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1 A Decision Support System to design
2 modified atmosphere packaging for fresh
3 produce based on a bipolar flexible
4 querying approach

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Abstract

19 To design new packaging for fresh food, stakeholders of the food
20 chain express their needs and requirements, according to some goals
21 and objectives. These requirements can be gathered into two groups:
22 (i) fresh food related characteristics and (ii) packaging intrinsic charac-
23 teristics. Modified Atmosphere Packaging (MAP) is an efficient way to
24 delay senescence and spoilage and thus to extend the very short shelf
25 life of respiring products such as fresh fruits and vegetables. Conse-
26 quently, packaging O_2/CO_2 permeabilities must fit the requirements
27 of fresh fruits and vegetable as predicted by virtual MAP simulating
28 tools. Beyond gas permeabilities, the choice of a packaging material
29 for fresh produce includes numerous other factors such as the cost,
30 availability, potential contaminants of raw materials, process ability,
31 waste management constraints, etc. For instance, the user may have
32 the following multi-criteria query for his/her product asking for a pack-
33 aging with optimal gas permeabilities that guarantee product quality
34 and optionally a transparent packaging material made from renew-
35 able resources with a cost for raw material less than 3 €/ kg. To
36 help stakeholders taking a rational decision based on the expressed
37 needs, a new multi-criteria Decision Support System (DSS) for design-
38 ing biodegradable packaging for fresh produce has been built. In this
39 paper we present the functional specification, the software architecture
40 and the implementation of the developed tool. This tool includes (i)
41 a MAP simulation module combining mass transfer models and respi-

42 ration of the food, (ii) a multi-criteria flexible querying module which
43 handles imprecise, uncertain and missing data stored in the database.
44 We detail its operational functioning through a real life case study to
45 determine the most satisfactory materials for apricots packaging.

46 **Keywords.** MAP modeling, multi-criteria querying, decision support
47 system, knowledge engineering, respiring product.

48 1 Introduction

49 Despite targeted campaigns and programs for promoting their health bene-
50 fits, consumption of fresh fruits and vegetable is still limited by their short
51 shelf life, which is not easily compatible with current modes of distribution
52 and purchase (once a week) in medium- to high-income countries.

53 Beyond respect of the chill chain and initial food quality, Modified Atmo-
54 sphere Packaging (MAP) was proved to be an efficient way to delay senes-
55 cence and spoilage, without using controversial preservative compounds, and
56 so to extend shelf life of fresh produce [Floros and Matsos, 2005, Guillaume et al., 2008,
57 Zagory and Kader, 1988]. MAP relies on the establishment of an optimal /rec-
58 ommended atmosphere for the produce and can be achieved by matching the
59 gas (O_2 and CO_2) permeation rate of the film with the respiration rate of the
60 produce. If a wealth of information has been published on MAP (more than
61 400 occurrences for “modified atmosphere packaging and fruit and vegetable”
62 in ISI Web of Knowledge), there is a lack of systematic treatment of the data

63 using knowledge management system in order to provide a full (complete)
64 Decision Support System (DSS).

65 By providing suitable information, such numerical tools could help de-
66 signers and users to select film properties that best fit particular purposes
67 and targets. This approach is especially important when developing packag-
68 ing made from biodegradable materials, which becomes a new trend, as their
69 limited barrier properties, possibly optimized using smart and/or composite
70 multilayer material [Guillaume et al., 2010], can turn out to be an asset to
71 extend shelf life of respiring foods [Cagnon et al., 2012, Guilbert et al., 2011,
72 Guillaume et al., 2008]. To facilitate MAP design, mathematical models, so-
73 called virtual MAP, have been developed by researchers working in this field
74 to design passive [Mahajan et al., 2007, Souza-Gallagher and Mahajan, 2013]
75 or active MAP [Cagnon et al., 2012, Charles et al., 2003, Charles et al., 2005]
76 for fresh and fresh-cut fruits and vegetable. Online applications are today
77 available for free (www.tailorpack.com) or charged access (www.packinmap.com).
78 Such numerical tools simplify the package design steps by predicting the gas
79 permeability values that permit to reach recommended atmosphere for the
80 target product and therefore to extend shelf life while maintaining quality
81 and safety of the packed food.

82 Up to now, all the aforementioned tools only considered the gas per-
83 meabilities of the packaging material as a basis for packaging design. The
84 design of food packaging is not only driven by maximizing shelf life of the
85 food, and numerous other requirements may interplay for final decision, re-

86 lated to processing, marketing, commercial, or distribution concerns (as cost,
87 process ability of constituents, industrial feasibility, environmental impact,
88 safety and stability of the packaging material all over the food life cycle, waste
89 management, etc.). Then, aside the constraint of food shelf life and quality,
90 correlated to gas permeation rates of the material, it also relies on user's
91 preferences, naturally expressed as wishes (e.g. transparent material would
92 be preferred) or constraints (e.g. cost of raw material must be less than
93 3€/kg). Some constraints and/or wishes are also related to the fact that
94 consumers may reject the use of some additives or of nano-technology in the
95 packaging material because of the unknown consequences on their health,
96 or more simply they may prefer transparent rather than opaque packaging.
97 To help stakeholders of the food chain in the choice of a packaging mate-
98 rial that would suit all the requirements of a given fresh fruit or vegetable,
99 development of decision aid tools is foreseen.

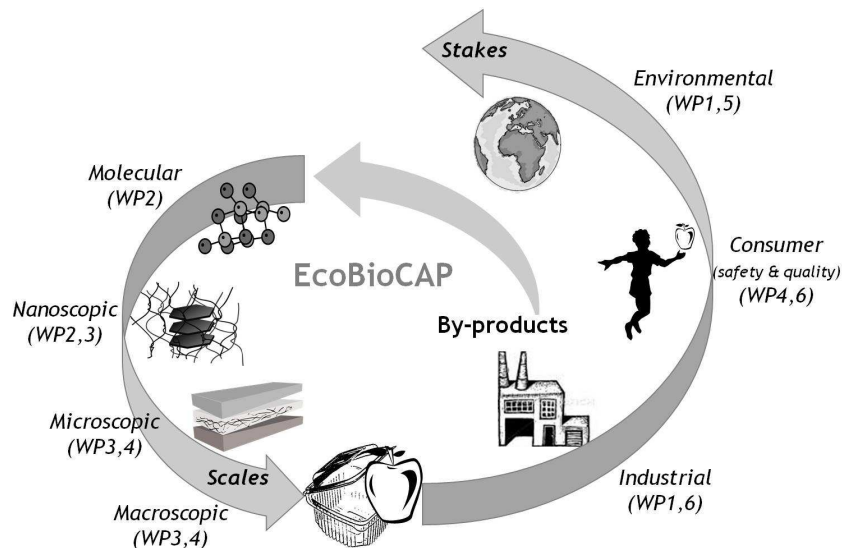


Figure 1: The EcoBioCap project.

100 The European project EcoBioCap (www.ecobiocap.eu) aims at designing
 101 the next generation of packaging material using advanced composite struc-
 102 tures based on constituents derived from the food industry (cf figure 1).
 103 In the framework of this project, we aim at developing a Decision Support
 104 System (DSS) to help parties involved in the packaging design to make ra-
 105 tional decisions based on knowledge expressed by the experts of the domain.
 106 The Decision Support System developed in this context aims at solving the
 107 dilemma of multi-criteria demands in the design of packaging for fresh pro-
 108 duce. This DSS relies on the development of a querying system (i) able to
 109 store and maintain data in dedicated databases (which could be incomplete or
 110 imprecise) about packaging material characteristics (e.g. gas permeabilities,
 111 cost, transparency, mechanical properties, etc.) and fresh food parameters

112 (e.g. respiration parameters, optimal storage conditions), (ii) allowing stake-
113 holders to express their needs and requirements as queries addressed to the
114 system databases, and (iii) retrieving the packaging materials ranked from
115 the most to the least satisfactory according to the expressed requirements.

116 The original contribution of this paper is to detail the design and the
117 implementation of the proposed Flexible and Bipolar Multi-criteria Querying
118 system, part of the DSS for the EcoBioCap project:

- 119 • Functional description of the system based on the approach described
120 in [Destercke et al., 2011],
- 121 • Databases development and filling with food and packaging character-
122 istics,
- 123 • Open source implementation with Java¹, R for numerical processing²,
124 and MySQL³ relational database management system.

125 Functional specifications of the bipolar flexible querying system are in-
126 troduced in Section 2. Its corresponding software architecture is detailed in
127 Section 3. Implementation aspects and some tests are displayed in Section
128 4. Section 5 concludes the paper.

¹www.java.com

²<http://www.r-project.org>

³www.mysql.com

129 2 Functional specifications of the system

130 We detail here the main functions that the bipolar flexible querying system
131 has to provide to the users. Prospective users of the EcoBioCap DSS have
132 been identified in the Stakeholder Advisory Board of the EcoBioCap FP7
133 project.

134 Functional requirements implemented in the EcoBioCap DSS are the fol-
135 lowing:

- 136 1. Collecting and managing data available about the packaging material
137 characteristics,
- 138 2. Collecting and managing data available about the respiration parame-
139 ters of fresh produce,
- 140 3. Managing users' preferences expressed over packaging material targeted
141 characteristics as constraints or wishes,
- 142 4. Dealing with missing data, since in real cases some required packaging
143 characteristics could be unknown, so stakeholders of the food chain
144 may face the problem of missing data,
- 145 5. Managing imprecise data, since characteristics associated with pack-
146 aging materials (eg. O_2 permeability values) and food products (eg.
147 maximal respiration rates) may be imprecise,

- 148 6. Retrieving the ranked list of all relevant packaging with their main
149 characteristics,
- 150 7. Guaranteeing the retrieval of packagings which are the closest to the
151 requirements (called guaranteed solutions) in case of empty set of so-
152 lutions,

153 **3 Architecture of the flexible querying system**

154 Figure 2 details the components of the developed flexible querying system
155 implementing the required functionalities. Namely, (i) two databases (for
156 fresh foods and packaging materials), (ii) the virtual MAP simulation and
157 (iii) the multi-criteria flexible querying system.

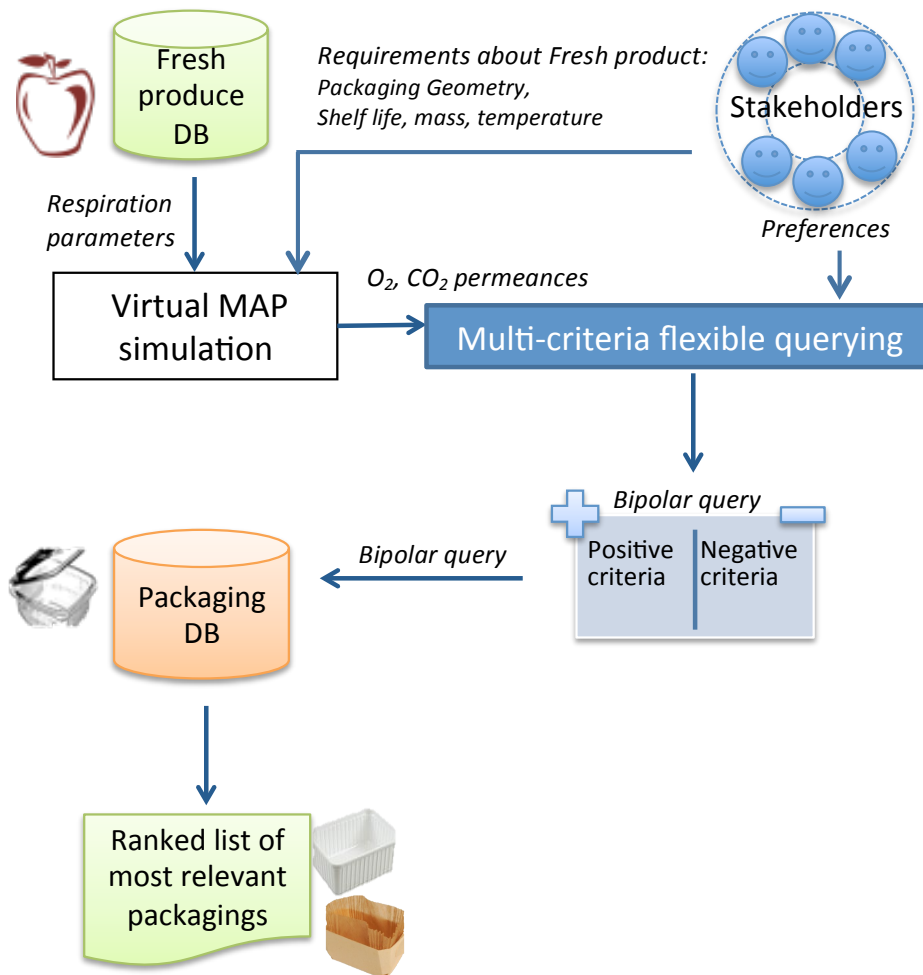


Figure 2: The flexible querying architecture.

158 3.1 Databases

159 The flexible querying system defines and implements two databases: (i) *fresh*
 160 *food* database containing the respiration parameters of the fresh produce used
 161 in the virtual MAP simulation (maximal respiration rate, Mickaëlis-Menten

162 constant, energy of activation, optimal gas concentration required for the
163 fresh produce optimal conservation, respiratory quotient), and (ii) *packaging*
164 *materials* database storing all the data related to the packaging material:
165 O_2 and CO_2 permeabilities, temperature at which the permeability measure-
166 ment was done, film thickness, mechanical properties, indication about the
167 cost, the renew-ability or not of the raw material used for producing the
168 packaging film, the biodegradability, the transparency, etc. Both databases
169 contain informations collected from the literature in the field and they are
170 maintained within MySQL (www.mysql.com) RDBMS (Relational DataBase
171 Management System).

172 Whenever available, each datum is stored with its confidence interval to
173 allow uncertainty propagation during simulations.

174 **3.2 The virtual MAP module**

175 *The virtual MAP simulation* module computes the optimal permeance which
176 guaranties the best shelf life for the packed food, by combining data from
177 the *fresh food* database and parameters given by the user. Inputs extracted
178 from the *fresh food* database are:

- 179 • parameters of the Mickaëlis-Menten type equations: maximal respira-
180 tion rate R_{max} , respiratory quotient RQ , Mickaëlis-Menten constant
181 Km , etc.
- 182 • optimal O_2 and CO_2 content targeted in the packaging headspace when

183 running simulation.

184 Parameters given by the user include the targeted shelf life, the food
185 mass to pack, the storage temperature, and the geometric dimensions of
186 the packaging (surface and volume). By using mass transfer mathematical
187 equations (based on Fick's law) coupled with Mickaëlis-Menten equation for
188 respiration, the virtual MAP returns the optimal O_2 and CO_2 permeances
189 and permeabilities for the preservation of the food.

190 The virtual MAP module has been implemented using the R software for
191 numerical computing (<http://www.r-project.org>).

192 **3.3 The multi-criteria flexible querying module**

193 To build such a querying system, methodologies based on Flexible Multi-
194 Criteria Querying process were used. The needs and requirements are mod-
195 eled as user preferences, approach widely studied in the field of flexible query-
196 ing of databases and information retrieval systems. Flexible querying systems
197 allow users expressing preferences in their queries. These queries are run on
198 regular relational databases and deliver a set of discriminated answers, which
199 are ranked from the most to the least preferred. Preferences are usually ex-
200 pressed as ordinary and binary sets. But they may lead to empty set of
201 answers and enlarged intervals of preferences relaxing the constraints could
202 be more expressive than a single value. In this context, fuzzy sets theory
203 [Zadeh, 1965] provides a general model for the interpretation of queries in-

204 volving preferences. The querying system [Destercke et al., 2011] can also
205 cope with lack of data or imprecise data in the database corresponding to
206 the characteristics related to the packagings like the optimal permeance, the
207 dimension of the packaging, its shape, etc.

208 Besides, expressed user preferences have different levels of importance or
209 priority. The shelf life and sanitary criteria ensuring a good preservation
210 of the packed product are intuitively more important than the color or the
211 transparency of the packaging. Therefore, some preferences are modeled as
212 constraints that the satisfaction is mandatory, and some others are wishes
213 that satisfaction is optional. Any packaging material which does not satisfy
214 the constraints is definitely discarded and the more packaging satisfies the
215 wishes the more preferred it is. It is natural then to make use in this context
216 of a bipolar approach for the querying process since it permits to handle
217 compound preferences made of mandatory conditions and optional condi-
218 tions. Bipolarity refers to the human reasoning which combines pro and con
219 information to take decisions, to make choices or judgments. It has been
220 widely studied during the last years in the field of preference modeling for
221 flexible querying. Several approaches have been introduced for the expression
222 and the evaluation of fuzzy bipolar conditions [Bordogna and Pasi, 1994,
223 Dubois and Prade, 2002b, Dubois and Prade, 2002a, de Tré et al., 2009],
224 [Zadrozny and Kacprzyk, 2007, Zadrozny and Kacprzyk, 2009, Liétard et al., 2011,
225 Tamani et al., 2013]. In this paper, we consider fuzzy bipolar conditions as
226 a particular case of fuzzy conditions, and we rely on the interpretation intro-

227 duced by Dubois and Prade [Dubois and Prade, 2002b, Dubois and Prade, 2002a,
228 Dubois and Prade, 2008], in which a bipolar condition is made of constraints
229 that are a mandatory condition (which refer to the negative pole or con infor-
230 mation) and wishes that are optional conditions (which refer to the positive
231 pole or pro information), and globally expressing “constraints, and if possible
232 wishes”.

233 Moreover, the main difference of our flexible querying approach in com-
234 parison with the aforementioned ones is that in our case we take into consider-
235 ation the fact that some values associated with packaging materials attributes
236 can be imprecise or uncertain, since they were obtained from experimental
237 data returned from repetitions corresponding to an interval instead of a single
238 value. Therefore, as for query preferences, values in the database are also con-
239 sidered as fuzzy sets, but with a semantic adapted to imprecise data instead of
240 preferences, as defined in [Dubois and Prade, 1997, Haemmerlé et al., 2007,
241 Buche et al., 2011].

242 Predicted optimal gas permeances, computed by the virtual MAP module
243 become two input parameters corresponding to one criterion (considered by
244 default as constraints since related to food quality, but could be also switched
245 to wishes in the GUI⁴) in the *multi-criteria flexible querying* module.

246 The *multi-criteria flexible querying* module combines these inputs to form
247 a bipolar query addressed to the packaging database. The returned list of
248 packagings is ranked from the most to the least relevant one with regard to

⁴Graphical User Interface

249 the expressed preferences. The user can finally specify whether the ranking
250 has to take into account unknown values for the mandatory criteria. If the
251 ranking must consider unknown values for the mandatory criteria, then each
252 delivered packaging is annotated with the percentage of known values over
253 which the ranking was carried out. In the opposite case, if the ranking must
254 only consider known values for the mandatory criteria and if no packaging in
255 the database has the required characteristics, (leading to empty set answer),
256 then the system activates the guaranteed result function which computes the
257 most similar packagings or the closest packagings to the ideal one.

258 As previously stated, the flexible querying system relies on a bipolar ap-
259 proach handling fuzzy conditions to model user preferences expressing pro
260 and con informations.

261 **Fuzzy sets theory:**

262 The fuzzy sets theory ⁵is introduced by Zadeh [Zadeh, 1965] to express the
263 gradual membership of an element to a set. A fuzzy set generalizes a crisp
264 set in which membership grades are in $\{0, 1\}$. If a fuzzy set is a discrete set
265 then it is denoted $F = \{(x_1, \mu_F(x_1)), \dots, (x_n, \mu_F(x_n))\}$, otherwise it is char-
266 acterized by its membership function, generally a trapezoidal function. For
267 instance, Figure 3 illustrates the membership (trapezoidal) function μ_{PeO_2}

⁵Formally, a fuzzy set F is defined on a referential U by a membership function $\mu_F : U \mapsto [0, 1]$, such that $\mu_F(x)$ denotes the membership grade of x in F . In particular, $\mu_F(x) = 1$ denotes the full membership of x in F , $\mu_F(x) = 0$ expresses the absolute non-membership and when $0 < \mu_F(x) < 1$, it reflects a partial membership (the closer to 1 $\mu_F(x)$, the more x belongs to F).

268 corresponding to an O_2 permeance preference.

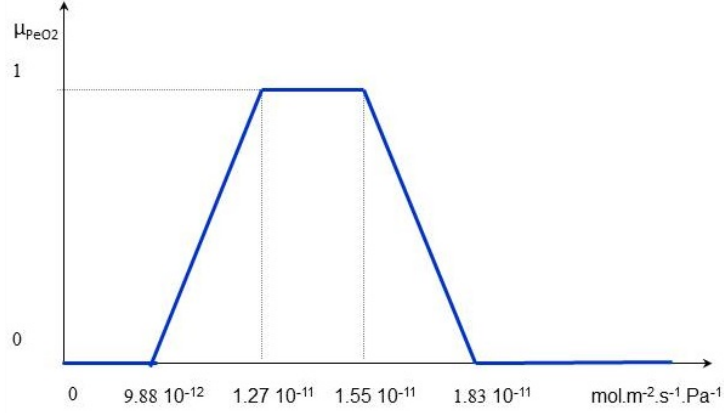


Figure 3: Example of a fuzzy set corresponding to O_2 permeance preference.

269 The union \cup and the intersection \cap operators are defined with a couple
 270 of (t-norm, t-conorm) such as (min, max) . Let F, G be two fuzzy sets,
 271 $\mu_{F \cup G}(x) = max(\mu_F(x), \mu_G(x))$, $\mu_{F \cap G}(x) = min(\mu_F(x), \mu_G(x))$, and the complement
 272 of F , denoted F^c , is defined by $\mu_{F^c}(x) = 1 - \mu_F(x)$.

273 The logical counterparts of \cap, \cup and the complement are respectively \wedge
 274 (AND operator), \vee (OR operator) and \neg (negation operator).

275 **The flexible bipolar querying method:**

276 The flexible bipolar querying method implemented in the DSS corresponds
 277 to a 'pros and cons' approach. Criteria chosen by the user (wishes and/or
 278 constraints) are multiple and also sorted by importance.

279 More formally, a bipolar query is pair of a sorted combination of constraints
 280 and wishes of the form $Q = (C, W)$, where $C = \{C_{(1)}, \dots, C_{(n)}\}$ and $W =$

281 $\{W_{(1)}, \dots, W_{(m)}\}$; each $C_{i,i=1,\dots,n}$ (resp. $W_{j,j=1,\dots,m}$) is a subset of constraints
 282 (resp. wishes) of the same importance or priority expressed on the attributes
 283 of packaging material such that:

- 284 • $\forall i, i' \in \{1, \dots, n\}$, if $i < i'$ then constraints in $C_{(i)}$ take priority over $C_{(i')}$
- 285 • $\forall j, j' \in \{1, \dots, m\}$ if $j < j'$, wishes in $W_{(j)}$ take priority over $W_{(j')}$

286 An example of such a query with two constraints and one wish is rep-
 287 resented as a sorted combination of fuzzy sets displayed in Figure 4. It
 288 corresponds to the following query:

$$289 \quad Q(C = \{\{Pref_{O_2Permeance}, Pref_{CO_2Permeance}\}, \{Pref_{Price}\}\},$$

$$290 \quad \quad \quad W = \{\{Pref_{Transparency}\}\}).$$

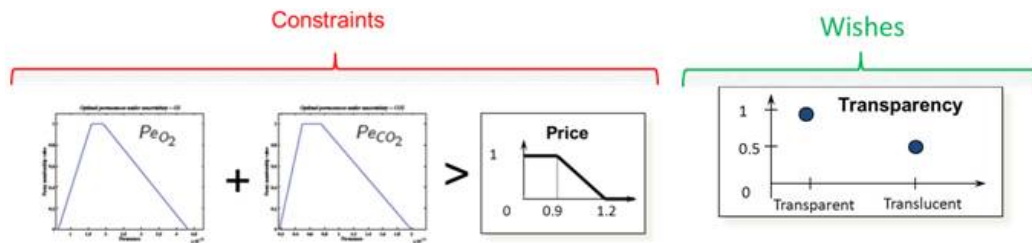


Figure 4: Example of a bipolar query.

291 **Handling imprecise and uncertain values.** Considering the food pack-
 292 aging application, enlarged intervals for the values could be taken into ac-
 293 count (e.g. uncertainties due to biological variability [Destercke et al., 2011]
 294 or tolerance threshold expressed by the user). In the flexible querying system,
 295 as for query preferences, values in the database are also considered as fuzzy

296 sets, but with a semantic adapted to imprecise data instead of preferences,
297 as defined in [Dubois and Prade, 1997].

298 Thanks to the homogeneous representation of preferences and uncertain
299 values, the comparison between a fuzzy set having a semantic of preference
300 with a fuzzy set having a semantic of imprecision can be defined using two
301 classical measures of possibility theory: a possibility degree of matching (de-
302 noted Π) and a necessity degree of matching (denoted N) [Dubois and Prade, 1988]
303 defined as follows:

- 304 • the possibility degree of matching between two fuzzy sets v and v'
305 defined on a referential domain Dom , denoted $\Pi(v, v')$, is $\Pi(v, v') =$
306 $Sup_{x \in Dom}(\min(\mu_v(x), \mu_{v'}(x)))$,
- 307 • the necessity degree of matching between v and v' denoted $N(v, v')$, is
308 $N(v, v') =$
309 $Inf_{x \in Dom}(\max(\mu_v(x), 1 - \mu_{v'}(x)))$ (see Figure 5 for a graphical repre-
310 sentation).

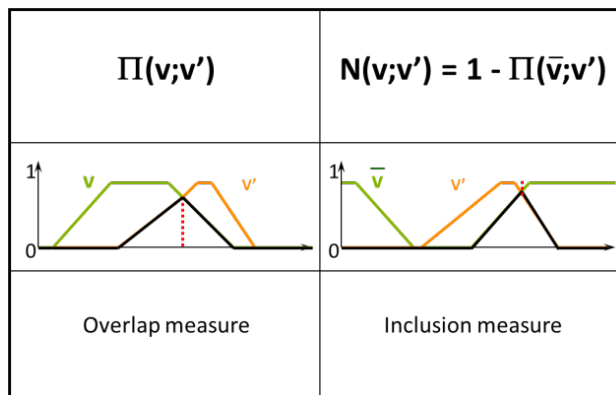


Figure 5: Example of overlapping and inclusion measures.

311 Intuitively, the possibility degree of matching is an optimistic compari-
312 son, as it corresponds to the maximum degree that satisfies simultaneously
313 the membership function of the two fuzzy sets (representing preferences and
314 uncertainty, respectively). The necessity degree may be considered as a pes-
315 simistic comparison, as it corresponds to the inverse of the degree of inclu-
316 sion of the fuzzy set associated with the uncertainty interpretation (i.e., our
317 knowledge stored in the database) with the one associated with the prefer-
318 ences.

319 When two criteria C_1 and C_2 of the query are of equal priority, the re-
320 spective couples of comparison degrees $[N_{C_1}, \Pi_{C_1}]$ and $[N_{C_2}, \Pi_{C_2}]$, for a given
321 material stored in the database, are aggregated to provide a unique couple
322 of comparison degrees $[N_{C_1 \cap C_2}, \Pi_{C_1 \cap C_2}]$ where $N_{C_1 \cap C_2} = \min(N_{C_1}, N_{C_2})$ and
323 $\Pi_{C_1 \cap C_2} = \min(\Pi_{C_1}, \Pi_{C_2})$. At the end, the algorithm provides a ranking of
324 equivalent classes: the first one contains the best materials that are of similar

325 quality and the last one contains those materials that are the less satisfac-
326 tory while still fulfilling the constraints. For further details about the ranking
327 process, the reader is referred to [Destercke et al., 2011].

328 **Handling missing data.** It's worth noticing that those comparison de-
329 grees may be evaluated even if, for a given material stored in the database,
330 some data are missing. For any fuzzy sets of preferences, comparison degrees
331 with packaging materials for which data are missing in the database will be
332 equal to $[N = 0, \Pi = 1]$.

333 That means that, when a material stored in the database is associated
334 with a missing datum, the DSS will consider that this material could po-
335 tentially match the food requirement related to this criteria ($\Pi = 1$) and,
336 simultaneously, that the degree of necessity that this material match the
337 food requirement is equal to 0 ($N = 0$).

338 **Handling empty set as answer.** In the case where every packaging ma-
339 terial has a possibility degree of matching of 0 for at least one constraint (no
340 material is candidate), the DSS warns the user and searches the materials
341 which are the closest, according to some distance, to satisfy the constraints.

342 That is, for each material M in the database, the system computes a
343 distance $d(M, C)$ between the material and the constraints C , and orders the
344 materials according to this distance. This distance can be seen as the minimal
345 modification the constraints C would have to undergo so that material M
346 satisfies it (see [Destercke et al., 2011] for more details). Finally, the user is

347 informed that the specified constraints are probably too restrictive but still
348 receives a list of materials that almost satisfy his/her needs.

349 **3.4 Validation of the flexible querying system**

350 The validation of the results delivered by the DSS has been done twofold.
351 Firstly, it relied on the validation of the virtual MAP model which has been
352 done in the past on endives and tomatoes [Charles et al., 2003, Charles et al., 2005,
353 Cagnon et al., 2012, Cagnon et al., 2013]. Secondly, it has been done using a
354 classical use-cases testing procedure of the functionalities associated with the
355 flexible bipolar querying system presented in section 3.3. This validation has
356 been done by involving stakeholders of the food chain participating to the
357 EcoBioCap project. Some collective testing sessions have been organized in
358 2012 and 2013 in order to validate by the potential users the functionalities
359 of the DSS. Following these testing sessions, the users have requested the
360 implementation of two possible behaviors of the database flexible querying
361 concerning missing data handling. The first request corresponds to the one
362 described in section 3.3 in which, to inform the user, a percentage of known
363 values corresponding to the querying criteria has been added to each answer.
364 The second request corresponds to the desire of having a more restrictive
365 querying mode forbidding the ranking of packagings with unknown values.
366 Consequently, now, both modes of querying are available in the DSS.

367 4 Implementation

368 The flexible querying system was implemented as a web application accessi-
369 ble on <http://pfl.grignon.inra.fr/EcoBioCapQuerying/>. A short demonstra-
370 tion video is available for download on
371 [http://umr-iate.cirad.fr/axes-de-recherche/ingenierie-des-connaissances/themes-](http://umr-iate.cirad.fr/axes-de-recherche/ingenierie-des-connaissances/themes-de-recherche/ecobiocap-dss)
372 [de-recherche/ecobiocap-dss](http://umr-iate.cirad.fr/axes-de-recherche/ingenierie-des-connaissances/themes-de-recherche/ecobiocap-dss).

373 The interface of the application is made of 3 parts:

- 374 • the upper part, shown on Figure 6, is dedicated to the permeance sim-
375 ulation and allows the setting of the fresh food and packaging parame-
376 ters. It is connected to the *fresh food* database to retrieve the charac-
377 teristics associated with the selected fresh food. Figure 6 displays in the
378 upper part the optimal permeance properties for the apricot Bergeron,
379 computed by the DSS, for a shelf life of 7 days in ambient temperature
380 ($20^{\circ}C$), mass food of 0.5 kg , volume of 1 l and surface of 756 cm^2 .
- 381 • the middle part allows the user expressing his/her preferences. In
382 this version, the user can only specify his/her preferences about the
383 O_2/CO_2 permeances, the storage temperature, the biodegradability
384 and the transparency of the packaging material. The text of the multi-
385 criteria querying shown on Figure 6 would be : “I want a packaging
386 material that suits to my product, apricot (eg. its O_2 and CO_2 per-
387 meances match the apricot requirement) for the range of temperature
388 between 14 and $26^{\circ}C$ ”. It must be noticed that the optimal permeances

389 computed by the DSS are automatically replicated in the middle part
 390 with a predefined deviation for the min-max and enlarge min-max in-
 391 tervals. Those values correspond to the fuzzy preferences associated
 392 with permeances as presented in Figure 3. They may be modified by
 393 the user before launching the querying of the packaging database.

The screenshot shows the 'EcoBioCap - Optimize permeabilities' software interface. It is divided into several sections:

- Food properties:** Includes a dropdown for 'Apricot Bergeron', input fields for 'Mass (kg): 0.5', 'Shelf life (day): 7', 'Temperature (°C):' (with a slider), 'Optimal atmosphere value:', 'O2 (%): 3', 'CO2 (%): 2', 'Respiration properties:' with 'RRO2 max (mmole/kg/h): 0.415', 'RQ (RRCO2 / RRO2): 0.78', 'KmO2 (Pa): 4500', and 'KICO2 (Pa): -1'.
- Packaging geometry:** Includes input fields for 'Surface (cm²): 756' and 'Volume (l): 1'.
- run simulation:** A button to execute the simulation.
- clear:** A button to reset the simulation.
- Permeance O2 (mol.m-2.s-1.Pa-1):** 1.411684e-11
- Permeance CO2 (mol.m-2.s-1.Pa-1):** 1.29492e-10
- Permeability O2 (mol.m-1.s-1.Pa-1 - 50 µm):** 7.058419e-16
- Permeability CO2 (mol.m-1.s-1.Pa-1 - 50 µm):** 6.474602e-15
- Preferences associated with criteria:** A section with a checked checkbox 'allow the ranking of packagings with unknown values for mandatory criteria'. It contains a table of preferences for various criteria:

	enlarge min	min	max	enlarge max	mandatory	optional
O2 permeance	9.881786e-12	1.270515e-11	1.552852e-11	1.835189e-11	<input checked="" type="checkbox"/>	<input type="checkbox"/>
CO2 permeance	9.064443e-11	1.165428e-10	1.424412e-10	1.683397e-10	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Temperature	14	18	22	26	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Biodegradability	<input type="checkbox"/>				<input type="checkbox"/>	<input type="checkbox"/>
Transparency	<input type="checkbox"/> transparent <input type="checkbox"/> translucent <input type="checkbox"/> opaque				<input type="checkbox"/>	<input type="checkbox"/>
- rank packagings:** A button to view the results of the simulation.

Figure 6: Permeance values obtained in the case of Apricot.

394 • The lower part is dedicated to the result of the query, as shown in
 395 Figure 7 in the case of Apricot. Please notice that in this example,

396 only constraints are considered and the process allows the ranking of
 397 the packaging with unknown values for mandatory criteria (the highest
 398 percentage of known values in the ranking is 66%).

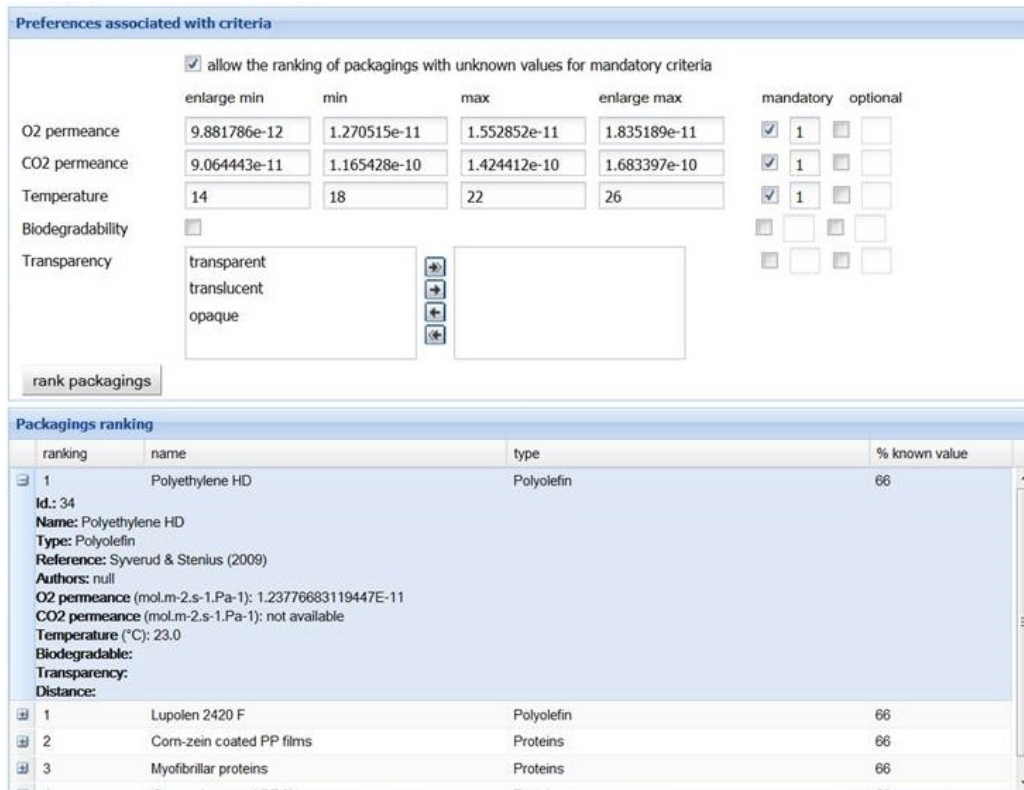


Figure 7: Ranked list of suitable packaging in the case of Apricot (only constraints are considered). Details are displayed for the first packaging.

399 Further details (commercial packaging or not, available reference of the
 400 scientific publication from where the information has been extracted,
 401 etc.) about delivered packaging materials can also be displayed as
 402 illustrated in Figure 7 for the same case of Apricot.

403 The DSS considers not only mandatory criteria such as packaging per-
404 meabilities but also wishes of the user. For instance the user may
405 have the following query: “I want a packaging material that permits to
406 preserve the shelf life of my product (Apricot) in the range of tempera-
407 ture 14-26°C and if possible biodegradable”. This query corresponds to
408 three constraints: O2 and CO2 permeabilities and temperature and one
409 wish. Figure 8 illustrates this query. We notice that the wish permits
410 to break tie between packagings having the same ranking with regard
411 to constraints. In the present case study (Apricot), the two materials
412 with number 1 in Figure 7 where polyolefins, oil-based materials, which
413 are not biodegradable. Therefore the segregation between them shown
414 in Figure 8 is not made on their biodegradability characteristics but on
415 the fact that in one case, this criterion is filled in the database (case
416 of lupolen, become rank 2 in the new classification) and in the case
417 of polyethylene (rank 1), this value is not filled and thus considered
418 as potentially reachable (cf section 3.3, paragraph Handling missing
419 data). The user is informed about lacking data thanks to the column
420 *% known values*. By example, for the case of polyethylene, it is 50 %
421 as only two values are known (see Figure 8): the O2 permeance and
422 the temperature.

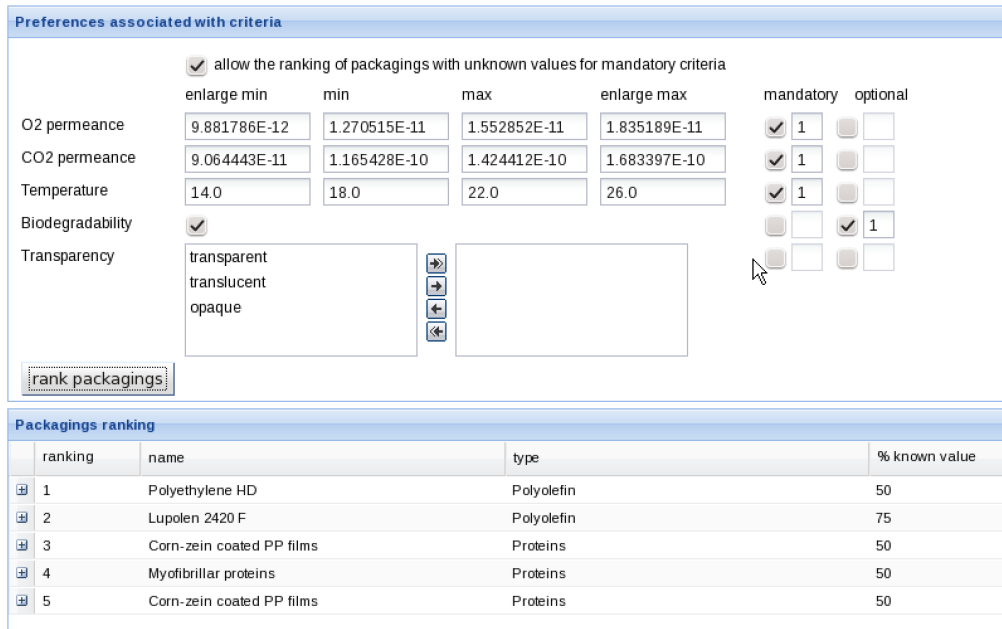


Figure 8: Ranked list of suitable packagings in the case of Apricot (a wish is also considered).

423 Finally, Figure 9 illustrates the guaranteed result function of the DSS
 424 which delivers the closest packaging materials according to a distance
 425 calculated between the query constraints and the actual value of those
 426 materials. The guaranteed result function is launched when there are
 427 not actually any packaging having all the criteria values fulfilled in the
 428 packaging database and satisfying the query constraints. In the query
 429 corresponding to the case study of Figure 9, the criteria biodegrad-
 430 ability is not a wish but a constraint. As no packaging material of
 431 the database fully satisfies this query, the guaranteed result function

432 is computed. A warning is sent to the user through a pop-up window
 433 (see Figure 9) in which is indicated, for each mandatory criterion, the
 434 percentage of packagings which do not fulfill the constraint or have an
 435 unknown value. The ranking of packaging materials proposed to the
 436 user is made with the packagings which are the closest to the targeted
 437 ones (constraints in the query). In the present case study, as biodegrad-
 438 ability became mandatory, the first ranked material is a biodegradable
 439 one “wheat gluten” even if its O₂/CO₂ permeabilities are further from
 440 the target than those of polyethylene, the material selected in the first
 441 query (Figure 7). This last query well illustrates how the DSS could
 442 always guarantee some results.

Preferences associated with criteria

allow the ranking of packagings with unknown values for mandatory criteria

O₂ permeance: enlarge min: 9.881786e-12, min: 1.270515e-11, max: 1.552852e-11
 CO₂ permeance: 9.064443e-11, 1.165428e-10, 1.424412e-10
 Temperature: 14, 18, 22
 Biodegradability:
 Transparency: transparent, translucent, opaque

rank packagings

Pop-up window:
 No packaging satisfies all the mandatory criteria. See below for each criterion, the % of packagings which don't fulfill the constraint or have unknown values, for the 4 tested packagings.
 A ranking of the most satisfying packagings is proposed.

criterion	% unsatisfied	% unknown
CO ₂ permeance	75	0
O ₂ permeance	50	0
Temperature	0	0

Packagings ranking

ranking	name	type	% known value
1	Wheat gluten	Proteins	100
2	Low-density polyethylene film	Polyolefin	100
3	PropaFresh P2G	Polyolefin	100
4	Cling film PVC	Polyvinyl Chloride	100

Figure 9: List of the closest packagings to the ideal one in the case of Apricot.

443 5 Conclusion and prospect

444 In this paper, we proposed a Decision Support System (DSS) for selecting
445 packaging material for fresh fruits and vegetables which relies on an interdis-
446 ciplinary approach, coupling process engineering with knowledge engineer-
447 ing and computer science. Mass transfer models aiming at realizing virtual
448 MAP simulations are gathered with packaging and fresh produce databases
449 in a web-application. A bipolar querying module was developed in order to
450 allow the user querying the packaging database starting from food require-
451 ments such as mass transfer properties and other criteria like transparency,
452 biodegradability, cost, etc. If several packaging materials are in the same
453 equivalent class after having satisfied the constraints, a refined ranking is
454 proposed on the wishes. In the querying process, the imprecision associated
455 with the data stored in the database is taken into account thanks to the use
456 of comparison degrees between user preferences and data. If none packag-
457 ing material satisfies the query, the DSS gives a ranking of the less distant
458 packaging material from the target constraints.

459 Compared to the current stakeholder decision-making practices, this DSS
460 is a significant breakthrough in the field of food packaging, especially that
461 of fresh respiring produce. As aforementioned, due to their intense respiring
462 metabolism, fresh produce necessitate, for their packaging material, specific
463 values of O₂/CO₂ permeabilites, belonging to a narrow and specific range of
464 values, that depends on the nature of the product. In practice, the choice

465 of this packaging material is based on the specifications defined by the food
466 manufacturer. To define the specifications of O₂/CO₂ permeabilities, exper-
467 imental trials on various materials with a large panel of gas permeabilites are
468 carried out until the packaging suitable to preserve the food is found. This
469 “pack-and-pray” approach is fully empirical and remains qualitative without
470 any formalization of the link between packaging properties and needs of the
471 food. We can easily imagine the added value that the use of a numerical tool
472 like this DSS would bring to food manufacturers by helping them to choose
473 the right packaging material. In addition to the main criterion associated
474 with food shelf life, the DSS proposed in this paper answers to multi-criteria
475 queries including other food packaging characteristics. Therefore, in addition
476 to the permeabilities criteria, it permits to analyze several other criteria that
477 could be constraints or wishes related to the food manufacturer constraints,
478 acceptances and needs: biodegradability, transparency etc. This type of tool
479 was never attempted previously in that field. Among the list of possible
480 packaging retrieved by the DSS, the user has to choose one (usually the one
481 ranked in first) and then to test it in real condition of use. Compared to
482 the empirical approach that requires numerous experimental trials, using the
483 DSS the user will have only one trial to perform (validation step). For the
484 reasons aforementioned, the DSS proposed in this paper definitively assists
485 decision-making in the field of food packaging for fresh produce.

486 This work has highlighted the importance of storage databases and of
487 their content. Data associated with new packaging materials developed dur-

488 ing the EcoBioCap have been stored in the DSS database. In the framework
489 of the project, the DSS will be used to benchmark the new packagings devel-
490 oped for different case studies (respiring cheese, strawberries and mushrooms)
491 (to be further presented). More generally, it is crucial to fill in databases and
492 especially the packaging database with a maximum of data in order to have
493 a panel of materials representative of the different possibilities available on
494 the market and in R&D. As the manual entering of data in databases is a
495 time consuming task, methodologies coming from the computer science field
496 allowing the semi-automatic “feeding” of databases from documents founds
497 on the Web should be developed and is a perspective of this work.

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