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Haulage sharing approach to achieve sustainability in material purchasing: New method and numerical applications

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ABSTRACT

Transportation costs are becoming increasingly important in inventory replenishment decisions and, in practice, lot sizing decisions are strongly affected by material handling equipment, transportation flow paths, vehicle capacities and technical constraints. Companies within a global sourcing context daily experience the cost of transportation as playing a major role in total purchasing costs. On the other hand, sustainability issues are always more urgent and environmental impact assessment is becoming a key requirement for materials purchasing and transportation choices. This work is particularly focusing on an interesting new area of research: the haulage-sharing in freight transportation when sustainability considerations are taken into account. The paper develops and discusses a new haulage-sharing lot sizing model in which two partners are cooperating in sharing transportation paths and handling units. A three step methodology based on multi-objective optimization approach is here proposed to permit the complete evaluation of the costs and savings that arise with an horizontal cooperation. The method is described here and applied to two different numerical cases in order to drive useful conclusions and discuss future research steps.

1. Introduction and background

Global warming is a rising concern in academic and industrial researches and we are all aware that the freight transport industry is responsible for large amounts of carbon dioxide emissions contributing to global warming. Government initiatives are increasing in order to favour the companies that are able to operate in the global supply chain setting in a responsible way. In 2010, the freight transport sector was responsible for 2.8 Gt CO_2 eq including international shipping (IEA, 2012), i.e. for more than 10% of global fossil-fuel based CO_2 emissions.

The need to assess material purchasing decisions by integrating economic and environmental objectives has been recently stressed in the academic literature (Andriolo et al, 2014). In a century of history from Harris's Economic Quantity model (EOQ), only a limited number of articles in the last three years have developed environmental considerations in lot sizing and material purchasing, focusing their attention on reducing CO_2 emission in transporting and stocking inventory (Tao et al., 2010; Bonney and Jaber, 2011; Hua et al., 2011; Wahab et al., 2011; Jaber et al., 2013; Benjaafar et al., 2013). Bouchery et al. (2012) underline that reducing all aspects of sustainable development to a single objective is not desirable. They reformulated the classical economic order quantity model as a multi-objective problem.

Battini et al. (2014) provide a "sustainable EOQ model" that incorporates and investigates according to an economic point of view the environmental impact of transportation and inventory. In particular, internal and external transportation costs, vendor and supplier location, and different freight vehicle utilization ratios are considered in order to provide an easy-to-use methodology.

Chen et al. (2013) discuss a carbon-constrained EOQ model and investigate the applicability of a variety of Governmental regulations including carbon caps, carbon tax, cap and offsets and cap and price. The main commonality in the aforementioned studies is the transportation strategy: a single buyer takes alone the decision of how much and when to purchase a specific item from a specific vendor, according to his own cost trade-off. In this research, we work towards a change in the problem point of view by considering two different buyers and a cooperative approach in sharing the transportation vehicle and the transportation mode. This approach is called "Haulage Sharing". In the present economic circumstances, an increase in high-mix, low-volume production and the extension of traveling paths results in lower-loading ratios and long-distance transportation (Kuse, 1998). The environmental impact of running empty commercial vehicles is very high. Worldwide Governmental

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Officials estimate large percentage of empty vehicles in their countries due to low purchasing quantities purchased "on demand". In Italy, for example, according to the data reported from the Ministry of Transport, a 25% of lorries and 15% of vans are traveling empty, that means with a very low saturation level (www.mit.gov.it). That is over 500,000 empty lorries and vans traveling the UK's roads every single day, releasing an incredible 36 million tonnes of CO_2 into the atmosphere every year for no good reason. By grouping different buyer order (when it's possible) and minimizing empty vehicles in the transportation path an immediate impact on reducing the harmful CO_2 released into the atmosphere by freight transportation. Haulage sharing can be easily included in the so-called "Horizontal Cooperation", which is defined by the European Union (2011) as concerted practices between companies operating at the same level(s) in the market. Horizontal cooperation in logistics is mainly gaining momentum in Western Europe. Through close collaboration, "the partnering aim at increasing productivity, e.g. by optimizing vehicle capacity utilization, reducing empty mileage and cutting costs of non-core/supporting activities to increase the competitiveness of their logistics networks" (Cruijssen et al., 2007). According to Cruijssen et al. (2007) survey, horizontal cooperation decreases empty hauling, provides a better usage of storage facilities, reduces purchasing costs (e.g. vehicles), and can offer better quality of service at lower costs, e.g. in terms of speed, frequency of deliveries, geographical coverage, reliability of delivery times and enables individual companies to tender with large shippers on larger contracts. According to Leitner et al. (2011), the overlapping of transportation networks based on similar source and sink regions are both prerequisite and indication of possible cooperation synergies.

Leitner et al. (2011) highlight that the most forms of horizontal cooperation require a neutral coordinator whose tasks and duties are similar to the current service offered by a Logistic service provider. Anyway, more intense the cooperation between the partners, the higher the resulting consolidation potential in terms of cost and emission savings. In published literature, fewer studies assess the evaluation and design of cooperative purchasing scenario by a quantitative point of view and the fewer examples available regards the development of Vehicle Routing Problem models (Wasner and Zapfel, 2004; Yang and Odani, 2006). Onoyama et al. (2008) developed a genetic algorithm for planning a long-distance transportation network consisting of several mutual sub-networks such as "parts-collection networks" covering parts suppliers and depots (distribution centers) and a "long-distance transportation network" covering depots and factories.

To our knowledge, current published works in "haulage sharing" and "cooperative logistic networks" do not yet consider multi-objective problems in which two competitive functions, costs and emissions, need to be modeled and investigated together.

We here propose, for the first time, a three step methodology that allow the decision maker to quickly identify the feasibility and profitability of a logistics cooperation modality, as the haulage sharing approach, in terms of costs and savings both in monetary value and CO_2 emissions. The proposed method is a new combination of multi-objective analysis techniques and it is complementary to the existing literature on sustainable purchasing and lot sizing. The two examples here discussed show that horizontal cooperation could be highly beneficial in increasing the sustainability of the freight transportation sector, while reducing the total logistics costs. This paper is organized as follows. In Section 2 we present two bi-objective lot sizing models: the first reflects the case in which two partners are not collaborating in material purchasing (named "individual planning"), the second the case in which the two partners are cooperating by a haulage sharing approach. In Section 3 the three step methodology is presented and applied in two different numerical cases. The results discussion is here provided. Finally Section 4 ends with conclusions and a summary of proposals for future research directions.

2. The models: individual planning vs haulage-sharing

2.1. The individual planning approach in material purchasing

One of the classic EOQ assumptions is that each replenishment happens instantaneously, at fixed time intervals. The buyer is fully autonomous in the planning of the replenishment strategy and order quantities. The mathematical formulation that follows tries to capture economic and environmental trade-offs of lot sizing in material purchasing according to the first results obtained in Battini et al. (2014). The authors consider the single-product replenishment problem and apply a bi-objective optimization approach by modeling the lot sizing problem for incoming goods to be purchased by a company in accordance with two distinctive objective functions: the total annual cost function and the total emission function. Battini et al. (2014) recently investigated internal and external transportation costs according to the vendor and supplier position and the different freight vehicle utilization ratios in order to provide an easy-to-use methodology for sustainable lot-sizing. In the following bi-objective model the authors apply the same formulation presented in Battini et al. (2014) to compute transportation cost functions (which is a discontinuous function by his real nature).

First, we introduce the notations used in the model as follows:
Indices

I	container/vehicle type
J	transportation mode

Decision variables and cost functions

Q	decision variable [units/purchasing order]
$C(Q)$	total average annual cost of replenishment [€/year]
$E(Q)$	total annual emission generated by the replenishment [$kgCO_2$ eq/year]
$Q_c{}^*$	optimal order quantity for the cost function [units/purchasing order]
$Q_e{}^*$	optimal order quantity for the emission function [units/purchasing order]

Input parameters

D	annual demand [units/year]
p	unit purchase cost [€/unit]
b	space occupied by a product unit with sale packaging [m^3/unit]
a	weight of a unit stored in the warehouse [ton/unit]
ρ	apparent density of the product with packaging [kg/m^3]
O	fixed ordering cost per order [€/order]
h	holding cost [€/unit]
y	full load-vehicle/container capacity [units or m^3]
v	average freight vehicle speed [km/year]
d_j	distance traveled by transportation mode j [km]
$c_{f,j}$	fixed transportation cost coefficient for transportation mode j [€/km]
$c_{v,j}$	variable transportation cost coefficient for transportation mode j [€/km m^3]
$c_{ef,j}$	fixed transportation emission coefficient for transportation mode j [$kgCO_2$ eq/km]
$c_{ev,j}$	variable transportation emission coefficient for transportation mode j [$kgCO_2$ eq/km m^3]
c_{eh}	warehouse emission coefficient [$kgCO_2$ eq/m^3]
n_i	number of full load-vehicle/container i [units]
y_i	full load-vehicle/container i capacity [units]
L_{tot}	maximum load capacity of a container [kg]
V_{tot}	maximum volumetric capacity of a container [m^3]