An Integrated Carbon Cap and Trade Policy based Low Carbon Supply Chain Configuration for an Enterprise for a New FMCG Product

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ABSTRACT
The integration of Green Supply Chain Configuration Decision Making with New Product Development is challenge before any enterprise in today's era of globalization and stiff competition. The real challenge is for a Fast Moving Consumer Goods (FMCG) manufacturer as these products have a short shelf life. The research paper tries to capture the economic and ecological aspect while designing a new product low carbon footprint supply chain configuration for a FMCG manufacturing enterprise under the effect of carbon cap and trade economic policy. First a conceptual framework is presented and then the situation is modelled *via* a mathematical model. Numerical illustration is presented to validate the proposed model.

Keywords
Carbon emission; Carbon cap; Environment protection; Global warming

1. INTRODUCTION
Global warming poses a threat as well as challenge before government organizations , agencies , government run enterprises as well as privately owned enterprises and non-profit organizations to either switch to greener alternatives or impose policies to account for carbon emissions. Some of them are switching to renewable sources of energy , others are redesigning products or adopting energy saving schemes and other measures to reduce carbon emissions generated during the process of manufacturing and transportation of goods. Regulations related to carbon emissions inevitably leads to a substantial increase in emissions related costs. This persuades enterprises as well as organizations worldwide to take emission related policies in to account. There are polices or schemes offered by government whereby enterprises are rewarded for emitting less than the carbon caps imposed by receiving payments or by selling their carbon credits to the enterprises (in the countries) with more CO_2e emissions.

Industry is increasingly recognizing the impact of an enterprise's action on the carbon emissions associated with its supply chain activities. A supply chain normally focuses on adjustments of manufacturing plants, demand or distribution centres and their association with suppliers and end customers. In this process, the potential sources of carbon emissions such as vehicles used to make deliveries, energy efficiency of vehicles, mode of transportation often gets overlooked by the entrepreneur. Similarly, if we talk about new product introduction of an FMCG product and its inception in to the potential market, it is quite possible that the manufacturing enterprise will launch the product within existing market set up owing to the short shelf life of the product. Sometimes an exclusive set up is possible but that depends on the product range and demand and also the expected profit from the product. Decisions related to facility location, potential suppliers of raw materials and semi-finished products also affect an enterprise's carbon footprints or level of carbon emissions. Hence decisions related to providing an adequate supply chain configuration that can manage both the ecologic, economic as well as environmental aspects is a challenging task before an entrepreneur and operational manager.

This paper analyses the effect of emission regulation based on carbon cap and trade on the supply chain configuration of an FMCG manufacturing enterprise. CO_2e emissions are assumed to have occurred during the procurement of packaging material, production of finished product and storage and transportation of finished and packed product. The situation is mathematically formulated as a single objective optimization problem which deals with minimization of usual production / procurement costs as well as carbon emission related costs subject to regulations based on carbon cap and trade and other operational constraints.

The research paper is arranged as follows. Section 2 presents the literature review. Section 3 defines the problem. Section 4 presents the basic assumptions, set of decision variables, parameters etc. Section 5 presents the mathematical modelling. Section 6 presents the Case Problem and the results. Finally Conclusions are presented in section 7.

2. LITERATURE REVIEW
Since 1970s, a wide range of literature is available in economics that incorporates environmental concerns through various policy instruments. These policies are both price based such as implementing carbon tax over firms for emitting more than the prescribed limit as well as quantity based such as imposing a carbon cap over emissions and allowing enterprises to trade by exchanging emission permits among each other. However, operational issues and corresponding inventory based models, their confluence with new product introduction and clubbing both with economic policies is quite limited.

Operations Research based models are needed to broaden formal supply chain models from cost minimization to more comprehensive aspects of eco efficiency and carbon footprints [1]. There are research papers in context to green logistics [2] as well as in OR applications for emission reduction in transportation and production design related issues [3]. Supply chain design models can be categorised based on the echelons of supply chains and considered products, the optimization objectives, modelling approach as well as demand requirements [4] and interplay of strategic, operational and tactical supply chain aspects [5]. As detected by [6], the ecologic performance is often measured by carbon emissions that result from production [7], transportation [8] and inventory and warehousing [9] . These emissions occur in all phases of product life cycle [10,11]. Benjaffaar, Li and Daskin [1] suggested that there exists a linear relationship between carbon emission and transportation quantity. The integration of supply chain configuration decision making into new product development processes offers large optimization potential for researchers [12] and can be explored further.

3. CONCEPTUAL FRAMEWORK & PROBLEM DEFINITION

A new kind of cosmetic product needs to be launched in the demand regions of Northern India. The packaging material gets delivered at manufacturing plant where the product gets manufactured and packed in boxes to be delivered to various demand centers in trucks. The supply chain of this FMCG product will therefore have a three echelon structure comprising of Supplier, Production plant (which acts as a buyer) and demand regions of North India. For the supplier as well as production plant, there are restrictions over the fixed quantity to be delivered and manufactured respectively. This results in minimum and maximum lot sizes constraints. The product is manufactured in a regular mode with no overtime. There are production related carbon emissions depending upon the quality of chosen plant. Then there are emissions due to the inbound delivery of packaging components as well as outbound delivery of the finished packed product from the plant to the various demand centers. The system works under the economic policy of *Carbon cap and trade*. This policy implemented by a regulating agency via a trading market , penalize or reward enterprises for emitting more or emitting less than the sum of the caps imposed on the participating enterprises.

4. CASE EXAMPLE

The problems considered here focuses in providing an optimal solution to objective of minimizing the total costs (taking into account three major costs viz. Production and packaging costs, storage costs and transportation costs) as well as carbon emission cost in context of cap and trade. There are constraints such as carbon emissions cap and other operational constraints such as minimum lot size restrictions and upper bounds lot sizes as per supplier's capacity, plant's capacity and carriers' capacity. Then there are demand restrictions as per demand centers' requirements.

4.1 List of Assumptions

- Supply chain comprises of supplier , an FMCG Manufacturer with a production plants and demand centres
- Supplier capacity is deterministic and known
- Deterministic Lead time
- Demand requirements at demand centres are deterministic and known
- Carbon emission are generated during the process of procurement , production , storage , and transportation of packaging material and finished goods
- Backorders are not allowed
- No lost sales
- Single mode of transport (Road : Truck / tempo carriers are considered)
- No make-to stock policy and hence no pipeline filling requirements
- Demand is the regional demand and is same in all demand regions of a particular Zone
- Capacity and demand variables are assumed to have no correlation
- Market price for carbon is fixed over the entire planning horizon

4.2 List of Indices

p: designates the type of product component ; p $= 1$ for packaging material and p $= 2$ for finished product

t: designates time period *; t=1,2,…T*

r: defines the demand region ; $r = 1,2..R$

m: designates the mode of transport used ; *m=1,2…M*

4.3 List of Parameters

Pr_{1mt}:Per unit Cost of procuring the product component in time period 't' through mth transport

Pr_{2mt}: Per unit Cost of producing the product in time period 't'

St_{prmt}: Per unit storage cost of 'p'th product component ($p = 1,2$) to be delivered to rth demand region through mth transport in 't'th time period

Tr_{prmt}:Per unit transportation cost of shipping 'p'th product unit ,($p = 1,2$) to rth demand region through mth transport in tth time period

π_{pmt}: amount of carbon emissions caused in procuring one unit of packaging component (p=1) through mth transport and producing one unit of product (for p=2)in time period 't' respectively

π_{prmt}: amount of carbon emissions caused in storing one unit of 'p'th product component ($p = 1,2$ at the warehouse in tth time period to be deliver to to rth demand region through mth transport in tth time period

π'_{prmt}: amount of carbon emissions caused in transporting one unit of 'p'th product component ($p = 1$) from the place of supplier to the manufacturing plant as well as from the production plant to the 'r'th demand centre (for p=2) in time period 't' through mth transport .

π_Q: Total carbon emission quota for the entire planning horizon

I_{2rt}: defines the inventory of finished product carried from the period 't' to 't+1'

D_{2rt}: defines the demand for finished product in rth demand region in time period 't'

Cap_{1t}: defines the packaging supplier's capacity in time period 't'

$LCap_{prmt}$: $d$efines the loading capacity of mth transport for pth product component ($p = 1,2$) to be supplied to rth demand region in time period 't'

$PCap_{2rt}$: $d$efines the plant's capacity for transporting finished product to rth demand region in time period 't'

Q'_t: defines the min lot size for packaging component in time period ‘t’

Q''_{rt}: defines the min lot size for finished product component to be transported in rth demand region in time period ‘t’

C_t^+: amount of carbon credit an enterprise buys in period t

C_t^-: amount of carbon credit an enterprise sell in period t

pc: price per unit of carbon emission

4.4 List of decision variables

X_{prmt}: amount of i^{th} product ($i = 1,2$) transported to r^{th} demand region in time period ‘t’ through m^{th} transport

Y_{1mt}: binary variable which takes value 1 if packaging supplier is selected to transport the material through m^{th} transport, 0 otherwise

Y_{2rmt}: binary variable which takes value 1 if finished product is transported to ‘r’ th demand region in time period ‘t’ through m^{th} transport, 0 otherwise

4.5 Model Formulation: Single Firm, strict carbon cap and trade

In this situation we are considering that the enterprise who is to manufacture a range of products over its manufacturing plants in different locations must adhere to a fixed cap π_Q on emissions over the entire planning horizon. The problem involved minimizing the total costs (i.e. procurement cost, production cost, storage costs as well as transportation cost and the costs due to carbon credits the firm buys or sell in period *t*. The problem faced by the firm can now be written as follows:

$$Min\ Z = \sum_{p=1,2}\sum_{t\in T}\sum_{m\epsilon M} Pr_{pmt}\,X_{prmt} + \sum_{p=1,2}\sum_{r\in R}\sum_{t\epsilon T}\sum_{m\in M} St_{prmt}X_{prmt} + \sum_{i=m,k\in K}\sum_{r\in R}\sum_{t\epsilon T}\sum_{c\in C} Tr_{prmt}X_{prmt} + p_c\sum_{t\epsilon T}\tilde{C}_{prmt} \quad (1)$$

Subject to

$$I_{2rt-1} + \sum_{m\epsilon M} X_{prmt} - I_{2rt} = D_{2rt} \quad \forall\ t\epsilon T\ , r\epsilon R \quad (2)$$

$$\sum_{m\epsilon M} X_{2rmt}Y_{2rmt} \le PCap_{2rt} \quad \forall t\epsilon T\ , \forall r\epsilon R \quad (3)$$

$$\sum_{m\epsilon M} X_{1rmt}\ Y_{1mt} \le Cap_{1t} \quad \forall\ t\epsilon T \quad (4)$$

$$0 \le X_{1rmt}Y_{1mt} \le LCap_{1mt} \quad \forall\ t\epsilon T\ , \quad \forall m\epsilon M \quad (5)$$

$$\sum_{r\epsilon R} X_{2rmt}\ \ Y_{2rmt} \le LCap_{1rmt} \quad \forall\ t\epsilon T\ ,\ \forall m\epsilon M \quad (6)$$

$$\sum_{m\epsilon M} X_{1rmt}Y_{1mt} \ge Q'_t \ \ \forall\ t\epsilon T \quad (7)$$

$$\sum_{m\epsilon M} X_{2rmt}Y_{2rmt} \ge \ Q''_{rt} \quad \forall\ t\epsilon T\ \ , \forall r\epsilon R, \quad (8)$$

$$\sum_{p=1,2}\sum_{t\epsilon T}\sum_{m\epsilon M} \pi_{pmt}\,X_{prmt} + \sum_{p=1,2}\sum_{r\in R}\sum_{t\epsilon T}\sum_{m\in M}\pi_{prmt}X_{prmt} + \sum_{p=1,2}\sum_{r\in R}\sum_{t\epsilon T}\sum_{m\in M}\pi'_{prmt}X_{prmt} \le \pi_Q + \sum_{t\epsilon T} C^+_{prmt} \quad (9)$$

$$Y_{prmt} \in [0,1]\ p = 1,2\ ,\ \forall\ t\epsilon T\ \ , \forall r\epsilon R,\ \forall m\epsilon M \quad (10)$$

$$X_{prmt} \ge 0 \quad \forall\ p = 1,2\ , \quad \forall\ t\epsilon T\ \ , \forall r\epsilon R, \ \forall m\epsilon M \quad (11)$$

$$C^+_{prmt} \ge 0\ \ , \forall\ t\epsilon T \quad (12)$$

$$C^-_{prmt} \ge 0, \forall\ t\epsilon T \quad (13)$$

$$\text{Where } \tilde{C}_{prmt} = C^+_{prmt} - C^-_{prmt} \quad (14)$$

Equation (1) minimizes the total costs which includes the procurement and production cost, storage costs and transportation costs along with costs associated with buying and selling of carbon credits. Equation (2) defines the net inventory balancing equation for demand. Inequality (3) defines the constraint of production plant capacity over the sum total of units transported from all the carriers to different regions over the time planning horizon. Inequality (4) represents the packaging supplier’s capacity on order quantity for every period. Constraint represented by Inequality (5) represents supplier capacity constraint on overall quantity i.e. total lot size quantity transported through all carriers is less than equal to supplier capacity. Inequality represented by (6) represents the lot size restrictions for packaging component whereas inequality (7) corresponds to lot size constraints for finished product. Carbon emission constraint is given by inequality (8). Equation (9) and equation (10) describes the binary nature of variable Y_{prmt} and Y_{1t} respectively whereas inequality (11), (12) and (13) represents the non- negativity of variables X_{prmt}, C_t^+ , C_t^- respectively.

5. CASE PROBLEM

The case problem considers a fast moving consumer goods product (FMCG) manufacturer having a single packaging supplier. The manufacturing plant has to manufacture a new product to be supplied to two demand centres (D1 and D2) both the demand regions has different product demands. The decision maker’s task in this case problem is therefore to choose a supply chain configuration for the new product *i.e* how much to order , produce and supply so that the total costs as well as lead time can be minimized along with the environmental evaluation which includes minimizing the carbon emissions caused by the inbound and outbound logistics (the total carbon emissions should satisfy the strict carbon emission cap), by manufacturing process and by storage or warehousing as well as minimizing the total costs which also includes costs due to carbon credits the firm buys or sell in period *t* .

(3)

5.1 Case Problem Data

Table 2 shows the monthly demand of each demand market. There is a pre - production period of two months which is for getting product components from packaging supplier. The PLC has the length of two years *(i.e.* T= 24 months) in each demand market which include new product introduction as well. Monthly production capacity is data is provided in table 3. Monthly packaging supplier's capacity are 500,000 pcs per month (Cap_{it}). Monthly carriers capacities for finished product to be delivered to both the regions from manufacturing plant for the finished product 100,000 pcs per truck per month for truck 1 and 200,000 pcs per truck per month for truck 2 . Minimum lot sizes for packaging component are 1000,000 pcs per month (Q'_t) to be delivered to manufacturing facility for two months ; minimum lot sizes for both the finished products are 50,000 pcs per month for region 1 (NR1) (Q''_{1t}) and 30,000 pcs per month for region 2 (NR2)(Q''_{2t}) respectively. Packaging material cost is Rs 7/pc for plant; Monthly storage cost is Rs 5/ pc and Production cost is Rs 12/ pc. Transportation cost is Rs 0.055/pc for truck 1 and Rs 0.06/pc for truck2 respectively. Price per unit (per Kg) of carbon emissions is taken as Rs3/- . Emission (CO_2e) data can be obtained from The World Bank website (http://databank.worldbank.org/data/home.aspx). The calculation of CO_2e caused by production and warehousing is based on energy consumption data of production equipment and of production plant's warehouses.

Table 2 : Monthly Demand data ('000 units) for each demand market

Month	DM1		DM2	
	Year 1	Year 2	Year 1	Year 2
Jan	60	70	65	65
Feb	70	70	55	70
Mar	70	65	60	70
Apr	60	65	60	70
May	50	60	70	60
Jun	40	70	70	65
Jul	60	70	60	70
Aug	65	70	60	70
Sep	70	70	75	70
Oct	75	80	80	70
Nov	80	80	85	70
Dec	85	80	85	70

Table 3: Capacity data at the production plant

Note: Number of units ('000) units (per truck)

Mo nth	Year 1		Year 2		Mo nth	Year 1		Year 2	
	D R1	D R2	D R1	D R2		D R1	D R2	D R1	D R2
Jan	50	50	45	55	Jul	55	65	65	45
Feb	40	45	50	60	Aug	70	70	70	45
Mar	45	55	50	65	Sep	60	75	70	50
Apr	40	60	55	65	Oct	75	70	55	50
May	40	60	55	70	Nov	80	80	75	75
Jun	45	65	65	70	Dec	70	80	75	80

5.2 Results

The problem is solved with a total of 466 variables out of which 200 are non-linear variables and 266 are integers. Lingo 10.0 generator memory used is 166K. Cost and number of units are evaluated taking carbon emission quota to be 5000 units (in Kgs) units. Total cost with carbon emission to be purchased is given as follows

Table 4: Results in terms of Cost ('000 INR); Generator Memory used: 166 K

Total Cost ('000 INR) (Value of Z)	Emissions to be purchased (in kgs)
1,49,733	18675

Table 5: Number of Units supplied ('000 units) when carbon emission quota is 5000 units

MT	MT 1		MT2			MT 1		MT2	
Mo nth	N R1	N R2	N R1	N R2	Mo nth	N R1	N R2	N R1	N R2
Jan	50	30	-	-	Jan	50	-	50	30
Feb	50	30	-	-	Feb	50	30	50	-
Mar	50	-	0	-	Mar	50	-	50	-
Apr	50	-	-	30	Apr	50	-	-	-
May	50	-	-	-	May	50	30	50	-
Jun	50	-	-	-	Jun	-	50	50	30
Jul	-	-	50	-	Jul	-	50	-	30
Aug	50	-	-	30	Aug	-	50	-	30
Sep	50	-	-	30	Sep	-	50	-	30
Oct	-	30	50	-	Oct	-	50	-	30
Nov	50	30	0	-	Nov	-	50	-	30
Dec	50	-	-	30	Dec	-	50	-	-

MT : Mode of transport ; MT1 : Mode of transport 1

6. CONCLUDING COMMENTS AND FUTURE DIRECTIONS

In this paper, using relatively simple inventory based models, it is shown as to how carbon emissions concerns such as carbon cap and trade could be integrated into operational decision making concerning new FMCG product introduction. However the proposed models can be modified and extended in various ways. Supply chain design model can include the impact of pipeline inventory especially in industries which manufactures products with short product life cycle. Concept of carbon offsets could be included. The analysis carried out was based on the traditional models of lot sizing. Similar analysis can be carried out using other common modes of operations such as the news vendor problems and economic order quantity models. Operational decisions such as supplier selection and / or choice of mode of transportation can be taken into consideration and accordingly solved case of uncertain demand can be incorporated.

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