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DESIGN OF A GREEN DISTRIBUTION NETWORK WITH MULTIPLE TRANPORTATION MODES

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ABSTRACT

The traditional purpose of the optimization of the distribution networks is the minimization of costs. The majority of researchers put emphasis on the cost as a criterion to measure the performance of the distribution networks. Today, with a greater competition, as well as the pressure that is being practiced upon companies by the regulations and the non-governmental organizations, it appears that it is essential that the distribution networks must operate under reduced environmental impacts and low operating costs. The purpose of our paper is to propose a bi-objective optimization for a green distribution network. Our approach of optimization highlights the compromise between the economic objective and the environmental objective. We are using the ε-constraint method to determine the Pareto front, which will serve us as a decision-making tool for the configuration of a green distribution network.

Keywords: green distribution networks, bi-objective optimization, environmental impact, ε-constraint method.

Nomenclature
MAD: Moroccan Dirham.

1. INTRODUCTION

Chopra [1] asserts that distribution networks are the main keys of profitability because they directly affect the cost of the supply chain as well as customer satisfaction. In reality, the optimization of a distribution network consists in studying the delivery planning of a product starting from the distribution centers (platforms) up to the demand points, and also for the slightest costs and for the highest level of service. Besides the economic performance, and the pressure that the regulations and the non-governmental organizations practice (NGOs) on companies, in order to reduce the environmental impacts of their distribution networks. An increasing number of scientists have suggested environmental sustainability as a relevant objective during the optimization of the distribution networks [2].

The most studied environmental impact in literature is the discharge rate of the greenhouse gases (GHG), particularly carbon dioxide [3]. The consumption of energy and the used resources, as well as the generated waste, are often neglected during the optimization of distribution networks. Our paper is related to the context of the literature of green distribution networks. The first part of the article exposes a literary review for the optimization of the distribution networks. The second part of the article describes the problematic. The third part explains the proposed model. The fourth part is the object of a discussion of the obtained results. We end our article with a conclusion and future research perspectives.

2. LITERATURE REVIEW

The optimization of the distribution networks are NP-hard problems [4]. The traditional purpose of this optimization was the minimization of operational costs, [5], [6], [7], [8]. On the other hand, the green supply chain management (GrSCM) aims at integrating an environmental vision into the practices of the supply chain management (SCM) [9]. The overall objective of this new concept is to reduce the ecological impact of an industrial activity without sacrificing the quality, the costs or the network performance [10].This environmental vision targets the reduction of the air pollution, the efficiency of energy usage, as well as the waste treatment. Fretti *et al.* (2007) present a model that simultaneously optimizes the costs and the pollution generated in a supply chain dedicated to the production of aluminum [11]. Whereas Sundarakani*et al.* (2010) propose a carbon footprint measuring model in all the supply chain (upstream and downstream) [9].

The configuration of the distribution networks and transportation are significant operational characteristics that affect the green supply chain [12]. Li *et al.* (2008) present a bi-objective optimization for the localization of the distribution centers by minimizing the costs and the transportation CO_2 emission rate [13].

Wang *et al.* (2011) studied the compromise between the minimization of both costs and the environmental impacts for a green supply chain [14]. A multi-objective optimization model is proposed by Chaabane *et al.* (2011) in order to assess the costs and the emissions of the greenhouse gases that are generated by the production and the distribution [15]. Afshari and al. (2014) incorporate the environmental sustainability into the design of a distribution network through collecting the returned products after use [16].

In the case of the distribution networks of processed food, Validi *et al.* (2015) present a bi-objective model for the reduction of costs and the carbon footprint [17]. In the same perspective, Bartolini *et al.* (2016) proposed a decision support system, furthermore considering the delivery time as the third objective [18].

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Other papers, discuss the supply chain optimization in an ecological context, they consider The GVRP (Green Vehicle Routing Problem) which aims offering vehicle routing with alternative sources of energy in favor of minimizing the GHG emissions of transportation [19]. Among these papers: Erdogan *et al.*(2012) [20], Xiao *et al.* (2012) [21] and Koç *et al.* (2016) [22].

Many methods have been used, in the literature, to evaluate the environmental impact. However, the Life Cycle Assessment (LCA) is the most scientifically reliable method to study and estimate the environmental impacts of a product or a process [23]. LCA quantifies the emissions and the consumed resources as well as their impacts on the human health and the resources depletion. It takes into account all of the life cycle of a product or a service, starting from the extraction of raw materials, the production, the use and the recycling up to the disposal [24]. There are two categories of environmental impacts, the effect oriented impacts (Midpoint impacts) and the damage oriented impacts (Endpoint impacts) [25].

For the sustainable supply chains management, the Table-3 in [26] shows that, among the methods used for the life cycle assessment (Eco-indicator 99 (EI-99), IMPACT 2002 +, CML92 and ReCiPe), Eco-indicator 99 is the most used one in literature. For the distribution networks, few authors consider the LCA as an evaluation method of the environmental impact.Wang *et al.* (2016) use two impact assessment methods: the Eco-indicator 99 and the EPS2000 to estimate the environmental impacts of transportation in two distribution networks in Taiwan [27]. However, the impact assessment method ReCiPe was only used once by Mota *et al.* (2015) in a multi-objective optimization of the supply chain by incorporating the score that was supplied by ReCiPe 2008 in the optimization model as an environmental objective function [23].

Our article proposes a bi-objective optimization for the design of a green distribution network, by studying the scenarios and the transportation modes. The fact that we deal with this criterion is justified in the paper of Cholette *et al.* (2009). They showed in their paper that the choice of transportation modes is more significant, and has a bigger incidence on the environmental impact in comparison with the minimization of the total traveled distance [28]. The emphasized problem aims to minimize the operational costs of the distribution and the correspondent environmental impact induced by transportation and by the installations (the distribution centers). For the modelling of the environmental objective, we plan to use the valuation method of LCA ReCiPe 2008 for the assessment of the environmental impacts.

3. PROBLEM STATEMENT

In this article, we tackle a bi-objective optimization problem of a green distribution network. Our optimization approach highlights the trade-off between the economic objective and the environmental one. This concession makes the reach of a single optimal solution impossible, which optimizes both objectives simultaneously. Our main contribution is the proposal of a model of optimization, which concedes with the following objectives:

- **First objective:** the minimization of costs related to the distribution;
- **The Second objective:** the minimization of ReCiPe 2008 score for the evaluation of the environmental impact of the distribution network. Our contribution compared to [23], is the study of transportation scenarios between two entities by taking into consideration other transportation modes.

4. THE PROPOSED MODEL

Our problem notably consists in solving two sub-problems:

- The first one is a location-allocation problem;
- The second one studies the possible scenarios of transportation modes concerning minimizing the environmental impact.

We wish to design the distribution network that is represented by figure 1 where we have to optimize:

- The number of distribution centers (CDs) to be opened?

-The plans of delivery (which CD serves which customer?)

- The quantities that are shipped to every CD that serves every customer and by what transportation mode?

-The environmental impact of the transport and the CDs.

Assumptions

Given:

- A unique product or a set of products that possesses the same characteristics;

- A single production site that can deliver directly to the customers;

-The production site and the distribution centers are subjected to capacity constraints;

- Distribution centers only handle the bulking / unbundling of the customers' orders, products will not be stored so as to generate storage costs;

- The demand and the location of the customers are deterministic.

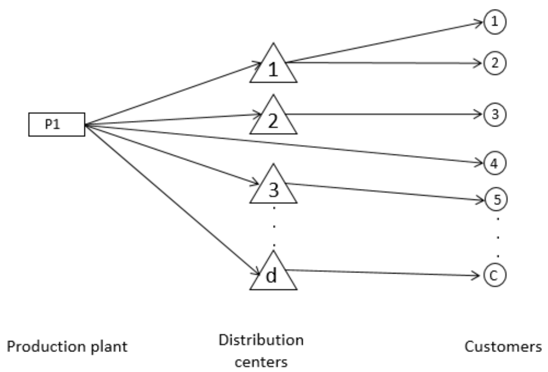

Figure-1. Structure of the distribution network studied (source: developed by the authors).

The sets

D: The set of the potential locations of distribution centers (CD) which each is represented by the set $i \in \{1,\ldots, D\}$

C: The set of the customers which each is represented by the set j {1, …, C}

K: the set of transportation mode $k \in \{1, \ldots, K\}$

The parameters

C_{fi} the fixed costs of maintaining a distribution center

D_i the distance between the production plant and the distribution center i.

D_{ij} the distance between the distribution center i and the customer j

D_j the distance between a customer j and the production pnat

C_i is the maximal capacity of a distribution center

C_u is the maximal capacity of the production site

$Demand_j$ is the demand of the customer j

C_k is the unit cost by kilometer for every mode of transportation.

Cap_k is the capacity of the mode of transportation k

I_{ck} the environmental impact for each impact category for each transportation mode supplied by ReCiPe

I_{cd} the environmental impact of the construction of a distribution center for each impact category supplied by ReCiPe

f_{nc} is the normalization factor of ReCiPe Midpoint for each impact category

Decision variables

$\mathbf{X_{ik}}$ the quantity of product shipped from the production plant to a distribution center using the transportation mode k;

$\mathbf{Y_{ijk}}$ the quantity of product shipped from a distribution center to a client using transportation mode k;

$\mathbf{Z_{jk}}$ the quantity of product shipped directly from the production plant to a client j using transportation mode k;

$\mathbf{W_i}$ binary variable whether a distribution center is open or not

Avec:

$$Wi = \begin{cases} 1 \; if \; the \; distibution \; center \; is \; open \\ 0 \; if \; not \end{cases}$$

We suppose that all the deliveries will be made in full load. We introduce: Tik, Tijk and Tjk which are the numbers of shuttles per transportation mode made between every entity of the distribution network. Calculated from the quantities shipped to every entity divided by the capacity of the transportation mode.

We will then have:

$T_{ik} = X_{ik} / Cap_k$

$T_{ijk} = Y_{ijk} / Cap_k$

$T_{jk} = Z_{jk} / Cap_k$

4.1 The economic objective

The economic objective function is represented by the equation (1). The first term corresponds to the costs of maintaining a distribution center; the other terms of the equation are the relative costs to the transportation of the product between two entities of the network.

a) $Obj1 = \min (\sum_i C_{fi} \times W_i + \sum_i \sum_k T_{ik} \times d_i \times C_k + T_{jk} \times D_{ij} \times C_k + \sum_j \sum_k T_{jk} \times d_j \times C_k)$

Constraints

b) Production plant capacity constraint

$$\sum_j \sum_k Z_{jk} + \sum_i \sum_k X_{ik} \leq C_u$$

c) Distribution center capacity constraint

$$\sum_j \sum_k Y_{ijk} - W_i \times C_i \leq 0 \; \forall \; i$$

d) All clients demands must be satisfied

$$\sum_k Z_{jk} + \sum_i \sum_k Y_{ijk} \geq D_j \, \forall j$$

e) Constraint of Variables definition

$$X_{ijk} \, , \, Y_{ik} \text{ et } Z_{jk} > 0 \; \forall \; i, j,k$$

f) Balance of the product flow constraint

$$\sum_i \sum_j \sum_k Y_{ijk} - \sum_i \sum_k X_{ik} \leq 0$$

4.2 Environmental objective

The environmental impact of the distribution network we are trying to minimize is calculated by the impact assessment method ReCiPe 2008. The functional unity (FU) is the distribution network. The LCA concerns the transportation of products and installations (distribution centers).The LCIA of the system is calculated from the database Ecoinvent 3, using the software OpenLCA. The assessment method of the life cycle is ReCiPe Midpoint conforming to a hierarchical approach. The choice of the evaluation with the method ReCiPe Midpoint H is sparked by the fact that the latter gets an easy score that can be incorporated into the environmental objective function.

The Environmental Impact (IE) considered in this study is the transportation and the distribution centers.

Transportation IE $= \sum_j \sum_k T_{jk} \times d_j \times Ic_k + \sum_i \sum_j \sum_k T_{ijk} \times d_{ij} \times Ic_k + \sum_i \sum_k T_{ik} \times d_i \times Ic_k$

Distribution centers IE $= \sum_i W_i \times I_{cd}$

Then we multiply the equations (7) and (8) by a normalization factor f_{nc} for each impact category

OBJ 2 = min [(IE du transport + IE des CD)$\times f_{nc}$]

4.3The bi-objective resolution approach

In this section, we intend to use the multi-objective optimization method: ε-constraint (also named the compromise method) to solve our bi-objective problem. Indeed, this method considers an order of priority between both objectives. It allows the optimization of the first objective under constraint of the second. Hence, our bi-objective problem of optimization will be transformed into a single objective problem [29].

We thus have to solve the problem of following optimization:

Min F_1 (X)
S.T $F2(X) \leq s \times \Delta\mathcal{E}_2 + F_{2min}(X)$
With $s \in \{1 \dots n\}$ and $\Delta\mathcal{E}_2 = (F_{2max} - F_{2min}) / n$.

5. CASE STUDY

To validate our mathematical model, we suggest studying the case of a company, which pursues a sustainable brand image by designing a green distribution network. Moreover, this can be achieved by the minimization of the operational costs of the distribution while reducing the environmental impact of transportation and the distribution centers.

5.1 Cost assessment

- **The product**

As regards to the product, the company packages its products in Euro pallets with the dimensions 800x1200 mm, the weight of every pallet is 0.5 tons. The customers' demand is conveyed through the number of pallets.

- **The transportation**

The operations of transport are subcontracted. At this moment, the company uses trucks as a transportation mode (k=1) which offers us the possibility of transporting up to 30 pallets (15 tons). We plan to study the configuration of the network by adopting trains as a second transportation mode (k=2) which allows us to transport up to 46 pallets (23 tons). The table 1 shows the unit costs as well as the capacity of every transportation mode.

Table-1. Data related to transportation modes.

	Capacity (in tons)	**Capacity in pallets**	**Unit cost** (in MAD per km)
k = 1	15	30	7.2
k = 2	23	46	11.15

The company possesses three potential locations for the Distribution centers. They are subjected to a capacity and operate under fixed costs.

5.2 Environmental impact assessment

To quantify the environmental impact of the distribution network, a LCA was attained. We used the software OpenLCA, under an academic license for the database "Ecoinvent 3.1", we calculated the Midpoint indicators for each impact category with the LCIA method ReCiPe 2008 following a hierarchical approach.

The Table-2 presents the calculations that were made for every transportation mode and for the distribution centers. The most concerned categories of impact are marine eco-toxicity, Freshwater Eco-toxicity followed by Human toxicity.

Table-2. Data retrieved from the software OpenLCA for the environmental impact of every transportation mode and for the distribution centers.

Impact categories	Reference unit	Transportation mode 1 per Km		Transportation mode 2 per Km		Distribution center per 1000m²	
		EI	Normalized EI(points)	EI	Normalized EI(points)	EI	Normalized EI(points)
Agricultural land occupation	m2*a	3,3275E-02	6,1351E-06	5,3081E-02	9,7869E-06	4,1028E+00	7,5667E-04
Climate Change	kg CO2 eq	2,5128E+00	3,6000E-04	1,0845E+00	1,6000E-04	1,6091E+01	2,3353E-03
Fossil depletion	kg oil eq	8,9735E-01	7,0000E-04	2,8439 -01	2,2000E-04	3,6516E+00	2,8313E-03
Freshwater eco-toxicity	kg 1,4-DB eq	1,8653E-02	4,3300E-03	1,3402E-02	3,1100E-03	8,4826E-01	1,9711E-01
Freshwater eutrophication	kg P eq	1,7206E-04	5,9000E-04	4,1857E-04	1,4400E-03	4,2131E-03	1,4535E-02
Human toxicity	kg 1,4-DB eq	9,6666E-01	2,9600E-03	4,3200E-01	1,3200E-03	7,4815E+00	2,2928E-02
Ionizing radiation	kg U235 eq	2,0190E-01	1,5000E-04	2,125E-01	1,6000E-04	9,8746E-01	7,4933E-04
Marine Eco toxicity	kg 1,4-DB eq	2,9015E-02	1,1780E-02	1,2683E-02	5,1500E-03	7,2816E-01	2,9571E-01
Marine eutrophication	kg N eq	6,5714E-04	8,9540E-05	1,2857E-03	1,8000E-04	2,1654E-02	2,9507E-03
Metal depletion	kg Fe eq	9,4855E-02	2,1000E-04	1,6135E-01	3,6000E-04	3,7400E+00	8,4007E-03
Natural land transformation	m2	9,1820E-04	7,6347E-05	2,1737E-04	1,8074E-05	1,8480E-03	1,5333E-04
Ozone depletion	kg CFC-11 eq	4,5790E-07	1,2169E-05	8,9034E-08	2,3661E-06	1,3355E-06	3,5333E-05
Particulate matter formation	kg PM10 eq	3,8975E-03	2,8000E-04	2,7688E-03	2,0000E-04	5,1744E-02	3,6807E-03
Photochemical oxidant formation	kg NMVOC	6,1352E-03	1,1000E-04	4,4925E-03	7,9183E-05	7,3393E-02	1,2933E-03
Terrestrial acidification	kg SO2 eq	6,0611E-03	1,6000E-04	6,2125E-03	1,6000E-04	1,3505E-01	3,5367E-03
Terrestrial Eco-toxicity	kg 1,4-DB eq	1,9991E-03	3,4000E-04	1,0017E-04	1,6896E-05	2,5596E-03	4,3200E-04
Urban land occupation	m2*a	1,3426E-01	1,7000E-04	5,8212E-02	7,5110E-05	2,2895E-01	2,9533E-04

6. DISCUSSIONS

We coded the proposed model under the GAMS 24.7.1 environment then we solved every objective separately with a PC Intel I5 with 4 GO of RAM with CPLEX 12.0 solver. The run time of the resolution program did not exceed 3 seconds. The Table-3 below illustrate the solutions of minimizing each objective separately.

Table-3. Results of minimization of each objective separately.

	Costs (in MAD)	IE (in points)	Network configuration (D1, D2, D3)	% transportation mode 1 usage	% transportation mode 2 usage
Minimize the costs	2065100	4060,137	(0, 0, 0)	100%	0%
Minimize EI	2963900 (+44%)	1270,095 (-68%)	(1, 0, 1)	0%	100,00%

On one hand, the configuration of the distribution network with minimum operational costs arrives with a significant environmental impact. The direct distribution from the production plant towards the customers is favored which implies that all the Distribution centers are closed. For the transportation, the usage of trucks in transportation has a 100 % rate, this can be easily explained by the fact that distribution centers engender maintaining costs and that the trucks remains the least expensive transportation mode.

On the other hand, if we proceed with a configuration of the distribution network with minimum environmental impact, we penalize the economic objective function. We shall then have to open distribution centers D1 and D3, and to use the 100% rail transportation. Having said that, we can deduct that to solve every

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objective separately does not allow the achievement of an optimal solution in terms of both objectives.

Given that, we firstly wish to minimize the environmental impact of the existing network by limiting the operational costs. We determine, by means of the method of compromise "ε-constraint ", the Pareto Front costs versus the environmental impact (Figure-2). We notice that, on one hand, in the first four solutions, we notably obtain significant reductions in the environmental impact going from -19 % to -58 % against a light increase of the costs going from +4 % to +17 %. On the other hand, for the rest of the solutions, we notice that the costs underwent an increase from +22 % to +44 % compared with a slow progress of the environmental impact going from -64 % to -69 %.

Therefore, we can conclude that for the company concerned by the case study, the introduction of a second more sustainable transportation mode, can bring us to realize an acceptable level of the environmental impact, in return of a light increase in the costs.

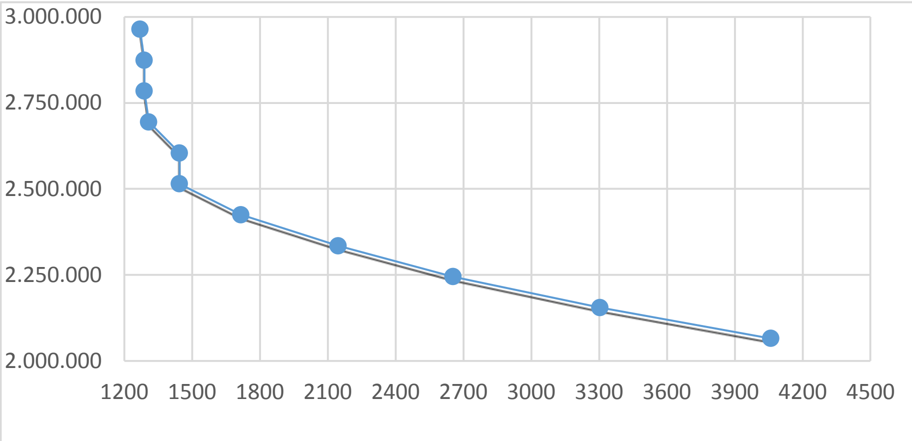

Figure-2. Costs versus environmental impact Pareto front.

7. CONCLUSIONS

In this article, we proposed a methodology for a bi-objective optimization for a green distribution network, where decisions concerning the choice of the transportation mode and the allocation of the demand of the customers, must be taken while reducing the costs relative to the distribution as well as the environmental impact.

For the evaluation of the environmental impact, we used the LCIA method ReCiPe on 2008. Our main contribution is the proposal of a model for decision making, which is allowing the decision-maker to estimate the possible configurations of his distribution network following two criteria, which are: the costs and the environmental impact

Our approach of resolution: "ε-constraint" highlighted the compromise, which exists between both objectives.

Even if our proposal allows the decision-makers to have an idea on the ecological impact of transportation in their distribution network. We plan to explore other future avenues of research. For example:

- We suggest introducing the transshipment as the solution of optimization of the environmental impact

- We subsequently plan to incorporate the social dimension into our model to reach a sustainable solution which considers three pillars of the sustainable development.

- We shall also intend to study the green distribution networks under uncertain demand, and which have for the third objective the minimization of the lead time of distribution.

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