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Operations Research for green logistics – An overview of aspects, issues, contributions and challenges

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ABSTRACT

The worldwide economic growth of the last century has given rise to a vast consumption of goods while globalization has led to large streams of goods all over the world. The production, transportation, storage and consumption of all these goods, however, have created large environmental problems. Today, global warming, created by large scale emissions of greenhouse gasses, is a top environmental concern. Governments, action groups and companies are asking for measures to counter this threat. Operations Research has a long tradition in improving operations and especially in reducing costs. In this paper, we present a review that highlights the contribution of Operations Research to green logistics, which involves the integration of environmental aspects in logistics. We give a sketch of the present and possible developments, focussing on design, planning and control in a supply chain for transportation, inventory of products and facility decisions. While doing this, we also indicate several areas where environmental aspects could be included in OR models for logistics.

1. Introduction

Operations Research (OR) has been described as the science of better (the slogan of the INFORMS society) as it mainly focuses on minimizing the costs of existing processes. Yet in today's society, it is not only profits that are important as many people, companies and governments are concerned about the sustainability of our society. So can Operations Research also contribute to a better environment? In our opinion, the role of OR for the environment should get more attention. Operations Research leads to a more efficient use of resources, which is not only cost attractive, but also tends to create less emissions of greenhouse gases. Secondly, Operations Research helps to identify the trade-offs between environmental aspects and costs. Very often, much reduction in emissions can be achieved with only a marginal increase in costs. Operations Research techniques and especially multi-criteria decision analysis is therefore an important method in this respect.

In this review, we will highlight its (possible) contributions to *green logistics*, which is the study of practices that aim to reduce the environmental externalities, mainly related to greenhouse gas emissions, noise and accidents, of logistics operations and therefore develop a sustainable balance between economic, environmental and social objectives (http://www.greenlogistics.org/, last accessed on August, 16, 2011). We deal with all aspects of logistics such as transportation, warehousing and inventories, and address the related environmental aspects such as emissions of greenhouse gases, noise and use of scarce resources. We will not differentiate between green logistics and green supply chain management. While we mainly focus on transportation, we take a broader (supply chain) perspective. However, we will not address environmentally conscious manufacturing or waste management. The purpose of this overview is to give a sketch of the present and possible developments. As many papers are presently being written, we do not claim to cover all. Instead we focus on the structure of the field and illustrate this with some representative papers, the choice of which always remains subjective. There are other overviews, such as Corbett and Kleindorfer (2001a,b), Kleindorfer et al. (2005) on sustainable operations management, Srivastava (2007) and Sarkis et al. (2011) on green supply chain management and Sbihi and Eglese (2010) on combinatorial optimization and green logistics, but ours is more comprehensive, up-to-date and more detailed with respect to transportation. In this sense, we fill the gap in industrial ecology as observed by Sheu et al. (2005) on the integration of logistics flows in a green supply chain. A recent book by McKinnon et al. (2010) has some overlap with this review, but we take a wider perspective. Finally, we would like to mention that our structuring is also in line with the business perspectives of consultants (see Palanivelu and Dhawan, 2011).

In our review, we follow to a large extent the supply chain structure given by Chopra and Meindl (2010). First we discuss the main physical drivers behind a supply chain and examine

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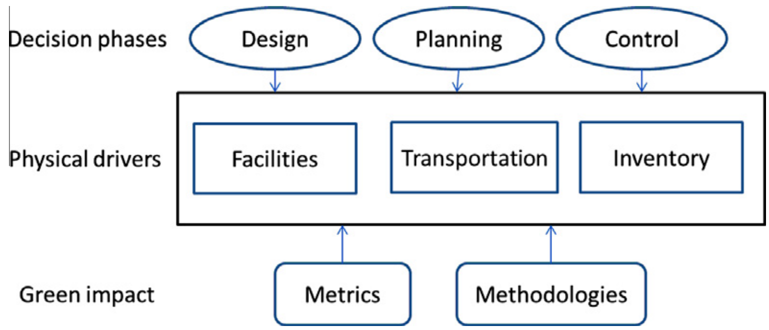

Fig. 1. Framework of the paper

transportation in Section 2, products and inventories in Section 3 and facilities in Section 4. We investigate the main choices in these drivers which affect environmental performance.

We consider these options in the three decision phases of a supply chain, namely design, planning and control, while we also discuss reverse supply chains. In Section 5, we discuss the design of a supply chain and how the combination of the drivers affects the environment. Section 6 examines the design of reverse and closed loop supply chains. Section 7 focuses on the three cross functional drivers, viz. sourcing, planning and pricing (revenue management) and in Section 8 we take a closer look at the operational planning of supply chains. Green supply chain metrics are examined in Sections 9 and 10 describes the OR methods that helps in making the trade-offs in green logistics, viz. multi-criteria decision making. Fig. 1 describes the proposed framework of this paper.

2. Transportation

With respect to the environment, transportation is the most visible aspect of supply chains. Transportation CO_2 emissions amount to some 14% of total emissions, both at global and EU level (Stern, 2006; EEA, 2011). Transportation is also a main source for NO_x, SO_2, and PM (particulate matter or fine dust) emissions. McKinnon and Woodburn (1996), Piecyk and McKinnon (2010) have done studies of the most relevant factors for CO_2 emissions in road transport. They developed a framework with five types of factors, viz. structural factors influencing modal split, commercial factors influencing load factors, operational factors, functional factors and finally external factors influencing carbon intensity of fuel. Since we also address other modes of transport in this paper, we will change their framework somewhat. We examine four choices with respect to transportation which are supported by Operations Research models, namely, mode choice (or modal split), use of intermodal transport, equipment choice and fuel choice. The commercial factors will be discussed in later sections.

2.1. Mode choice

One of the main choices in transport is the mode of transportation, viz. transport by plane, ship, truck, rail, barge or pipelines. Each mode has different characteristics in terms of costs, transit time, accessibility, and also different environmental performance. In reality, the choices are limited, as the transport mode is often determined by the type of product (e.g. liquid, bulk or package) and the distance to be travelled. In case of intercontinental supply chains, the main choice is between air and sea. For continental chains, it is mostly between truck, airplane, train or short sea ship. Time sensitive goods are often supplied by air, while large volumes of commodities (like coal, iron ore) are transported by rail, inland barge or pipeline (in case of gas or oils). Technological innovations such as cooled (reefer) containers and data loggers for temperature history have enabled a shift from air to slower modes, like truck or sea ship. There are few OR papers that deal with these issues. Leal and D'Agosto (2011) use the modal choice method to choose alternative ways of transporting bio-ethanol using financial and socio-environmental considerations. They find that the best choice is to use local road transport to feed long distance pipelines which deliver bio-ethanol directly to the ports. Long distance road transport appears to be the worst of the alternatives considered.

Within transportation there is a large stream of papers identifying the shipper's preferences with respect to the different transportation characteristics, such as cost, quality, and speed. Although one has to be cautious with figures, because they depend heavily on the way they are calculated, we would like to present in Table 1 the following illustrative comparison of emissions between equipment types in several modes. The source is the Network for Transport and the Environment (see http://www.ntmcalc.se/index.html, last accessed on February 12, 2011). TEU is the standard measure for containers and one TEU is equivalent to a 20 ft. container and PM stands for Particulate Matters, also called fine dust.

We would like to highlight some important general relations which can be observed in this table. First of all, the bigger the transport unit in the same mode, the fewer the CO_2 emissions per g/t/km (under fixed utilization loads). When comparing transport modes, we observe that water can easily carry heavy loads, hence water transport is CO_2 efficient, that rail is more efficient than trucks, and a Boeing 747, though being a large plane, is not at all CO_2 efficient when compared to the other modes. The modes do not differ much in SO_x emissions, except for the Boeing which clearly emits much more. Ships are responsible for high NO_x emissions whereas trucks and diesel rail are relatively clean compared to other modes. Finally the figures for fine dust (PM) do not differ much; here it depends very much on the particular engine type and whether soot filters are applied. It will be clear that not one mode is the preferred one from an environmental point of view and that OR methods are quite useful to identify the trade-offs between different mode choices. Below we sketch some recent contributions.

Bloemhof et al. (2011) use sustainability radar diagrams to investigate the environmental impacts of inland navigation compared to

Table 1
Energy use and emissions for typical transport units of different modes (*Source*: NTM).

Energy use/ emissions g/t/km	PS-type container vessel (11,000 TEU)	S-type container vessel (6,600 TEU)	Rail-electric	Rail-Diesel	Heavy Truck	Boeing 747–400
kW h/t/km	0.014	0.018	0.043	0.067	0.18	2.00
CO_2	7.48	8.36	18	17	50	552
SO_x	0.19	0.21	0.44	0.35	0.31	5.69
NO_x	0.12	0.162	0.10	0.00005	0.00006	0.17
PM	0.008	0.009	n/a	0.008	0.005	n/a