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Emission rates of intermodal rail/road and road-only transportation in Europe: A comprehensive simulation study

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ABSTRACT

Intermodal rail/road transportation combines advantages of both modes of transport and is often seen as an effective approach for reducing the environmental impact of freight transportation. This is because it is often expected that rail transportation emits less greenhouse gases than road transportation. However, the actual emissions of both modes of transport depend on various factors like vehicle type, traction type, fuel emission factors, payload utilization, slope profile or traffic conditions. Still, comprehensive experimental results for estimating emission rates from heavy and voluminous goods in large-scale transportation systems are hardly available so far. This study describes an intermodal rail/road network model that covers the majority of European countries. Using this network model, we estimate emission rates with a mesoscopic model within and between the considered countries by conducting a large-scale simulation of road-only transports and intermodal transports. We show that there are high variations of emission rates for both road-only transportation and intermodal rail/road transportation over the different transport relations in Europe. We found that intermodal routing is more eco-friendly than road-only routing for more than 90% of the simulated shipments. Again, this value varies strongly among country pairs.

1. Introduction

In 2015, a total of 4452 million tons of anthropogenic CO_2 equivalent greenhouse gases were emitted in the European Union (EU), see Eurostat (2018b). Around 20% of these emissions resulted from transportation (Eurostat, 2018b), where road transportation is the dominant mode in the freight sector. For example, 75.3% of the total inland freight ton-kilometers (ton-km) in the EU were transported by truck, 18.3% by train and 6.4% by inland waterways in 2015 (Eurostat, 2018a). Recent research and political initiatives that seek for a reduction of the human-made environmental impact therefore also focus on emissions from transportation, see e.g. McKinnon et al. (2012), Psaraftis and Kontovas (2016), or DIN EN 16258 (2012). The amount of greenhouse gases (GHG) emitted per ton-km are used as a typical measure for the environmental impact of freight transportation. Although greenhouse gases subsume various substances like carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, their global warming potential can be expressed as carbon dioxide equivalents (CO_2e) and, therefore, the amount of CO_2e per ton-km is considered a valid indicator of the environmental performance of freight transportation. Shifting freight from road to rail is often seen as an effective option to improve this measure (e.g. Dekker et al., 2012; McKinnon et al., 2012). Thereby, an objective comparison of transport options requires to consider well-to-wheel emissions that include not just the actual emissions of the transport operation (so called tank-to-wheel emissions) but also the emissions caused by producing and providing the fuel or energy to the

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vehicle (so called well-to-tank emissions), see Hoffrichter et al. (2012), Moro and Lonza (2017).

Research in the field of environmental transportation focusses on the development of eco-oriented routing and transport flow models (e.g. Bauer et al., 2010; Behnke and Kirschstein, 2017; Bektaş and Laporte, 2011; Ehmke et al., 2016; Rudi et al., 2016). Such studies usually consider emission rates obtained from emission estimation models or they use aggregated empirical rates reported in the literature. Experimental results in such papers typically refer to artificial networks or to relatively small real networks that cover a specific region. A comprehensive overview of emission rates that are observed in large-scale transportation systems like the European rail/road system is not provided by these studies. With our paper, we fill this gap and provide a systematic and broad overview of emission rates from intermodal rail/road and road-only transportation in Europe. More precisely, we analyze intra- and inter-country freight shipments for 27 European countries. We conduct a comprehensive simulation study that respects country specific attributes like the electrification and density of the rail network and geographical characteristics. To this end, we (i) collect data of an intermodal rail network across the considered countries, based on the corridors from the Trans-European Transport Network policy (TEN-T), see European Commission (2018), (ii) adapt a suitable emission estimation model for rail and road transportation and (iii) present results from an extensive simulation study that covers numerous experimental settings. We focus on relatively large shipments of several truck loads of heavy and voluminous goods, as these are candidates for rail transportation. Next to the differentiation between heavy and voluminous goods, we analyze the impact of further vehicle characteristics, shipment characteristics, and route characteristics such as traction type, electric emission factors, cargo size, gradient or traffic conditions. To estimate emissions, we adapt the mesoscopic model from Kirschstein and Meisel (2015). This model can capture both road and rail transportation and allows us to test the relevance of the previously mentioned parameters for the European transport system. We also contribute to the improvement of this estimation model by presenting an alternative way of approximating the gradient of a route. With these contributions, we present a broad and holistic overview of intermodal rail/road emission rates for European countries. The results of this study can be used to further facilitate research in areas where emission rates serve as an input to environmentally oriented decision problems, such as location planning or routing problems. They might also be used for companies to benchmark their environmental performance. In addition, the derived model of the European rail and road network can be used for follow-up research in the field of intermodal transportation.

The paper is organized as follows. Section 2 formally describes the intermodal rail/road network and the used data. Section 3 briefly reviews literature on emission estimation models and provides details about the mesoscopic estimation model. Section 4 describes the simulation settings and Section 5 presents the obtained results. Section 6 concludes this paper. The paper is supplemented by an extensive appendix that provides look-up tables for emission rates of road, rail and intermodal rail/road transportation for all country combinations and simulation settings considered in this study.

2. Modelling the European rail/road network

2.1. Multilayer network structure for intermodal transportation

Intermodal networks can be formally modelled as multilayer networks (e.g. Southworth and Peterson, 2000). An example of such network models is the Geospatial Intermodal Freight Transportation (GIFT) model for the United States that is also implemented as a web-tool (WebGIFT, 2018). This model covers various modes (rail, road, water) and enables the exploration of tradeoffs between cost, time and environmental measures. A description of the model and case studies can be found in Hawker et al. (2010),Winebrake et al. (2008) and Comer et al. (2010). For our study, we define here a rail/road network $\mathcal{G}(\mathcal{N}, \mathcal{E})$, where nodes $\mathcal{N} = \mathcal{N}^{rail} \cup \mathcal{N}^{trans} \cup \mathcal{N}^{road} \cup \mathcal{N}^{cust}$ and edges $\mathcal{E} \subset \mathcal{N} \times \mathcal{N}$ form four interconnected layers with subgraphs $\mathcal{G}^{rail}$, $\mathcal{G}^{trans}$, $\mathcal{G}^{road}$ and $\mathcal{G}^{cust}$, see Fig. 1. Nodes on these four layers are: (i) customer nodes $\mathcal{N}^{cust}$ that are origins and destinations of shipments, (ii) nodes $\mathcal{N}^{road}$ that

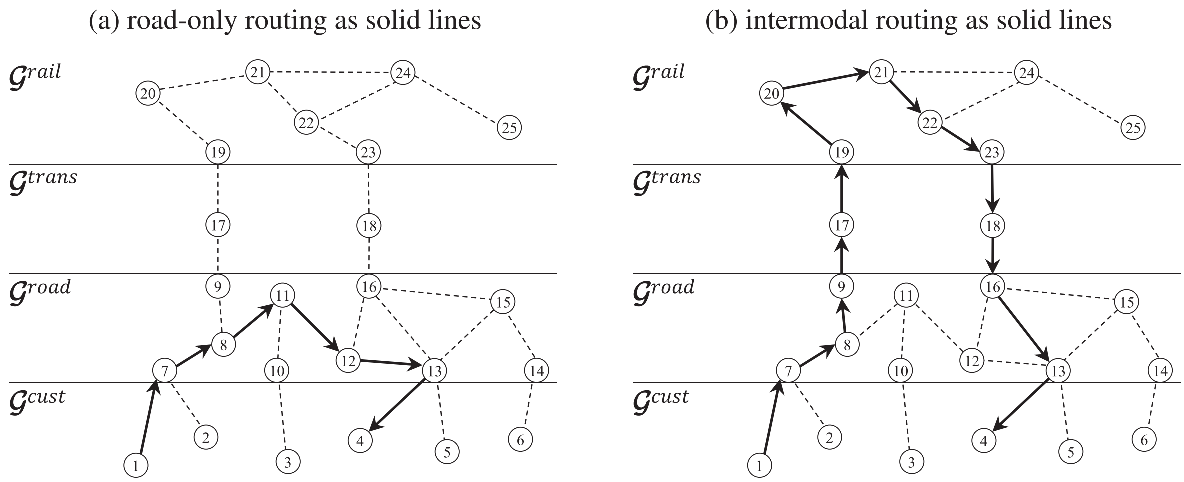

Fig. 1. Exemplary routings through an intermodal multilayer network.