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Tactical Planning Model for Procurement and Manufacturing Decisions under Environmental Regulations

Julien Trochu*. Amin Chaabane. Mustapha Ouhimmou*****

École de Technologie Supérieure (ÉTS), Montreal, QC, H3C 1K3 CANADA

(e-mails: julien.trochu.1@ens.etsmtl.ca*; Amin.Chaabane@etsmtl.ca **; Mustapha.Ouhimmou@etsmtl.ca ***)

Abstract: In this paper, we study the problem of procurement and manufacturing planning under environmental regulations. This work introduces an integer linear programming model (ILP) considering supply chain purchasing and manufacturing tactical decisions under the compensation regulation. The proposed model allows the use of clean production technologies to manufacture one product family based on two versions of bill of materials (BOM): standard and green. As the compensation regulation penalizes companies for the excessive weight of products sold on the market, this green version with lighter BOM is used to demonstrate the impact of this new regulation on the total supply chain cost for companies operating in the province of Quebec. The results may yield cost reduction through the development of eco designed products and the use of clean technologies. In this case, the compensation decreases significantly and the company remains competitive.

Keywords: Supply chain, environmental legislations, compensation scheme, purchasing, manufacturing

1. INTRODUCTION

Practitioners and academics have been interested in environmental damage caused by industrial activities of supply chains. This problem is one of the biggest challenges in the twenty-first century for national and international logistics. Since the emergence of the sustainable supply chain concept [1], considering supply chains only as entities that convert raw materials to final products to satisfy consumers' requirements has been changed. Research in this field is constantly evolving even though the integration of the social aspect is rare in the supply chain literature [2, 3]. Main topics studied are related to product life cycle analysis, eco-design or end of life product, extended producer responsibility and reverse logistics, reuse, refurbishing or recycling raw materials, and also clean technology use.

The reasons to move toward more sustainable activities are mostly customers' needs, reputation loss, and environmental pressure groups. Moreover, government's regulations play an important role to force organizations to move toward better environmental practices. Legislations are getting more stringent so that supply chain managers either have to take actions to comply or to incur penalty costs. Nowadays many companies, even the most successful ones, are suffering from their bad environmental behaviour for many years. For example the electronic giant Apple has faced repeatedly criticism from the Greenpeace environmental group about short life lithium battery. This pressure had a negative impact on its sales, and forced the company to take measures and modify iphone's components. Moreover, this type of information can typically cause a reputation loss just as it happened for the fuel company British Petroleum after being accused of activities causing massive air pollution. Today, a lot of supply chains are forced to move toward sustainable practices in response to their stakeholders' pressures. However, this evolution in business practices can be seen as major competitive advantage in some sectors. For instance, the textile company, Puma, chose to apply a transparency policy and posted on the website reports that show the impacts of the company's activities on greenhouse gases emissions and water consumption. Compliance with governmental regulations remains the main motivation for supply chains to move toward sustainability. It was the case for the global solvent industry after the adoption in 2006 of the Restriction of Hazardous Substance (RoHS) restriction in Europe. The Waste on Electric and Electronic Equipment (WEEE) regulation imposes the collection and recycling of a minimum proportion of the products available on the market to end consumers [4, 5]. Such measures also exist in other industrial sectors such as the automotive with the End of Life Vehicle regulation (ELV). This directive encourages vehicle manufacturers to use raw materials and components easy to reuse and recycle [6]. Reverse logistics is the most studied field in the context of sustainable supply chains literature [7]. Among this particular field, the Extended Producer Responsibility (EPR) plays an important role to increase the product return and recycling of products at their end of life (EOL) [8, 9]. EPR regulations exist in many countries around the world including a wide variety of products. The rest of paper is structured as follow. Section 2 describes the problem statement, while section 3 presents the literature review. Sections 4 and 5 respectively introduce the mathematical formulation and experiments' results of the case study.

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2. PROBLEM STATEMENT

The present research work focuses on the Compensation Regulation, an EPR initiative effective in the province of Quebec-Canada since 2010. The compensation regulation aims to make companies contribute to the cost incurred by municipalities for recovering and collecting residual material. This legislation involves several entities starting with the Quebec government through the Ministry of Sustainable Development, Environment, Wildlife and Parks. First, Éco-Enterprise Québec (ÉEQ) estimates the appropriate tariffs for one kilogram unit of raw material collected by municipal services. Then, a tariff proposal is sent to another governmental organism for approbation or revision. Finally the proposal is sent to the ministry for official acceptance. Today there are over three thousands companies that are subject to this regulation in the province of Quebec. Based on raw material types and weights in the bill of materials, the tariffs applied allow determining the amount of the contribution due to municipalities. Material types involved in the compensation scheme are: plastic, glass, steel, cardboard, aluminium, and packaging. Thus, each material has an associated unit cost based on one kilogram collected by municipal services. At the end of each year, all companies subject to the compensation have to fill a declaration specifying quantities and types of raw materials within the products sold in the market. This legislation effective since 2005 is getting more stringent since then as tariffs are being revised every year. Moreover, if companies had to contribute initially only at a 60% rate, they are today responsible for the total costs of municipal collect services. This situation might be a real concern depending on the quantity, proportion and type of raw materials that companies are using in the manufacturing and distribution process. Thus, the main goal of this work is to analyse the potential impact of the compensation on actual supply chains and propose some alternatives to deal with it in an effective manner. To the best of our knowledge this problem is not addressed in the literature yet. In order to cover all these aspects, we propose an optimization model evaluating the impact of tactical planning decisions such as purchasing and manufacturing.

3. LITERATURE REVIEW

Reverse logistics has become a very popular topic in the literature [10]. Closed Loop Supply Chains (CLSCs) quantitative models are numerous and all three decision levels are addressed: strategic, tactic and operational. While strategic decisions usually focus on network design, operational issues deal with lot sizing, routing or disassembly planning. However the tactical level is rather focused on flows between logistics units such as collecting, dismantling, remanufacturing, recycling and disposal centers [11]. In fact, the tactical decisions are directly impacted by take back legislations part of the EPR such as WEEE and ELV. While the previous work assumes that product recovery and recycling is under the manufacturer's responsibility, other considers that this task is shared by supply chain's partners [12]. Thus, their two-echelon mathematical formulation allows modelling new and recycled product flows between logistic infrastructures. The profit maximizing function leads to the conclusion that under the legislation, it is profitable for supply chain partners to cooperate in reverse logistics operations. In addition to reverse logistics and CLSCs under EPR legislations, many quantitative models have been developed to support sustainable purchasing and manufacturing tactical planning decisions. These mathematical formulations mainly deal with waste management and energy used depending on the selected raw material [13, 14]. Indeed, the procurement decisions will impact the environment due to multiple factors such as carbon emissions, waste and energy consumption during the manufacturing process. Nowadays many research works also focus on optimizing production systems. For instance, two (2) different models for production planning under uncertainty were developed in the textile industry. Both models analyze pollution prevention; one maximizes profit while the other minimizes the risk of pollution [15]. Later on, two scenarios are compared: the first one considers the case of a company whose production is subject to strict environmental regulations while the second analyzes the case of a production policy which sets voluntarily environmental goals [16]. Among the most recent works, some authors take into consideration production technologies in conjunction with greenhouse gas emissions. First they consider carbon trading system comparing to a carbon tax depending on the level of emissions. The model maximizes profits giving the choice between using one or more standard production technologies [17]. Then, various carbon management policies are studied to compare emissions from supply chain's manufacturing processes [18]. Although the authors often deal with mathematical models optimizing decisions related to technology selection or production quantities of finished products [19], it has been recently pointed out that a green alternative can actually be better than the lean one [20] .

4. MATHEMATICAL FORMULATION

4.1 Assumptions

In this paper, we consider a three-echelon supply chain. The network structure is depicted in Fig.1. First, a set of potential suppliers are considered for raw materials procurement. As the compensation regulation penalizes an excessive weight of finished products sold on the market for end-customers, we assume that the company has the possibility to use two Bill of Materials (BOM) versions for the same finished product. Indeed we allow manufacturing the single product family in two different versions: the standard one and the greener one which contains lighter and more expensive eco designed raw material parts. We suppose also that the green version of finished product is lighter and also less bulky due to the individual weight and volume of eco designed raw material parts. Raw materials are then shipped to a set of manufacturing plants where the final product is assembled using either standard or clean technology process. Note that standard technology produces standard version only whereas clean technology produces green version and requires skilled workers with special training. In this work, we will focus only on the tactical decision level. Thus, we assume that technology acquisition has already been made by the company. Then, products are distributed through a set of potential warehouses and finally they are shipped to customers. Transportation activities between logistics units are performed with trucks of various capacities both in terms of weight and volume.

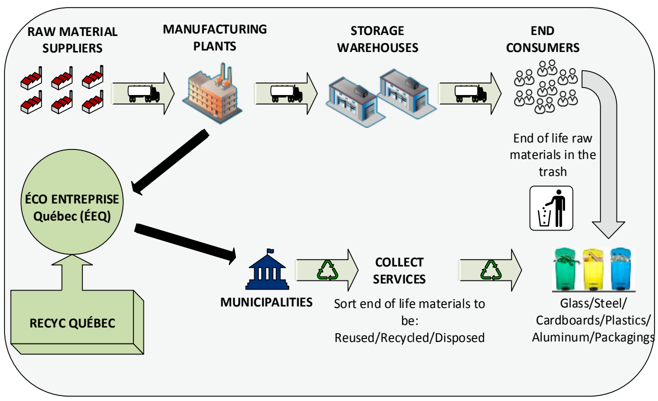

Fig.1. Supply chain under the compensation legislation

4.2 Model formulation

We consider a mixed integer linear programming (MILP) model in order to represent the reality of the compensation regulation structure. The mathematical formulation allows companies under the compensation legislation to adapt their tactical purchasing and manufacturing planning decisions. The proposed quantitative approach ultimately aims to help Quebec companies to reduce the compensation bill. The sets, parameters and decisions variables of the mathematical model are listed as below.

Sets

$\{i, j\} \in N$ nodes of the network
$s \in S \subset N$ Set of suppliers
$u \in U \subset N$ Set of plants
$w \in W \subset N$ Set of warehouses
$c \in C \subset N$ Set of customers
$p \in P$ Set of products
$r \in R \subset P$ Set of raw materials
$f \in F \subset P$ Set of finished products
$t \in T$ Set of periods in the planning horizon
$m \in M$ Set of technology modes

Parameters

b_{rf} = Number of raw material parts $r\epsilon R$ in finished product $f\epsilon F$
z_{fct} = Demand of finished products $f\epsilon F$ for customer $c\epsilon C$ during period $t\epsilon T$
p_p = Weight of product $p\epsilon P$ (kg)
v_p = Volume of product $p\epsilon P$ (m^3)
θ_{fm} = Time required to process finished product $f\epsilon F$ with technology mode $m\epsilon M$ (hours)
v^{ij} = Volume capacity of truck between node $i\epsilon N$ and node $j\epsilon N$ (m^3)
w^{ij} = Weight capacity of truck between node $i\epsilon N$ and node $j\epsilon N$ (kg)
α_{rst} = procurement cost of raw material $r\epsilon R$ for supplier $s\epsilon S$ during period $t\epsilon T$ (\$)
β_{fut} = Production cost of finished product $f\epsilon F$ in plant $u\epsilon U$ during period $t\epsilon T$ (\$)
δ_{fwt} = Handling cost of finished product $f\epsilon F$ at warehouse $w\epsilon W$ during period $t\epsilon T$ (\$)
n_{ij} = Number of trucks available for delivery between node $i\epsilon N$ and node $j\epsilon N$ (UN)
c_p^{ij} = Unit transportation cost of product $p\epsilon P$ between node type $i\epsilon N$ and node type $j\epsilon N$ (\$)
d_{ij} = Distance between node $i\epsilon N$ and node $j\epsilon N$ (km)
φ = Training cost of regular worker on the new technology mode (\$)
g = Number of available working hours per period
e_m = Hourly rate cost of an employee working on technology mode $m\epsilon M$ (\$)
a_{mut} = Cost of a maintenance operation on technology mode $m\epsilon M$ at plant $u\epsilon U$ during period $t\epsilon T$ (\$)
$\mathcal{E}_{mut}$ = Penalty cost incurred by temporary production stop for a maintenance operation on technology mode $m\epsilon M$ at plant $u\epsilon U$ during period $t\epsilon T$ (\$)
o_{mut} = Quantity of products manufactured after what a maintenance operation is required on technology mode $m\epsilon M$ at plant $u\epsilon U$ during period $t\epsilon T$ (UN)
Ω_{srt} = Capacity of supplier $s\epsilon S$ to supply raw material type $r\epsilon R$ during period $t\epsilon T$
ψ_{rt} = Compensation tariff for one kilogram unit of raw material $r\epsilon R$ on the market during period $t\epsilon T$ (\$)
h_{pit} = Holding cost of product $p\epsilon P$ at node $i\epsilon N$ during period $t\epsilon T$
ξ_{it} = Throuhhput capacity at node $i\epsilon N$ during period $t\epsilon T$ (kg)

Decision variables

E_{umt} = Number of required employees to work on technology mode $m\epsilon M$ at plant $u\epsilon U$ at period $t\epsilon T$
X_{ijpt} = Flow of products $p\epsilon P$ between node $i\epsilon N$ and node$j\epsilon N$ during period $t\epsilon T$
I_{ipt} = Inventory level of product $p\epsilon P$ at node $i\epsilon N$ during period $t\epsilon T$
K_{fmut} = Quantity of product $f\epsilon F$ manufactured with technology mode $m\epsilon M$ at plant $u\epsilon U$ during period $t\epsilon T$ (UN)

Mixed integer linear programming formulation

The tactical procurement and manufacturing problem can be formulated as follows:

$$Min \sum_{t\in T}\sum_{r\in R}\sum_{s\in S}\sum_{u\in U} \alpha_{rst} \,.\, X_{furt} + \sum_{t\in T}\sum_{f\in F}\sum_{u\in U}\sum_{m\in M} \beta_{fut} \,.\, K_{fmut}$$
$$+ \sum_{t\in T}\sum_{f\in F}\sum_{w\in W}\sum_{c\in C} \delta_{fwt} \,.\, X_{wcft} \;) + \sum_{u\in U}\sum_{t\in T} E_{u2t} \,.\, \varphi$$
$$+ \sum_{m\in M}\sum_{u\in U}\sum_{t\in T} \left(\frac{\sum_f K_{fmut}\,(a_{mut} + \mathcal{E}_{mut})}{o_{mut}} + E_{umt} \,.\, e_m \,.\, g\right)$$
$$+ \sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{t\in T} \frac{p_p c_p^{ij} d_{ij}}{w^{ij}} X_{ijpt} + \sum_{t\in T}\sum_{p\in P}\sum_{i\in I} Q_{ipt} \,.\, h_{pit}$$
$$+ \sum_{r\in R}\sum_{t\in T} \psi_{rt} \sum_{f\in F}\sum_{u\in U} \left(X_{furt} \,.\, p_r\right)$$

Subject to

$$\sum_{u\in U} X_{surt} \leq \Omega_{srt} \qquad \forall s\in S, \forall r\in R, \forall t\in T \qquad (1)$$

$$\sum_{p\in P}\sum_{w\in W} X_{wcft} = z_{fct} \quad \forall c\in C, \forall f\in F, \forall t\in T \qquad (2)$$

$$\sum_{s\in S} X_{surt} + I_{ur(t-1)} = \sum_{w\in W} X_{uwft} \sum_{f\in F} b_{rf} + I_{urt}$$
$$\forall r\in R, \forall u\in U, \forall t\in T \qquad (3)$$

$$\sum_{u\in U} X_{uwft} + Q_{wf(t-1)} = \sum_{c\in C} X_{wcft} + Q_{wft}$$
$$\forall f\in F, \forall w\in W, \forall t\in T \qquad (4)$$

$$\sum_{m\in M} K_{fmut} = \sum_{w\in W} X_{uwft} \qquad \forall f\in F, \forall u\in U, \forall t\in T \qquad (5)$$

$$\sum_{r\in R}\sum_{s\in S} (X_{surt} + I_{urt}) p_r + \sum_{f\in F}\sum_{w\in W} \left[X_{uwft}.p_f\right] \leq \xi_{ut}$$
$$\forall u\in U, \forall t\in T \qquad (6)$$

$$\sum_{f\in F}\sum_{u\in U} X_{uwft}.p_f + \sum_{f\in F}\sum_{c\in C} \left[X_{wcft} + Q_{wft}\right] p_f \leq \xi_{wt}$$
$$\forall w\in W, \forall t\in T \qquad (7)$$

$$\sum_{p\in P}\sum_{i\in I}\sum_{j\in J} \left[X_{ijpt}.p_p\right] \leq n_{ij} \, . \, \mathrm{w}^{ij} \qquad \forall t\in T \qquad (8)$$

$$\sum_{p\in P}\sum_{i\in I}\sum_{j\in J} \left[X_{ijpt}.v_p\right] \leq n_{ij}.v^{ij} \qquad \forall t\in T \qquad (9)$$

$$K_{12ut} = K_{21ut} = 0 \qquad \forall u\in U, \forall t\in T \qquad (10)$$

$$E_{umt} \leq \sum_{f\in F} \frac{K_{fmut}.\theta_{fm}}{g} \qquad \forall u\in U, \forall t\in T, \forall m\in M \quad (11)$$

$$X_{ijpt}, E_{umt}, I_{ipt}, K_{fmut} \in \mathbb{N} \qquad (12)$$

The objective function above minimizes the total supply chain cost. The latter is composed of procurement costs, production costs, warehousing costs transportation costs, training and maintenances costs, and compensation cost. Constraint (1) ensures the respect of suppliers' capacities. Constraint (2) guarantees that customer's demand is fully satisfied. Constraints (3) and (4) are the flow balance constraints at plants and warehouses, respectively. Constraint (5) guarantees that there is no finished product stored in the manufacturing plants because production is shipped directly to warehouses. Constraints (6) and (7) express production capacity in manufacturing plants and throughput in warehouses. Constraints (8) and (9) ensure that trucks' capacities are not exceed in terms of weight and volume. Constraint (10) guarantees that each product type, standard or green, can be manufactured only using a single technology mode, while constraint (11) defines the minimal required number of employees. Finally constraint (12) ensures that decision variables are positive integers. The formulated problem was solved using Lingo 15.0 and presents 6.680 variables, 3.360 integers, 36.497 non-zeros and 4.077 constraints.

5. EXPERIMENTS AND RESULTS

5.1 Data

The model is applied with data in the context of fast-moving consumer goods (FMCG). Manufacturers in this sector generate a lot of containers, packaging or printed matter and millions of those are available on the market for consumers every day. Thus, the impact of the compensation legislation is really important in the FMCG industry, leading sometimes to several hundred thousand dollars compensation bill. In this application, 10 potential suppliers are identified for raw material procurement (r_1… r_8) used in final products. Two (2) production technologies are identified to manufacture final products: the standard and the green one. These technologies are available at 4 manufacturing sites. Eight (8) potential warehouses are identified for product distribution to 25 customers. Customer demand can be fulfilled from both standard and the green version of the product. We generate the model using 4 time periods covering one year planning horizon which corresponds to the compensation regulation time period. For this study, only one product family is considered. Although the standard and the green versions of the product are different, they share two raw material parts: r_1 and r_2. Fig. 2 shows the difference between classical BOM 1 and eco-designed BOM 2.

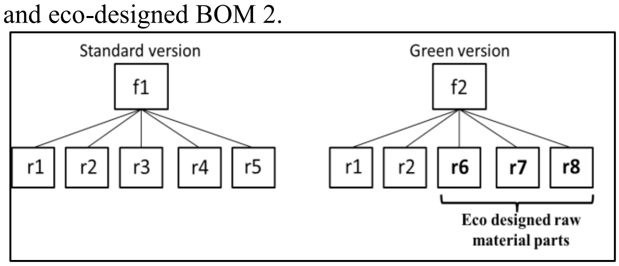

Fig.2. Standard versus Green products' BOMs

The Green version of the product is lighter with less volume than the Standard one. Table 1 describe the main products' characteristics.

Table 1. Products' characteristics

Product	Volume (m^3)	Weight (kg)
Standard	0.005	0.5
Green	0.0043	0.36

The supply chain is targeted by the compensation regulation. Table 1 shows the tariffs applied for one kilogram of raw material collected by municipal services using real life compensation costs.

Table 2. Compensation tariffs of year 2014

Raw material type	(1)	(2)	(3)	(4)	(5)
Tariff (cents per kg)	26.47	68.13	18.78	9.71	11.49

(1) Represents the cardboards, (2) are plastics, (3) for the aluminium category, (4) is the steel and finally (5) corresponds to glass raw material type.

The following section shows the preliminary results of this specific case study. For the purpose of this case, the objective is to analyse how supply chain managers should adjust procurement and manufacturing planning decisions in the context of EPR in order to reduce their compensation bill.

5.2 Results

The supply chain cost structure in the 'base case' scenario is shown by fig. 3, being the actual situation before the use of an alternative BOM. In the base case scenario, the company incurred 215,327 $ annual compensation fee which represents 2.6% of the total supply chain cost. In this base case solution, raw material cost is the most important one.

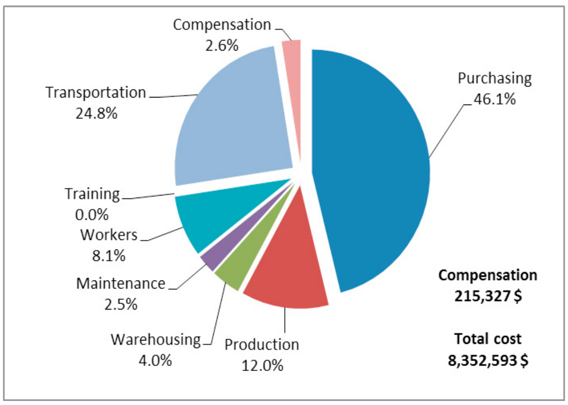

Fig. 3 Supply chain cost structure: 'Base case'

By introducing the second option of production, potential changes are observed. In the green scenario, the company uses the clean technology and the alternative BOM for the entire production. Fig. 4 shows the new cost structure. The results suggests that is possible to reduce the compensation fee from 215,327 $ to 153,601 $, thus representing a 28.7% decrease. Moreover the proposed model allows total supply chain cost reduction by 4.9%.

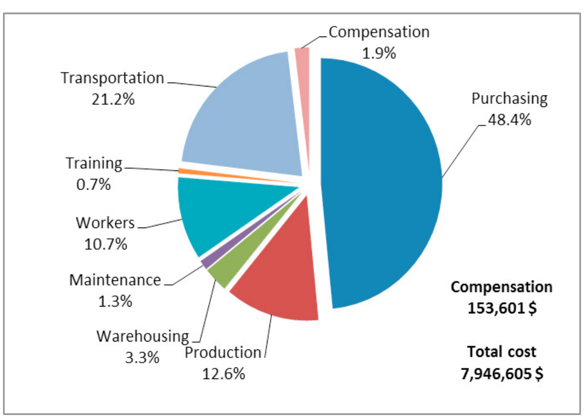

Fig.4. Supply chain potential savings with green scenario

Moreover, the total cost structure shows that the green scenario leads to cost reduction in some logistics activities such as warehousing and maintenance. The best improvement is observed through transportation activities. Indeed, the eco-designed finished product leads to a considerable reduction of the overall weight transported between logistic units. Reducing the overall weight of products (raw material and finished products) across the supply chain has a positive impact. This directly affects the total number of required deliveries to satisfy customer's demand. In the base case scenario, we need 1,169 deliveries against 1018 with a full green production which almost represents a 13% decrease. Unfortunately this improvement in transportation is limited by the volume of the products. Indeed, although the trucks are full in term of volume, they are not at their maximum weight per shipment. We also observe that shifting to greener production requires skilled workers. In this case, workforce cost increase by 3.3%.

Since 2013, Québec companies are responsible for the entire cost of collection services. From 2013 to 2014, 3.2% increase in raw materials tariffs are applied to the containers and packaging. Thus, based on this average compensation cost increase, we estimated the tariffs that might be applied in the future. Table 3 shows the estimated tariffs for raw materials (1), (2), (3), (4) and (5).

Raw material type	(1)	(2)	(3)	(4)	(5)
Tariff (cents per kg)	36.3	93.4	25.7	13.3	15.7

Table 3. Compensation tariffs expected in 2024

Fig. 5 shows the expected cost structure of the same supply chain in 2024 with the expected tariffs increase.

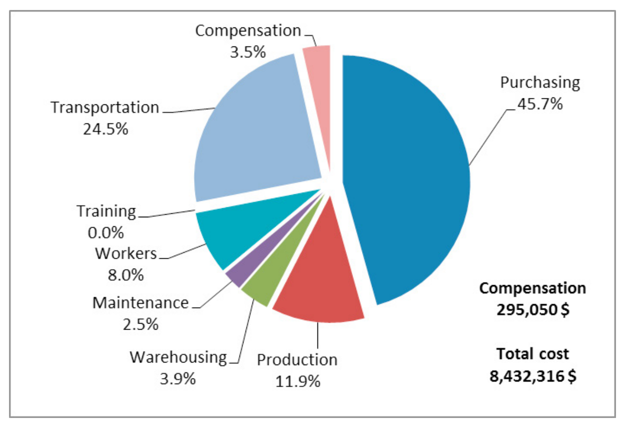

Fig.5. Impact of the compensation rate increase in 2024

In this scenario we expect the compensation fee to increase from 215,327 $ to 295,050 $ (27%). Meanwhile the total supply chain cost would increase by 1%. However, we showed previously that the proposed model formulation allowed a 28.7% decrease of the compensation cost. Indeed, if we decide to implement the proposed solution, the company will pay the same compensation as in the base case scenario.

In this study, the cost of raw material plays an important role in this alternative solution. Indeed, the procurement activities represent almost 50% of the total supply chain cost. The compensation cost being less than 3%. Thus, if the new and green components are too expensive, the solution might not be viable. Fig. 6 illustrates the impact of the purchasing costs on production decisions. Also managers should maintain the production using the standard BOM if purchasing prices for green components (r_6 , r_7, r_8) are almost 40% more than the standard ones (r_3, r_4, r_5) . However, with a 16.5% price increase, standard and green products should be manufactured equally to fulfill the demand. Finally, green production is preferred if the cost increase is less than 16.5%.

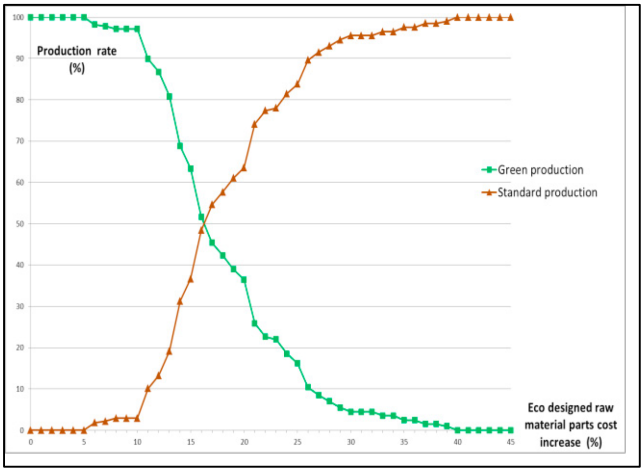

Fig.6. Impact of raw material costs on production planning

6. CONCLUSION

The main contribution of this paper is the development of an integrated model for procurement and manufacturing planning under the environmental compensation regulation in the province of Quebec. To the best of our knowledge this is the first model that integrates the compensation legislation in the supply chain decision making process. Using this model, companies could adjust their purchasing and manufacturing activities to reduce the compensation bill. We demonstrate that if the trend of prices' increase remains during the next few years, the proposed approach is useful for supply chain managers. However, the solution proposed in this work is based on the integration of Eco- BOM which is highly affected by raw material purchasing costs. Moreover it would be interesting to analyze in what extend the coexistence of both standard and green products is problematic inside logistic units. Obviously there is still a lot of work improving supply chains behavior facing large compensation bills. Shipments consolidation is a promising field which might allow companies to reduce their total cost while remaining competitive. Although this particular case study is focused on a governmental regulation targeting especially Quebec companies, extended producer responsibility however is a worldwide concept and organizations all over the world could benefit from such a mathematical model.

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