Identifying the optimal strategy for suppliers' involvement in product design: A case study

Ch. Achillas[1,2], D. Aidonis[3], D. Folinas[3*], N. Moussiopoulos[1,2], D. Triantafillou[3]

(1. *School of Economics & Business Administration, International Hellenic University, Thermi, Greece*;

2. *Department of Mechanical Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece*;

3. *Department of Logistics, Alexander Technological Educational Institute of Thessaloniki, Katerini, Greece*)

Abstract: In order to increase efficiency and improve competitiveness, manufacturers around the globe are focusing on developing their core businesses. On the other hand, standard activities of engineering are optimally accomplished outside the borders of the firm; thus outsourcing of non-core businesses has become lately a common practice. Product design is considered as one of the most important phases in a product's life cycle, since the majority of most critical decisions in terms of products' overall performance are considered during the Research & Development (R&D) phase. Involving suppliers in a firm's R&D offers significant benefits in various directions, such as feasibility, practicability, sustainability, competitiveness and innovativeness. However, selecting the optimal outsourcing strategy is not an easy decision. On the contrary, it is most challenging since it encompasses a number of different and in many cases mutually conflicting criteria. This paper presents a methodological approach for the selection of the optimal outsourcing strategy for a manufacturer's R&D. The methodology is based on outranking multicriteria methods and more specifically ELECTRE III. The approach is illustrated and validated through a real world case study of a Greek olive oil producer.

Keywords: product design, suppliers, R&D, outsourcing strategy, multicriteria analysis, ELECTRE III

Citation: Achillas, Ch., D. Aidonis, D. Folinas, N. Moussiopoulos, D. Triantafillou. 2014. Identifying the optimal strategy for suppliers' involvement in product design: A case study. Agric Eng Int: CIGR Journal, Special issue 2014: Agri-food and biomass supply chains, 30−41.

1 Introduction

Industrial products' life cycle is divided into four distinct phases: product design, manufacturing, use, and disposal. Within product design phase, products' concept design is realized and specifications are detailed, followed by detailed manufacturing design, validation, and analysis. As a first step, requirements are defined, based on the customer needs and the company's overall strategy. This is followed by the technical parameters which are initially roughly defined and the basic functional features that are described. After the aesthetics are also defined during concept design, the design process continues with detailed designs, prototype testing, and pilot launch of end products. Notwithstanding the fact that product manufacturing is relatively costly, use phase is the longest and most resources consuming (e.g. energy, water, etc.).

Research & Development (R&D) during the design stage is widely thought as the most important phase. This is based on the critical decisions concerning products' overall performance and logistics procedures which are considered during this phase. R&D has become an important strategy for companies in order to develop and maintain a leading position in the business world (van Echtelt et al., 2007).

Received date: 2013-01-23 **Accepted date:** 2013-12-23

*** Corresponding author: Dimitris Folinas,** Department of Logistics, TEI of Central Macedonia, Kanellopoulou 2, 60100, Katerini, Greece; Phone +30–2351020940, Fax: +30–2351047864, Email: daidonis77@gmail.com.

In the work of Dowlatshahi (1999) there are many examples from the real life business world that illustrate the critical role of R&D process. For example, Ford Motor Company estimated that 70% of all production savings stem from improvements in design. Respectively, Rolls Royce revealed that design determined 80% of the final production cost of 2.000 components. In this light, in order Original Equipment Manufacturers (OEMs) to compete in the modern globalized business environment, they need to launch new products into market that are characterized among others by high efficiency, innovativeness, ergonomics and aesthetics. In a fast changing industry, OEMs are required to continually improve their products' design in order to satisfy modern trends and follow consumer changing behavior. Moreover, an OEM needs to cope with continuous technology change which is not always simple.

For many companies worldwide, investing in R&D seems as an unbearable luxury. Due to their size, this is more evident for Small and Medium Enterprises (SMEs) which represent the vast majority of the current industrial sector. To this end, there is always the alternative for OEMs to closely cooperate with already established design labs or freelance product designers. This paper presents a decision support system for OEMs in order the latter to identify optimal outsourcing strategies for their R&D. The methodological framework is based on Multi Criteria Decision Aid (MCDA) techniques. More specifically, the approach follows the path of an outranking multicriteria method, namely ELECTRE III. Up to the author's knowledge, this is the first attempt to employ multicriteria analysis in order firms to answer the critical question of outsourcing or not R&D of new products. The remainder of this paper begins in Section 2 with a description of the benefits from outsourcing logistics services and more specifically the involvement of suppliers in the OEM's R&D, the problem description and a brief literature review. The following Section describes analytically the multicriteria methodological approach, its structure and mathematical background. Section 4 presents the application of the MCDA model in a real-world case study of an olive oil producer and discusses the results, while the paper concludes in Section 5 with arguments arising from this study, useful managerial insights and definition of future research challenges for the authors.

2 Outsourcing of a firm's Research & Development

Until the 1990s, the collaboration between manufacturers and suppliers was mainly focused on cost, quality and delivery issues, making the relationships to seem more transactional and adversarial (Goffin et al., 2006). Nowadays, things in this field have changed dramatically. In modern supply chains, suppliers' role is upgraded from simply delivering parts, components or materials to provision of design information and knowledge (Culley et al., 1999). In the business world there are plenty of success stories and "win-win" situations if supplier integration is managed cautiously (Wynstra and Pierick, 2000) and thus it greatly motivates practitioners and researchers internationally (Rouibah and Caskey, 2005). Moreover, the outsourcing of logistics functions has become a very common practice, which involves the use of external companies to perform some or all of the OEM's logistics activities (Hertz and Alfredsson 2003; Jayaram and Tan, 2010).

On these grounds, there is always the alternative for OEMs to actively involve suppliers early in a product's life cycle, i.e. in their R&D phase. Early supplier involvement indicates the vertical cooperation in which manufacturers involve suppliers at an early stage in the product development projects (Le Dain et al., 2011; Bidault et al., 1998; Dowlatshahi, 1998). The early contribution of suppliers may significantly assist the development of cooperative inter-organizational relationships within the product network, where competition between companies is replaced by competition between networks (Bozdogan et al., 1998; Gerlach, 1992; Provan, 1993). In order the R&D network to be effective and flexible, a continuous information flow between partners needs to be ensured (Emden et al., 2006; Sivadas and Dwyer, 2000).

Concurrent engineering and involving suppliers in an enterprise's R&D presents significant merits in various directions, such as feasibility, practicability, sustainability, branding, quality, competitiveness and innovativeness. Another interesting aspect is the reduction of the products' overall costs, including the development costs, the operational costs and the possible future redesign costs. Moreover, collaboration may lead to shared research and development risks (Perks, 2000). Both OEMs and their supply chain as a whole may profit by the close collaboration, as it can result to the strengthening of their product's market penetration strategy. Among others, such strategies provide: (i) multidisciplinary approach of product design, promotion of product innovation (idea generation, product design, detail engineering, market research and marketing analysis), (ii) bridging between opportunities identification and idea generation with introducing new products to market (opportunity recognition, shaping and reshaping), (iii) identification and influence of customers' needs, (iv) advanced product design. In this sense, involvement of suppliers in new product design is challenging. OEMs can focus on their main objectives, hence strengthening their core competencies and effectively coordinate and run business issues (Koufteros et al., 2007; Handfield and Nichols, 2002).

However at the same time, it is important to note that strategic partnerships in R&D phase can pose threat to corporate failure and disappointment too, in cases where there are differences in organizational cultures, mindsets, expectations, and behavior, making the whole project extremely costly and difficult (Emden et al. 2006; Von Corswant and Tunälv, 2002; Hanson and Lackman, 1998). Another potential risk raised by the involvement of suppliers in product's R&D is the reduced control over the development process (Bruce et al., 1995), which under certain circumstances can lead to a loss of proprietary knowledge.

It becomes obvious that early contribution of suppliers in a product's design and development is a challenging issue, since successful suppliers' integration in practice can be both complex but also very effective, especially when not involving a single partner but a number of an OEM's suppliers. The most important issue for managers at the "C" level is the definition of the kind of collaboration with suppliers in new product design and development projects. There are many research works in the relative literature that present different typologies categorizations of supplier involvement in product development. According to Petersen et al., (2005) there are two basic forms of supplier involvement in product design and development: the gray-box and the black-box approaches. In the gray-box approach, the role of supplier is focused mainly on providing expertise, suggestions and other inputs towards the product design and development. With this approach, the level of supplier's responsibility for the development of the product is rather low. On the other hand, in the black-box approach the role of the supplier is upgraded, since the outsourcing of design and development of specific parts, components or subassemblies to suppliers is occurred.

In the work of Le Dain et al. (2011), the early supplier involvement is divided into two exclusive kinds of collaboration, namely the collaborative development and the collaborative design. In the collaborative development, the participation of the supplier is targeted in industrialization and manufacturing of the delegated product. The role of the supplier as a consultant in the design phase is limited to the provision of information regarding the process and manufacturing know-how of the product. In the contrary, with collaborative design the supplier's involvement relies on the design phase of the product, being responsible to provide the OEM with functional requirements (performance, interface requirements, space constraints, etc.).

Moreover, in the work of Bonaccorsi and Lipparini (1994), three different approaches regarding the involvement of suppliers in new product design are presented: the "traditional", the "Japanese" and the "advanced" models. In the "traditional" model, the suppliers are not involved in the design process, as they are only responsible for the provision of parts or components in product's development phase. In the "Japanese" model the involvement of suppliers starts in the concept stage before the design of the product. The role of suppliers in the R&D is crucial, as they are responsible for the design, development and sometimes assembly of integrated parts, components or systems.

According to the authors, this type of collaboration can speed up the pace of new product introduction and develop sustainable long-term performance. The role of the suppliers in the "advanced" model is mainly focused on the provision of detailed technical solutions in the phase of the definition of product's specifications. This type of collaboration is very common in high-tech industries (i.e. the aircraft industry).

Taking into consideration the above, there are several questions that need to be answered. Most importantly, there are three critical queries that should be considered, which are integrated in the methodology herein presented. Firstly, which of the suppliers should an OEM involve in the R&D phase, secondly when should an OEM involve the selected suppliers, and last but not least, whether the OEM should involve the selected suppliers fully or partially and to what extent if partially.

3 Methodological framework

3.1 Basic concept

The proposed methodology follows the path of multicriteria analysis, since these mathematical models are able to take into account conflicting criteria in the decision-making process (e.g. Achillas et al., 2013; Iakovou et al., 2009; Erkut et al., 2008; Rousis et al., 2008; Steuer and Na, 2003; Hokkanen and Salminen, 1997). In the literature, applications of multicriteria methods gain wide acceptance in the last few years over quantitative models, as the former embody many variables, quantitative as well as qualitative in their analysis (e.g. Achillas et al., 2011; Queiruga et al., 2008). The special characteristics of alternative suppliers and the potential to involve them in an OEM's R&D are simultaneously assessed. Alternative scenarios' performances are quantified over a number of selected criteria in order to export the optimal solution. Outsourcing R&D to suppliers with the use of MCDA techniques requires the adoption of a number of logical steps, as those are presented in the flowchart of Figure 1.

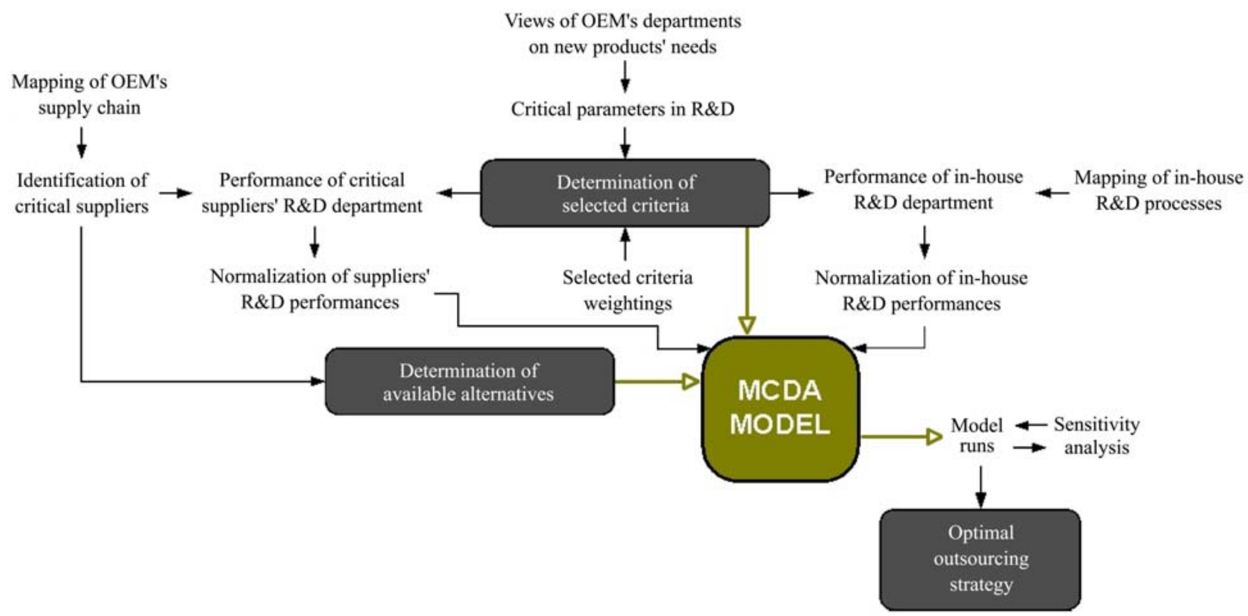

Figure 1 Conceptual approach

3.2 Steps of the conceptual approach

As a first step, the OEM should scholastically assess its Departments' needs concerning new product development. This is crucial since Departments within a firm; although sharing a number of common goals, they have different and many times mutually conflicting requirements in respect to products' design. For instance, the Marketing Department of a car industry may highly promote focus on the aesthetics of the vehicles brought to market, the After Sales would prefer to foster reliability and durability, while Production would mostly pay attention on cost of materials and requirements in manufacturing equipment. Since all views are well communicated to all involved stakeholders, the critical parameters are assessed and the criteria that decision will be based upon are decided. It should be emphasized that the exact number of criteria for the decision making process depends on the decision-maker (Munier, 2004).

This step is followed by the determination of the selected criteria's relative significance (weighting factors). This particular judgment allows the incorporation of OEM's specific strategic goals in the decision-making process. As depicted in Figure 1, selection of criteria is one of the key steps for any MCDA methodological framework. The other one is the identification of the available alternatives among which the OEM will decide upon the optimal outsourcing strategy. To that end, one of the first steps of the proposed decision-making process focuses on mapping the firm's supply chain and the identification of the most critical suppliers. Together with the usual R&D strategy (keeping R&D processes in-house), which always represents a potential alternative, specific outsourcing R&D scenarios are determined. Both for the cases of scenarios involving suppliers in the OEM's R&D, as well as the one that keeps R&D processes in-house performances of alternatives are quantified in respect to the selected criteria. As a next step, in order to facilitate monitoring and direct comparison between individual criteria, the quantified values of all criteria j for all alternative scenarios S are scaled in a 1-10 range with the use of the $N_j(S)$ index, as follows:

$$N_j(S) = \frac{g_j(S) - g_j^{\min}}{g_j^{\max} - g_j^{\min}} \cdot (P^{\max} - P^{\min}) + 1$$

where, $g_j(S)$: Performance of criterion j for alternative scenario S; $g_j^{\min}$: Minimum performance of criterion j; $g_j^{\max}$: Maximum performance of criterion j; $P^{\max}$: Maximum value of selected scale; $P^{\min}$: Minimum value of selected scale.

After having identified alternative scenarios, selection of criteria and quantification of performances, the methodological framework carries on with the development of the model. The MCDA model for outsourcing R&D strategies is formulated by using a set of alternatives (S_1, S_2, S_3…) and a set of criteria (C_1, C_2, C_3…).

As a last step of the developed methodology, sensitivity analysis is available, since parameter values in real life applications originate from estimations which are sometimes more or less reliable (weighting factors, thresholds, qualitative values of criteria, etc.) (Banias et al., 2010).

3.3 Mathematical background

The approach adopted in the framework of this analysis uses a ranking scheme, following ELECTRE III principles (Roy, 1978). ELECTRE III is selected on the basis that the outranking technique has the ability to incorporate a large number of evaluation criteria, coupled with the possibility of a large number of different decision-makers. It should be also emphasized that data uncertainty is likely to drive-decision makers to misleading conclusions. ELECTRE III requires the determination of three thresholds, namely negligence threshold, preference threshold, and veto threshold in the effort to better adapt to such uncertainties (Roy and Bouysou, 1993). With the use of those thresholds, the technique does not address only the two ends of the problem, but also intermediate levels in between. Last but not least, with the adoption of ELECTRE III, the decision-maker is able to take into account either quantitative (e.g. cost, years of experience, key performance indicators, etc.) or qualitative criteria (e.g. reputation, reliability, flexibility, quality, etc.), since the technique shows a very good fit of data in such applications (Achillas et al., 2010).

ELECTRE III is based on binary outranking relations in two major concepts: "Concordance" (c_j) when alternative S_1 outranks alternative S_2 if a sufficient majority of criteria are in favour of alternative S_1 and "Non-Discordance" (d_j) when the concordance condition holds, none of the criteria in the minority should be opposed too strongly to the outranking of S_2 by S_1. The assertion that S_1 outranks S_2 is characterized by a credibility index which permits knowing the true degree of this assertion (Roussat et al., 2009). To compare a pair of alternatives (S_1, S_2) for each criterion, the assertion "S_1 outranks S_2" is evaluated with the help of pseudo-criteria. The pseudo-criterion is built with two thresholds, namely indifference (q_j) and preference (p_j). The inclusion of these thresholds results into zones of indifference and preference between performances. The q_j threshold represents the maximum difference between performances on each criterion to which the decision-maker remains indifferent. Similarly, the p_j threshold represents the minimum difference between performances on each criterion to which the decision-maker favors one alternative over the other. Values in between the two aforementioned thresholds indicate that the decision-maker shows only a weak preference of one alternative over the other. For those two types of thresholds, the following apply:

- When $g_j(S_1) - g_j(S_2) \leq q_j$, then no difference between alternatives S_1 and S_2 for the specific criterion j under study is identified. In this case $c_j(S_1, S_2) = 0$.
- When $g_j(S_1) - g_j(S_2) > p_j$, then S_1 is strictly preferred to S_2 for criterion j. In this case $c_j(S_1, S_2) = 1$.

For a criterion j and a pair of alternatives (S_1, S_2), the concordance index is defined as follows:

$$\begin{cases} g_j(S_1) - g_j(S_2) \leq q_j \rightarrow c_j(S_1, S_2) = 0 \\ q_j < g_j(S_1) - g_j(S_2) < p_j \rightarrow c_j(S_1, S_2) = \\ \dfrac{g_j(S_1) - g_j(S_2) - q_j}{p_j - q_j} \\ g_j(S_1) - g_j(S_2) \geq p_j \rightarrow c_j(S_1, S_2) = 1 \end{cases}$$

A global concordance index $C_{S_1S_2}$ for each pair of alternatives (S_1, S_2), is computed with the concordance index $c_j(S_1, S_2)$ of each criterion j:

$$C_{S_1S_2} = \frac{\sum_{j=1}^{n} w_j \times c_j(S_1, S_2)}{\sum_{j=1}^{n} w_j}$$

where, w_j is the weight of criterion j.

As already mentioned, a discordance index $d_j(S_1, S_2)$ is also taken into consideration for all pairs of alternatives and each criterion j. Discordance index (d_j) is evaluated with the help of pseudo-criteria with a veto threshold (v_j), which represents the maximum difference $g_j(S_1) - g_j(S_2)$ acceptable to not reject the assertion "S_1 outranks S_2", as follows:

- When $g_j(S_1) - g_j(S_2) \leq p_j$, then there is no discordance and therefore $d_j(S_1, S_2) = 0$.
- When $g_j(S_1) - g_j(S_2) > v_j$, then $d_j(S_1, S_2) = 1$.

Discordance index (d_j) can be represented as follows:

$$\begin{cases} g_j(S_2) - g_j(S_1) \leq p_j \rightarrow d_j(S_1, S_2) = 0 \\ p_j < g_j(S_2) - g_j(S_1) < v_j \rightarrow d_j(S_1, S_2) = \\ \dfrac{g_j(S_2) - g_j(S_1) - p_j}{v_j - p_j} \\ g_j(S_2) - g_j(S_1) \geq v_j \rightarrow d_j(S_1, S_2) = 1 \end{cases}$$

The index of credibility $\delta_{S_1S_2}$ of the assertion "S_1 outranks S_2" is defined as follows:

$$\delta_{S_1S_2} = C_{S_1S_2} \prod_{j \in \overline{F}} \frac{1 - d_j(S_1, S_2)}{1 - C_{S_1S_2}}, \text{ with}$$

$$\overline{F} = \{j \in F, d_j(S_1, S_2) > C_{S_1S_2}\}$$

In the case that a veto threshold is exceeded for at least one of the selected criteria, the index of credibility is null. In other words, the assertion "S_1 outranks S_2" is rejected. As regards the ranking procedure of all available alternative scenarios S_j, two complete pre-orders are constructed through a descending and an ascending distillation procedure. Descending distillation refers to the ranking from the best available alternative to the worst, while ascending distillation refers to the ranking from the worst available alternative to the optimal.

4 Application of the model

The developed methodology is tested on its applicability through its demonstration in a real-world case study. More specifically, the methodology is applied for the case of the "House of Olive", a Greek extra virgin olive oil producer. The "House of Olive" is set on the hills of Eastern Peloponnese, an area which is globally acclaimed for its top quality olives. The company "houses" small producers of high quality extra virgin and organic extra virgin olive oil produced of "manaki" olives' variety. Olive trees are environmental consciously cultivated. After their harvest olives, are led to the olive press where their juice is taken in very low temperature. The "House of Olive" currently sells extra virgin olive oil from selected olive groves wholesale in 50 L plastic barrels. However, it is within the firm's intentions for the near future to launch to market a variety of new products. Potentially, the "House of Olive" can bring to market 15 L tin cans, as well as 1000/750/500/250 mL tin/glass/plastic bottles of conventional/organic extra virgin olive oil. In total, there are 26 different combinations of the aforementioned potentialities. The question for the firm's CEO lies on the optimal outsourcing strategy as regards the new products' design. The company faces challenges in two major axes: product development and operational design. As regards the former, the process follows seven steps: (i) cleaning of the olives (removing stems, leaves, twigs, debris, pesticides, etc.), (ii) grinding olives into paste (in order to release the oil from the vacuoles), (iii) malaxing the paste (in order to allow small oil droplets to combine into bigger ones, (iv) separating the oil from the vegetable water and solids (with the use of centrifuges), (v) filtration (to eliminate remaining particles), (vi) storing, and (vii) labeling/filling/packing (including chemical analysis of the product). Although the procedure is standardized, there exists a plethora of alternatives for the selection of the specific characteristics for each of the aforementioned steps. For instance, as regards malaxing, the process can last from 20 up to 30 min. The paste can be heated or water may be added during this process to increase the yield, although this generally results in lowering the quality of the oil. In that sense, the decision-maker may choose to produce less quantities of higher quality olive oil from the same quantity of olives (Process I), or alternatively may choose to increase the quantity of olive oil produced with the simultaneous decrease in its products' quality (Process II). Apparently, there are also alternative processes in between those two extremes. Moreover, material selection for the products' packaging can be significantly differentiated. In respect to the firm's operational design a number of critical issues may rise. Among others, the firm's CEO needs to decide on product's morphology and aesthetics, marketing, branding, consumer behavior and supply chain management (e.g. distribution network) issues. Following the methodological scheme described in Figure 1, the two critical questions for building up the MCDA model focus on the determination of the available alternatives and most suitable criteria, respectively. As regards the alternatives, in the framework of the present analysis, the following different strategies are compared, based on the firm's CEO's requirements:

- S_{A1}: Design of the products in-house - Use of Process I for the production of the olive oil.
- S_{A2}: Design of the products in-house - Use of Process II for the production of the olive oil.
- S_{B1}: The firm designs the new production's processes in-house and outsources products' packaging to Company X - Use of Process I for the production of the olive oil.
- S_{B2}: The firm designs the new production's processes in-house and outsources products' packaging to Company X - Use of Process II for the production of the olive oil.
- S_C: The firm designs the new production's processes in-house and outsources branding, marketing and packaging to the Design Group Y, a highly acknowledged for creating high aesthetics products ensuring thus the confidence of the consumers around the world. Use of Process I for the production of the olive oil due to Design Group's requirements.
- S_D: The new products' design is outsourced to Manufacturer Z. The company only provides its olive oil and the whole production and supply chain is designed by the partnering Manufacturer. Use of Process II for the production of the olive oil due to the Manufacturer's characteristics

After the determination of all available alternative product design strategies, the criteria to be taken into account are decided upon. To that end, 26 companies which are activated within the agrifood industry were interviewed in order to decide on the most critical criteria that were further used in the case under study. Those criteria included:

- C_1: Development Cost (in €)
- C_2: Production Cost (in €/L)
- C_3: Quality (in 1-10 scale)
- C_4: Future Redesign Cost (in 1-10 scale)
- C_5: Aesthetics (in 1-10 scale)
- C_6: Market Penetration (in 1-10 scale)

- C_7: Branding (in 1-10 scale)

The significance of the selected criteria is analytically discussed in section 2. Criteria C_3 - C_6 are quantified in a qualitative scale 1-10, where "1" is the minimum possible value and "10" the maximum one. Towards selection of optimal outsourcing strategy, the values of criteria "Development Cost" (C_1), "Production Cost" (C_2) and "Future Redesign Cost" (C_4) need to be minimized. On the contrary, the values of criteria "Quality" (C_3), "Aesthetics" (C_5), "Market Penetration" (C_6) and "Branding" (C_7) should be maximized. The individual performances of the available alternatives are quantified for the selected criteria as depicted in Table 1. The performances of the alternatives over the selected criteria were quantified (quantitatively for the first two criteria and qualitatively in a scale 1-10 for the remaining ones) by the company's operations manager, based on the findings of a preliminary market research.

Table 1 Performance of the available alternative strategies

Alternative strategy	Development Cost		Production Cost		Quality scaled	Future redesign cost scaled	Aesthetics scaled	Market penetration scaled	Branding scaled
	€	scaled	€/L	scaled					
S_{A1}	2,000	1	3.15	1	1	10	1	2	1
S_{A2}	2,000	1	3.35	3,77	3	9	1	3	3
S_{B1}	7,000	2,61	3.25	2,38	3	7	7	6	7
S_{B2}	7,000	2,61	3.45	5,15	5	6	7	7	7
S_C	18,000	6,14	3.50	5,85	8	2	10	10	10
S_D	30,000	10	3.80	10	9	5	10	10	8

In order to efficiently discriminate among alternative scenarios, preference thresholds are connected with the total number of alternatives. This provides the decision-maker with a smoothed "relative distance" between available alternatives. To that end, preference and indifference thresholds for each criterion (Table 3) are calculated with the use of referenced Equations (1) (Haralambopoulos and Polatidis, 2003; Rogers and Bruen, 1998) and (2) (Kourmpanis et al., 2008), respectively:

$$p_j = \frac{1}{n}(g_{aj}^{\max} - g_{aj}^{\min}),\ a \in (A_1, A_2, B_1, B_2, C, D);$$

$$j \in (1, 2, 3, ..., 7) \qquad (1)$$

$$q_j = 0.3 \cdot p_j,\ j \in (1, 2, 3, ..., 7) \qquad (2)$$

where, $g_{aj}^{\max}$: Maximum average performance of scenario a for criterion j; $g_{aj}^{\min}$: Minimum average performance of scenario a for criterion j and n: Number of available alternative strategies (for the case under study: n = 6).

Moreover, for the case under consideration, values for the selected weighting factors are calculated as averages of the corresponding views of various managers involved in this study. In most real life problems, budget constraints are most often applicable in decision-making processes. Thus, the veto threshold taken into consideration for the study's needs referred to maximum cost difference between alternatives. For "The House of Olive", the veto thresholds for development, production and redesign cost are assigned by the company's operations manager at "15,000 €", "0.4 €/L" and "5", respectively. In the 1-10 scale, this is reflected in the values presented in Table 2. Obviously, veto thresholds could possibly be applied on other criteria also without altering the methodological process. In order to overcome subjectivity issues, the sensitivity analysis that follows, as well as the ease to re-calculate optimal solution with modified parameters, provides the decision-maker with an easy-to-use tool.

Table 2 Weighting factors and thresholds

	Development Cost	Production Cost	Quality	Future Redesign Cost	Aesthetics	Market Penetration	Branding
Weighting factor	10%	20%	15%	5%	15%	30%	5%
Threshold of negligence	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Threshold of preference	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Veto threshold	4.82	5.54	-	5.63	-	-	-

Following the definition of all available alternatives, the calculation of the normalized values of the selected criteria, weighting factors and thresholds, the selection of the optimal outsourcing strategy for the company continues with the application of ELECTRE III. In our case, model runs are carried out with the use of the LAMSADE ELECTRE III-IV software package which makes use of an outranking relation for modelling decision-maker' s preferences. Its final result is a partial pre-order of alternatives presented in a graph form. More information on the software is reported in Vallée and Zielniewicz (1994). The problem was solved on a Pentium 4 computer with 3.8 GHz CPU and 2GB RAM. The computational time is practically negligible. The model's performance in terms of size and computational time is acceptable, taking also into account that it represents a strategic decision support tool and thus it needs to be run only sporadically by the decision-maker. Figure 2 illustrates both ascending and descending distillations for the optimal outsourcing strategy in the "basic" scenario. Based on the two pre-orders, the final ranking results were calculated following the ELECTRE III technique. Both distillations show that alternative Scenario S_C outweigh all other available alternatives, thus this particular outsourcing strategy appears optimal. Figure 3 illustrates the final ranking of the available alternatives. Despite the fact that Alternative S_C is optimal only in one criterion ("Branding") which weighs only 5% of the overall ranking, and also is co-ranked 1st together with S_D in the criteria "Market penetration" (weighting factor 30%) and "Aesthetics" (weighting factor 15%), the optimal strategy can be interpreted as a result of the specific alternative's well balanced performances in all selected criteria.

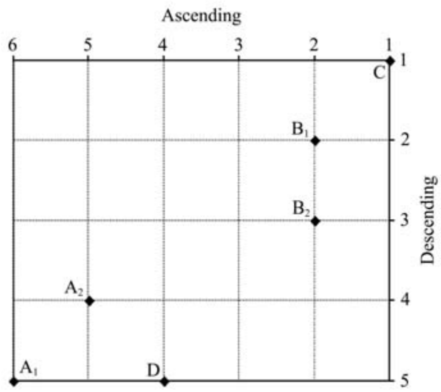

Figure 2 Ascending and descending distillations

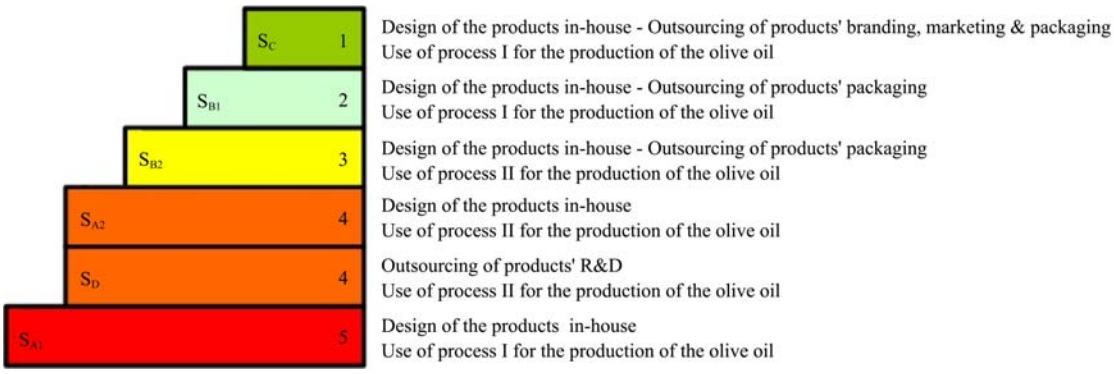

Figure 3 Hierarchy of available alternative strategies

As a result of the methodology, the "House of Olive" is proposed to bring to market 250/500/750 mL tin bottled conventional extra virgin olive oil (Figure 4a) and 250/500/750 mL tin bottled organic extra virgin olive oil (Figure 4b), following the product design suggestions of Design Group Y. The methodology concludes with a sensitivity analysis on the parameter values. Sensitivity analysis is an advantage of the presented methodological approach on the grounds that real life applications input data originate from estimations which, although assumed constant, are sometimes more or sometimes less reliable. General sources of individual uncertainties could come from data series uncertainties, uncertainty about the future, synergies and idiosyncrasies in the interpretation of ambiguous or incomplete information. In any case, it should be underlined that the simultaneous consequences of potential variations of parameter values, decision variables and constraints could be studied by new runs model, since the low computational time gives the opportunity for fast reformed optimal solutions. On this basis, ELECTRE III is preferable, since it is considered to better adapt to uncertainties (Roy and Bouysou, 1993). For the case under examination, the problem is resettled with modified thresholds from those calculated with empirical Equations (1) and (2). Five parameter-based scenarios S with differentiating preference and indifference thresholds by 50% (increasing and decreasing) were examined in addition to the "basic" scenario, as depicted in Table 3. The ranking of the alternative strategies remains practically unaltered for most threshold-based scenarios, which provides the decision-maker with additional confidence that the ranking is adequately robust.

a b

Figure 4 The "House of Olive" products brought to market

Table 3 Thresholds' variations

	S_1	S_2	S_3	S_4	S_5
Preference	p_i	$1.25\times p_i$	$1.5\times p_i$	$0.75\times p_i$	$0.5\times p_i$
Negligence	$0.3\times p_i$	$0.38\times p_i$	$0.45\times p_i$	$0.23\times p_i$	$0.15\times p_i$
Variation	-	25%	50%	-25%	-50%

5 Conclusions

Collaboration between manufacturers and suppliers has gained considerable attendance over the past decades. Globally, manufacturers tend to upgrade their supply chain's collaborators from providing parts, components or materials, also to sharing information and knowledge. In this light, there are many cases where manufacturers decide to outsource R&D instead of executing it "in-house". Moreover, for many firms' outsourcing critical functions of their operations such as R&D has become the only choice, recognizing the competitive advantages of employing this particular strategy. Mainly, the advantages stem from the high level of expertise and specialization of their suppliers on designing parts and/or components that better suit the product under development. In many cases, logistics outsourcing can also help in reducing cost elements and lead times.

In this paper a decision-support approach was presented, developed to help companies in their selection of optimal outsourcing strategy for their R&D operations. The presented methodological framework provides firms with an easy-to-use tool that enables them to simultaneously assess several -often mutually conflicting- parameters that influence such strategic decisions. To that end, multicriteria analysis can play a critical role, since the formulation potentialities are wide. The methodology was implemented in a real-world case study of the "House of Olive", seeking to select among six available R&D strategies for bringing to market an extra virgin olive oil produced of conventional and organic farming. However, the procedure could be easily adopted -with slight modifications and adjustments to the special requirements of the problem under consideration- in order to solve similar problems other than the one examined in the present work. Necessary adjustments mainly have to do with the company's specific objectives and strategic goals, which influence the selection of the specific criteria to be selected and their corresponding weighting factors. In case companies' needs are different than the ones herein presented, different criteria may be decided to be utilized. However, the overall methodology remains practically unaltered. Moreover, multicriteria decisions aid methodologies other than ELECTRE III (e.g. PROMETHEE, AHP etc.) could be also employed for sensitivity analysis purposes. This remains among the authors' future challenges.

Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7-REGPOT-2012-2013-1) under grant agreement no 316167 (Project Acronym: GREEN-AgriChains), as well as the European Social Fund – ESF and Greek national funds through the Operational

Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) (Research Funding Program: THALES) entitled "Investing in knowledge society through the European Social Fund (No. OPS 379411)". Moreover, the present scientific paper was partially executed in the context of the project entitled "International Hellenic University (Operation – Development)", which is part of the Operational Programme "Education and Lifelong Learning" of the Ministry of Education, Lifelong Learning and Religious affairs and is funded by the European Commission (European Social Fund – ESF) and from national resources. Last but not least, the authors would like to thank Mr. Anastasios Kalaitzidis, Operations Manager of the "House of Olive" for his assistance in preparing a real-world case study for the demonstration of the methodological framework.

References

Achillas, Ch., N. Moussiopoulos, A. Karagiannidis, G. Banias, and G. Perkoulidis. 2013. Use of multi-criteria decision analysis to tackle waste management problems: A literature review. *Waste Management and Research*, 31(2): 115-129.

Achillas, Ch., Ch. Vlachokostas, N. Moussiopoulos, and G. Banias. 2011. Prioritise strategies to confront environmental deterioration in urban areas: Multicriteria assessment of public opinion and experts' views. *Cities*, 28(5): 414-423.

Achillas, Ch., Ch. Vlachokostas, N. Moussiopoulos, and G. Banias. 2010. Decision support system for the optimal location of electrical and electronic waste treatment plants. *Waste Management,* 30(5): 870-879.

Banias, G., Ch. Achillas, Ch. Vlachokostas, N. Moussiopoulos, and S. Tarsenis. 2010. Assessing multiple criteria for the optimal location of a construction and demolition waste management facility. *Building and Environment,* 45(10): 2317-2326.

Bidault, F., C. Despres, and C. Butler. 1998. Leveraged innovation: Unlocking the innovation potential of strategic supply. London: MacMillan Business.

Bonaccorsi, A. and A. Lipparini. 1994. Strategic partnerships in new product development: An Italian case study. *The Journal of Product Innovation Management,* 11(): 134-145.

Bozdogan, K., J. Deyst, D. Hoult, and M. Lucas. 1998. Architectural innovation in product development through early supplier intergration. *R & D Management*, 28(3): 163-173.

Bruce, M., F. Leverick, D. Littler, and D. Wilson. 1995. Success factors for collaborative product development: A study of suppliers of information and communication technology. *R & D Management*, 25(1): 33-44.

Culley, S.J., O. P. Boston, and A. Christopher. 1999. Suppliers in new product development: Their information and integration. *Journal of Engineering Design*, 10(1): 59-75.

Dowlatshahi, S. 1999. A modeling approach to logistics in concurrent engineering. *European Journal of Operational Research*, 115(1): 59-76.

Dowlatshahi, S. 1998. Implementing early supplier involvement: A conceptual framework. *International Journal of Operations and Production Management*, 18(2): 143-167.

Emden, Z., R. J. Calantone, and C. Droge. 2006. Collaborating for new product development: Selecting the partner with maximum potential to create value. *The Journal of Product Innovation Management*, 23(): 330-341.

Erkut, E., A. Karagiannidis, G. Perkoulidis, and S. Tjandra. 2008. A multicriteria facility location model for municipal solid waste management in North Greece. *European Journal of Operational Research*, 187(3): 1402-1421.

Gerlach, M. 1992. The Japanese corporate network: A blockmodel analysis. *Administrative Science Quarterly*, 37(): 105-139.

Goffin, K., F. Lemke, and M. Szwejczewski. 2006. An exploratory study of 'close' supplier–manufacturer relationships. *Journal of Operations Management*, 24(): 189-209.

Handfield, R. and E. L. Nichols. 2002. Supply chain redesign: Transforming supply chains into integrated value systems. Financial Times Prentice Hall.

Hanson, D. and C. Lackman. 1998. Managing through cultural differences. *Competitiveness Review*, 8(2): 46-54.

Hertz, S. and M. Alfredsson. 2003. Strategic development of third party logistics providers. *Industrial Marketing Management*, 32(2): 139-149.

Hokkanen, J. and P. Salminen. 1997. Choosing a solid waste management system using multicriteria decision analysis. *European Journal of Operational Research*, 98(1): 19-36.

Iakovou, E., N. Moussiopoulos, A. Xanthopoulos, Ch. Achillas, N. Michailidis, M. Chatzipanagioti, C. Koroneos, K. D. Bouzakis, and V. Kikis. 2009. A methodological framework for end-of-life management of electronic products. *Resources, Conservation and Recycling*, 53(): 329-339.

Jayaram, J. and K. C. Tan. 2010. Supply chain integration with third-party logistics providers. *International Journal Production Economics,* 125(2): 262-271.

Koufteros, X. A., T. C. E. Cheng, and K. H. Lai. 2007. "Black-Box" and "Gray-Box" supplier integration in product development: Antecedents, Consequences and the moderating role of firm size. *Journal of Operations Management*, 25(): 847-870.

Le Dain, M. A., R. Calvi, and S. Cherity. 2011. Measuring supplier performance in collaborative design: Proposition of a framework. *R and D Management,* 41(1): 61-79.

Munier, N. 2004. Multicriteria environmental assessment: A practical guide. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Perks, H. 2000. Marketing information exchange mechanisms in collaborative new product development. *Industrial Marketing Management*, 29(2): 179-189.

Petersen, K. J., R. Handfield, and G. Ragatz. 2005. Supplier integration into new product development: Coordinating product, process and supply chain design. *Journal of Operations Management*, 23(): 371-388.

Provan, K. G. 1993. Embeddedness, interdependence and opportunism in organizational supplier-buyer networks. *Journal of Management,* 19(4): 841-856.

Queiruga, D., G. Walther, J. Gonzalez-Benito, and T. Spengler. 2008. Evaluation of sites for the location of WEEE recycling plants in Spain. *Waste Management*, 28(): 181-190.

Rouibah, K. and K. R. Caskey. 2005. Managing concurrent engineering with early supplier involvement: a case study. *International Journal of Computer Integrated Manufacturing*, 18(6): 509-521.

Rousis, K., K. Moustakas, S. Malamis, A. Papadopoulos, and M. Loizidou. 2008. Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus. *Waste Management*, 28(10): 1941-1954.

Roussat, N., C. Dujet, and J. Méhu. 2009. Choosing a sustainable demolition waste management strategy using multicriteria decision analysis. *Waste Management,* 29(1): 12-20.

Roy, B. 1978. Electre III; Algorithme de classement base sur une representation floue des preferences en presence de criteres multiples. *Cahiers de CERO*, 20(1): 3-24.

Roy, B. and D. Bouyssou. 1993. Aide multicritere a la decision: Methods et cas. Economica, Paris.

Sivadas, E. and F. R. Dwyer. 2000. An examination of organizational factors influencing new product success in internal and alliance-based processes. *Journal of Marketing*, 64(1): 31-49.

Steuer, R. E. and P. Na. 2003. Multiple criteria decision making combined with finance: A categorized bibliographic study. *European Journal of Operational Research*, 150(3): 496-515.

Vallée, D. and P. Zielniewicz. 1994. ELECTRE III-IV, version 3.x, Aspects Méthodologiques (Tome 1), Guide d'utilisation (Tome 2). Document du LAMSADE No. 85 et 85 bis, Université de Paris Dauphine, France.

Van Echtelt, F.E.A., F. Wynstra, and A. J. van Weele. 2007. Strategic and operational management of supplier involvement in new product development: A contingency perspective. *IEEE Transactions on Engineering Management*, 54(4): 644-661.

Von Corswant, F. and C. Tunälv. 2002. Coordinating customers and proactive suppliers - A case study of supplier collaboration in product development. *Journal of Engineering and Technology Management*, 19(3-4): 249-261.

Wynstra, F. and E. T. Pierick. 2000. Managing supplier involvement in new product development: A portfolio approach. *European Journal of Purchasing and Supply Management*, 6(): 49-57.