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A service network design model for multimodal municipal solid waste transport

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ABSTRACT

A modal shift from road transport towards inland water or rail transport could reduce the total Green House Gas emissions and societal impact associated with Municipal Solid Waste management. However, this shift will take place only if demonstrated to be at least cost-neutral for the decision makers. In this paper we examine the feasibility of using multimodal truck and inland water transport, instead of truck transport, for shipping separated household waste in bulk from collection centres to waste treatment facilities. We present a dynamic tactical planning model that minimises the sum of transportation costs, external environmental and societal costs. The Municipal Solid Waste Service Network Design Problem allocates Municipal Solid Waste volumes to transport modes and determines transportation frequencies over a planning horizon. This generic model is applied to a real-life case in Flanders, the northern region of Belgium. Computational results show that multimodal truck and inland water transportation can compete with truck transport by avoiding or reducing transhipments and using barge convoys.

1. Introduction

Green House Gas (GHG) emissions associated with the transport of Municipal Solid Waste (MSW) in the European Union (EU) have been increasing over the last decades. Barring interventions, this evolution is expected to continue (EEA, 2011a). The European Environment Agency (EEA) recognises the growing importance of the transport component in the total net GHG emissions associated with MSW management: "*The collection and transport of waste, closely linked to waste volumes, is estimated to account for less than 5 percent of the direct greenhouse gas emissions of the waste sector, primarily due to the short distances over which municipal waste is usually transported. However, this figure represents 40 percent of the net emissions in 2020*" (EEA, 2008).

MSW is defined as the waste collected by or on behalf of municipalities. In reality, it also includes waste that is identical or similar in nature but collected directly by the private sector (business or private non-profit institutions) (Eurostat, 2012). MSW can be recycled, incinerated with or without energy recuperation, or landfilled by Waste Treatment Facilities (WTF). The transport of MSW can be organised by a carrier or shipper. A carrier is a person or organisation that offers transportation services and a shipper is either the supplier or the owner of the cargo to be shipped (Agarwal & Ergun, 2008).

The increase in GHG emissions associated with MSW transport follows the same unfavourable evolution as the fast growth in EU GHG emissions associated with transport modes in general over recent decades. To mitigate this trend several technology or behaviour-based solutions have been developed (Waisman, Guivarch, & Lecocq, 2013). On the technological side, carbon intensity can be lowered through the introduction of bio fuels and alternative energy carriers (electricity and hydrogen). Additionally, the energy intensity of transport and mobility can be lowered by developing more energy-efficient vehicles. On the behavioural side, transport GHG emissions can be reduced through policy choices that cause decision makers to choose transportation options that will lower GHG emissions. On the one hand, the modal structure of mobility can be shifted from carbon-intensive options (air, passenger cars and trucks) to less carbon intensive ones (public transport and non-motorised modes for passengers, rail, and shipping; and inland waterways for freight). On the other hand, the volume of transport can be decreased by a more efficient spatial distribution of transport movements (Waisman et al., 2013).

These same strategies are formulated in a European Commission white paper to establish a competitive and resource-efficient transport system (EC, 2011). In addition to the development and deployment of new and sustainable fuels and propulsion systems, the European Commission advocates the increased use of more

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energy-efficient modes. Its goal is to shift 30 percent of road freight over 300 km to other modes (such as rail or waterborne transport) by 2030, and to shift more than 50 percent by 2050. In principle, moving a portion of the MSW currently transported by truck to other transport modes could contribute to lowering the growth in GHG emissions and congestion (EC, 2011). In practice, however, such a modal shift will take place only if it is at least cost neutral compared to truck transport. The main issue that arises when considering such a move is that a modal shift is generally more expensive for long-haul distances shorter than 100 km. The break-even distances for a modal shift from truck transport to Inland Water Transport (IWT) differ across studies. Van Duin and Van Ham (1998) report break-even distances of 100–250 km for IWT and 200–400 km for railway transport. Pekin (2010) states that IWT can be cheaper than road transport above 99 km. The MIRA (2010) reports a break-even distance of 250 km for continental container transport with IWT or truck. The break-even distance for intermodal rail is longer than for intermodal barge transport (Macharis, Vanhaverbeke, van Lier, Pekin, & Meers, 2012).

In consideration of the options presented by Waisman et al. (2013) to reduce GHG emissions for transport in general, we aim to examine whether a modal shift from truck to IWT for long-haul transport can be beneficial, given that transport distances shorter than 100 km are typical for MSW transport (see e.g. Sweden: Sonesson, 2000). We will not address the technological evolution towards more environment-friendly fuels and engines. For the impact of alternative, greener fuels in freight transport we refer to Erdogan and Miller-Hooks (2012) and Bektas and Eglese (2014).

To support strategic decision making towards a modal shift in MSW transport it is crucial to evaluate the conditions that influence the feasibility of multimodal MSW transport. By demonstrating the feasibility of multimodal MSW truck/barge transport based on real life cases research could support strategic decision makers to consider this option. To this end, we formulate a tactical planning problem that minimises the transportation costs for a given waste handling and processing infrastructure composed of multiple collection centres and multiple WTFs. Solving this problem enables decision makers to choose services and associated transportation modes (truck and/or barge), allocate volumes to orders while taking available capacities into account, and plan shipping itineraries. This tactical planning problem will be modelled as a Service Network Design Problem (SNDP) applied to a practical case of MSW transport in Europe. This approach is in line with a majority of research conducted at the tactical planning level that addresses specific real-world problems using algorithms designed for those problems (SteadieSeifi, Dellaert, Nuijten, Van Woensel, & Raoufi, 2014).

Generally speaking, multimodal transport has increased significantly due to the use of standardised containers that enable both faster loading/unloading at intermodal terminals and transportation of multiple commodities on the same mode (Ayar & Yaman, 2012). However, in the case of MSW, using dedicated containers for hygienic reasons leads to both empty backhaul and additional handling costs. For transport over distances shorter than 100 km, transportation costs can be significantly higher compared to truck transport, according to logistic experts that were interviewed. Therefore, in this paper we will examine the transport of MSW in bulk only. To the best of our knowledge, this is the first feasibility study of multimodal barge-truck bulk transport on distances shorter than 100 km.

The remainder of this paper is organised as follows. The literature on multimodal waste transport is discussed in the next section. The research objectives are formulated in Section 3. The methods for addressing the issue as a tactical planning problem, as well as the model, are presented in Section 4; and the application to a practical case study is presented in Section 5. Finally, results are discussed in Section 6.

2. Literature review

In this section we begin by highlighting how MSW management optimisation models have evolved in recent decades and which transport-related aspects have been taken into account. Next, in order to better position our choice to formulate a possible modal shift for MSW as a tactical planning problem, we will provide an overview of how modal-shift problems typically have been modelled. Finally we review recent articles addressing way to incorporate environmental concerns into (operational) planning models.

2.1. MSW modelling

Morrissey and Browne (2004) present an overview of the evolution of MSW modelling over recent decades. In their view, changes in MSW modelling reflect an evolution in the societal debate on MSW. Initial MSW models were developed in the 1960s and dealt with the optimisation of specific topics within MSW, such as e.g. waste collection problems. The major shortcoming of these models was their simplicity and lack of consideration for recyclability aspects. In the 1980s, MSW models adopted a systems approach and began taking into account relationships among various MSW management factors. These models were focussed mainly on minimising the cost of waste management, although a few of them also encompassed some environmental and societal aspects. Models developed in the 1990s addressed waste minimisation and prevention and, in the early 2000s, they began to reflect a shift from a narrower focus on landfills towards a wider range of waste management processing techniques based on the principles of Integrated Solid Waste Management (ISWM). ISWM considers the full range of waste streams to be managed and views available waste management practices as a menu from which to select a preferred option based on site-specific environmental and economic considerations. More recent MSW models consider the environmental impact of MSW management options over their entire life cycle. For examples of recent MSW models we refer to Eriksson et al. (2005), Minciardi, Paolucci, Robba, and Roberto (2008), Reich (2005), Tavares, Zsigraiova, Semiao, and Carvalho (2009) and Ghiani, Laganà, Manni, Musmanno, and Vigo (2014).

As regards transport, recently developed MSW models are focussed on lowering waste collection and haulage costs by means of scheduling strategies. However these models fail to address the influence of transport mode or its associated environmental and societal impact. Johansson (2006) acknowledges that collection and haulage of transport in modern MSW management systems are accountable for the greater part of total costs associated with MSW management. To manage these costs he presents a model that optimises MSW collection and haulage by means of dynamic scheduling and routing allocation. McLeod and Cherrett (2008) model the effect of three different options for MSW collection to reduce vehicle mileage. Tavares et al. (2009) discuss a model for choosing optimal waste collection and haulage to lower the transport cost associated with the collection and haulage of MSW. The cost associated with MSW transport accounts for the majority of total MSW management costs in the discussed case studies.

The MSW models using Life Cycle Assessment (LCA) to minimise environmental impact over the entire life cycle of MSW have the same shortcoming as the models discussed in the previous paragraph: they do not take into account the role of transport mode. Reich (2005) includes transport in Life Cycle Costing (LCC)