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Developing a Mathematical Model for Trade-off Analysis of New Green Products

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***Abstract*—**In the near future, companies will be increasingly forced to shift their activities along a new road in order to decrease the harmful effects of their design, production and after-life on our environment. Products must meet environmental standards to not only prevent penalties but to consider the sustainability for future generations. However, the most important factor that companies will face is selecting a reasonable strategy to maximize their profit. Thus, companies need to have precise forecast from their profit after design stage through Trade-off analysis. This paper is an attempt to introduce a mathematical model that considers effective factors that impact the total profit when products are designed for resource and energy efficiency or recyclability. The modification is according to different strategies based on a Cost-Volume-Profit model. Here, the cost structure consists of Recycling cost, Development cost, Ramp-up cost, Production cost, and Pollution cost. Also, the model shows the effect of implementation of design for recyclable on revenue structure through revenue of used parts and revenue of recycled materials. A numerical example is used to evaluate the proposed model. Results show that fulfillment of Green Product Development not only can reduce the environmental impact of products but also it will increase profit of company in long term.

***Keywords*—**Green Product, Design for Environment, C-V-P Model, Trade-off analysis.

I. Introduction

SINCE 2008, the number of customers that prefer to purchase a 'green' or environmentally friendly product instead of a comparably priced ordinary product obviously has boosted [1]. In order to reduce the environmental impact of human activities and improve the knowledge of their effects on human health and ecosystems, many firms adopt sustainable practices in their product designs and production processes. At the same time, many laws and legislations have been established by international organizations and governments to protect the environment against both global and local pollution. Regarding these concerns, manufacturing enterprises have to modify their business or production process in the direction of environmental policies, inevitably. So, new goals have to be considered by companies in order to reduce or eliminate current waste, air pollution, and energy consumption throughout their products' life cycle. More than 80 percent of all product–related environmental impacts are determined during the design phase of a product [2], [3]. During the design process, in order to reduce the environmental impact, different goals can be defined by a company, as for example: reducing energy consumption and choosing the right materials, both of which can cause critical environmental problems [2]. That's why many companies need to redesign their current products in order to reach the environmental protection goals. The effects of product development and manufacture on pollution emission are recent threats that push firms to move towards producing new generations of products, i.e. green products.

Many studies have been performed on various aspects of green products and green production [4]-[8].However few of them investigated the effects of going green on a company's profit [9]-[11] while the financial effect of green products in the future is a main concern of managers in charge of new product development projects. In this research we focus on green products which are designed to minimize the environmental impact during its life-cycle. Companies can redesign their products for the environment based on three main strategies [3]:

1. Resource and emission efficiency and energy saving;
2. Recyclability, disassembly, and environmentally friendly disposal;
3. Reducing products packaging.

The implementation of these strategies needs different facilities that not only affect production factors but also have different product development processes with dissimilar costs for the company. Indeed, the conditions under which green products are developed and manufactured can be significantly different from traditional methods since one of the main goals becomes the minimization of environmental impact [2]. On the other hand, the acceptability of a design and compliance with environment of this new product, as with other products, has to be assessed based on different verification methods whether through physical tests or numerical calculations. These methods have three main purposes: screening, performance assessment, and trade-off analysis. This paper is focused on the trade-off analysis of green products.

"Trade-off analysis methods are used to compare the expected cost and performance of several alternative design approaches." [12]

The main objective is designing for the environment. Consequently, we need to consider other parameters related to energy consumption, and recycling activities as part of cash flows in the product development project. So, recycling cost

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and benefit such as: cost of disassembly, cost of shredding, revenue of used parts, revenue of recycled material, etc. and benefit of energy reduction from energy saving as effective parameters have to be considered in the estimation of profits.

Before introducing the products to market, it is essential for companies to know the precise number of products that have to be produced in order to achieve maximum profit in a given period. They can decide about the future of their new products based on the acquired results of the trade-off analysis to compare with their current situation. In this paper, we present a mathematical model for trade-off analysis of new products which are designed for the environment. The model can determine how many products should be produced and how many of them should be recycled in order to maximize the profit of the companies. In the process of modeling, cost and revenue parameters will be affected. Hence, the cost parameters can be broadly divided into four categories: recycling cost, development cost, production cost, and emission tax. The revenue generated by the implementation of environmental friendly strategies can be defined in three sections: it includes revenue of used parts, revenue of recycled materials, and sales revenue. Each of these parameters will be explained in the next sections.

II. Model

Energy, recycling process, and taxes are parameters that cannot be considered in the short-term. Recycling, for example, is a time consuming process which takes place in part at the end of the product life cycle. Similarly, carbon price is to be paid annually as a tax by companies. Thus, the product life cycle analysis, against a cross-sectional analysis, can be indicated proper forecast of associated costs and revenues of the product in the future.

Costs and revenues of a product life cycle can occur in three phases; development, utility, and recycling or reprocessing. Development is an initial cost which includes production, sales, and the product development process, while usage and recycling phases, as a subsequent cost, include recycling cost [13]. This model focuses on the initial cost and recycling cost, as a subsequent cost. These costs can be broadly divided into four categories; Development Cost, Production Cost, Recycling Cost, and Pollution Cost. Analogous to costs, revenues also can be allocated via product sale and used parts and recycled materials, in the recycling process. The main effect of the implementation of the recycling process in the product life cycle is reducing the environmental impact of a product via conserving natural resources and decreasing the amount of harmful effects in the manufacturing process [14]. Also, the energy needed to recycle many materials and components of a product is less than the energy required to produce originally [15]. In the paper industry, for example, every tonne of recycled fiber that displaces a tonne of virgin fiber will bring 27% of total energy consumption saving for a company [14]. The energy consumption, fuel for manufacturing, directly affects pollution emissions. Thus, companies can reduce their pollution emission via energy conserved.

It this paper, the effective parameters are formulated based on the recycling process, development process, production process and energy consumption in order to calculate the pollution emissions tax.

This model is formulated based on the Cost-Volume-Profit (C-V-P) model framework. The CVP analysis is the traditional approach to assess profitability among manufacturing enterprises. The original model of C-V-P, presented by Hess (1903), was used for one product and no uncertainty with fixed and variable costs. This model was further developed by other researchers to more diversified and complex designs with multiproduct situations and uncertainty [16]. In fact, this model could show the relationships between costs, revenue and profit in a multiproduct situation [17].

A. Model Assumptions

In order to develop the model, the following simplifying assumptions were made:

1. All components and connections are homogeneous.
2. Recycling technology is already available in the factory.
3. The market is competitive and the unit selling prices are constant for the product.
4. All parameters are considered based on multi period and medium term planning horizons.
5. Only a given percent of the products can be gathered for recycling at the product's end of life.

III. Recycling

A product is made of a number of discrete parts, which are called the components, and connections, which physically link between the components [18]. Some of these components and connections can be sent back to operation process via recycling in the product life cycle. Product life cycle recycling can include material recycling, production waste recycling, reusing and remanufacturing, and or disposable product recycling. In general, the recycling process can be divided to four main steps, including disassembly of components, shredding of some components for material recycling, recovery of reusable components and connections, and disposal of the remaining components which are not usable in the manufacturing process [9].

A. Recycling Costs

Typically, a company needs to install a set of machines and assign a group of workers in order to separate the desired components and retrieval of usable components from accumulated products. Consequently, recycling of a product has a given cost for the company in each stage. So, the recycling cost comprises cost of disassembly, cost of shredding, cost of recovery, and cost of disposal. Also, the company will be faced by some limitations due to machines and labor works capacities which are typically captured by working time.

1) Cost of Disassembly

The disassembly process is a time consuming process in which product parts will be separated by machine or labor.

Disassembly has a given cost in period t for company which can be denoted as C_{d_t} for each product in the model. Furthermore, total requirement time of separating part i from connection j can be defined through $\sum_{j=1}^{n}\sum_{i=1}^{m-g} k_{ij}$ where n represents the number of different type of connections and m is the number of same type of joints in products, and g represents number of joints that connect parts of the same material [9]. Equation (1) restricts the number of products that can be disassembled according to available working time in period t (ϑ_t).

$$\sum_{j=1}^{n}\sum_{i=1}^{m-g} k_{ij}\, y_t \le \vartheta_t \qquad \forall\, t \in T \tag{1}$$

2) Cost of Shredding

After disassembling the desired parts, some of these components cannot be repaired for reuse while their raw materials can be returned in the production process. These components could be shredded, breaking components at particle size into small pieces, via milling, grinding, etc. in order to increasing the materials homogeneity [18]. The cost of shredding has to be estimated for each part separately since different types of parts which need different shredding methods might exist. The specific cost of shredding (C_{sh}) can be defined for part i in period t. Then, the cost of shredding related to each product can be calculated from the summation of the shredding cost of the parts, as shown in (2). Also, a limitation should be defined for the number of products according to the maximum capacity shredding machine z in period t (φ_{zt}) based on the weight of the part i which have to be shredded by machine z (W_{iz}), as shown in (3).

$$C_{shredding} = \sum_{t\in T}\sum_{i\in V_1} C_{sh_{it}} \tag{2}$$

$$\sum_{i\in V_1} W_{iz}\, y_t \le \varphi_{zt} \qquad \forall\, z \in M_1 \text{and} \forall\, t \in T \tag{3}$$

3) Cost of Recovery

Some parts are worked on at the end of a product's useful life. The use of the secondary materials reduces environmental impact [18]. So companies try to return some reusable parts or materials to the production process via recovery. In general, the recovery process includes recycling of materials in the manufacturing process and reuse of parts in assembly process. After disassembly, both shredded materials and disassembled parts need to be repaired before being returned to the production process. However, the effective factor of accounting a component recovery cost is its suitability for recovery. It can be determined by companies based on durability and separability. Thus, after selection testing, proper parts and materials will be sent for a recovery process. The cost of recovery becomes expensive with increasing depth of recovery operation. Thus, it is important to determine the volume of recovery [19]. Hence, cost of recovery for materials in each period can be calculated via material recovery cost of type k material in period t ($l_{r_{kt}}$), k may be steel, plastics, etc. based on weight of type k material to be recovered in a product (W_{r_k}) [9]. Furthermore, recovery cost of parts can be calculated based on the sum of the cost of required materials to repair part i in period t (R_{ikt}). So, based on (4), the recovery cost can be defined from the sum of material recovery cost and part recovery cost.

$$C_{recovery} = \sum_{t\in T}\sum_{i\in V_2}\sum_{k=1}^{m} R_{ikt} + \sum_{t\in T}\sum_{k\in H_1} l_{r_{kt}}\, W_{r_k} \tag{4}$$

4) Cost of Disposal

Once the suitable components and materials have been recovered, the useless parts of the product will be sent to waste disposal sites. The waste will be dumped via incineration or landfill. Incineration can bring energy recovery while it is reducing the waste volume [18]. Many wastes have organic materials which can be burnt in an incinerator. So, the produced energy can be recovered via a boiler, for example, to generation electricity. Finally, the rest of the waste will be sent to landfill sites. In fact, landfill is the least attractive option in waste management [20]. We assumed the same cost for incineration and landfill, to model the disposal cost of materials and components, based on the weight of dumped waste of the product (W_d). Disposal cost can thus be estimated via (5) [9]:

$$C_{disposal} = \sum_{t\in T} d_{c_t} W_d \tag{5}$$

where, d_c is the disposal cost of one tonne of solid waste in period t.

B. Recycling Benefits

As mentioned before, some parts and materials of recycled products can be returned to the production process via recovery. So two type of revenues can be defined based on recycling of reusable parts or the recycled materials [9]. Each type of revenue can be formulated according to following parameters.

1) Revenue of Used Parts

"Reuse is the employment of components and modules obtained from end-of-life products as spare parts or in other items." [18] All the usable parts will be recovered to be reused in new products. Thus, instead of each part which is used in the new products, companies acquire given revenues according to value of the part. Revenue of used parts for a product can be estimated based on total value of recovered parts that used in the product, (6):

$$R_{part} = \sum_{t\in T}\sum_{i\in V_2} P_{u_{it}} \tag{6}$$

where, $P_{u_{it}}$ represents the value of part i in period t, and n is number of reusable parts disassembled in the product.

2) Revenue of Recycled Material

An important part of recycling is the recovery of materials out of scrap from end-of-life products [18]. Recovered materials can be returned to the production process with other raw materials. That's why these are as valuable as recovered parts for companies. Hence, revenue of recycled materials can be estimated from total value of recovered materials in producing of a product, as in (7):

$$R_{\text{material}} = \sum_{t \in T} \sum_{k \in H_1} P_{m_k} \tag{7}$$

where, $P_{m_{kt}}$ is the value of type j of recycled material to produce one unit of product in period t, while H_1 is the set of recycled materials in the product.

IV. Product Development Cost

New product development is a multi-stage process [21]. Each stage of this process needs a given budget which is typically calculated based on the number of people that work as a project team, duration of the development project, and tools that are needed for production up to the design process. Design cost, for example, includes direct cost (includes number of designers, duration of product design, number of models required, and materials), manufacturing cost (includes all expenses that need to implement new product detail created such as surface finishes and stylized shapes), and time cost (include opportunity cost that will appear due to delay in the product's introduction to market) [2]. Moreover, in the planning phase, the company needs to focus on customer and market insights as a key reason of top innovators to keep winning activities [22]. Thus an independent marketing budget helps the product development team to provide an overview of some of the most useful market analytics.

These costs are not related to the number of products. So the development costs are fixed costs. In this model, Dc denotes the fixed cost of product development.

V. Carbon Price

The main purpose of the carbon tax is to reduce emissions of carbon dioxide via forcing producers to pay a part of the cost of its negative effects.

The main sources of carbon dioxide emissions in industrial plants are combustion of fossil fuels (e.g. coal, oil and natural gas) and chemical reactions that do not involve combustion (such as reactions in production of metals and mineral products) [23]. Additionally, an important indirect effect of industries on the CO2 emission is the electricity generated in power plants that causes greenhouse gas emission. Energy use of a production system in typical plants can be divided into two parts including: 1) fixed energy overhead, and 2) marginal energy per unit of product [24].

In this model, we assumed a stepwise function in order to calculate the manufacturer's carbon tax, as shown in Fig. 1. Thus the carbon tax is calculated by 8, while the amount of CO_2 is estimated based on the energy used in production and recycling process.

$$R_{CO_2} = \sum_{l=1}^{n} T_l \eta_l E_{CO_2} \tag{8/1}$$

$$E_{CO_2} \leq \sum_{l=1}^{n} E_l \eta_l \tag{8/2}$$

$$\sum_{l=1}^{n} \eta_l = 1 \tag{8/3}$$

$$\eta_l \in \{0,1\} \qquad l = \{1,2,3,\dots,n\} \tag{8/4}$$

where, T_l is the carbon tax rate in level l and R_{CO_2} represents the total carbon tax while the factory produced E_{CO_2} kilograms of CO_2 emission.

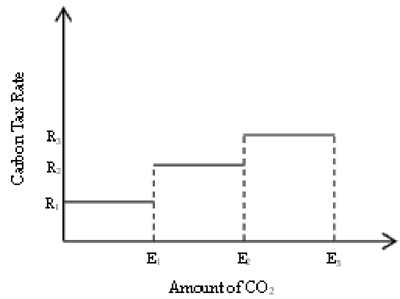

Fig. 1 Stepwise function of Carbon Tax

Equation (9) represents the total emission which is produced in production and recycling processes. Therefore the CO2 produced by energy consumed for producing products can be estimated through the following equations:

$$E_{CO_2} = \sum_{t \in T} (E_{\text{production}_t} + E_{\text{recycing}_t}) \tag{9}$$

$$E_{\text{production}_t} = \sum_{i \in V_2} e_i (x_t - y_t) + \sum_{i \in V - V_2} e_i x_t + \sum_{j=1}^{n} \sum_{i=1}^{m-g} \emptyset_{ij} x_t + O_{p_t} \mu_{1_t} \qquad \forall t \in T \tag{10/1}$$

$$x_t \leq R \mu_1 \qquad \forall t \in T \tag{10/2}$$

$$\mu_{1_t} \in \{0,1\} \qquad \forall t \in T \tag{10/3}$$

where, emissions for producing one unit of part i is captured by e_i, while, n1 is a set of parts that can be obtained from recycled products and n2 is otherwise. And $\emptyset_{ij}$ is the emission produced from assembling part i and j. Also, a company produces fixed CO_2 emission via its fixed energy overhead in period t (O_{p_t}), when x is greater than or equal to one in period t.

Moreover, the energy used for recycling products is producing a given CO_2 emission that is estimated by the following equations:

$$E_{\text{recycing}_t} = F y_t + O_{r_t} \mu_{2_t} \qquad \forall t \in T \tag{11/1}$$

$$y_t \leq R \mu_{2_t} \qquad \forall t \in T \tag{11/2}$$

$$\mu_{2_t} \in \{0,1\} \qquad \forall t \in T \tag{11/3}$$

where, F is the CO_2 produced in order to recycle one unit of product and O_{r_t} represents the fixed energy overhead, when y is greater than or equal to one in period t.

VI. Production Cost

Production as a beginning phase of product life cycle has a given cost for each product which traditionally can be divided into machine, labor, and material cost. However, when a product is designed based on recycling capability, production cost can be defined according to three main parameters; material cost, manufacturing cost, and assembly cost [19]. Thus the machine and labor costs will be accounted for in the manufacturing and assembly costs. Also, a company may have inventory or backorder according to customer demand, so holding and backlogged cost can occur based on a difference between the amount demanded and the amount of produced in each period.

A. Manufacturing Cost

Manufacturing is a collection of technologies and methods, such as casting, forming, molding, etc., in order to produce a product which has a different process based on product features. Two main parameters of manufacturing are labor and machine costs. Cost and limitation of production can be assessed based on these parameters. If each part of the product has a given cost, the manufacturing cost of the product can be calculated by (12).

In a production process different type of machines will be used to assemble or form the components of the product, so a set of machines (B) with a limited capacity (φ_{zt}) are considered in order to produce the component of products in period t. Equation (13) limits the number of products produced according to capacity of the machines. Where, δ_{iz} is required time for manufacturing the component i which should be made by machine z.

$$C_{mnufacturing} = \sum_{t\in T}\sum_{i=1}^{n} C_{mfct_{it}} \tag{12}$$

$$\sum_{i=1}^{n} \delta_{iz}\, x_t \le \varphi_{zt} \qquad \forall\, z \in M_2 \text{and} \forall\, t \in T \tag{13}$$

Likewise, a company has a limited work force in a manufacturing process. This limitation can be captured by time. So, if σ_i represents the required time for fabricating the component i by workers, (14) restricts the number of products according to available working hours in period t (ϑ_t).

$$\sum_{i=1}^{n} \sigma_i\, x_t \le \vartheta_t \qquad \forall\, t \in T \tag{14}$$

B. Assembly Cost

Assembly cost can be calculated based on total cost of connecting parts i and j together, as shown in (15). The number of products can be limited in the assembly process according to (16). $L_{a_t}$is the available time for assembling. Also, just as in the disassembly process, a given time (β_{ij}) is needed to connect between part i and j. n is the number of different type of connections and m is the number of the same type of joints in the product, and g represents the number of joints that connect parts of same materials.

$$C_{assembly} = \sum_{t\in T}\sum_{j=1}^{n}\sum_{i=1}^{m-g} C_{a_{ijt}} \tag{15}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{m-g} \beta_{ij}\, x_t \le L_{a_t} \qquad \forall\, t \in T \tag{16}$$

C. Materials Cost

Material is a prime element of production. A product is composed of different types of materials. If we assume a given volume of material i to fabricate the parts of one unit product, then (17) can be defined as the related cost of materials per unit of products in period t.

$$C_{material} = \sum_{t\in T}\sum_{i=1}^{n} U_{it} \tag{17}$$

D. Holding and Backlogged Cost

Holding and backlogged cost will occur when a manufacturer will be faced with positive stock due to shortage of demand (inventory) or negative stock because of excess demand (backorder) in each period. Equation (18) can be defined as the related cost of holding and backlogged per unit of products in period t.

$$C_{hb} = \sum_{t\in T} h_t I_t + \sum_{t\in T} g_t B_t \tag{18}$$

where, I_t is a number of inventory and h_t is holding cost of per unit of products in period t. Also, B_t represents a number of backorder and g_t is backorder cost of per unit of products.

The number of products is restricted by demand in each period, as shown in (19).

$$x_t + I_{t-1} - B_{t-1} - d_t = I_t - B_t \qquad \forall t \in T \tag{19}$$

where, d_t represents the demand of product in period t.

VII. Sales Revenue

Different strategies can be performed regarding the pricing of products by companies which can be different based on market features, type of industry, company's brand and so on. However, in this model, a competitive price (P_s) is assumed that can be estimated based on price of same products in the market in each period. Hence, the sales revenue can be calculated through the multiplication of the price of one unit product and the number of products, (20).

$$R_{sale} = \sum_{t\in T} x_t\, P_{s_t} \tag{20}$$

TABLE I
CONSTRAINTS' PARAMETERS

Symbol	Cost ($)	Scale	Symbol	Cost ($)	Scale
ϑ	962	hours per week	F	0.36	kilogram
t_{12}	10	Sec.	O_r	50	kilogram
t_{13}	25	Sec.	φ_1	5.79	hours per day
t_{16}	31	Sec.	φ_2	5.18	hours per day
t_{35}	12	Sec.	φ_3	5.34	hours per day
t_{46}	8	Sec.	φ_4	5.26	hours per day
t_{57}	27	Sec.	φ_5	9615	Kilogram per week
e_1	0.017	kilogram	φ_6	7500	Kilogram per week
e_2	0.014	kilogram	β_{12}	10	Sec.
e_3	0.027	kilogram	β_{13}	25	Sec.
e_4	0.09	kilogram	β_{16}	31	Sec.
e_5	0.0175	kilogram	β_{35}	12	Sec.
e_6	0.027	kilogram	β_{46}	8	Sec.
e_7	0.1	kilogram	β_{57}	27	Sec.
$\emptyset_{12}$	0.012	kilogram	σ_1	20	Sec.
$\emptyset_{13}$	0.017	kilogram	σ_2	16	Sec.
$\emptyset_{16}$	0.012	kilogram	σ_3	29	Sec.
$\emptyset_{35}$	0.016	kilogram	σ_4	39	Sec.
$\emptyset_{46}$	0.007	kilogram	σ_5	48	Sec.
$\emptyset_{57}$	0.09	kilogram	σ_6	10	Sec.
δ_{21}	19	Sec.	σ_7	12	Sec.
δ_{22}	12	Sec.	E_1	20000	kilogram
δ_{31}	21	Sec.	E_2	30000	kilogram
δ_{32}	16	Sec.	E_3	400000	kilogram
δ_{43}	5	Sec.	α	0.8	-
δ_{44}	9	Sec.	L_a	2991	hours per week
δ_{53}	4	Sec.	δ_{11}	12	Sec.
δ_{54}	10	Sec.	δ_{12}	5	Sec.
δ_{63}	3	Sec.	d_1	22000	product
δ_{64}	1	Sec.	d_2	20000	product
δ_{73}	1	Sec.	d_3	18000	product
δ_{74}	1	Sec.	d_4	10200	product
W_{15}	0.03	kilogram	O_p	1000	kilogram
W_{25}	0.05	kilogram	h	5	product
W_{46}	0.012	kilogram	g	10	product

VIII. NUMERICAL EXAMPLE

An electric juicer producer decides to develop a current model (A-0) of a blender which has a given seasonal demand with $2,300,000 annual profit. The producer wants to introduce a new model (A-1) with recyclable capability which is designed based on new materials which are compatible with the environment and it can be disassembled easily. The blender consists of seven parts each of which needs a different type of process for recycling.

Before starting the test and prototype processes, managers need a proper forecast of the economic performance of this product in the future based on a trade-off analysis. They need useful information in this step (such as: number of products that have to be produced, number of recycled products and the amount of CO_2 emission based on produced and recycled products) in order to take a decision about the future of the project. Also, they expect a given percent of total produced products in previous seasons (0.5%, 15%, and 30% in season two, season three, and season four respectively) can be returned for recycling process. Thus, based on following data, crucial information can be obtained via the model presented in order to help the managers make decisions.

TABLE II
OBJECTIVE FUNCTION PARAMETERS

Symbol	Cost ($)	Scale	Symbol	Cost ($)	Scale
P_s	40	Per unit	U_7	0.1185	Per unit
P_{u_1}	1.578	Per unit	C_{mfct_1}	1	Per unit
P_{u_2}	1.53	Per unit	C_{mfct_2}	0.9	Per unit
P_{u_3}	2.672	Per unit	C_{mfct_3}	1.5	Per unit
P_{u_4}	2.238	Per unit	C_{mfct_4}	1.38	Per unit
P_{u_5}	1.159	Per unit	C_{mfct_5}	0.5	Per unit
P_{u_6}	1.038	Per unit	C_{mfct_6}	0.2	Per unit
P_{u_7}	0.2385	Per unit	C_{mfct_7}	0.12	Per unit
P_{m_1}	0.078	Per tonne	$C_{a_{13}}$	0.5	Per unit
P_{m_2}	0.075	Per tonne	$C_{a_{16}}$	0.5	Per unit
P_{m_3}	0.06	Per tonne	$C_{a_{21}}$	0.85	Per unit
P_{m_4}	0.186	Per tonne	$C_{a_{35}}$	0.84	Per unit
U_1	0.078	Per unit	$C_{a_{46}}$	0.53	Per unit
U_2	0.13	Per unit	$C_{a_{57}}$	0.73	Per unit
U_3	0.322	Per unit	C_{sh_1}	0.0002	Per unit
U_4	0.018	Per unit	C_{sh_2}	0.0003	Per unit
U_5	0.129	Per unit	C_{sh_4}	0.0006	Per unit
U_6	0.108	Per unit	R_{31}	0.0104	Per unit
l_{r_1}	0.04	Per tonne	R_{32}	0.045	Per unit
l_{r_2}	0.07	Per tonne	R_{53}	0.012	Per unit
l_{r_3}	0.01	Per tonne	R_{54}	0.027	Per unit
l_{r_4}	0.05	Per tonne	R_{63}	0.0015	Per unit
W_{r_1}	0.004	Per tonne	R_{64}	0.03	Per unit
W_{r_2}	0.006	Per tonne	T_1	0.21	Per kilogram
W_{r_3}	0.009	Per tonne	T_2	0.26	Per kilogram
W_{r_4}	0.019	Per tonne	T_3	0.32	Per kilogram
d_c	0.02	Per tonne	W_d	0.053	Per tonne

TABLE III
RESULTS

t	x_t	y_t	I_t	B_t	Eproduction	Erecycling
1	20769	0	0	1231	7626.8	0
2	20769	1038	0	462	7552.6	413.68
3	20769	6075	2307	0	7192.5	2227
4	20769	16558	12876	0	6442.9	6000.9

The result shows that the company needs to produce and sell 20,769 units of the product seasonally while it will have 1231 units and 462 units of backordered demand in season one and season two respectively and 2307 units and 12,876 units inventory at season three and season four respectively according to the current demand of the product in each season in the market. Also, 23,671 units (23671=1038+6075+16558) should be collected for recycling in a year. For example, 1038 units of 20769 products that produced in season one should be recycled at season two. Eventually, the company can be achieved greater than $2,385,000 annual profit which is about 3.7% greater than of the company's current annual profit, from this product. Therefore, the managers can be assured that continuing the development project will not only decrease the environmental impact, but the company will also obtain increased profits. On the other hand, the results show the total CO_2 is 37,456 kilograms, which means that the maximum carbon tax rate ($0.32 per kilogram) should be paid by the company.

In general, the model gives a forecast from the amount of products that should be produced and the amount of products that should be returned to the recycling process in each period to reach the maximum profit in over expected time. In this example, the expected time is one year that is divided into four periods, which represents seasons of the year, while it can be defined for different years, months, or even weeks. Also, it shows the amount of CO_2 which is produced in each period based on the amount of produced and recycled products in order to calculate the carbon tax. In this example, a stepwise function is defined for calculating the tax. This information gives managers have a view of the economical effect of the project in the future. Nevertheless, it has some limitations, such as: it cannot calculate the net profit of the recycling process separately. And, it cannot help managers estimate the company's return on investment on the project. Also, logistic costs (such as warehouse or collection center for recycling) are not considered in this model, although it can have a significant effect on profit in some industries.

IX. Conclusion

In this paper, we propose a mathematical model in order to help managers in their decision making to the forecast future profit of a product after the design phase in the product development process based on different parameters. We suggest using maximum profit approach in product life cycle to select a reasonable strategy of producing green products. The model is designed based on cost and revenue parameters throughout the product life cycle, from development to disposal. The model's constraints present some major limitations that companies are facing in production and recycling processes, in addition to effects of these limitations on economical parameters. The crucial point of this model is the consideration of product development and recycling costs in addition to manufacturing cost, which affects the managers' decision in the production process. Also, we attempted to reflect different aspects of typical problems that companies are faced with in production and recycling processes such as: machine and labor limitations, and carbon tax.

A generalized model has been designed so that it makes it applicable to many manufacturers such as: electronic, toy, automotive, and furniture industries. It can help managers to obtain appropriate information about the future of a product in the design step of product development. They can calculate the economical amount of the product to produce and know how many products should be recycled according to a factory's throughput to reach the maximum profit. Also, it releases very useful information about the amount of emission produced for producing and recycling processes. Managers can compare this information with the current situation of the product and decide about the continuation of the product development project. A numerical example is defined in order to show how a manager can use the model's results.

The model's parameters are divided into three main parts, development and production, CO_2 emission, and recycling. Development, manufacturing, assembly, and material costs are identified as basic parameters in development and production part. Also, disassembly, shredding, recovery, and disposal costs are defined as fundamental parameters of recycling of a product. Finally we considered two different parameters (emission produced for producing and emission produced for recycling) to measure total CO_2 emission tax in stepwise model.

For future investigation, the model can be developed by adding relevant costs of upgrading and usage part of product life cycle. And it can be modified for different period time. Also, it can be customized for a given industry (i.e. dairy industry) to find green product development process and calculation of emission tax.

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