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Towards an integrated multi-agent urban transport model of passenger and freight

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ABSTRACT

Transport policy defines ever more challenging goals to reduce the negative impacts of freight transport and to make freight transport more efficient. To achieve these goals, there are a number of policy measures that are tailored to specific actors to alter their behaviour by changing their transport context. To analyse such measure in advance, we propose a multi agent transport simulation of passenger and freight. We specify the objectives of the agents and analyse whether our model is sensitive to a typical policy measure, i.e. a distance dependent toll for heavy vehicles within a low emission zone. Additionally, we study the computational costs of our model. Based on a sandbox scenario, we illustrate that our model is able to capture the behavioural adaptations and interdependencies of passenger and freight traffic, and that we are able to take into account that policy measures for a specific subset can affect the entire transport system.

1. Introduction

UN projects the world's population to reach 8.1 billion people in 2025 and 9.6 billion in 2050 (UN, 2013a). Today 54% of the world's population live in urban areas. By 2050, this share is expected to increase to 66% (UN, 2014). Today, there are 28 cities with over 10 million inhabitants. UN prospects that even by 2025, there will be 41 of such Mega-Cities (UN, 2013b). Thus, the world continues to urbanise at great speed. It is an ongoing agglomeration process (Quinet & Vickerman, 2004) that "depend to a great extend on the quality of transport" [p.53]. To take the chance of the manifold activities a city can offer, firms and consumers demand for transport. People travel to satisfy a need for conducting activities at specific locations. Firms demand for goods - and thus for freight transport - produced at distant locations to sell these goods to consumers or to further refine and sell them to other firms - which in turn usually requires transport. Thus, "a good transport system widens the opportunity to satisfy these needs; a heavily congested or poorly connected system restricts options and limits economic and social development" (de Dios Ortúzar & Willumsen, 2011, p.3).

Urban freight transport (UFT) is an important part of "a good urban transport system". It is "the movement of freight vehicles whose primary purpose is to carry goods into, out of and within urban areas" (MDS Transmodal, 2012, p. 2). There is no doubt that urban freight transport significantly contributes to the wealth of cities and urban economies.

The vast majority of urban freight transports are conducted by means of road transport. In relation to the overall road transport in cities, empirical studies indicate that the share of freight transport amount in average to 8–15% of total vehicle kilometre travelled (see Cambridge Systematics (2004), Hunt and Stefan (2007)).

Even if this share constitutes a relatively small proportion of urban transport, its negative impacts are disproportionally high (Dablanc, 2009; MDS Transmodal, 2012; Filippi, Nuzzolo, Comi, & Delle Site, 2010). The most important burdens are road congestion, air quality issues, green house gas emissions (GHG), noise, infrastructural damage and intimidation and accidents. Most of these negative impacts do not occur at efficient levels which is one reason for policy intervention (Quinet & Vickerman, 2004).

Therefore, transport policy defines ever more challenging goals such as CO2-free urban logistics (EU, 2011). To achieve these goals,

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policy-maker can implement a wide range of policy measures to control UFT (see Quinet and Vickerman (2004), Munuzuri, Larraneta, Onieva, and Cortes (2005), Holguin-Veras et al. (2014a), Holguin-Veras et al. (2014b)). These measures need to be evaluated in advance to identify their effects on the transport system and the environment and to identify winners and losers of such measures. Therefore, transport models are required.

A number of reasons has led transport policy to change its strategy from "predict and provide" to demand management, i.e. measures that are tailored to specific actors to alter their behaviour by changing their transport context. A typical example for such a measure is a congestion charge that differentiates between actors, vehicles, time of day and locations. To model the effects of such a measure, models are required that can map high temporal (peak vs. off-peak hours) and spatial (congested vs. non-congested areas) resolution, the interactions of passenger cars and freight vehicles in constrained physical networks to model congestion, the ever-increasing heterogeneousness of actors and their corresponding decisions as well as spatial and temporal behavioural adaptations to such policy measures. This constitutes a major challenge for transportation research.

Since the 1950s the *classical* four-step transport model has influenced and stimulated the modelling debate up to now (see for example de Dios Ortúzar and Willumsen (2011)). It is a trip based approach using a few traveller types to represent travel behaviour and a very aggregate representation of time. This approach proved to be very effective in analysing long-term investment decisions. However, when it comes to short-term policy measures to control transport demand, such as congestion pricing, it features some drawbacks. It significantly abstracts, for example, from the distinct characteristics of individual travellers and households which significantly determine travel behaviour. Moreover, to analyse congestion pricing, the temporal resolution is inadequate. Therefore, the "[trip based] paradigm itself seems to be approaching a dead end" and the need for evaluating demand oriented policy measures calls for an explicit consideration of the temporal dimension and thus "for a more disaggregate and behaviourally-realistic approach than the four-step paradigm is able to offer" (Davidson et al., 2007, p.469).

Activity based models rest upon the fundamental idea, that travel (i.e. trips) is a derived demand, "derived from the need to pursue activities distributed in space. […] The conceptual appeal of this approach originates from the realisation that the need and desire to participate in activities is more basic than the travel that some of these participations may entail." (Bhat & Koppelman, 2003, p. 40). Hence, the essence of activity based modelling is to examine individual decisions that result in travel. This includes "all the factors that influence the why, how, when and where of performed activities" (Pinjari & Bhat, 2011; ch.17, p.3). Accordingly, in contrast to trips in trip based models, the basic unit of activity based models is the individual actor (or household and firm). Resting upon these models, there has been a rapid development of utility based econometric models (e.g. Ben-Akiva and Bowman (1998), Bhat and Koppelman (2003)) and micro/multi-agent simulations (e.g. Charypar, Nagel, and Axhausen (2003), Balmer et al. (2007)). Latter are known to consistently map high temporal and spatial resolution, heterogeneous decision makers, i.e. their ambitions, desires and constraints as well as spatial and temporal adaptations to demand oriented policy measures.

Most of these developments focus on passenger transport. Freight traffic has essentially served as a background load of the traffic system, without much adaptive behaviour. The development of disaggregate freight models is still way behind the development of passenger transport models.

Recently, however, several promising freight models have been developed. The achievements can be clustered into two groups of models: The first model category transmutes freight flows into shipments and shipments into truck tours (see, for instance, the models described by Ramstedt, 2008; Wisetjindawat et al., 2007, 2009; Liedtke, 2009; De Jong and Ben Akiva, 2007). Furthermore, Roorda et al. (2010) proposed a conceptual framework for agent-based modelling of logistic services. The second model category, the tour-based models, focuses on the execution of complex tours in space (e.g. Hunt and Stefan (2007), Joubert, Fourie, & Axhausen, (2010)). The tour-based models are well defined to support classical urban transport planning. Once it comes to the assessment of measures tailored to individuals, their sensitivity is still limited. One reason is that these models focus on individual vehicle movements rather than logistics behaviour yielding to these movements.

A number of models address this logistics behaviour and take into account "the logistics and transport activities by private companies in urban areas while considering the traffic environment, traffic congestion and energy consumption within the framework of a free market economy" (Taniguchi, Thompson, Yamada, & van Duin, 2001). These models have been successfully applied for ex-ante evaluation of urban freight policies and city logistic schemes (e.g. Taniguchi and Shimamoto (2004), Anderson, Allen, and Browne (2005), Quak and de Koster (2009), Muñuzuri, Grosso, Cortés, and Guadix (2013), Teo, Taniguchi, and Qureshi (2012)).

A relatively new research stream has been developed by Gatta and Marcucci (2014). They combine a utility based econometric model with an agent based approach to support ex-ante evaluation of urban freight policies.

The traffic environment and traffic congestion in these models are mostly represented by exogenous parameters. A number of policy measures, however, impact the entire transport system, e.g. a prohibition for heavy vehicles in the city centre, and thus influence these exogenous parameters itself. One way to deal with these interdependencies is to consider some of them within the model. This, however, requires models that can map both passenger and freight transport. We are not aware of any model in literature that models passenger and freight actors in a disaggregated utility based microsimulation.

The model we develop integrates freight actors into an existing utility based microsimulation called MATSim (Balmer et al. (2007)). Our contribution is a preliminary evaluation of the introduction of urban freight transport in a multi-agent passenger model. After these introductory words, in the second section, we start with introducing the utility models of passengers and freight actors. Furthermore, we introduce the behavioural modules to model the decisions of passenger and freight actors within the simulation. To illustrate our approach and to study the functioning of the proposed model (third section), we set up a simple scenario. The objective of the sensitivity studies that follow are twofold. First, we study the sensitivity of this model according to demand orientated policy measures. To be more precise, we introduce an area dependent distance toll for heavy vehicles and vary the toll to analyse behavioural reactions. Second, as opposed to above - we keep a specific toll amount fixed and analyse the sensitivities of the model outcome according to the main model parameter, the probabilities to choose certain behavioural modules and, thus, the share of agents that re-plan in each iteration. A conclusion finalises our work.

2. Introducing the model

We add freight carriers as autonomous agents and the related

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