Three level fuzzy signature based decision methodology for packaging system design

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Abstract: *In the field of logistics packaging, companies have to take decisions on determining the optimal packaging solutions and expenses. The decisions often involve a choice between one-way (disposable) and reusable (returnable) packaging solutions. Even nowadays, in most cases the decisions are made based on traditions and mainly consider the material and investment costs. Although cost is an important factor, it might not be sufficient for finding the optimal solution. Traditional (two-valued) logic is not suitable for modelling this problem, so here the application of a fuzzy approach, because of the metrical aspects, a fuzzy signature approach is considered. In this paper three different fuzzy signatures connected by fuzzy rules modelling the packaging decision are suggested, based on logistics expert opinions, in order to support the decision making process of choosing the right packaging system. Two real life examples are also given, one in the field of customer packaging and one in industrial packaging.*

Keywords: *fuzzy signature, one-way packaging, returnable packaging*

1. Introduction

Packaging is a significant element in any logistics system [12]. Without proper packaging handling and transportation would be difficult and expensive along the supply chain (SC). Although cost is an important factor, it is not enough to consider only the costs of material and investment while choosing the right pack-aging system, many other aspects should be considered.

It has been found that paying limited attention to packaging can cause higher costs in the physical distribution. Furthermore, researchers argue that packaging should not only be considered from the point of view of cost, but focus should be put on its role as a value-added function in the SC [5].

The best packaging solutions are those that, beside the optimal cost levels maximize the use of packaging capacity so that all the products can easily be packed and stacked, and at the same time reduce packaging waste [9].

As a matter of course, the environmental aspects are also part of these important processes, including the reduction of waste during production [11]. Furthermore, improving the efficiency of packaging is an important strategic goal for the organizations considering the aspects of sustainability and economy [7]. Legislation has also forced companies to rethink their packaging operations [6].

The functions of packaging in general can be classified as follows [4]:

- Product and environment protection (physical, safety, natural deterioration, waste reduction)
- Logistics containment and handling (unit, bulk, pallet, containers)
- Information (symbol, logo, description)

Packaging systems can have different levels: primary, secondary and tertiary packaging (Figure 1).

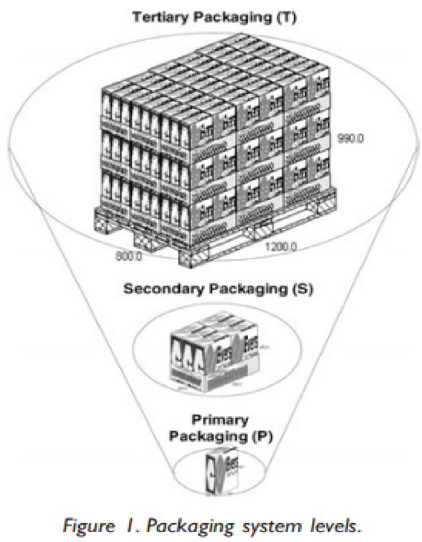

Fig. 1. Use Packaging system levels [8]

Primary packaging is the main package that holds the product that is being processed [8]. The aim of **secondary packaging** (it is also called transport or distribution packaging) is to preserve the product on its way from the point of manufacture to the customer. It includes the shipping container, the internal protective packaging and any utilizing materials for shipping. It does not include packaging for consumer products (primary packaging) [16]. **Tertiary packaging** combines all of the secondary packages for example into one pallet [8].

The functions of **transport packaging** are:

- Containment (basic purpose, supplying use value to products)
- Protection (ensuring integrity and safety of the contents and occasionally also protecting the environment from the product)
- Performance (transportation, handling, storing, selling and use of the product)
- Communication (identification of the contents and informing about package features and requirements) [16].

The most important actors of an industrial **packaging supply chain** (PSC) are suppliers, assembly factories and packaging collectors (if returnable packaging is used) [13]. Packaging producers are also important, but choosing the right packaging for the product belongs to the competency of the factories, their suppliers, or both together.

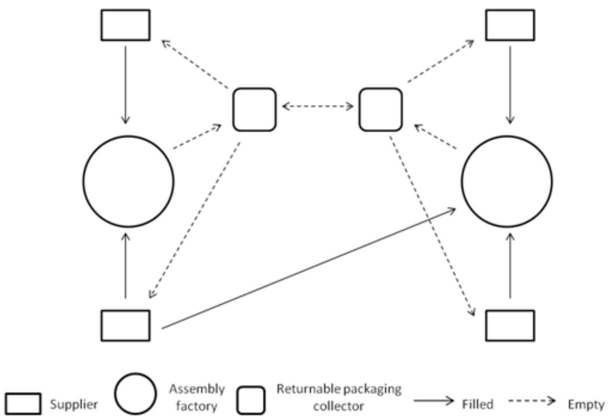

Fig. 2. Packaging supply chain – open loop system [14]

In the field of logistic packaging (industrial transportation, or even consumer packaging) the companies take decisions in order to determine the optimal packaging expenses. This decision-making situation practically means a choice between one-way (disposable) and reusable (returnable) packaging systems [1] [2]. The former is only suitable for one use as far as reusable containers and packaging are loaded with products and shipped to the destination, then the empty container is sent back to the supplier, refilled with products and this cycle is repeated over and over again as a closed-loop system. In case of an open-loop system reusable packaging is collected at a centralized return handling center, where it is cleaned, stocked, and distributed for refilling [16]. In the second case the packaging is not necessarily returning back to the initial partner who filled it.

The main problem with one-way packaging is the waste created after the usage while relative production cost is lower. On the other hand, transportation and maintaining cost is a relevant issue in case of returnable packaging [2] [10]. Returnable packaging has been frequently used for example in the US automotive industry in order to reduce waste, costs, transport damages and for enabling just in time (JIT) deliveries [15].

Managing returnable packaging systems requires more than just inverse transportation. The cleaning and maintenance of containers, as well as the storage and the administration are also involved in the process [3].

In most cases distance decides if the packaging comes back, but it also depends on the complexity of the supply chain. Transport modes also can play a noticeable role (for example road, rail or maritime transport).

Packaging waste is an important issue in disposable-returnable packaging system design. The management of packaging waste has been an integral part of European waste policies since the 1990s. The European Union formulated new regulations in the Directive 2018/852 on packaging and packaging waste. According to that waste prevention is the most efficient way to improve resource efficiency and to reduce the environmental impact of waste. It is important therefore that Member States take appropriate measures to encourage the increase in the share of reusable packaging placed on the market and the reuse of packaging.

Collaboration is crucial to packaging success. Many successful companies work closely with their suppliers to establish consistent shipping specifications before a new production program starts. [17]

2. The Fuzzy Signature Model

In this section, the structure of three different fuzzy signatures (S1, S2, S3) and the fuzzy rules among them modelling the packaging problem on hand will be proposed including the tree graphs and the aggregation operations in the intermediate nodes.

In the FSig in the intermediate nodes the use of weighted arithmetic mean operations is proposed.

Based on expert knowledge three main aspects were defined earlier, this in used as the base of the improved model (the first level in the new model) when a decision has to be made about one-way or returnable packaging. Thus the three aspects in the first FSig will be as follows:

- characteristics of the product to be packaged
- characteristics of the supply chain and
- external factors

After considering the first three aspects, an additional aspect will be examined at the second level:

• characteristics of the packaging material.

In the third signature, also cost factors will be added in order to get the final result of the model.

The relation among the three signatures is determined by the following rules:

If $\mu S1 \geq 0.5$ then check S2

If $\mu S1 \geq 0.5$ & $\mu S2 \geq 0.5$ then check S3

If $\mu S1 \geq 0.5$ & $\mu S2 \geq 0.5$ & $\mu S3 \geq 0.5$ then returnable.

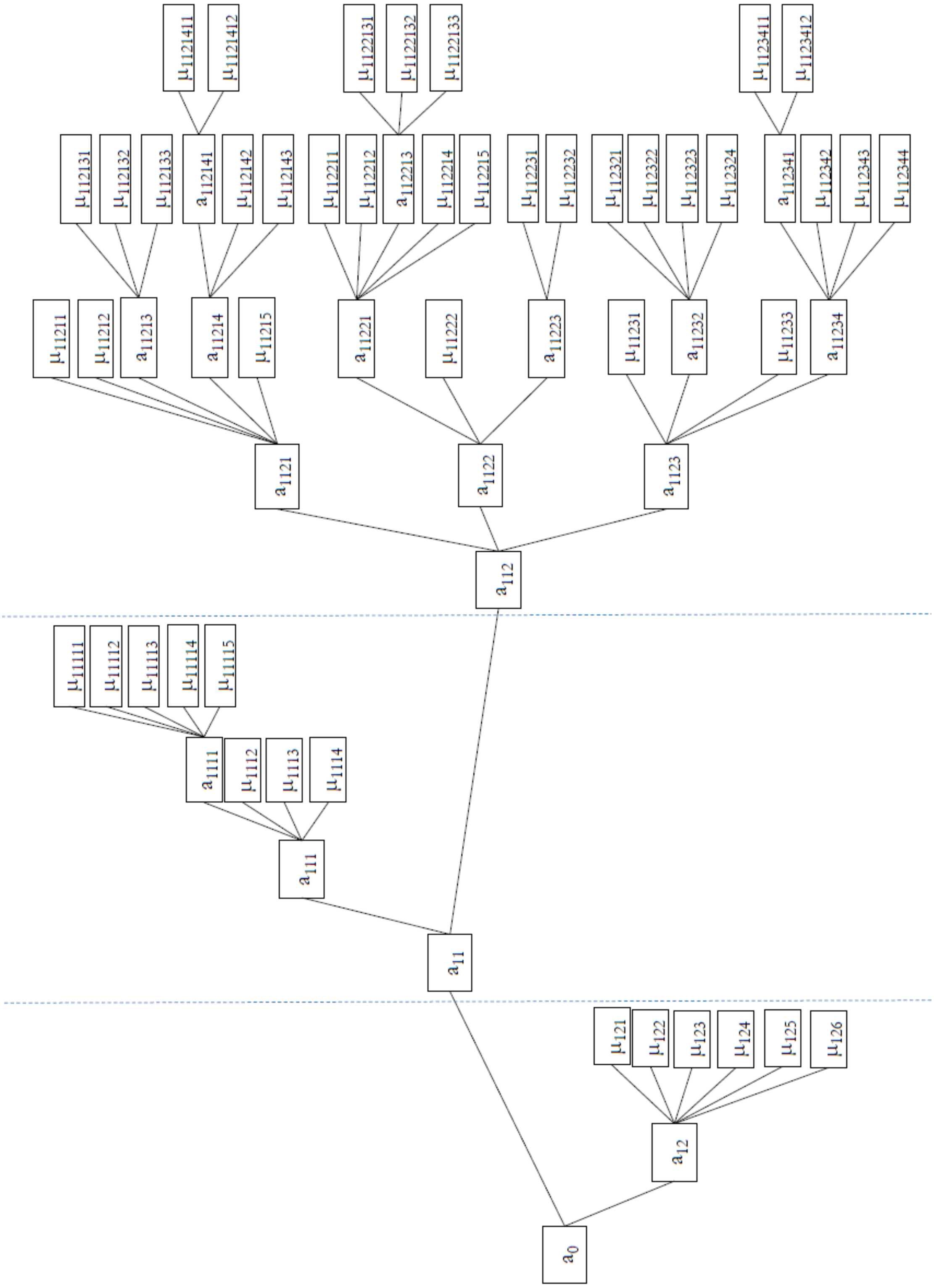

Fig. 3. Tree structure of the fuzzy signatures

All leaves of the tree assume their values (µi) from the interval [0,1]. [18] The values belonging to the intermediate nodes are calculated by respective functions specified to each leaf according to the logistics meaning and role. The relations among the individual descendants on the same level are determined with respective aggregations (see in chapter 2.1). The final purpose of the model is to sup-port the decision whether a disposable (one-way) or returnable packaging system should be used. When the final value created by the aggregation in the root (a0) is close to 0, it should rather be one-way, if the result of a7 is close to 1, the packaging should rather be returnable.

2.1. Definition of the Aggregation Operators

Based on the opinion of a panel of logistics experts is was decided that all aggregations are of the weighted arithmetic mean type, because the components of the individual characteristics and features are comparably importance, which may be expressed by weights of the same order of magnitude (given in tables 2-6).

The examples based on real life goods packaging technologies used by real companies have confirmed the values and the type of aggregations used in this rather complex fuzzy signature.

2.2. Defining the Main Aspects and the Weights

In the following the parent and child nodes are described in groups: weights (wi) with aggregations of the intermediate nodes are listed in Tables 1-6.

Table 1 determines the weights of aggregation operators (weights of the roots of the different sub-trees which are not further defined in the following section, but essential for the calculation).

Tab. 1. Weights of the aggregation operators in the model

ID	*Features*	*Weights*
1121	product characteristics	3
1122	supply chain	9
1123	external factors	2
112	S1 root	4
111	packaging material	8
11	S2 root	4
12	cost	8

Product characteristics. This attribute represents the technical aspects of designing the right packaging for a particular product.

Production batch size and turnover are two strong aspects, but also geometrical characteristics like shape, size and weight of the product should be considered. Furthermore, physical, biological, chemical sensitivity and value of the goods also play an important role. Within physical sensitivity the mechanical and climate effects must be differentiated. The ranking and weights in the fuzzy aggregation can be seen in Table 2. ID represents the position of the aspect (as a leaf or aggregation) in the fuzzy signature.

Tab. 2. Ranking and aggregation weights of product characteristics and its sub-trees

1 product characteristics			
ID	*Features*	*Ranking*	*Weights*
11211	batch size	1-2.	9
11212	turnover	1-2.	9
11213	geometrical	3.	7
11214	sensitivity	4-5.	2
11215	value	4-5.	2
1.3 geometrical characteristics			
ID	*Features*	*Ranking*	*Weights*
112131	shape	1.	4
112132	size	2-3.	1
112133	weight	2-3.	1
1.4 sensitivity			
ID	*Features*	*Ranking*	*Weights*
112141	physical	1.	6
112142	biological	2.	3
112143	chemical	3.	2
1.4.1 physical			
ID	*Features*	*Ranking*	*Weights*
1121411	mechanical	1.	6
1121412	climate	2.	4

Supply chain (logistics) characteristics. This attribute represents the logistics aspects of designing the right packaging for the given product. Transportation represents the main part of logistics activities in the supply chain (SC), but material handling and IT support are also essential for an effectively working SC. As it was mentioned earlier, transportation distance is highly important, as well as the volume of goods delivered at the same time. From the packaging point of view environmental circumstances during transportation (temperature, vibration and humidity) evidently influencing the decision. Quality of the infrastructure and the transport modes used (modality) should also not be left out of consideration. Material handling means all operations related to handling of the goods in the supply chain, including warehousing, unloading, uploading and transshipments. The organizational level of truck loads (full truck load – FTL, less than truck load – LTL) is also significant when deciding about returnable packaging because the complexity of the task is growing with the number of participants in the process. The ranking and aggregation weights in the fuzzy sub model can be seen in Table 3.

Packaging material. After the results of the first signature show that returnable packaging may be used, an additional aspect should be considered. In the second signature planning aspects and characteristics of the packaging material will be examined. In respect of the used material robustness represents the quality and quantity of the material used in order to make the packaging strong enough. Availability is connected to the procurement options of the material while recyclability and reusability play an important role within the supply chain after the material is used. Tare weight, collapsibility and packaging fill rate determine the capacity usage while transport and especially return transport. Number of uses represents here the technical suitability for reuse. The ranking and weights in the second fuzzy signature can be seen in Table 5.

Tab. 3. Ranking and aggregation weights of supply chain characteristics and its sub-trees

2 supply chain characteristics			
ID	*Features*	*Ranking*	*Weights*
11221	transportation	1.	8
11222	IT support	2.	7
11223	material handling	3.	2
2.1 transportation			
ID	*Features*	*Ranking*	*Weights*
112211	distance	1.	8
112212	volume	2.	7
112213	impacts	3.	5
112214	infrastructure	4.	3
112215	modality	5.	1
2.3 material handling			
ID	*Features*	*Ranking*	*Weights*
112231	transshipment	1.	8
112232	FTL/LTL	2.	2
2.1.3 environmental impacts			
ID	*Features*	*Ranking*	*Weights*
1122131	temperature	1.	4
1122132	vibration	2.	3
1122133	humidity	3.	2

Tab. 4. Ranking and aggregation weights of the external factors and its sub-trees

3 external factors			
ID	*Features*	*Ranking*	*Weights*
11231	cooperation	1.	8
11232	regulations	2.	3
11233	legal	3-4.	2
11234	environmental effects	3-4.	2
3.2 regulations			
ID	*Features*	*Ranking*	*Weights*
112321	environmental	1-4.	2
112322	health	1-4.	2
112323	benefits	1-4.	2
112324	standards	1-4.	2
3.4 environmental effects			
ID	*Features*	*Ranking*	*Weights*
112341	production related	1	10
112342	CO2 emission	2	8
112343	pool size	3	7
112345	effective vehicle utilisation	4	5
3.4.1 production related			
ID	*Features*	*Ranking*	*Weights*
1123411	raw material	1.	10
1123412	energy	2.	8

Tab. 5. Ranking and aggregation weights of the packaging material and its sub-trees

4 packaging material			
ID	*Features*	*Ranking*	*Weights*
1111	used material	1.	9
1112	packaging fill rate	2-4.	8
1113	number of uses	2-4.	7
1114	collapsibility	2-4.	7
4.1 Used material			
ID	*Features*	*Ranking*	*Weights*
11111	robustness	1.	8
11112	availability	2.	7
11113	recyclability	3-4.	4
11114	reusability	3-4.	4
11115	tare weight	5.	2

External factors. This attribute represents the external conditions, regulations and legal aspects. The degree of cooperation among the participants is a very important aspect and it fundamentally determines the possibility of using returnable packaging sys-tems. Environmental effects cannot always be clearly expressed and considered enough in corporate practice, but they are necessary to be built in the model. These are the following: quantity of raw materials and energy consumed in pro-duction, CO2 emission while return transportation, effective vehicle utilization and pool size (it means the total quantity of returnable packaging devices circu-lating in the system to ensure the stabile operation). The ranking and weights in the fuzzy model can be seen in Table 4.

Cost. Cost aspects in corporate decisions have obviously major importance, still we consider them merely in the third signature. The reason for that is because of the different cost structure of one-way and returnable packaging systems, there are certain cost components that only occur in case of returnable packaging solutions (i.e. cleaning and maintenance or administration). At this point the results already justified the opportunity for returnable packaging, according to the fuzzy rules in the model, cost will be only examined in this case. The ranking and weights in the third fuzzy signature can be seen in Table 6.

Tab. 6. Ranking and aggregation weights of the packaging material and its sub-trees

5 cost			
ID	*Features*	*Ranking*	*Weights*
121	packaging material	1-6.	5
122	disposal	1-6.	5
123	capital asset	1-6.	5
124	cleaning & maintenance	1-6.	5
125	storage	1-6.	5
126	administration	1-6.	5

All membership functions are variants of the triangular or trapezoidal member-ship functions (see e.g. Figure 4).

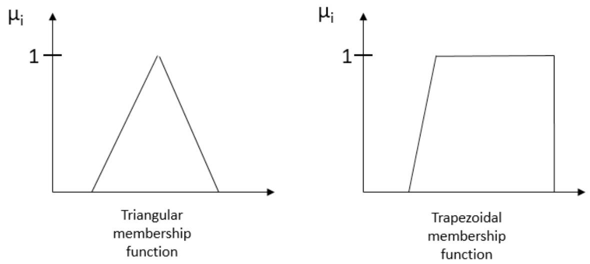

Fig. 4. Membership function examples

3. Application of the Model

In this chapter two real life examples (an industrial and a customer packaging) will be shown in order to illustrate the applicability of the proposed model.

3.1. Case Study 1

The products considered are automotive engines (CKD) transported from Eu-rope to two different destinations in India and China. The finished engines are sensitive products therefore special (wooden) crates are used mainly to store and transport them in the practice. These ensure safe and reliable transport and stor-age. The columns of the crates are usually collapsible in order to save space while returning back as empty packaging transportation. There are posts inside the crate which are supposed to keep the engine in place, but these can be also collapsed.

Fig. 5. Returnable packaging used for overseas CKD transport

The program counts every sub-tree according to the fuzzy signature. The values of all leaves (μi) are fuzzy membership degrees calculated from membership functions and all values of the parents are calculated according to an aggregation and the respective weights. The characteristics of the engine crate are described by logistics experts. The result of the first FSig was calculated by all aggregations according to Tables 2-4 is a112 = 0.6089. If we recalculate it with the additional signatures, the result in the improved model is a0=0.6103.

According to the aspects considered in the model, the packaging system should rather be returnable. This is in full accordance with the practice of the automotive engine factory providing data for the case study.

Some of the sub sub-models result in $\mu<0.5$ which should induce one way packaging but these values may be compensated by the other two sub-models, so the final result and the aggregated final membership degree all suggest returnable packaging.

3.2. Case Study 2

The packaging problem considered here is a well known customer packaging: the pet bottle. The methodology is the same like in the case of the wooden crates. The result is calculated by the first FSig of the model above described is a112 = 0.519534. In the improved model the result of S2 is a0=0.481103 which means according to the rule the program stops the calculation here. Although reusable plastic bottles existed and they are still used today in some places, according to the aspects considered in the model this packaging system should rather be one way. Reusable pet bottles really had issues in the practice.

4. Conclusion

In both case study examples the use of fuzzy signature models led to overall membership degrees, supporting the use of the type of packaging that is in accordance with expert domain knowledge.

As a conclusion we may state that the improved model with the additional two signatures is even more suitable for decision support than the previous basic model we proposed earlier.

Further research is going on, towards refining the model, especially separating customer and industrial products; and modeling the environmental issues in more detail.

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