Environmental Tax Approach (ETA) application for the product and supply chain configuration problem

Mohamed Barane [1][0009-0000-5458-9373], Latifa Ouzizi[2]

Mohammed Douimi[3]

[123] Ecole Nationale Supérieure d'Arts et Métiers (ENSAM), Meknès
[1]m.barane@edu.umi.ac.ma,[2]l.ouzizi@ensam-umi.ac.ma,
[3]m.douimi@umi.ac.ma

Abstract. Due to the rising awarness of the environmental aspect, industrial companies are struggling to introduce products respecting the legislations imposed by authorities in terms of greenhouse gas emissions, that's why assessing the enivironmental effect of products from the design stage is becoming more and more conclusive. In this contribution, we initiate the notion of the environmental taxes applied to products having a harmfull impact towards the environment. We study an existing product, and then we will try to generate an eco-alternative that minimize the cost of the overall logistic chain. To do that, a generated mdel is used to move from a bi-objectif mathematical model to a mono-objectif one in ordre to identify the best compromise among the cost and the environmental impact. The best-selected configuration has to optimize the cost of the selected product. A mixed integer linear programming is proposed to optimize the problem. A case study example is used to validate the model.

Keywords: Mono-objective optimization; Logistic chain optimization; Eco product; Environmental tax.

1 Introduction

The concept of treating simultaneously the configuration of the product and its logistic chain is getting interesting to obtain the full advantages from a product's entire life cycle.

Back to literature, it has been demonstrated that there exists a solid link among product structuration and logistic chain performance. [1] Discovered that companies which focus on optimizing the product architecture and the configuration of their logistic chain simultaneously has always the lead compared to firms focusing only on supply chain configuration or product characteristics. This method has in fact a lot of interest, and many scientists have been focused in this orientation.

Besides, [2] prove that 85% of logistics cost are conditioned by design decisions and more than 70% of product price is fixed by decisions during this stage. Consequently, both the constraints of the supply chain and product specification must be taken in the earlier stage of the product development [3].

On the other hand, another product criteria which is becoming more and more crucial, is the dimension of the environmental impact. In fact, incorporating environmental criteria from the product design stage exhibit a very interesting outcomes in contributions dealing with friendly design proposition, other works demonstrate that the environmental effect of a product is also fixed in this phase. A statistic shows that 50% of harmful environmental effect can be prevented from the design stage.

From the authorities' side, they have established plenty actions to minimise greenhouse gas emissions. In the logistic chain network, the producer and the vendor are involved to pay for their negative effects toward the environment. One of the commonly employed action is the environmental tax applied on the activities generating damaging outcomes to the environment, such as the carbon emission from the manufacturing process, or throughout the shipment step [4]. In Australia, they fixed a carbon tax price to be $23 per ton [5]. In Japan, they exploited the receipt gathered from the carbon tax to support clean energy's projects[6].

That is why our work aims to determine simultaneously the design of the product that optimize the cost and the environmental effect at once using the concept of the environmental taxes.

The article is organised as follow: the upcoming part depict a literature review that dealt with the concurrent configuration of the product and its logistic network under environmental impact constraint. The third part presents the problem and describe the methodology used. A real case study is provided to approve the model in the fourth part. To sum up, a conclusion is listed in the fifth part. At the end of the paper, a list of references is mentioned.

2 Literature Review

Based on the scanned literature, we found that many articles have covered the problem of the joint configuration of the product and its supply chain by studying the whole problem taking into account the cost and the environmental aspect.

[7] Have depicted a method that search for a durable product taking into account its materials, assembly chain and line balance at the beginning of design step using particle swarm optimization PSO-algorithm to find the optimal product along with the optimal assembly sequence.

[8] Propose a new decentralized decision-making method that assesses the compromise among the total price and the greenhouse gas emission appeared during the extraction of the material, the manufacturing process, and the needed transportation. They used a real case study to illustrate the method used.

[9] Exhibited a method to evaluate the effect of the carbon emission and the cost of product for companies. For each product configuration, the assembly architecture, assembly process, and the logistic chain structure are configured to reduce the CO2 emission. A genetic algorithm is employed to find the optimal assembly structure along with the optimal sequence.

[10] propose a new method incorporating the environmental constraint in product choice based on multi-agent system. The optimal product has to optimize both the carbon emission and the cost of the logistic chain.

All the above articles have proposed methods to calculate the environmental impact along with the whole supply chain cost, but none of them have proposed the concept of the environmental taxes. That's why our contribution is to propose a new easy model that enable the user to choose between a list of products alternatives the suitable one that respond simultaneously to the cots and the environmental constraint by using the concept of the environmental taxes applied to products.

3 Methods

The supply chain network considered in this research is composed from Procurements, Production Centers, Subcontractor, Delivery Center and Clients. (Fig.1)

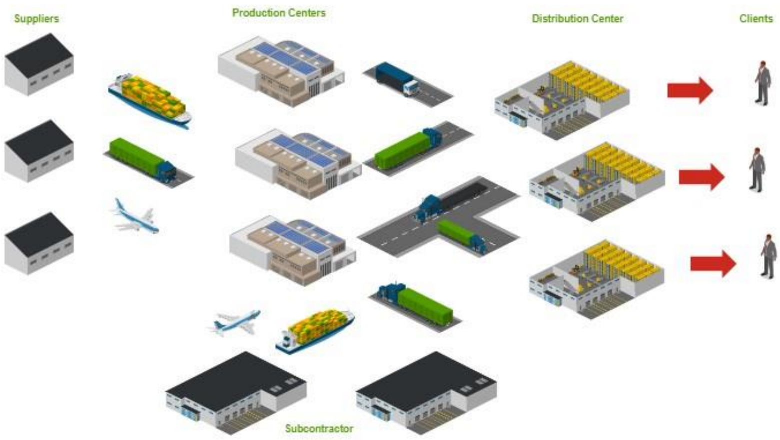

Fig. 1. Supply chain network

3.1 Problem definition

We are in the case of redesigning a product and we want to determine the optimal eco-product that optimize both the cost of the logistic network and the environmental effect presented by the CO2 emission. At the design phase, several design alternatives are proposed by the design team. For each corresponding alternative a supply chain configuration is determined. The chosen eco-product with its logistic network has to optimize simultaneously the cost of the logistic chain and the emission of the CO2. To solve this problem means that we have to find the set of the Pareto Efficiency.

In our work we will propose a new method to solve this bi-objective problem by transforming it to a mono-objective one using Environmental taxes added to products presenting a harmful impact towards the environment. The resolution process conducted in this work is presented in the below schema (Fig.2):

Fig. 2. Resolution process Schema

3.2 Vector Normalization

Vector normalization is the technique of harmonizing a vector to have a length or magnitude of 1, while preserving its direction. The primary benefit of vector normalization is that it allows for the comparison of vectors independent of their values. In our case the vector normalization technique is used to normalize CO2 values of each product's component within the bill of material to be compared, thereafter, by a determined threshold designated by experts. The normalize value found is called an environmental performance related to each product's components.

The threshold designated by experts is considered as a limit, if exceeded, a penalty knowing as taxes has to be applied in the overall cost of the corresponding product.

As long as our aim is to minimize the CO2 emission, [11] present a formula that is preferable to be applied when we aim to minimize values :

$$b_{i,j} = 1 - \frac{a_{i,j}}{\sqrt{\sum_i a_{i,j}^2}}, b_{i,j} \in [0,1] \tag{1}$$

3.3 Environmental tax calculation

To calculate the penalty tax applied to each alternative products we apply the below formula:

$$\alpha_{i,j} = 1 - \frac{b_{i,j}}{Th_{min}} \tag{2}$$

Such that:

$$Th_{min} \textit{ is the minimum threshold designated by experts}$$

3.4 Mathematical modelling

We consider that each alternative $\boldsymbol{P_i, i \in P}$ $(\boldsymbol{Set\ of\ generated\ alternatives})$ from designers is composed from an assembly of a list of components $\boldsymbol{C_j}$, $\boldsymbol{j \in J}$ $(\boldsymbol{Set\ of\ possible\ components})$. Each $\boldsymbol{C_j}$ is produced from $\boldsymbol{R_j}$, $\boldsymbol{R_j \in R}$ $(\boldsymbol{Set\ of\ raw\ materials})$. In the above architecture we admit that the factors of any component and raw of materials in the bill of material equals to one (Fig.3).

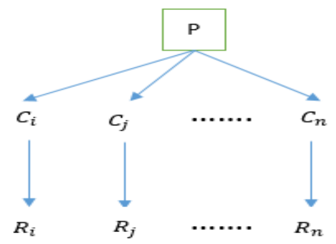

Fig. 3. General structure of a giving product

Mathematical model assumption

The considered assumptions are as follows:

- The logistic network structure is composed from Suppliers, Sub-contractors, Production center, Distribution center and Clients.
- The component's demand is already known,
- The supplier ensures the transportation of components,
- Unit cost of components transportation is in the interval capacity of suppliers,
- All components have the same quality index.
- The company may call upon subcontractors to meet the product need,

Problem sets and data:

We propose the following definition:

- **AC**: The Production center,
- **S**: The set of suppliers,
- **STR:** The set of subcontractors;
- $\boldsymbol{C_a}$: The set of alternative components indexed by 'a',
- $\boldsymbol{R_a}$: The set of raw material of the alternative 'a'.

Constraints:

- Components demand satisfaction:

$$\sum_{f \epsilon F} \boldsymbol{Q_{c,f}} \geq \boldsymbol{Dem_c} \tag{3}$$

- Supplier's capacity:

$$\boldsymbol{Q_{c,f}} \leq \boldsymbol{capmax_{c,f}} * \boldsymbol{Z_{c,f}} \tag{4}$$

- Subassembly demand satisfaction:

$$\sum_s \boldsymbol{Q_{a,s}} + \boldsymbol{Q_a} \geq \boldsymbol{D_a} \tag{5}$$

- Subcontractor's capacity:

$$\boldsymbol{Q_{a,s} \leq capmax_{a,s} * Z_{a,s}} \tag{6}$$

- Sub-assembly capacity:

$$\boldsymbol{Q_a \leq capmax_a} \tag{7}$$

- Non-negativity:

$$\boldsymbol{Q_{a,s} \geq 0;\ Q_a \geq 0;\ \ Q_{c,f,t} \geq 0;} \tag{8}$$

3.5 MILP for logistic operations

Since we are dealing with two objectives to be solved, we introduce the two objective functions as below:

Cost function:

$$f_{Cost:}\quad _{Min}\ \sum_{f\epsilon F}\sum_{c\epsilon Ca}\left(\sum_{r\epsilon Ra} Density_r * N_{r,c,a} * V_{c,a} * CA_r + CP_{c,f} + CT * D_f\right) * Q_{c,f} + CF_f * Z_{c,f} + \sum_a CA_a * Q_a + \sum_a \sum_s Q_{a,s} * \left(CS_{a,s} + CT_s * D_s\right) + Z_{a,s} * CF_{a,s} \tag{9}$$

Environmental impact function:

$$f_{CO2:\min}\quad \sum_{f\varepsilon F}\sum_{(c,r)\epsilon(Ca,R)} Density_{r,c} * Vc * N_{r,c,a} * D_f * Q_{c,f} * \alpha + \sum_{f\varepsilon F}\sum_{c\epsilon Ca} EP_{c,f} * Q_{c,f} + \sum_{f\epsilon F}\sum_{c\epsilon Ca}\sum_{r\varepsilon Ra} Ext_{r,f} * N_{r,c,a} * Q_{c,f} \tag{10}$$

To move from the bi-objective model to a mono-objective one, the idea is to calculate the cost function and then adding the ratio generated from component's normalization to harmful products which their environmental threshold is less than it requested by experts. Thus, we define the new price as:

$$\boldsymbol{P'_a = \left(1 + \mathbf{average}\left(\alpha_{ac_i}\right)\right) * P_a} \tag{11}$$

Such that:

$$\alpha_{ac_i} = 1 - \frac{b_{ac_i}}{Th_{min}}, \text{if }\ b_{ac_i} \geq Th_{min} \tag{12}$$

$$\alpha_{ac_i} = 0\ , \text{otherwise} \tag{13}$$

and

$$b_{ac_i} = 1 - \frac{v_{aci}}{\sqrt{\sum_i {v_{aci}}^2}} \tag{14}$$

P.S:

- P_a is the overall price of cost function,
- v_{aci}: is the CO2 value of the component "C_i" in the alternative "a"

4 Result and Discussion

To validate our model, we've decided to use a real case study of a real world lamp reconfiguration proposed by [8]. The table below presents the list of components along with their associated material:

Table 1. Components and their material related to each product

Design	C1	C2	C3	C4	C5
Product1	PP	PP	PP	LED	PP
Product2	Magnesium Alloy	PP	PP	LED	PP
Product3	PP	PP	Aluminium	LED	PP
Product4	LED	PP	PP	PP	Magnesium Alloy

The general bill of material applied for each product is presented as follow (Fig.4):

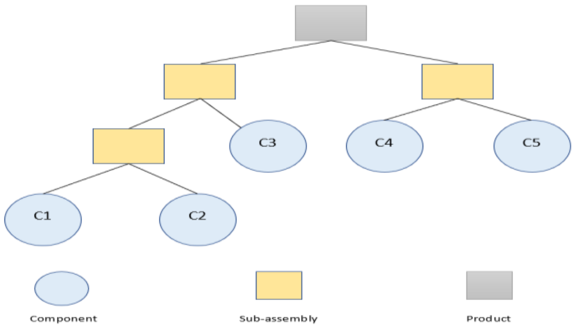

Fig. 4. Standard Bill of material configuration

We suggest the following definitions:

- Production Center P= {AF, A1, A2, A3, A4, A5, A6, A7}
- Set of Suppliers F= {F1, F2, F3, F4, F5}
- Set of Subcontractors S= {S1, S2, S3}
- Set of Components C= {C1: Base, C2: Shaft, C3: Support, C4: Light case, C5: Light tube},
- Set of raw material R= {R1: PP, R2: PVC, R3: Cast Mg AZ91, R4: Cast Al 380, R5: LED}.

The mathematical model was implemented and simulated using IBM ILOG CPLEX, Version: 22.1.1.0. The calculation result of the four designs is giving in the table2 below, and two graphical representations (Fig.5, Fig.6) are established to present the tax effect on the overall price.

Table 2. Cost's Computational result for the two designs

Product	Overall cost	Tax applied	New price
Product1	17721223,16	0,39	24674974,18
Product2	17739430,86	0,57	27887079,2
Product3	17648987,37	0,48	26053962,39
Product4	17717630,86	0,57	27852808,75

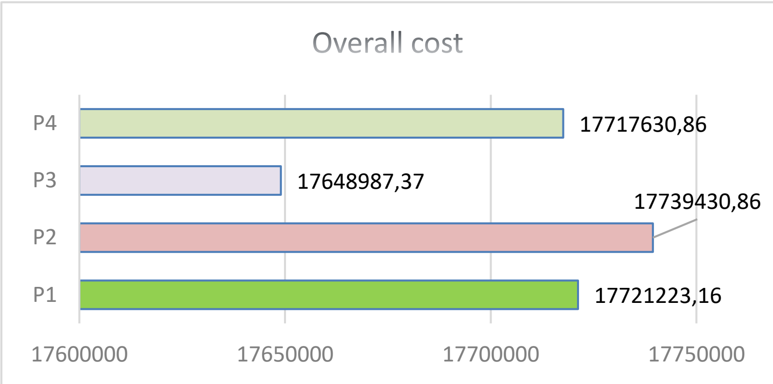

Fig. 5. Overall cost of the four alternative products

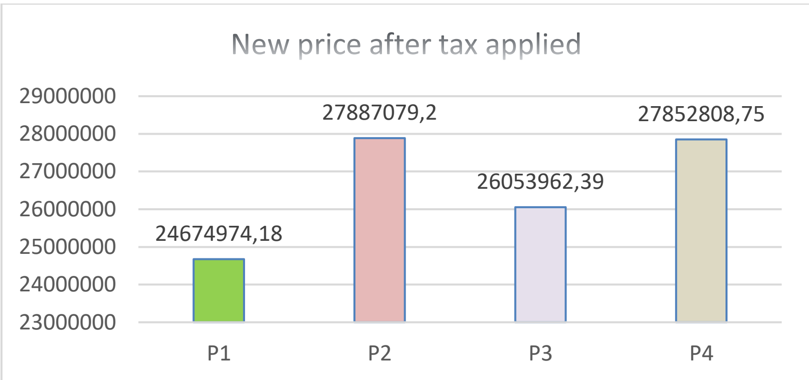

Fig. 6. The new cost after tax applied

Result interpretation

From results above, two major points to underline:

- **Product3** is the cheapest one before applying tax,
- After applying environmental tax, the **Product1** is becoming the optimal (cheapest) comparing to the others.

Thus, the **Product1** is the selected product responding to both cost and environmental constraints at once.

This numerical example demonstrates the importance of the environmental tax application and how the proposed method can be exploited to determine between a list of proposed alternatives which one can be the best one according to its environmental performance.

5 Conclusion

To conclude, this research points out a very interesting field, which is the concurrent configuration of the product and its logistic network under the cost and the environmental constraints. We suppose that we want to reconfigure a new product alternative starting from an existing one, our objective is to determine the product optimizing both the cost and the environmental aspect.

We provided a new method allowing us to move from a bi-objective model to a mono-objective one, which is very easy to implement and solve, by using the concept of the environmental taxes.

First, we generate a list of alternatives and then we calculate their overall cost by solving a mathematical model using CPLEX software. After that, we calculate for each generated alternatives the environmental tax applied by computing the environmental performance of their components in the bill of materials. This environmental performance is calculated based on a minimum threshold designated by the experts. The final cost, consequently, is obtained by adding the tax coefficient associated to each cost of the alternative product.

Although this method is easy to implement and give solutions in an advantageous calculation time, but this advantageous seems not always the case if the number of variables is huge. Another inconvenient of this method is that it's based essentially on experts' point of view. So, results founded my differ from an expert to another.

Future work will focus on fixing those inconvenient and providing new methods to solve the problem of the concurrent configuration of product and logistic network integrating other constraints and using famous methods of resolution like genetic algorithm.

6 References

[1] S. D. Novak Steven Eppinger *et al.*, "Massachusetts Institute of Technology Sourcing By Design Product Complexity and the Supply Chain Sourcing By Design: Product Complexity and the Supply Chain," 2000.

[2] I. Bouhaddou, A. Benabdelhafid, L. Ouzizi, and Y. Benghabrit, "PLM (Product Lifecycle Management) model for supply chain optimization," *IFIP Adv. Inf. Commun. Technol.*, vol. 388 AICT, pp. 134–146, 2012, doi: 10.1007/978-3-642-35758-9_12.

[3] B. Nepal, L. Monplaisir, and O. Famuyiwa, "Matching product architecture

with supply chain design," *Eur. J. Oper. Res.*, vol. 216, no. 2, pp. 312–325, 2012, doi: 10.1016/j.ejor.2011.07.041.

[4] H. L. Chan, T. M. Choi, Y. J. Cai, and B. Shen, "Environmental Taxes in Newsvendor Supply Chains: A Mean-Downside-Risk Analysis," *IEEE Trans. Syst. Man, Cybern. Syst.*, vol. 50, no. 12, pp. 4856–4869, 2020, doi: 10.1109/TSMC.2018.2870881.

[5] B. Fahimnia, J. Sarkis, A. Choudhary, and A. Eshragh, "Tactical supply chain planning under a carbon tax policy scheme: A case study," *Int. J. Prod. Econ.*, vol. 164, pp. 206–215, 2015, doi: 10.1016/j.ijpe.2014.12.015.

[6] P. He, W. Zhang, X. Xu, and Y. Bian, "Production lot-sizing and carbon emissions under cap-and-trade and carbon tax regulations," *J. Clean. Prod.*, vol. 103, pp. 241–248, 2015, doi: 10.1016/j.jclepro.2014.08.102.

[7] M. C. Chiu, C. H. Chang, Y. T. Chen, J. Y. Chiou, and Y. J. Chang, "Redesign for sustainability and assemblability using particle swarm optimization method," *J. Ind. Prod. Eng.*, vol. 33, no. 2, pp. 103–113, 2016, doi: 10.1080/21681015.2015.1111264.

[8] I. H. Hong, J. C. P. Su, C. H. Chu, and C. Y. Yen, "Decentralized decision framework to coordinate product design and supply chain decisions: Evaluating tradeoffs between cost and carbon emission," *J. Clean. Prod.*, vol. 204, pp. 107–116, 2018, doi: 10.1016/j.jclepro.2018.08.239.

[9] J. C. P. Su, C. H. Chu, and Y. Te Wang, "A decision support system to estimate the carbon emission and cost of product designs," *Int. J. Precis. Eng. Manuf.*, vol. 13, no. 7, pp. 1037–1045, 2012, doi: 10.1007/s12541-012-0135-y.

[10] I. Ballouki, M. Douimi, and L. Ouzizi, "A distributed and collaborative model for product design selection considering its supply chain costs and environmental footprint," *Int. J. Syst. Sci. Oper. Logist.*, 2021, doi: 10.1080/23302674.2021.1958949.

[11] E. K. Zavadskas and Z. Turskis, "A new logarithmic normalization method in games theory," *Informatica*, vol. 19, no. 2, pp. 303–314, 2008, doi: 10.15388/informatica.2008.215.