Sustainable consideration in a continuous review inventory model with integrated transportation decisions under the Carbon Emission Regulations Policies

W.Ritha[1],

I.Francina Nishandhi[2]

Department of Mathematics
Holy Cross College (Autonomous), Trichirappalli-620-002

Abstract:

Sustainability transportation systems make a positive contribution to the environmental, social and economic sustainability of the communities they serve. In this paper we present an integrated continuous review inventory and transportation models with carbon emission regulations. We discuss the economic order quantity model with less than truckload (LTL) and truckload (TL) transportation under carbon tax, carbon cap and cap and trade policies. We find the retailer's optimal order quantity under the carbon emission regulations. We illustrated the numerical examples to compare the expected emission cost under carbon emission regulations.

Keywords:

Sustainability, Inventory, Carbon emission regulations, Economic order quality model, Transportations.

1. Introduction with Literature View.

We already known that the greenhouse gas emissions are threatening the earth's ecology and unless controlled might pose great danger to the human race. According to the sources it is noted that trucking (i.e.), road transportation constitutes the second largest GHG emission generators following passenger transportation. This implies that freight transportation by trucks dominates the GHG emissions compared to the other freight transportation modes such as rail, air, and marine transportation.

Aside from manufacturing inventory holding freight transportation, logistics and warehousing operations are the main supply chain activities that generate emission in many industries. Inventory control policy of a company derives the level of transportation, logistics and warehousing activities. Nowadays companies are motivated to green their operations by regulatory requirements and increasing awareness of customers on climate change. In particular, policy makers implement environmental regulations such as carbon taxing, carbon cap and carbon cap and trade as incentives for firms to increase sustainability of their operations.

In this paper we analyze the sustainability in an inventory control system with integrated transportation decisions under stochastic demand along with the carbon emissions regulations.

We review the studies in the intersection of sustainability and inventory control. In general most of the sustainable inventory control models assume deterministic demand and most of the studies with deterministic demand investigate the well known Economic order quantity model. The EOQ model has been integrated with sustainability by associating direct cost with the environmental damage such as waste disposal and emission from transportation, inventory holding, warehousing activities and packaging. (Bonney and Jaber, 2011, Digiesi et al., 2012, Battini et al 2014) We consider different transportation modes; however our focus is on a stochastic inventory control model and do not associate direct cost with emissions.

In practice, deterministic demand assumption is very restrictive, compared to the deterministic inventory control models with sustainability considerations, there is a limited number of studies examining sustainability of inventory control systems under stochastic demand. Particularly the single period stochastic inventory control models (i.e.). The news vendor problem has been recently analyzed with environmental regulations. Song and Leng (2012) revisit the news vendor problem with carbon cap, trading and taxing regulations. Similarly Liu et al (2013) study the news vendor problem with carbon trading. Hoen et al (2014a) analyze transportation mode selection problem under environmental regulations. In this study we discuss the bi-objective (Q, R) model with LTL and TL transportation along with the carbon emission regulations.

The rest of the study organised as follows, section 2 provides the notations for the mathematical model, section 3 provides a brief explanation of the mathematical model, section 4 presents a numerical example, and finally we conclude the paper in section 5.

2. Notations:

The following notations are used in this paper.

Demand parameters:

λ : expected demand rate units/year

v : standard deviation of demand rate units

τ : lead time duration year

D(τ) : random variable defining lead time demand units

f(D(τ)) : probability density function D(τ)

F(D(τ)) : cumulative distribution function of D(τ)

$\mu(\tau)$: expected lead time demand units

$\sigma(\tau)$: standard deviation of lead time demand units

Retailer's cost parameters:

C : procurement cost $/unit

K : fixed order setup cost $/order

h : inventory holding cost $/unit/year

p : unit backorder cost

Retailer's emission parameters:

$\hat{C}$:emissions due to per unit procurement co_2 Ibs/unit

$\hat{K}$:emissions due to order placement co_2 Ibs/unit

$\hat{h}$: emissions due to inventory holding per unit per unit time co_2 Ibs/unit/year

$\hat{p}$: emissions due to per unit backorder co_2 Ibs/unit/year

Retailer's decision variable:

Q : Retailer's order quantity per order units

LTL transportation parameters:

t : transportation cost per unit by LTL carrier \$/unit

$\hat{t}$: emissions due to per unit transportation with LTL carrier co_2 Ibs/unit/year

τ^{ltl} : LTL carrier's delivery lead time year

TL transportation parameters:

e : transportation cost per unit by TL carrier \$/unit

w : transportation cost per truck by TL carrier \$/truck

v : transportation capacity per truck by TL carrier units/truck

$\hat{w}$: emissions due to per capacity truck transportation with TL carrier co_2 Ibs/unit/year

$\hat{e}$: emissions due to per unit transportation with TL carrier co_2 Ibs/unit/year

τ^{tl} : TL carrier's delivery lead time year

Carbon emission regulation parameters

C : Carbon cap co_2 Ibs/year

α : Carbon emission trading price \$ co_2 Ibs

γ : Carbon tax \$ co_2 Ibs

3. Mathematical Model:

We consider a retailer's continuous review inventory control policy for a single product. In particular the demand per unit time for the product is a random variable with mean λ and standard deviation v. We assume that the demand per unit time is normally distributed. The retailer adopt a (Q, R) policy such that an order of Q units is placed whenever R units are left in the inventory. That is Q and R denotes the order quantity and the reorder point respectively. Let f(D(τ)) and F(D(τ)) denote the probability density and cumulative distribution functions of the lead time demand D(τ) respectively, given that the lead time is τ time units let $\mu(\tau)$ and $\sigma(\tau)$ denote the expected lead time demand and standard deviation of the lead time demand

$\therefore \quad \mu(\tau) = \lambda\tau$ and $\sigma(\tau) = v\sqrt{\tau}$.

Under the classical (Q,R) model , the retailer's expected procurement cost, inventory holding cost , order setup cost and penalty cost per unit time amount to $C\lambda$, $h\left(R-\mu+\frac{Q}{2}\right), \frac{K\lambda}{Q}$, and $\frac{p\lambda n(R,\tau)}{Q}$ respectively , where $n(R,\tau)$ is the expected number of shortages backordered during the lead time of τ time units .

Similarly the cost components, we can observe that the retailer's expected carbon emissions per unit time from procurement, inventory holding order setup and shortages amount to $\hat{C}\lambda, \hat{h}\left(R-\mu+\frac{Q}{2}\right), \frac{\hat{K}\lambda}{Q}$,and $\frac{\hat{p}\lambda n(R,\tau)}{Q}$ respectively given that the Lead time of τ time units. Transportation cost and Transportation emission are the major part of the total cost in retailing industries. We consider that the retailer wishes to minimize not only cost but also carbon emissions of the (Q, R) policy adopted, so we can consider that the retailer can use either a LTL carrier or a TL carrier, which are the two most common modes of transportation. The super-/sub –scripts 1 and 2 are associated with LTL and TL transportation respectively.

(Q, R) Model with the LTL Transportation:

In the case the retailer uses a LTL carrier, we assume that there is a unit transportation cost, let t denote per unit transportation cost, let τ^{ltl} denote the delivery lead time of LTL carrier. Then unit transportation cost can be included within the unit procurement cost and the retailer's expected cost per unit time under LTL transportation reads as,

$$C^1(Q,R) = (C+t)\lambda + h(R-\mu+\frac{Q}{2}) + \frac{K\lambda}{Q} + \frac{p\lambda n(R,\tau^{ltl})}{Q} \quad (1)$$

Let $\hat{t}$ denote the per unit transportation emission under LTL transportation Then, similar to the cost function, unit transportation emissions can be included within the unit procurement emissions and the retailer's expected carbon emissions per unit time under LTL transportation reads as,

$$E^1(Q,R) = (\hat{C}+\hat{t})\lambda + \hat{h}(R-\mu+\frac{Q}{2}) + \frac{\hat{K}\lambda}{Q} + \frac{\hat{p}\lambda n(R,\tau^{ltl})}{Q} \quad (2)$$

Similarly the retailer uses a TL carrier he/she charged based on number of trucks used for inbound shipment. Particularly let v denote the capacity of one truck and w the cost charged by a TL carrier for one truck. Let e denote the per unit transportation cost, it should be noted that t > e in a particular case as t is the LTL carrier's only charge while TL carrier also charges the retailer for the truck. So the retailer's order quantity is Q, the retailer will use $\left\lceil \frac{Q}{v} \right\rceil$ trucks that is the retailer will pay $eQ+\left\lceil \frac{Q}{v} \right\rceil w$ for inbound shipment. Let τ^{tl} denote the delivery lead time of the TL carrier. Then the retailer's expected cost per unit time under TL transportation reads as,

$$C^2(Q,R) = (C+e)\lambda + h(R-\mu+\frac{Q}{2}) + \frac{(K+\left\lceil \frac{Q}{v} \right\rceil w)\lambda}{Q} + \frac{p\lambda n(R,\tau^{tl})}{Q} \quad (3)$$

When the retailer uses a TL carrier they are the responsible for the emissions generated from the trucks used. Let $\hat{w}$ as the carbon emissions generated by an empty truck that is the truck's weight. Let $\hat{e}$ denote the emissions generated by unit loaded to the truck. Then, the retailer's expected carbon emissions per unit time under TL transportation reads as,

$$E^2(Q,R) = (\hat{C}+\hat{e})\lambda + \hat{h}(R-\mu+\frac{Q}{2}) + \frac{(\hat{K}+\left\lceil\frac{Q}{v}\right\rceil\hat{w})\lambda}{Q} + \frac{\hat{p}\,\lambda n(R,\tau^{tl})}{Q} \qquad (4)$$

3.1. Analysis with the carbon emission regulations:

Here we discuss the retailer's expected emissions under the carbon emissions regulations policies such as, carbon tax, carbon cap, carbon trade.

3.1.1 Analysis under carbon Cap:

Under the carbon taxing model the retailer's objective is to minimize the total inventory and transportation costs along with the additional costs paid in taxes for carbon emissions. In particular let γ money units be charged as tax for unit carbon emission per unit time.

Carbon taxing model with LTL carrier

In this emission regulation the retailer is charged γE^{LTL} (Q) in taxes per unit time, so the total cost and total emission cost of a LTL carrier reads,

min C^1 (Q, R) =

$$(C+t+\gamma\hat{C}+\gamma\hat{t})\lambda + (h+\gamma\hat{h})(R-\mu+\frac{Q}{2}) + \frac{(K+\gamma\hat{K})\lambda}{Q} + \frac{(p+\gamma\hat{p})\lambda n(R,\tau^{ltl})}{Q} \qquad (5)$$

s.t. Q $\geq$ 0.

The optimal order quantity of cost and emission function of LTL transportation is expressed as,

$$Q^C = \sqrt{\frac{2\lambda[(K+\gamma\hat{K})+(p+\gamma\hat{p})n(R,\tau^{ltl})]}{h+\gamma\hat{h}}} \qquad (6)$$

Carbon taxing model with TL carriers reads as,

$$\min C^2(Q,R) = (C+e+\gamma\hat{C}+\gamma\hat{e})\lambda + (h+\gamma\hat{h})(R-\mu+\frac{Q}{2}) + \frac{[K+\gamma\hat{K}+i(w+\gamma\hat{w})\lambda]}{Q} + \frac{(p+\gamma\hat{p})\lambda n(R,\tau^{tl})}{Q} \qquad (7)$$

s.t. Q $\geq$ 0

The optimal order quantity of cost and emission function of TL transportation is expressed as,

$$Q = \sqrt{\frac{2\lambda[(K+\gamma\hat{K})+i(w+\gamma\hat{w})+(p+\gamma\hat{p})n(R,\tau^{tl})]}{h+\gamma\hat{h}}} \qquad (8)$$

3.1.2: Analysis under carbon cap:

Under carbon cap model, the retailer's objective is to minimize the total inventory and transportation cost per unit time, while the carbon emissions rate does not exceed a targeted level (i.e.) the carbon cap. Let C > 0 denote the carbon cap per unit time.

Carbon cap model under LTL carrier reads as,

$$\min C^1(Q,R) = (C+t)\lambda + h(R-\mu+\frac{Q}{2}) + \frac{K\lambda}{Q} + \frac{p\lambda n(R,\tau^{ltl})}{Q} \quad (9)$$

$$\text{s.t } E^1(Q,R) = \left(\hat{C}+\hat{t}\right)\lambda + \hat{h}(R-\mu+\frac{Q}{2}) + \frac{\hat{K}\lambda}{Q} + \frac{\hat{p}\lambda n(R,\tau^{ltl})}{Q} \le C \quad (10)$$

$E^{LTL}(Q)$ being a quadratic function, the optimum solution characterized by following way,

$$q_1^{LTL} = \frac{C-(\hat{C}+\hat{t}) - \sqrt{[C-(\hat{C}+\hat{t})]^2 - 2\left\{(\hat{K}\lambda + \hat{p}\lambda n(R,\tau^{ltl}))\hat{h}\right\}}}{\hat{h}}, \text{ and}$$

$$q_u^{LTL} = \frac{C-(\hat{C}+\hat{t}) + \sqrt{[C-(\hat{C}+\hat{t})]^2 - 2\left\{\left(\hat{K}\lambda + \hat{p}\lambda n(R,\tau^{ltl})\right)\hat{h}\right\}}}{\hat{h}}$$

Note that $E^{LTL}(Q) < C$ for $q_l^{LTL} \le Q \le q_u^{LTL}$. We assume that both q_l^{LTL}, q_u^{LTL} are real numbers.

Carbon cap model under TL carrier:

$$\min C^2(Q,R) = (C+e)\lambda + h(R-\mu+\frac{Q}{2}) + \frac{K\lambda + \left\lceil \frac{Q}{v} \right\rceil w\lambda}{Q} + \frac{p\lambda n(R,\tau^{tl})}{Q} \quad (11)$$

$$\text{s.t. } E^2(Q,R) = (\hat{C}+\hat{e})\lambda + \hat{h}(R-\mu+\frac{Q}{2}) + \frac{(\hat{K}+\left\lceil \frac{Q}{v} \right\rceil \hat{w})\lambda}{Q} + \frac{\hat{p}\lambda n(R,\tau^{tl})}{Q} \le C \quad (12)$$

We assume that the carbon cap is sufficiently large that there exist feasible order quantities for TL transportation. The optimum solution of TL transportation is denoted by Q_1^{TL}, that is the detailed analysis of $C_1^{TL}(Q)$ and $E_1^{TL}(Q)$ simultaneously. Konur (2014) considers the TL transportation with heterogeneous freight trucks and they propose a heuristic solution method. In their heuristic, they discuss an upper bound on the number of trucks to be used when there is a single truck type. It is easy to verify that $E_i^{TL}(Q) \le C$ for Q ∈ $\left[q_l^{TL(i)}, q_u^{TL(i)}\right]$ where,

$$q_l^{TL(i)} = \frac{C-(\hat{C}+\hat{e}) - \sqrt{\left(C-(\hat{C}+\hat{e})\right)^2 - 2\left\{[(\hat{K}+i\,\hat{w})\lambda + \hat{p}\lambda n(R,\tau^{tl})]\hat{h}\right\}}}{\hat{h}}, \quad (13)$$

$$q_u^{TL(i)} = \frac{C-(\hat{C}+\hat{e})+\sqrt{\left(C-(\hat{C}+\hat{e})\right)^2-2\left\{[(\hat{K}+i\,\hat{w})\lambda+\hat{p}\,\lambda n(R,\tau^{tl})]\hat{h}\right\}}}{\hat{h}} \quad (14)$$

Consider the equations (13) and (14) imply that $q_l^{TL(i)} < q_l^{TL(i+1)} \le q_u^{TL(i+1)} \le q_u^{TL(i)}$.It follows $Q^{TL} \le q_u^{TL(i)}$.

3.1.3 Analysis under cap and trade:

Under the carbon cap and trade model the retailer is subject to carbon emissions cap C per unit time, however a carbon emission trading system is available for buying carbon emission permits or selling extra carbon emissions. The retailer's aim to minimize the total inventory and transportation cost along with the additional costs or revenue gained through carbon emissions trading. In particular X denote the traded carbon emission amount per unit time, if X > 0 additional carbon emission capacity is purchased and if X < 0 excess carbon capacity is sold. Similar to Hua et al (2011a) it is assumed that the market price for per unit carbon emissions is fixed at α money units and there is sufficient supply and sufficient demand for buying and selling carbon emissions capacity, respectively.

Carbon trade model with LTL carrier:

In this model the retailer's total cost per unit time is $C^{LTL}(Q) + \alpha X$

Furthermore the retailer's traded carbon emissions amount to $X = E^{LTL}(Q) - C$

$$TC(Q) = (C+t+\alpha\hat{C}+\alpha\hat{t})\lambda + \left(h+\alpha\hat{h}\right)(R-\mu+\frac{Q}{2}) + \frac{(K+\alpha\hat{K})\lambda}{Q} + \frac{(p+\alpha\hat{p})\lambda n(R,\tau^{ltl})}{Q} - \alpha C$$

s.t $Q \ge 0$ (15)

The optimal order quantity is,

$$Q^{LTL} = \sqrt{\frac{2\lambda[(K+\alpha\hat{K})+\left(p+\alpha\hat{p}\right)n(R,\tau^{ltl})]}{(h+\alpha\hat{h})}} \quad (16)$$

Carbon trade model with TL carrier:

TC(Q)=

$$(C+e+\alpha\hat{C}+\alpha\hat{e})\lambda+(h+\alpha\hat{h})(R-\mu+\frac{Q}{2})+\frac{(K+iw+\alpha\hat{K}+\alpha i\hat{w})\lambda}{Q}+\frac{(p+\alpha\hat{p})\lambda n(R,\tau^{tl})}{Q}-\alpha C$$

s.t $Q \ge 0$

(17)

The optimal order quantity is,

$$Q^{TL} = \sqrt{\frac{2\lambda\{[(K+\alpha \hat{K})+i(w+\alpha \hat{w})]+(p+\alpha \hat{p})n(R,\tau^{tl})\}}{(h+\alpha \hat{h})}} \quad (18)$$

4. Numerical Examples:

For the clear understanding we analyse the carbon emission regulations with the numerical example.

Carbon tax:

The following specification used for the numerical examples. C= $\hat{C}$ =1, K=100, h=2, t=2.77, $\hat{K}$ =150, $\hat{h}$ =6, $\hat{t}$ =1.96, p=5, $\hat{p}$ =7, w=250, $\hat{w}$ =150, e=1.75, $\hat{e}$ =1, $\gamma = 0.2$ $\lambda = 2000$

So the expected total cost per unit time is 10856 for LTL transportation and. Expected cost per unit time is 14359 for TL transportation. Using carbon tax policy we estimated the retailers expected emission cost, for that we increasing the values of γ from 0 to 1 as a result γ values increases, the expected carbon emission per unit time also increases for both LTL and TL transportation. It's explained in the following table.

Carbon Tax (γ) Values	Total Emission cost for LTL Transportation	Total Emission cost for TL Transportation
0.2	2187	2303
0.4	4011	4607
0.6	6550	6909
0.8	8745	9212
1	10933	11515

Carbon Cap:

Under this model the expected cost for LTL transportation is 9885, and the expected cost of TL transportation is 12025.

We increasing the values of Cap C, the expected emission per unit time also increase for both LTL and TL transportation. The following specification used for LTL transportation. $\hat{K}$ =150, $\hat{w}$ =150, $\hat{h}$ = 6, $\hat{p}$ =7, $\hat{t}$ =1.96, $\hat{C}$ =1, λ =2000, σ =100, τ =0.3, the following specification used for TL transportation $\hat{K}$ =50, $\hat{w}$ =50, $\hat{h}$ = 6, $\hat{p}$ =4, $\hat{e}$ =1, $\hat{C}$ =1, λ =2000, σ =50, τ =0.3. It should be noted in the following table.

Carbon Cap C values	LTL transportation	Carbon Cap C Values	TL transportation
5000	4245	10200	10058
6000	5094	10250	10108
7000	6177	10290	10148
8000	7297	10300	10158
9000	8435	10350	10208

Carbon trading:

Cap and trade policy explains that emissions and cost can increase or decrease as trading price increase. The retailer's traded carbon emissions amount of LTL transportation is 4933 and the retailer's traded carbon emissions amount of TL transportation is 2849. We consider the carbon trading price α from 0 to 1 in equal increments. As a result the expected total cost increased as α value increases. It's explained in the following table.

Carbon Trade (α)Values	Total cost for LTL Transportation	Total Emission cost for TL Transportation
0.2	10916	12289
0.4	11927	12552
0.6	12929	12815
0.8	13926	13078
1	14920	13341

6. Conclusion:

In this paper we study about the sustainability in an inventory control system with integrated transportation decisions under stochastic demand along with the carbon emission regulations. We compare the expected emission cost along with carbon emission regulations for both LTL and TL transportation, it shows that the value of carbon emission regulations increases the expected emission cost per unit time also increases. We use the carbon emission regulations to lead a 'Sustainable path' and the carbon regulations are help the country to reduce the carbon emissions.

References:

1. Absi, N., Dauzere –peres, S., Keded-Sidhoum, S., Penz,B., Rapine,C., 2013 Lot sizing with carbon emission constraints. European Journal of Operations research, 227 55-61

2. Arikan, E., Fichtinger,J., Ries J.M., 2014 Impact of transportation lead time variability on the economic and environmental performance of inventory system. International Journal of production economics, 157, 279-288.

3. Arslan, M., Turkay,M., 2013, EOQ revisted with sustainability considerations, Fundamental computer Decisions science 38, 223-249.

4. Battini, D., Persona, A., Sgarbosa,F., 2014 A sustainable EOQ model. Theoritical formulation and application, International Journal of production Economics, 149,145-153.

5. Benjaafar, S., Li, Yi. Daskin,M., 2012 Carbon footprint and the management of supply chains: insights from simple models. IEEE, Transaction on Automation Science and Engineering, pp (99), 1.

6. Bonney, M., Jaber,M.Y., 2011,Environmentally responsible inventory models:Non classical models for a non classical era.International Journal of Production Economics,133,43-53.

7. Chen,X., Benjaafar,S., Elomi,A., 2013. The Carbon Constrained EOQ, Operations Research Letters 41,172-179.

8. Hadley,G., Whitin,T.M., 1963.Analysis of Inventory System. Englewood Cliffs, N.J., Prentice-Hall, 1963.

9. Hariga, M.A., 2010 A Single –item continuous review inventory problem with space restriction. International Journal of production Economics,128,153-158.

10. Hoen, K.M.R., Tan, T., fransoo,J.C., Van Houtum G.J., 2014a Effect of Carbon emission regulations on transport mode selection under stochastic demand. Flexible Service and Manufacturer Journal 26,170-195.

11. Hua, G., Cheng, T., Wang, S., 2011 Managing Carbon footprints in inventory management, International Journal of Production Economics 132(2), 178-185.

12. Jaber, M.Y., Glock, C.H., Saadany,A.M.E., 2013 Supply Chain Coordination with emission reduction incentives. International Journal of Production research 51, 68-82.

13. Konur, D., Carbon Constrained integrated inventory control and truckload transportation with heterogeneous freight trucks. International Journal of Production Economics, 153,268-279.

14. Konur, D., Schaefar,B., 2014 ,Integrated inventory control and transportation decisions under carbon emission regulations: LTL vs. TL carrier.

15. Konur, D., schaefar,B., 2015, Economic and Environmental considerations in a continuous review inventory control system with integrated transportation decisions, Transportation Research Part E. 80(2015) 142-165.

16. Mallidis, I., Vlachos,D., lakovou, E., Dekker,R., 2014. Design and planning for green global supply chains under periodic review replenishment policies. Transportation Research. Part E 72,210-235.

17. Marler, R., Arora, J., 2010.The Weighted sum method for multi – objective optimization: new sights. Structural and Multidisciplinary Optimization, 41,853-862.

18. Song.J., Leng .M., 2012. Analysis of the single period problem under carbon emission policies.In:Choi,T.M(Ed),Handbook of Newsvendor problems,Internatioal Series in Operations research and Management Science,Volume.176,Springer,New York.

19. Toptal, A., Cetinkaya, S., Lee, C-Y., 2003.The Buyer-Vendor co ordination problem: modelling inbound and outbound cargo capacity and costs.IIE Transaction 35 (11), 987-1002.

20. Toptal, A., Ozlu, H., Konur,D., 2014.Joint decisions on inventory replenishment and emission reduction investment under different emission regulations. International Journal of Production Research.52, 243-269.