Summary and Critique of Battani *et al*. (2014) paper entitled "A Sustainable EOQ Model: Theoretical Formulation and Applications"

Project assignment for Probabilistic Operations Research course (OR 7230)

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1 Introduction

Due to the increase in concern to environment, inventory models that determine the optimal lot size are revised to consider sustainability issues. Thus, not only the economic aspects of order quantity or production quantity are analyzed but also the environmental impacts. For example, Hua *et al.* (2011) analyzed the impact of carbon trade, carbon price and carbon cap on order decision and total cost. Bouchery *et al.* (2012) also formulated the classical Economic Order Quantity (EOQ) model as multi-objective problem to incorporate sustainability concerns.

Further research by Battini *et al* (2014) conducted to formulate the Sustainable Economic Order Quantity(S-EOQ) model that consider the environmental issues from handling and transporting the ordered quantity to the end of its life inside the buyer plant. In their work, cost factors and different transportation mode were compared between a model that consider sustainability (S-EOQ model) and a model that does not consider sustainability (traditional EOQ model).

In this report, Battini *et al.* (2014) paper is reviewed and the basic assumptions, model formulations, numerical example and limitations of the paper are provided. The report is organized as follows: section 2 describes the scope of the study; section 3 summarizes the assumptions of the paper; section 4 describes the formulation of both traditional and sustainable EOQ models and section 5 explain the results obtained from the numerical example. The critique and comments are provided in section 6 of the report.

2 Scope of the study

In order to clarify the environmental impact of purchasing order, the authors used the Life Cycle Assessment technique (LCA) shown in Fig. 1. The dotted line in the figure represents the system boundary under study where the life of the purchasing order starts and ends. The mathematical formulation is bounded to the economic and environmental trade-offs within the system boundary. In the figure, environmental inputs are drawn by red arrows (the vertical arrows) to the system boundary and environmental outputs out of the system boundary.

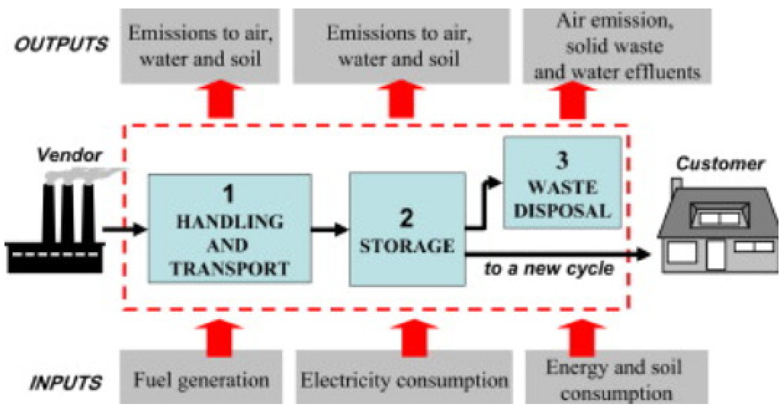

Fig. 1 LCA general scheme of a material purchasing order (Battini et al., 2014)

3 Assumptions

Battini *et al. (2014)* performed the analysis based on the following assumptions:

- Environmental issues associated with logistics and warehousing were formulated as objectives rather than constraints
- Single product replenishment problem was considered
- Direct accounting approach was applied (that is, environmental issues are translated into costs and modeled as part of the total cost).
- Deterministic demand was assumed
- Product price was exogenous and the buyers decides on the lot size
- Environmental and social costs associated to transportation, warehousing and waste disposal were jointly counted as “external costs”

4 Model formulation

Battini *et al.(2014)* formulated the optimal order quantity with sustainability (S-EOQ) or without sustainability(traditional EOQ) consideration. The traditional EOQ model was first formulated and then extended to sustainability. For both approaches the total average annual cost of replenishment is expressed in equation (1).

$$C(Q) = p * D + C_o(Q) + C_h(Q) + C_{obs}(Q) + C_t(Q) \qquad \textbf{(1)}$$

Where C(Q) is the total average annual cost of replenishment with or without sustainability consideration depending on the model, p is unit purchase cost, D is annual demand, $C_o(Q)$ is ordering cost, $C_h(Q)$ is holding cost, $C_{obs}(Q)$ is inventory obsolescence cost, and $C_t(Q)$ is transportation cost. The full details of mathematical formulas and notations are provided in Battini et al.(2014) paper.

The difference between the traditional and sustainable EOQ models lays on the formulation of holding, inventory obsolescence and transportation costs. On top of the traditional model, the sustainability model incorporates external costs as a means to consider sustainability in all these three cost parameters. The mathematical formulations of the three cost parameters are summarized in Table 1.

Table 1 Cost comparison between traditional and sustainable model

	Traditional EOQ model	Sustainable EOQ model	Additional costs for sustainable EOQ model
Holding cost($C_h(Q)$)	$\frac{Q}{2} * h$	$\frac{Q}{2} * (h + c_{eh} * b)$	carbon emission generated by warehouse
Inventory obsolescence cost ($C_{obs}(Q)$)	$\frac{Q}{2} * (p - p`) * \beta$	$\frac{Q}{2} * \beta * [(p - p`) + a * c_{eo}]$	cost associated with carbon emission of waste disposal
Transportation cost ($C_t(Q)$)	$\sum_j C_{t-int}(Q, d_j, S_j)_j$	$\sum_j [C_{t-int}(Q, d_j, S_j)_j + C_{t-ext}(Q, d_j, S_j)_j]$	external costs (including costs of congestion, accidents and road way facility)

After the total cost was formulated, the optimal order quantity that minimizes the total cost was calculated. Due to the discontinuity nature of transportation cost function, order quantity for each feasible range k=(DPk, DPk+1) was derived from the total cost function locally(see the mathematical detail in Battini *et al.* paper). The local optimal ordering quantity for each range is:

$$Q^{k*} = \begin{cases} Q'^{k*} & for\ DP_k < Q'^{k*} \leq DP_{k+1} \\ DP_k, & for\ C(DP_k) \leq C(DP_{k+1}) \\ DP_{k+1}, & for\ C(DP_k) > C(DP_{k+1}) \end{cases} \quad \textbf{(2)}$$

Where, for the traditional model Q'^{k*} is given by

$$Q`^{k*} = \sqrt{\frac{2*\{D*O+[\sum_j(c_{int-f,j}*d_j*\sum_i n_i+c_{int-v,j}*d_j*DP_k)]*D\}}{h+\beta*(p-p`)}} \quad \textbf{(3)}$$

And for the sustainability model Q'^{k*} (also called $Q_S^{`k*}$) is given by

$$Q_S^{`k*} = \sqrt{\frac{2*\{D*O+\{\sum_j[(c_{int-f,j}+c_{ext-f,j})*d_j*\sum_i n_i+(c_{int-v,j}+c_{ext-v,j})*d_j*DP_k]\}*D}{(h+c_{eh}*b)+\beta*[(p-p`)+a*c_{eo}]}} \quad \textbf{(4)}$$

The total minimum cost was obtained by taking the minimum of local total minimum costs Mathematically, the total minimum cost is: C(EOQ)=min(C(Q^{k*})) for traditional model; and C_s(S-EOQ)=min(C_s(Q_s^{k*})) for sustainable model for all k. The quantity Q^{k*} and Q_s^{k*} that satisfies these equations are economic order quantity (EOQ) and sustainable economic order quantity (S-EOQ), respectively.

5 Numerical example

The above model was applied to a buyer company of DVD readers located in North-East Italy. The company purchases the product from two vendors; 1) local vendor located 600km from the buyer’s location and can be accessed by road (600km) or road(100km)-rail(500km) transportation and 2) International vendor located 14,100km from the buyer’s location and accessed by road(100km)-ship(14,000km) transportation. The purchasing price was assumed the same from the two vendors. **Table 2** shows the input data and **Table 3** compares EOQ and S-EOQ and related costs for the three cases (intermodal transportations considered).

Table 2 Input data given for numerical example in Battini et al.(2014) paper

Transportation mode	Input data	Local vendor			International vendor	
		Case 1: road	**Case 2: road-rail**		**Case 3: road- ship**	
			Road	Rail	Road	Ship
Road(j=1)	d_1(km on the road)	600	100		100	
	$c_{int-f,1}$(€/km)	0.8	0.8		0.8	
	$c_{int-v,1}$(€/km m^3)	0.01	0.01		0.01	
	$c_{ext-f,1}$(€/km)	0.2	0.2		0.2	
	$c_{ext-v,1}$(€/km m^3)	0.02	0.02		0.02	
Rail(j=2)	d_2(km by train)			500		
	$c_{int-f,2}$(€/km)			0.6		
	$c_{int-v,2}$(€/km m^3)			0.007		
	$c_{ext-f,2}$(€/km)			0.0066		
	$c_{ext-v,2}$(€/km m^3)			0		
Ship(j=3)	d_3(km by ship)					14000
	$c_{int-f,3}$(€/km)					0.048
	$c_{int-v,3}$(€/km m^3)					0.003
	$c_{ext-f,3}$(€/km)					0.0044
	$c_{ext-v,3}$(€/km m^3)					0

Input Parameter	Value
D	40000
O[€/order]	400
p[€/unit]	10
p`[€/unit]	5
h[€/unit]	2.5
y1[units/container 1]	1700
y2[units/container 2]	3400
β[%]	10%
a[tons/unit]	0.002
b[m3/unit]	0.017
ceh[€/m3]	0.55
ceo[€/ton]	13

Note: Refer Battini et al. (2014) paper for the description of symbols in this table

Table 3 Comparison between traditional EOQ and S-EOQ and related costs for the three transportation cases considered (Battini et al., 2014)

Case	*EOQ*	*S-EOQ*	*C(EOQ)*	*C(S-EOQ)*	*Internal transportation cost*	*External transportation cost*
Case 1	3400	3400	419,532.94	429,105.32	9727.06	9571.76
Case 2	3400	3400	419,716.47	421,367.07	9910.59	1634.12
Case 3	3400	3400	447,987.06	450,323.54	38,181.18	2320.00

Table 3 shows that the total annual cost that accounts sustainability (C(S-EOQ))is higher than the total annual cost that did not account sustainability (C(EOQ). Comparing the total annual cost difference calculated with and without sustainability, the difference is larger for mono-modal road transportation (case1, 9572.38) compared to multi-modal transportations (case 2 and case 3, both less than 2500). When external transportation cost increases, C(S-EOQ) increases and therefore the difference with C(EOQ) becomes higher. Case 2(road-rail) has low C(S-EOQ) and is therefore the most sustainable mode of transportation to buy the product. The S-EOQ cost function is more important to choose the most sustainable mode of transportation than lot sizing. As sown in table 3, EOQ and S-EOQ are the same for the same transportation modality. However, sustainable EOQ reaches as high as 20% of EOQ when the purchasing price increases.

Sensitivity analysis was performed to see the effect of purchasing price on the difference between emission and cost optimal solution. For the analysis, a single transportation mode (case 1) was considered and all parameter except purchasing price were kept constant. The result showed that emission reduction could be obtained by significant increment of the total cost with higher purchasing price. And, the direct account approach may not be effective when purchasing price increases.

6 Critiques and comments

6.1 Pros and Cons

Battani *et al.* (2014) formulated and compared both the traditional and sustainable EOQ models that account transportation costs. In addition, different modes of transportation and vendor options are considered in the analysis. Regardless of all these parameters inclusion, the models are easy to understand.

However, in real world the data for some of the parameters are not easily accessible, and therefore it will be expensive in terms of time and cost.

6.2 Limitation

The paper has the following limitations:

- The purchasing price was assumed constant. But this may not be true in reality. Price might vary with time and with the amount of purchase. The extended formulation increases the flexibility of the formulation.
- The paper doesn't include the emission associated with ordering.
- In the given example, the purchasing price for each vendor was assumed the same. But, in reality unit price may vary from vendor to vendor. This affects the total cost calculation and vendor selection.
- The paper performed sensitivity analysis for a single transportation mode. I did not perform sensitivity analysis for the other cases

6.3 Comments

I have the following comments about the article:

- Perform sensitivity analysis for other cases considered(case 2 and case 3) to see the real difference or clearly justify why sensitivity analysis was done for one case and not for the others
- External costs are used to consider sustainability. Practically it may be difficult to measure some sustainability issue in monetary value. Therefore, the definition of external costs and how they can be measured should be clearly specified.
- Minor comments to consider are, (1) use different line types instead of color to distinguish different lines in a graph. For example, in Fig.6 of the original paper, it is difficult to differentiate the lines if one print the article in black and white (2) Include unit /dimension/ in the graph so that it is easily readable.

7 Reference

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2. Bouchery, Y., Ghaffari. A., Jemai, Z., and Dallery, Y. (2012). Including sustainability criteria into inventory models. European Journal of Operations Research, 222, 229-240.
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Appendix

I. First page of Battini et al. (2014) paper

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A sustainable EOQ model: Theoretical formulation and applications

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abstract

Traditional inventory models involve different decisions that attempt to optimize material lot sizes by minimizing total annual supply chain costs. However, the increasing concern on environmental issues stresses the need to treat inventory management decisions as a whole, by integrating economic and environmental objectives. Recent studies have underlined the need to incorporate additional criteria in traditional inventory models in order to design "responsible inventory systems". This paper explores the integration of factors affecting the environmental impact within the traditional EOQ model and proposes a "Sustainable EOQ Model". All sustainability factors linked to the material lot size are analyzed from the beginning of the purchasing order to the end of its life inside the buyer plant. Thus, the environmental impact of transportation and inventory is incorporated in the model and investigated by an economic point of view. In particular internal and external transportation costs, vendor and supplier location and the different freight vehicle utilization ratio are considered in order to provide an easy-to-use methodology. The optimization approach is applied to representative data from industrial problems to assess the impact of sustainability considerations on purchasing decisions if compared with the traditional approaches. Finally, an illustration of the effect of using the new "Sustainable EOQ model" is presented and discussed.

1. Introduction

Lot sizing is a critical issue that directly impacts the economic efficiency of both purchasing and production activities, and for this reason it has been addressed several times in the literature with different approaches. Most of those approaches consider the same cost factors in different ways, with specific advantages and disadvantages.

The "Economic Order Quantity" (EOQ) developed by Harris and generally referred to as the basic model, as well as a similar approach developed by Andler, is allocated in the literature to "traditional" static methods. Static methods are then converted to dynamic lot sizing approaches thanks to the relevant and well-known contributions (Wagner and Whitin, 1958; Silver and Meal, 1973; De Matteis and Mendoza, 1968; Gahse, 1965; Trux, 1966). From a practical point of view, selecting the method to determine the lot size is not as critical as its implementation for optimization. For this reason, the simplicity and the minimal amount of data needed in the Harris' basic model make it considerably more attractive than the other more complex methods. Moreover, the increasing concern on environmental issues stresses the need to treat inventory management decisions as a whole with economic and environmental objectives (i.e. Bonney and Jaber, 2011; Wahab et al., 2011).

Today worldwide firms need to incorporate carbon footprint management into their business decision. In this context, the environmental suitability of currently known lot sizing methods is debated. In this work the authors explore the economic lot sizing problem in purchasing materials when environmental concerns are considered; propose a new easy-to-use theoretical model to calculate a sustainable economic order quantity, called S-EOQ; study how S-EOQ compares the traditional approach (simply called EOQ); and discuss results and cost factors with particular regard to the transportation mode selection.

2. Literature review

A few works have been published in the past years with the aim of incorporating sustainability issue in EOQ theory. Turkay (2008) revised the standard EOQ model to incorporate sustainability considerations that include environmental criteria, by adding objectives and constraints to the original methods, and analyzing five different approaches: Direct Accounting, Carbon Tax, Direct Cap, Cap & Trade and Carbon Offsets. The most prudent approach is the Direct Accounting approach, since sustainability issues are translated into costs and modeled as a part of the total cost function. The other four methods better express different kinds of governmental policies, such as taxes on carbon emissions,

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Including sustainability criteria into inventory models

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ABSTRACT

Research on sustainability performance has considerably enriched operations management literature in recent years. However, work with quantitative models is still scarce. This paper contributes by revisiting classical inventory methods taking sustainability concerns into account. We believe that reducing all aspects of sustainable development to a single objective is not desirable. We thus reformulate the classical economic order quantity model as a multiobjective problem. We refer to this model as the sustainable order quantity model. Then, a multi-echelon extension of the sustainable order quantity model is studied. For both models, the set of efficient solutions (Pareto optimal solutions) is analytically characterized. These results are used to provide some insights about the effectiveness of different regulatory policies to control carbon emissions. We also use an interactive procedure that allows the decision maker to quickly identify the best option among these solutions. The proposed interactive procedure is a new combination of multi-criteria decision analysis techniques.

1. Introduction

Sustainable development (SD) is becoming a key issue for companies worldwide. Facing governments, customers and other stakeholders' pressures, the firms are undertaking initiatives to reduce their environmental and social impacts while continuing to be profitable. Following this trend, the literature dealing with SD and operations is becoming abundant (Linton et al., 2007; Carter and Rogers, 2008; Kleindorfer et al., 2005; Seuring and Müller, 2008). However, the papers dealing with quantitative models have up to now mainly focused on reverse and closed-loop logistics or on waste management (Sbihi and Eglese, 2007). We are interested here in investigating the potential for optimizing operations with SD concerns. Operations management decisions can be classified into three levels, i.e. strategic, tactical and operational. Although sustainable supply chains have to be considered globally, researchers and practitioners lack clear guidelines on how to allocate efforts between these three decision levels (Carter and Rogers, 2008). This paper focuses on the operational level for two reasons. First, operational adjustments are effective to improve the sustainability of supply chains (Hua et al., 2011). Second, operational decisions can be easily adjusted in connection with the other decision levels if needed.

This paper aims to include SD criteria into inventory models. The related literature is quite limited and has mainly focused on carbon footprint. Venkat (2007) considers a two-echelon serial system and studies the impact of batch size in terms of carbon emissions. Two main conclusions are presented. First, frequent deliveries of small batches can increase the carbon footprint of the supply chain if the distances are important. Second, carbon emissions associated with the storage of products that require refrigeration can counterbalance the advantages of full truck-load deliveries. Benjaafar et al. (2010) incorporate carbon emission constraints on single and multi-stage lot-sizing models with a cost minimization objective. Four regulatory policy settings are considered, based respectively on a strict carbon cap, a tax on the amount of emissions, the cap-and-trade system and the possibility to invest in carbon offsets to mitigate carbon caps. Insights are derived from an extensive numerical study. In a paper proposing a research agenda for designing environmentally responsible inventory systems, Bonney and Jaber (2011) briefly present an illustrative model that includes vehicle emissions cost into the economic order quantity (EOQ) model. The authors refer to this model as the environmental economic order quantity. Emissions associated with the storage of products are not taken into account. The order quantity is thus larger than the classical EOQ. Tao et al. (2010) studies the integration of a green cost into the economic production quantity model and the EOQ model. A green cost per product unit and time unit is added to the classical models and optimal solutions are analytically derived. Hua et al. (2011) extend the EOQ model to take carbon emissions into account under the cap and trade system. Analytical and numerical results are presented and managerial insights are derived. Jaber et al. (in press) include emissions from manufacturing processes into a two-echelon supply chain model. Different emissions trading schemes are studied. Analytical and numerical results are used to provide managerial insights. The efficiency of the different emissions trading schemes under study

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Managing carbon footprints in inventory management ☆

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ABSTRACT

There is a broad consensus that mankind must reduce carbon emissions to mitigate global warming. It is generally accepted that carbon emission trading is one of the most effective market-based mechanisms to curb the amount of carbon emissions. This paper investigates how firms manage carbon footprints in inventory management under the carbon emission trading mechanism. We derive the optimal order quantity, and analytically and numerically examine the impacts of carbon trade, carbon price, and carbon cap on order decisions, carbon emissions, and total cost. We make interesting observations from the numerical examples and provide managerial insights from the analytical results.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) reports that global warming poses a grave threat to the world's ecological system and the human race, and it is very likely caused by increasing concentrations of carbon emissions, which mainly results from such human activities as fossil fuel burning and deforestation (IPCC, 2007). In order to alleviate global warming, the United Nations (UN), the European Union (EU), and many countries have enacted legislation or designed mechanisms to curb the total amount of carbon emissions. These include the Kyoto Protocol (UNFCCC, 1997) and the European Union Emission Trading System (EU-ETS), which implements a mandatory "cap and trade" system in the 27 EU (2009) member countries. Among these legislation and mechanisms, carbon emission trading is generally accepted as one of the most effective market-based mechanisms, which has been broadly adopted by UN, EU, and many governments. There are now more than 20 platforms for trading carbon in the world. Australia, Canada, Japan, and the USA are also paving the way for domestic carbon emission markets. The global carbon market is expected to reach US$2 trillion by 2025. The EU carbon market is estimated to be worth US$131 billion a year (Bothra, 2010), while that in the USA will reach US$60 billion in 2012 (Environmentalleader, 2009).

To respond to the regulations on carbon emissions, firms tend to adopt more energy efficient equipment, facilities, or vehicles. On the other hand, they can also optimize their operations decisions in production, transportation, and inventory to reduce carbon emissions. This approach may reduce more carbon emissions with less or no cost than adopting low-energy-consumption technologies (Benjaafar et al., 2010). However, industry and academia seem to have largely ignored this approach to environmental protection. According to a survey by Accenture, only 10% of companies actively model their supply chain carbon footprints and have implemented successful sustainability initiatives. More than one-third (37%) of supply chain executives have no awareness of the levels of supply chain emissions in their supply chain networks (Accenture, 2009).

The literature on carbon footprint management in supply chain is also very sparse. Some studies focus on the measurement method of carbon emissions in supply chains. Carbontrust (2006) develops a methodology to determine the carbon footprints of different products by analyzing the carbon emissions generated by the energy used across the supply chain. Cholette and Venkat (2009) calculate the energy and carbon emissions associated with each transportation link and storage echelon in a wine supply chain. They find that different supply chain configurations can result in vastly different energy consumption and carbon emissions. Mtalaa et al. (2009) review the current measurement and calculation models that compute CO_2 emissions from truck transportation. Sundarakani et al. (2009) present an analytical model that measures carbon emissions from both stationary and non-stationary supply chain processes. Chaabane et al. (2010) introduced a mixed-integer linear programming based framework for sustainable supply chain design, their model demonstrated that efficient carbon management strategies will help decision makers to achieve sustainability objectives in a cost-effective manner.

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