An outline of Transport Link Scanner: A GIS-based model to simulate the geographic expansion of a transport network

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Abstract

This article gives an outline of Transport Link Scanner, a model developed to simulate transport network growth, and a case study in which that model is applied to simulate the historical development of the Dutch railway network. The article concentrates on model structure and discusses promising model accuracy results. The conclusions touch on plans for the future development and use of the Transport Link Scanner model.

Keywords

Network growth, Transport modelling, Accessibility

Introduction

Although the development of transport networks is considered an important factor for the spatial distribution of activities and receives considerable politic and academic attention, relatively little is known about the factors involved

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in transport network development. Models of transport network growth that aim to reproduce transport network development are few and they are hardly ever empirically validated (Xie and Levinson, 2009). In this paper we outline Transport Link Scanner, an agent-based model that simulates the overall geographic diffusion of a transport network through the individual investment decisions involved in constructing transport links. The model is illustrated with a case study in which the construction of the Dutch railway network between 1839 and 1929 is simulated. In that case study the transport market is driven by passenger transport, for which decennial municipal population counts are included as an exogenous factor.

A range of features makes the model a novel tool that is fit to explore the relevance of path dependencies, the importance of network externalities and how different institutional and investor characteristics affect network form and subsequent land-use distributions. It produces a network of transport links as chief output, which enables outputs and the measurement of model performance based on indicators relevant to transportation networks such as accessibility and network efficiency (Geurs and Van Wee, 2004). The model is developed in the open-source GeoDMS GIS platform (ObjectVision, 2014) and is currently operational. In the case study it takes roughly four hours to allocate one investment on a high-end computer, and 50 investments to grow a reasonably mature network. The authors have made all scripts and data freely available under public license through http://www.jacobs-crisioni.nl/publications/download_tls.

Model structure

The model simulates the geographic diffusion of the connections of a new transport mode over spatially separate origins and destinations, assuming a context in which the origins and destinations are already connected by means of one or more existing transport modes. The introduced transport mode is expected to lower generalized transport costs for passengers or commodities. The model presumes distinct investors that are assumed to invest in the new transport network mode with identifiable and quantifiable goals. The modelled network investments are discrete choices for which parameter values are obtained using conditional logit estimation to analyse historical network additions, and are selected from a limited set of potential network extensions with dynamically generated optimal geographic paths. The selection of that set of potential extensions is based on a set of a-priori set rules that in the case study aim to select links with optimal benefit-cost ratios. These benefit-cost ratios are obtained using on the one hand estimated construction cost factors linked to various soil types, and on the other hand increases in passenger kilometres on the railway network, which in turn are estimated using a spatial interaction model obtained from Alonso's (1978) General Theory of Movement.

The allocation of investments is turn-based, and the market conditions that govern investment choices are dynamic: thus, only one investment decision from one investor is simulated in any model iteration, adding one distinct link to the modelled transport network. The transport link allocated in that iteration affects the market conditions that are relevant for the generated choice set and for the estimated revenues of subsequent investments. In the case study, Transport Link Scanner allows multiple investors to construct network links in subsequent turns; and the partaking investors are allowed differing investment objectives. The investments modelled in the case study concern newly constructed links; however, the model can be set up to model improvements in speed or capacity as well.

The selection of potential extensions and the final selection of one network addition is an iterative process. In the case study, first 10 origin-destination pairs with likely high benefit-cost rates are selected. Subsequently optimal routes between those origin-destination pairs are obtained using a regularly latticed network of potential links and an adapted shortest path algorithm. The attractiveness of all 10 routes is subsequently evaluated. Attractiveness includes all variables that have been found important in the previously described analysis of the historical network development. In the case study, these variables include construction costs and increases in passenger kilometres. For the latter, a complete evaluation of the effects of link construction on passenger flows on each of the investors' networks is computed for the selected 10 alternatives. Other variables are computed as well for those 10 alternatives, such as whether the link connects to the existing network; the impact of the link on disparities in accessibility; and whether the link potentially connects to a sea harbour or a border zone. Based on the computed variables the attractiveness of links for separate investors is evaluated. Finally the most attractive link-investor combination is selected as the individual addition to the network in the model iteration at hand. The process of searching for investment alternatives and selecting an individual addition is repeated, so that the simulated network gradually grows. In the case study the simulation stops when attractive investment alternatives can no longer be found or when the simulation end year (1929) is reached.

Results and model performance

In its current form Transport Link Scanner simulates the development of roughly 1500 kilometres of railways in the Netherlands; this is still much lower than the roughly 3500 kilometres that have historically been built. This lack of allocated links will need to be tackled in parameters such as minimum investment attractiveness. Model accuracy is measured by means of two indicators. A first indicator observes the level of geographic agreement by computing the degree in which the municipalities connected by the modelled network correspond with the municipalities connected by the historically built network. A second indicator observes the level of travel time agreement by computing the mean absolute percentage error of municipality to municipality travel times obtained from the modelled network, compared with the travel times obtained with the historically built network. Results from the case study demonstrate that Transport Link Scanner is able to reproduce the historical travel time gains obtained through Dutch railway network development with a 25% average error, while about 25% to 30% of the historically connected population is not connected by the simulated network.

Conclusions

This paper has outlined the structure of an agent based model that can simulate the geographic expansion of a transport network based on deductive rules of investor behaviour. Concurrent results indicate that the outlined model is able to simulate the development of a historically built network with reasonable accuracy. Work is ongoing to further increase the accuracy and fine-tune the impact that the context of multiple investors with differing objectives has had on the development of the railway network. In that form Transport Link Scanner will be used to explore the importance of path dependencies on network development and subsequent population movements, and to evaluate the impacts of the atypical role that the Dutch state has played in the development of the Dutch railway network.

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