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Khaoula Besbes

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## A two-phase approach for supply chain design with product life cycle and green procurement considerations

K.BESBES, H.ALLAOUI, G. GONCALVES

Université Lille Nord de France,  
U. Artois, LGI2A, F-62400 Béthune, France  
Khaoula\_besbes@yahoo.fr  
Hamid.allaoui@univ-artois.fr  
Gilles.goncalves@univ-artois.fr

T. LOUKIL

LOGIQ-ISGIs Route de Mharza B.P. 954 – 3018,  
Sfax, Tunisie  
Taicir.loukil@fsegs.rnu.tn

**ABSTRACT:** A supply chain is an alliance of independent business processes, such as supplier, manufacturing, and distribution processes that perform the critical functions in the order fulfillment process. Effective design and management of supply chains assist in production and delivery of a variety of products at low cost, high quality, and short lead times. However, the discussions in marketing and logistic literature universally conclude that it would be desirable to determine the life cycle of products in the firm, as they have a great impact on appropriate supply chain design. On the other hand, industry practitioners and policy makers are under increasing pressure to continuously reduce the negative environmental impact of their supply chains.

This paper presents a two-phase mathematical programming approach for effective supply chain design with product life cycle and environmental impact considerations. More specifically, the methodology develops and applies a combination of multi-criteria decision making models, based on aggregation concepts, and linear and integer programming methods. Model application and insights are detailed through numerical illustrations.

**KEYWORDS:** supply chain design, product life cycle, multi-criteria decision making, green procurement.

### 1 INTRODUCTION

The Product life cycle describes the stages a product goes through from beginning to end (Aitken et al. 2003). If a curve is drawn showing product sales volume, over a fixed time horizon H, it may take one of many different shapes, the most classical of which is shown in “fig.1”.

The competitive criteria generally differ during the different phases of product life cycle; for instance, availability and technology are needed at the “introduction” phase, and cost, quality and speed are needed at the “maturity” phase (Chang et al. 2006)

The discussions in marketing and logistic literature universally conclude that it would be desirable to determine the life cycle of each product in the firm. In fact they could be very useful as marketing models. Moreover, the life cycle stages also have a great impact on appropriate supply chain design.

This implies that a firm’s product-specific procurement, manufacturing, and distribution priorities must change over time. To be effective, a firm’s supply chain design strategy should have a strategic orientation and be governed by objectives that are different from traditional objectives.

On the other hand, industry practitioners and policy makers are under increasing pressure to continuously reduce the negative environmental impact of their supply chains.

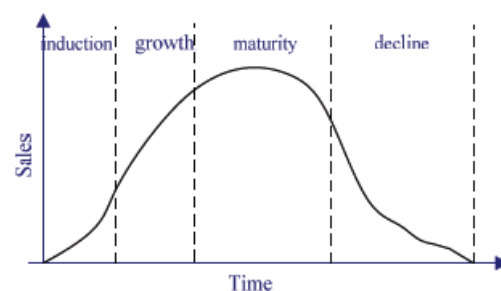


Figure 1: Marketable product life cycle

Effectively, the variations of the production volume during the product life cycle, highlight the importance of taking into consideration the green procurement, which involves buying a product or a service that mitigates the environmental impacts.

This study develops a mathematical model that incorporates the firm’s PLC-oriented relative preferences for multiple purchasing, manufacturing and distributing criteria, so as to minimize the supply chain total cost, including the CO2 emissions costs. The proposed model

incorporates subjective priorities for decision criteria in selecting the supply chain partners, with respect to cost, quality, R&D, service, CO<sub>2</sub> emissions, and delivery performance, of supply, manufacturing and distributing arrangements.

## 2 LITERATURE REVIEW

Christopher and Towill (2000) developed the product classification system with five parameters, Duration of life cycle, Time Windows for delivery, Volume, Variety and Variability, with the acronym DWV3. Childerhouse et al. (2002) applied the system to the supply chain management approach of their case company in the lighting industry. Interestingly, the product life cycle appears to be best suited to explain the five different supply chain strategies identified. According to the authors, the product life cycle provides not only the basis for shaping the supply chain to suit particular marketplaces, but it incorporates the dynamic perspective needed in order to adapt to changing marketplace conditions. The dynamic product routing through its product life cycle is best supported by supply chain strategies ranging from “design and build” in the introduction phase, via “Material Requirements Planning” and “Kanban” in the growth and maturity phases, to “packaging centre” and “Material Requirements Planning” in the product’s saturation and decline phases. Aitken et al. (2003) provided some important considerations about the relationship of life-cycle stages with supply-chain strategy. They discussed the matching of products to pipelines for maximizing competitiveness with respect to order-winner and market-qualifier product characteristics. Vonderembse et al. (2006) developed a typology for supply chain design based on product characteristics, customer expectations, and stage of the product life cycle. They observed that the key success factors for a product are expected to change as it moves through its life cycle and this may require different supply chain characteristics and capabilities. Chang, Wang, and Wang (2006) observed that supply chain product development strategy should depend on the particular phase of the product life cycle. This in turn affects core competencies and outsourcing synergies. They considered a multi-attribute quantitative approach for decision support in the supplier-selection context. Narasimhan et al. (2006) studied supplier selection in connection with the life cycle stage of products. They proposed that in industrial purchasing contexts firms often procure a set of products from the same suppliers to benefit from economies of scale and scope. These products often are at different stages of their respective product life cycles. Moreover, firms consider multiple criteria in purchasing products, and the relative importance of these criteria varies depending on the product life cycle stage of a given product.

Punakivi and Hinkka (2006) did not discuss modeling, they provided a logistics case study on transportation mode selection from the industry point of view. Their

study hopes to better inform current and future logistics service needs. They identified the shortening of product and service life cycles as one of the four major influential trends, along with globalization, concentration on core competencies, and the growth and expansion of e-business in supply chain networks. A useful table ranks the importance of the four criteria of convenience, price, quality, and speed in the industries of construction, electronics, machinery, and pharmaceuticals, respectively. Wang et al. (2004) considered the supplier selection problem using a combination of the Analytic Hierarchy Process (AHP) and preemptive goal programming (PGP).

The uniqueness of the approach proposed in this paper for SCN design is that it not only addresses the operational aspects, but more importantly it incorporates efficiencies of individual supply chain processes, developed from robust productivity models, and capacity and location constraints into the decision making process. The incorporation of efficiencies into the analysis is critical because it prevents the decision maker from selecting inefficient processes in the corresponding product life cycle stage, which if included in the network may adversely affect its overall performance in terms of cost, quality, delivery, and flexibility. Finally, this solution procedure is developed in alignment with the opinion of many experts urging the need for efficient, agile, and compatible business processes for effective SCN design and operation.

## 3 METHODOLOGY

In this paper, a two- phase approach is proposed. Phase I evaluates potential suppliers, manufacturers, and distributors in determining their efficiencies with respect to the product life cycle stage. The models utilized in phase I include a combination of the AHP and the OWA aggregation models, for performance evaluation. In order to minimize the total cost supply chain design, the phase II involves the application of a linear integer programming model, which optimally selects candidates for SCN design, and identifies the optimal routing decisions for all entities in the network by integrating the efficiencies identified in phase I, demand, capacity requirements, CO<sub>2</sub> emissions, location and flow conservation constraints.

### 3.1 Phase I :a multi-criteria decision making problem

The decision makers initiate phase I with the identification of the required business process types, which is followed by the consideration of potential candidates for each process.

The criteria encompass the most important resources utilized by the business process, and the attributes should include a range of performance and activity measures. An extension of the AHP process using OWA operators (Yager et al., 1999), is then utilized to evaluate all the

candidates of each process, at each product life cycle phase. However, these two procedures do not operate at the same level. The AHP is a global tool for creating a hierarchical model of the spatial decision problem, analyzing the whole process and evaluating each alternative. The evaluation process in the AHP uses a simple weighted linear combination to calculate the local scores of each alternative. The OWA operators, alternatively, provide a general framework for making a serie of local aggregations used in the AHP. The very nature of these two procedures gives rise to their combination and creates a more powerful decision making tool (Yager et al. 1999).

**3.1.1. Problem structuring**

As in the AHP procedure, we begin by structuring the problem. This step consists on the creation of the decision hierarchy by structuring the decision problem into a hierarchy of decision elements, generally going from the most general objectives to the most specific ones. The last level of the hierarchy contains the alternatives, the possible choices. In the context of this paper, a typical four-level hierarchy of objective, criteria, attributes and alternatives has been considered. The hierarchical structure of the decision problem is shown in the figure 2.

**3.1.2 Data collection**

Table 1, revised from Wang et al. (2009) lists an integral description of the different criteria and attributes considered and the corresponding original scale measurement. This table will be adapted to our case study for the three different business process types, namely procurement, production and distribution processes. Numerical and linguistic interval scales are used in this approach. Figure 3 presents the linguistic rating on membership function corresponding to fuzzy number, (Herrera et al. 2000).

		scale
R&D	Design	L
	Technique	L
	Innovation	L
Cost	Normal unit cost	N
	Minimum order quantity	N
	Discount	N
Quality	Characteristic 1	N
	Characteristic 2	N
	Characteristic 3	N
Environmental impact	Energy requirement	N
Service	Flexibility	N
	Stockout	N
	Additional service	L
Response	Normal delivery lead-time	N
	Requiring lead-time to changing volume	N
	Requiring lead-time to changing design	N
	Minimum delivery lead-time	N

“L” means linguistic scale; “N” means numerical scale  
 Table 1: The core of factors on supply chain performance

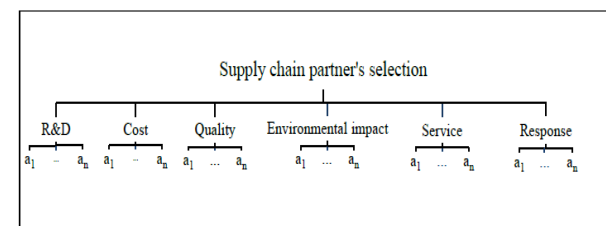


Figure 2: Hierarchical structure of the decision problem

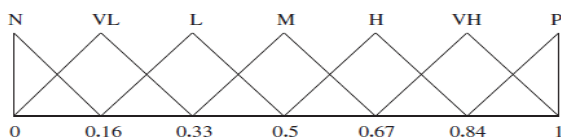


Figure 3. Linguistic rating on membership function corresponding to fuzzy number

Criteria	Attributes	Original
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**3.1.3 Determination of component weights**

The AHP allows the weights to be given through a pairwise comparisons; made on a semantic scale; of the elements emanating from a node of the hierarchy with regard to the parent node. All these pairwise comparisons are stored in matrices. Ratios scale are shown in table 2. The eigenvector associated with each pairwise comparison matrix represents then the relative weight of the decision elements.

Intensity of importance	Verbal judgment of performance
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

Table 2: Ratio scale

**3.1.4 Inclusion of criteria importances**

Now we consider the situation in which each of the criteria has an associated importance, and consider an overall aggregation function of the form:

*Q* of the important criteria are satisfied by an acceptable solution.

The OWA aggregation operator, presents a parametrization which allows the decision maker to go from the extreme of requiring “all the criteria” to be

satisfied, to the other extreme of requiring “at last one criterion” and includes the case of taking the average of the criteria scores. As an extension of these two-well known quantifiers, Zadeh (1983) proposed the concept of the fuzzy linguistic quantifiers  $Q$ , where the membership function  $Q(r)$  represents the membership grade on  $r$  that belongs to  $Q$ .

This study uses three quantifiers to fit the supply chain strategy depending on the importance of the criteria, as illustrated in figure 4.

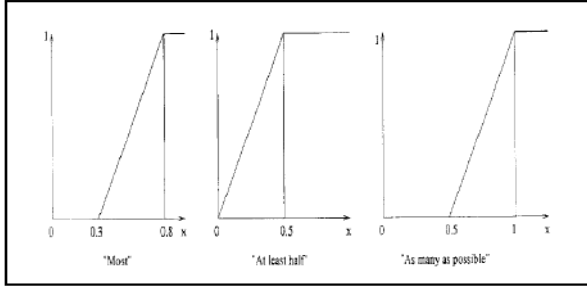


Figure 4: Monotonically non-decreasing fuzzy linguistic quantifier

However, to gain the competitive advantages, the focal company must adopt different supply chain strategies during the different phases of the product life cycle. Inspired from Aitken et al. (2003) the table 3 presents the importance, expressed in linguistic quantifier, associated with the different criteria in each product life cycle phase. At this point, the quantifier guided OWA procedures take the lead for the rest of the analysis. The procedure at this stage involves three main steps : (i) specifying the linguistic quantifiers  $Q$  corresponding to each criterion , (ii) generating a set of ordered weights associated with  $Q$ , and (iii) computing the overall evaluation for each alternative, at each level of the hierarchy, at each product life cycle stage, by means of the OWA combination function, (Malczewski, 2006).

### 3.1.5 The overall evaluation

For evaluating this type of decision function, we use the method proposed by Yager (1996)

Let us assume that  $\{A_1, \dots, A_n\}$  are our attributes, and that the  $V_i$  are the importances of each attribute. Let  $x \in X$  be an alternative. First, we reorder the  $A_i(x)$  such that  $b_j$  is the  $j$ -th largest element of the  $\{A_1(x), \dots, A_n(x)\}$ . Furthermore, let  $u_j$  denote the importance associated with the attribute that has the  $j$ -th largest satisfaction.

We use this information to construct an OWA operator of dimension  $n$  with weighting vector defined by:

$$w_j(x) = Q\left(\frac{\sum_{k=1}^j u_k}{T}\right) - Q\left(\frac{\sum_{k=1}^{j-1} u_k}{T}\right)$$

Linguistic Quantifier \ Phase	Introduction	Growth	Maturity	Decline
At least half	R&D	Service	Cost	Service
Most	Quality	Cost	Environmental impact	Cost
	Cost	Quality	Quality	Quality
	Response	Response	Service	Response
	Environmental impact	Environmental impact	Response	Environmental impact
As many as possible	Service	R&D	R&D	R&D

Table 3: Product attributes and supply chain strategy on product life cycle

where

$$T = \sum_{k=1}^n u_k$$

and

$$Q(r) = \begin{cases} 0 & \text{if } r < a \\ \frac{r-a}{b-a} & \text{if } a \leq r \leq b \\ 1 & \text{if } r > b \end{cases}$$

Where the parameters  $(a, b)$  corresponding to the relative quantifiers “most”, “at least half” and “as many as possible” are  $(0.3, 0.8)$ ,  $(0, 0.5)$ , and  $(0.5, 1)$ , respectively.

Finally the decision aggregator is :

$$D(x) = \sum_{j=1}^n b_j w_j(x)$$

The above problem is solved separately for each of the three business process types at each product life cycle stage, and the solutions identify the efficiency scores; corresponding to the potential suppliers, manufacturers, and distributors ; to be utilized in the supply chain design model.

## 3.2 Phase II: the supply chain design

At each product life cycle stage; taking into account the efficiency scores, the capacity, the location, the demand, and the co2 emissions constraints; the supply chain network design framework needs to identify the optimal supply chain actors, as well as the deployment plans.

The proposed model allows identifying, at each product life cycle stage, the optimal routing of material from selected suppliers to manufacturers to warehouses by minimizing the supply chain total cost.

### 3.2.1 Notation

To formulate the problem, the following parameters are used:

$CF_{i,t}$  Fixed cost to open and operate the supplier

	i at stage t		Ton per Kwh
$CF_{j,t}$	Fixed cost to open and operate the producer j at stage t	$\alpha_k$	CO2 emission factor, for the distributor k, in Ton per Kwh
$CF_{k,t}$	Fixed cost to open and operate the distributor k at stage t	$\alpha_s$	CO2 emission factor for transportation, in Ton per Ton.Km
$c_{ij,t}$	Unit production and transportation cost from supplier i to producer j , at stage t	$CO_2^{MAX}$	Maximum amount of CO2 that can be emitted( allocated by the government), in Ton
$c_{jk,t}$	Unit production and transportation cost from producer j to distributor k, at stage t		Carbon tax, in € per Ton CO2
$c_{kz,t}$	Unit production and transportation cost from distributor k to customer zone z, at stage t	$\theta_1$ $\theta_2$	Weight of the logistical costs function Weight of the CO2 emission costs function
		Decision variables:	
$e_{i,t}$	Mean efficiency score of the supplier i, at stage t	$X_{i,t}$	=1 if the supplier i is selected at stage t, 0 otherwise
$e_{j,t}$	Mean efficiency score of the producer j, at stage t	$X_{j,t}$	=1 if the producer j is selected at stage t, 0 otherwise
$e_{k,t}$	Mean efficiency score of the distributor k, at stage t	$X_{k,t}$	=1 if the distributor k is selected at stage t, 0 otherwise
$e_{exp,i,t}$	The minimum expected group efficiency average set forth by the decision maker for the suppliers at stage t	$X_{ij,t}$	Quantity shipped from supplier i to producer j, at stage t, in Ton
$e_{exp,j,t}$	The minimum expected group efficiency average set forth by the decision maker for the producers at stage t	$X_{jk,t}$	Quantity shipped from producer j to distributor k, at stage t, in Ton
$e_{exp,k,t}$	The minimum expected group efficiency average set forth by the decision maker for the distributors at stage t	$X_{kz,t}$	Quantity shipped from distributor k to customer zone z, at stage t, in Ton
$cap_{i,t}$	Capacity limit of the supplier i, at stage t	$CO_2^{CUR}$	Amount of CO2, in Ton, that is currently emitted
$cap_{j,t}$	Capacity limit of the producer j, at stage t	<b>3.2.2 The model</b>	
$cap_{k,t}$	Capacity limit of the distributor k at stage t	$\min \sum_t [\theta_1 (\sum_{i=1}^m CF_{i,t} * X_{i,t} + \sum_{j=1}^n CF_{j,t} * X_{j,t} + \sum_{k=1}^p CF_{k,t} * X_{k,t} + \sum_{i=1}^m \sum_{j=1}^n c_{ij,t} * X_{ij,t} + \sum_{j=1}^n \sum_{k=1}^p c_{jk,t} * X_{jk,t}) + \theta_2 * \gamma (CO_2^{CUR} - CO_2^{MAX})]$	
$D_{z,t}$	Minimum downstream demand of the customer zone z, at stage t	s.t	
$d_{ij}$	Distance, in Km, between the supplier i, and the producer j	<i>Efficiency constraints:</i>	
$d_{jk}$	Distance, in Km, between the producer j, and the distributor k	$\sum_{i=1}^m e_{i,t} X_{i,t} - e_{exp,i,t} \sum_{i=1}^m X_{i,t} \geq 0 \quad \forall t \quad (1)$	
$d_{kz}$	Distance, in Km, between distributor k and the customer zone z	$\sum_{j=1}^n e_{j,t} X_{j,t} - e_{exp,j,t} \sum_{j=1}^n X_{j,t} \geq 0 \quad \forall t \quad (2)$	
$\alpha_i$	CO2 emission factor, for the supplier i, in Ton per Kwh	$\sum_{k=1}^p e_{k,t} X_{k,t} - e_{exp,k,t} \sum_{k=1}^p X_{k,t} \geq 0 \quad \forall t \quad (3)$	
$\alpha_j$	CO2 emission factor, for the producer j, in		

Capacity limits constraints:

$$\sum_{j=1}^n X_{ij,t} \leq \text{cap}_{i,t} * X_{i,t} \quad \forall i, t \quad (4)$$

$$\sum_{k=1}^p X_{jk,t} \leq \text{cap}_{j,t} * X_{j,t} \quad \forall j, t \quad (5)$$

$$\sum_{z=1}^q X_{kz,t} \leq \text{cap}_{k,t} * X_{k,t} \quad \forall k, t \quad (6)$$

CO2 emissions constraint :

$$\begin{aligned} & CO_2^{CUR} \\ &= \sum_{i \in I} \alpha_i \varepsilon_i X_{i,t} + \sum_{j \in J} \alpha_j \varepsilon_j X_{j,t} + \sum_{k \in K} \alpha_k \varepsilon_k X_{k,t} \\ &+ \sum_{i \in I} \sum_{j \in J} \alpha_s d_{ij} X_{ij,t} \\ &+ \sum_{j \in J} \sum_{k \in K} \alpha_s d_{jk} X_{jk,t} \\ &+ \sum_{k \in K} \sum_{z \in Z} \alpha_s d_{kz} X_{kz,t} \end{aligned} \quad (7)$$

Flow conservation constraints:

$$\sum_{i=1}^m X_{ij,t} - \sum_{k=1}^p X_{jk,t} = 0 \quad \forall j, t \quad (8)$$

$$\sum_{j=1}^n X_{jk,t} - \sum_{z=1}^q X_{kz,t} = 0 \quad \forall k, t \quad (9)$$

Total market demand satisfaction constraint:

$$\sum_{k=1}^p X_{kz,t} \geq D_{z,t} \quad \forall z, t \quad (10)$$

Positivity constraints :

$$X_{ij,t} \geq 0 \quad \forall i, j, t \quad (11)$$

$$X_{jk,t} \geq 0 \quad \forall j, k, t \quad (12)$$

$$X_{kz,t} \geq 0 \quad \forall k, z, t \quad (13)$$

$$X_{i,t} \in \{0,1\} \quad \forall i, t \quad (14)$$

$$X_{j,t} \in \{0,1\} \quad \forall j, t \quad (15)$$

$$X_{k,t} \in \{0,1\} \quad \forall k, t \quad (16)$$

$$i = 1, \dots, m,$$

$$j = 1, \dots, n,$$

$$k = 1, \dots, p,$$

$$z = 1, \dots, q$$

The developed MIP model aims to select suppliers from a candidate set of suppliers, as well as to locate a given number of producers, and distributors, to satisfy the demand requirements at the customer zones at each product life cycle stage, in order to minimize the overall supply chain management cost, subject to supplier, producer and distributor capacity restrictions, and efficiency scores.

We assume that the customer zone locations and their specific demand estimates are given in advance. The

potential supplier, producer and distributor locations as well as their capacities are also known. For each selected actor, a decision must be made on the total units of products that need to be transported from the selected supplier, to the open producer to the open distributor, and the total units of products that need to be distributed from the open distributor to the customer zones. The total cost of the supply chain includes purchasing and transportation cost, production cost, distribution cost, fixed costs such as the fixed ordering cost, the fixed cost to open and operate a producer, the fixed cost to open and operate a distributor, and the CO2 emission cost. The different cost function weights are to be determined using the AHP process, these weights can also change from one phase of the product life cycle, to another.

#### 4 NUMERICAL EXAMPLE

This section presents a small-scale supply chain design problem adapted from a real-life situation. The purpose is neither to show any advantage of the modeling process by comparing with other MIP models, nor to exhibit the efficiency of problem solving by benchmarking the computation time to other algorithms. Indeed, we aim to illustrate the effectiveness and convenience of the product life cycle consideration in the supply chain design, by introducing a multi-criteria decision making model to select the effective supply chain actors in the different product life cycles stages, and the efficiency constraints into the model . We consider the case of a focal company which is in the launching process of a new product on the market, namely, the environmentally coal from the olive pomace. The company has to design its supply chain with a minimal cost, considering the product life cycle stages.

The figure 5 shows the sales distribution in Ton for the 3 different customer zones.

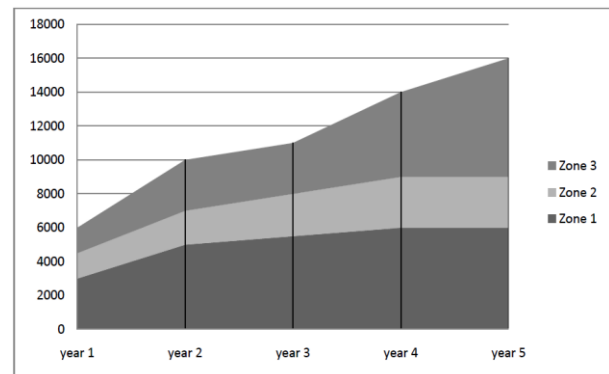


Figure 5: Sales distribution of the product in Ton

The multiple attribute matrices and the efficiency scores, for the introduction and maturity phases, obtained from phase I are shown in the tables 4,5 and 6, for the suppliers, producers and distributors respectively.

The mathematical model is solved to identify the optimum solution.



Criteria	Attributes	S1	S2	S3	S4	S5	S6
R&D	Grinding technique	0.67	0.5	0.5	0.33	0.5	0.5
	Drying technique	0.67	0.67	0.5	0.67	0.67	0.33
	Innovation	0.5	0.5	0.67	0.5	0.67	0.5
Cost	Fixed cost in €	5000	3000	0	5000	0	3000
	Normal unit cost in €	55	50	52	53	53	55
	Minimum order quantity in Ton	2000	2000	1000	2000	2000	1000
Quality	Humidity	0.08	0.1	0.06	0.05	0.08	0.1
	Rate of oil	0.03	0.025	0.02	0.02	0.03	0.025
	Grain size in mm	2	2	1.5	3	2.5	3
Environmental impact	Energy requirement in Kwh	89000	104500	157200	72000	262500	285000
Service	Packaging	90%	95%	85%	95%	99%	90%
	Stockout	2%	8%	5%	6%	8%	2%
	Additional service	99%	99%	95%	90%	95%	99%
Response	Normal delivery lead-time in week	4	3	3	2	4	4
	Requiring lead-time to changing volume in week	2	2	1	1	2	1
	Requiring lead-time to changing design in week	1	1	1	1	2	1
Efficiency Score in the introduction phase		0.19	0.18	0.36	0.24	0.15	0.1
Efficiency Score in the maturity phase		0.07	0.26	0.21	0.17	0.12	0.04

Table 4: Multiple attribute matrix on supply performance and efficiency scores

Table 7 illustrates the optimal deployment plans for the supply chain network for the introduction phase, the first year of operation of the company. The optimal supply chain actors and the number of units to be shipped from each source to each destination is clearly depicted in this transshipment solution.

## 5 SENSITIVITY ANALYSIS

Different supply chain strategies could be adopted at different phases of the product life cycle, significantly influencing the supply chain actors' selection decisions. Using the same focal company and the same data values as in Section 4, table 8 gives the optimal supply chain network for the maturity phase, the fifth year of operation of the company. The model demonstrates that the proposed approach cannot only adopt the supply chain strategy according to the degree of concern at different phases, but also consider the trade-off effect to avoid selecting inefficient actors in the correspondent product life cycle stage.

Criteria	Attributes	P1	P2	P3
R&D	Grinding technique	0.84	0.5	0.5
	Drying technique	0.84	0.67	0.5
	Innovation	0.84	0.5	0.3
Cost	Normal unit cost in €	170	160	155
	Minimum order quantity in Ton	2000	1000	1000
	Discount	7%	5%	3%
Quality	Humidity	0.05	0.08	0.08
	Rate of oil	0.015	0.025	0.025
	Calorific in Mj per Kg	19.8	18.5	18
Environmental impact	Energy requirement in Kwh	1310.000	1762.500	1260.000
Service	Packing	0.84	0.67	0.5
	Stockout	2%	6%	8%
	Additional service	99%	90%	80%
Response	Normal delivery lead-time in week	8	10	12
	Requiring lead-time to changing volume in week	2	5	5
	Requiring lead-time to changing design in week	3	5	8
Efficiency Score in the introduction phase		0.75	0.18	0.06
Efficiency Score in the maturity phase		0.68	0.19	0.2

Table 5: Multiple attribute matrix on production performance and efficiency scores

Criteria	Attributes	D1	D2	D3
R&D	Technical market timing	0.84	0.67	0.5
	Distribution technique	0.84	0.84	0.67
	Marketing technique	0.67	0.67	0.5
Cost	Normal unit cost in €	19	19	18
	Minimum order quantity in Ton	500	500	1000
	Unit express delivery cost	22	21	20
Quality	Reliability	99%	90%	85%
	Stability	99%	98%	95%
	Quality business relationships	0.84	0.67	0.5
Environmental impact	Energy requirement in Kwh	900.000	837.500	1200.000
Service	Flexibility	0.84	0.67	0.5
	In store advertising	0.67	0.5	0.16
	Continuity index in min	170	330	350
Response	Normal delivery lead-time in week	10	12	8
	Minimum delivery lead-time in week	7	7	5
	Requiring lead-time to changing volume in week	3	3	2
Efficiency Score in the introduction phase		0.47	0.32	0.09
Efficiency Score in the maturity phase		0.15	0.19	0.35

Table 6: Multiple attribute matrix on distribution performance and efficiency scores



	P <sub>1</sub>	P <sub>2</sub>	D <sub>1</sub>	D <sub>2</sub>	Z <sub>1</sub>	Z <sub>2</sub>	Z <sub>3</sub>
S <sub>3</sub>	2000	12000					
S <sub>4</sub>		2000					
P <sub>1</sub>			2000				
P <sub>2</sub>			1500	12500			
D <sub>1</sub>						3500	
D <sub>2</sub>					8000		4500
Demand					>=8000	>=3500	>=4500

Table7: Optimal supply chain network for the introduction stage

From the results listed in table 8 for the maturity phase, it is interesting to note that supplier 2, which was considered to be inefficient in the introduction phase, was selected as an efficient actor in the maturity phase, and similarly for the producer 3 and the distributor 3.

	P <sub>1</sub>	P <sub>3</sub>	D <sub>2</sub>	D <sub>3</sub>	Z <sub>1</sub>	Z <sub>2</sub>	Z <sub>3</sub>
S <sub>2</sub>		2000					
S <sub>3</sub>	2000	2000					
S <sub>4</sub>		10000					
P <sub>1</sub>			2000				
P <sub>3</sub>			4000	10000			
D <sub>2</sub>					6000		
D <sub>3</sub>					2000	3500	4500
Demand					>=8000	>=3500	>=4500

Table8: Optimal supply chain network for the maturity stage

## 6 CONCLUSION

Effective supply chain management envisioned as a solution to meet the constantly changing needs of the customer at low cost, high quality, short lead times, and high variety. In this paper, a Two-phase mathematical programming approach with product life cycle considerations is proposed for effective supply chain network design.

In phase I of the decision making process, a multi-criteria decision making model is utilized, based on an aggregation model using an extension of the AHP process by the OWA operators, to evaluate the performance of suppliers, manufacturers and distributors. The efficiency scores obtained in this phase will be useful for the efficiency constraints of the phase II. Consequently, this approach has its practical meaning in aggregating supply chain performance and assessing the supply chain partners under different phases of product life cycle.

In phase II, a mixed integer programming problem is utilized to design the supply chain network and identify the optimal routing decisions. The case of production and delivery of multiple products that are in different product life cycle stages is another interesting issue that needs to be considered.

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