involvement of the relevant influencing variables in the system behavior. Variables with a strong impact on the system are located in the “active” area of the portfolio, they execute a strong and direct impact on the whole system. Those variables can be used as control variables for the regulation of the system development in one desired direction. These variables are the levers for the system control and in the specific system we can define the variables “Product dimensions”, “Product shape”, “Packaging applicable for re-use”, “Standardization and modularization” or “Mode of transportation” as such levers.

On the opposite side of the portfolio, we can locate the reactive variables, e.g. “Manufacturing process”, which cannot be reached easily by direct actions but which act on many variables themselves. They boost certain impacts into the system. For strategic decisions these variables are important as their reaction into the system might enhance or reduce the desired result.



Material selection	B
Demand of resources	C
Emissions	D
Packaging applicable for re-use	E
Amount of packaging waste	F
Product dimensions	G
Product shape	H
Fragility of the packaged product	I
Structural packaging design	J
Complaint rate	K
Packaging dimensions	L
Information and communication	M
Standardization and modularization	N
Manufacturing process	O
Mode of transportation	P
Number of handling stages	Q
User experience	R

Figure 1: The roles of the variables in the system

The complexity in the interactions between the relevant system variables can be illustrated best using a causal loop diagram (Figure 2). It visualizes the holistic network representing a packaging system and its interconnections to the outer world. This model takes account of the variety and the connectivity of complex systems and represents the holistic field of tension of the packaging and its environment.

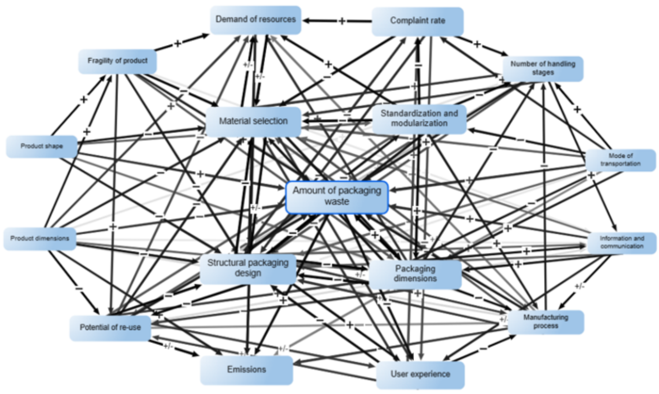


Figure 2: Causal Loop Diagram of a packaging system

The initial evaluation targeted the optimization of the packaging system for the product portfolio of the industry partner. The results of this first investigation show a holistic causal loop diagram, considering the connectivity and dynamics based on complex packaging systems of the company example. This approach expands the one-sided analysis of the Packaging Scorecard Model which considers the variety only. However, a further collection, in depth analysis, and validation of the influencing systems variables in line with the guideline of Malik Sensitivity Modell®Prof.Vester needs to be completed. To prove the holistic approach and exclude possible subjectivity in the variables, further investigation in industry and science is necessary. The revision of the system variables will lead to a new model which will be simulated and analyzed. Subsystems and submodels will help to dive into specific questions without ignoring the environmental impact of the overall system.

With regard to the Commission's proposal for a Packaging and Packaging Waste Regulation, the initial analysis has shown that the planned requirements cannot be put into effect without major side-effects on the product quality, logistics system efficiency, packaging material usage as well as the surrounding packaging system, meaning the underlayer and the next layer of the specific packaging. The variety of products, packaging materials and designs as well as dynamic changes in the logistics processes and customer needs make the measurement of the overall packaging performance through one key performance indicator impossible. A limitation such as this of the system's complexity to one metric might only provoke one-sided actions of the industry such as the usage of more material, of material with more robust characteristics, less recyclable packaging, heavier packaging, longer process times or even higher rates on damaged products. Without a systems analysis, there can be no guarantee that space reduction in the packaging will decrease or even increase packaging waste, and even if this goal is met there is no guarantee that it is not met at the expense of higher CO_2 emissions, pollution through damaged goods, and packaging materials requiring higher energy for production and recycling.

4. Conclusions

Packaging systems are complex and thus only a holistic analysis with a systems-theoretical approach is appropriate to make recommendations for the development of optimized packaging systems. Isolated considerations of individual influencing factors on the field of tension of the packaging, such as from a legal or from a company perspective, neglect the complexity of systems and are therefore not effective. Even the packaging scorecard does not meet all the complexity criteria required to view the packaging system holistically. A systems-theoretical approach such as the Malik Sensitivity Model®Prof.Vester helps to analyze the variety, connectivity, and dynamics of the overall packaging system. As a result, recommendations for the development of optimized packaging systems can be derived after implementation of further research requirements.

Future work should include validation, revision, and completion of the variables for exemplary packaging systems. Industrial partners and experts in the field of packaging life cycles should be consulted and involved in further research, creating working groups, which will contribute to the establishment of requirements for packaging systems including practical insights. The wide revision of the variables and their interdependencies aims to reduce subjectivity to build up an increasingly universal model for packaging systems.

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