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The dynamics of modal split for freight transport

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ABSTRACT

The paper presents a dynamic model of modal split in a multimodal freight transport system, which supposes that the evolution over time of transport demand is accompanied by a corresponding evolution of transport modes, and that users react with delay to cost variations. Starting with these hypotheses, and following the paradigm of random utility, a recursive equation is obtained, whose iterated application furnishes the sequence of the demand fractions on the various transport modes in the successive epochs of the time period during which the evolution of the transport system is studied and enables forecasting the future modal split evolution.

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1. Introduction

Consider two territories, between which there is exchange of freight carried by n transport modes, where we mean by transport mode a solution to transfer freight from an origin to a destination, which uses a particular set of technologies, of organizational structures and of itineraries, in a given environment. A carrier, who sends regularly goods between these two territories, tends to use the mode that he deems to be the best. His behaviour stems from the evaluation of the attributes of the modes – monetary expense, travel time, flexibility, reliability, safety (see e.g. Law and Small, 2001; de Jong et al., 2014) and from relevant psychological attitudes concerning e.g. the image he has of each transport mode and the vision of its future evolution. We suppose that to make his choice the carrier arranges the transport alternatives in a set, which we name *choice set*, and, with the purpose of ordering this set, he assigns to each alternative a number: the higher it is, the less preferable the alternative is. We define this number *transport cost* per transport unit, and suppose that the latter is the weight unit, because we are interested in the quantities carried by each transport mode.

In general freight transport models consider for each transport mode a relation between average transport cost and freight flow, the characteristics of the transport mode being fixed: this relationship is a monotonically increasing function, named *cost function*. However in real life the evolution over time of freight flow is accompanied by a corresponding evolution of the transport mode characteristics. If we consider the evolution over time of the freight flow carried between an origin–destination (O/D) pair by a transport mode during a given time period, we can divide this time period in a sequence of intervals, such that the characteristics of the transport mode are fixed for each interval, but different for the various intervals, so that we can define a sequence of cost functions in the range of the freight flow evolution.

An example of sequence of cost functions is given in Fig. 1, which shows the relations between monetary transhipment cost and number of transshipments in intermodal rail–road freight transport terminals. The terminals considered in the figure have different designs, depending on the type of handling equipment, the number and the length of the transhipment tracks, the way in which the transhipment tracks are utilized. The figure reports a sequence of curves computed by Ballis

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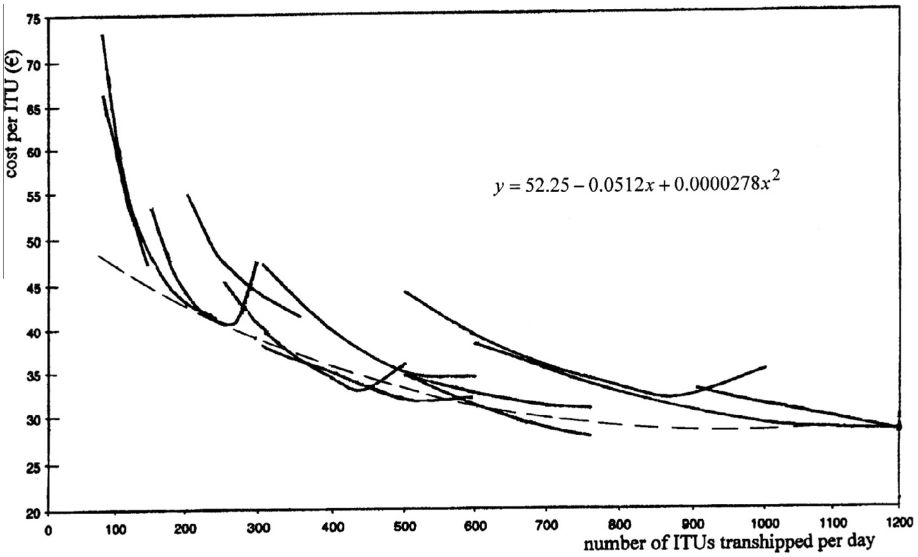

Fig. 1. Monetary cost functions for freight transhipment at road-rail intermodal terminals, computed by Ballis and Golias, 2002, and dynamic cost function (broken line) whose analytic expression is shown in the figure.

and Golias (2002), each of which furnishes, for a given interval of freight flow – measured as the number of ITUs (Intermodal Transport Units) transhipped per day – the monetary transhipment cost of one ITU as a function of freight flow, and is relative to the type of terminal design suitable for that freight flow interval. The broken line shown in the figure, computed by the author of this paper, is a second order polynomial curve interpolating the minimum points of the successive curves, which represents a continuous relationship between cost and freight flow where, unlike the usual cost functions, the terminal characteristics are not fixed, but vary with freight flow. It refers to the monetary cost of one component of intermodal transport – the transhipment at terminals – but a curve of this type can be defined for the average overall transport cost of any transport mode between an O/D pair, and its analytic expression depends on the way in which the characteristics of the transport mode vary with freight flow. The curve reported in Fig. 1 shows that the per unit transhipment cost decreases as freight flow increases. In other cases, e.g., for road haulage, it is possible that transport cost increases with freight flow: in fact the increase over time in traffic flow causes increase in congestion, which can be reduced only in part by the improvement in the geometric characteristics of the infrastructures, and by the increase in vehicle capacity and load factor. We define this type of relationship between transport cost and freight flow between an O/D pair for a transport mode, which supposes that freight flow varies over time accompanied by corresponding variations in the characteristics of transport modes, *dynamic cost function*.

This evolution over time of transport cost of the various transport modes brings about the evolution of modal split, but it is not the only cause of this evolution. An important role is played by the delay with which users shift from a transport mode to another deemed more suitable. Such lag is due to many factors, including limited confidence in the future possibilities of a new transport mode, difficulties in adapting the logistical organization, and simple inertia, in general.

This paper presents a dynamic model of modal split for freight transport, which supposes that, given a sequence of time periods, at the beginning of a period a carrier, who sends regularly goods between an O/D pair, assigns to each mode connecting the O/D pair a cost on the basis of his knowledge of the performance of the mode in the previous period, decides what is the best mode by comparing the costs, but shifts with a certain delay to another mode deemed more suitable than that used currently. Transport costs evolve over time as a consequence of the overall freight flow increase, of the proportion of the overall freight flow that uses each transport mode, of the users' attitudes, and of the changes in the transport mode technology and organization. The interaction between these causes determines the evolution over time of transport costs, and thus, along with the users' delay, the evolution of the modal split. This model is different from the models usually employed in freight modal split research (see e.g., Abdelwahab and Sargious, 1992; Cascetta, 2001; Chow et al., 2010; Dalla et al., 2008; de Jong and Ben-Akiva, 2007; Masiero and Rose, 2013; Norojono and Joung, 2003; Winston, 1983). In fact the latter are static, and hence, on the one hand they do not consider the evolution over time of costs, due to technological and organizational changes in transport modes, which accompany the evolution of freight flow, and on the other, they do not take into account delays in users' reaction. The new model is based, like the static models, on the paradigm of random utility (Luce, 1958; McFadden, 2000), but introduces the dynamic cost functions and takes into account the users' delays.

The paper is organized in this way. Section 2 presents a review of the main literature on the dynamic choice models, putting out the substantial differences with the new model. The latter is illustrated in Sections 3 and 4, and then applied in Section 5 to the study of the dynamics of freight transport in two cases, the freight traffic through the Swiss Alps and

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