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A bilevel mathematical programming model to optimize the design of cycle paths

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Abstract

In this article, we present a methodology to simultaneously modelize car, bus, and bicycle transport modes, considering the interactions among the three modes through the modelling of the modal split and the network assignment of the different travels of each mode. Later, this model was utilized to optimize the design of cycling paths network to achieve an efficient and sustainable transport system. The proposed methodology has two levels. In the lower level there is a transport network, over which cars users, bus passengers and bicycles users could be simulated at the same time Applied to this is a combined model (modal split-assignment model) with its inputs come from a global matrix (car, bus and bicycle trips). The Multinomial Logit model for modal split and network assignment models will follow an iterative process, to provide the final matrices and service variables for each mode of transport. Finally, in the upper level, an optimization model has been developed, based on bilevel mathematical programming. The objective is to optimize the design of cycling paths, determining which typology of bike lane will be the optimal for each street. For this specific model, we considered only three typologies (segregated, non-segregated, and no bike lane).
The optimization criteria utilized aims to maximize the number of cycling users. These have been applied to the real scenario of the city of Santander (Spain).

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1. Introduction

During the 1990s, science started to propose alternatives to existing mobility models. Society at the time had doubts about the validity of the existing model, the pollution management and the loss of public space. Society needs to address these subjects through urban planning and environmental policies. Attempts are being made to recuperate part of these lost public spaces, the most obvious being the pedestrianization of historic town centers and increasing investment in public transport. The increasing presence of the bicycle in urban areas has meant that; people friendly spaces are being created to allow circulation either on foot or by bicycle, safe zones are being created with fewer or no vehicles and as a result, a changing mentality is beginning to spread among the population. The current challenges cities face are to plan a mobility system aimed at the citizen and to plan the city on a more local scale, where the concept of nearness has greater relevance (Pozueta, Daudén, & Schettino, 2009).

Although the bicycle is not the only solution to traffic and environmental problems in urban areas, it does constitute a response that can easily be inserted into any urban renewal legislation and policy at a relatively low economic outlay. The individual evolution of different towns and cities has led to great diversity in urban morphologies over the years and the cyclist has always looked for the shortest available route to optimize their trip that, depending on the particular urban morphology of the town in question, will be longer or shorter.

Urban architecture is a key element in the promotion of cycling, and the type of infrastructure (the cycle lane) has a great influence on speed, physical exertion and safety, which are all important factors when considering whether to travel by bicycle. A positive correlation between the number of bicycle journeys and the density of the bicycle lanes has been observed in a study of the largest cities in the United States of America (Dill y Carr, 2003). Cyclists make variable choices, they adjust their routes in order to use the infrastructure prepared specifically for their use (Howard and Burns, 2001).

Nevertheless, cycling infrastructure does come at a cost, which depends on the characteristics of the dedicated cycle lane: segregated or non-segregated, width, type of surface, etc. This infrastructure is also limited by the space available for it in urban areas.

Modeling the mobility of an urban or intercity area is a frequent topic in international transportation literature; sometimes considering just private transport users (the mode that historically has been studied the most), and other times including different motorized transport modes, both private and public (buses).

However, it is difficult to find a model that simultaneously considers private and public transport and the bicycle mode, taking into account the interactions between the three modes through the modeling of the modal split, and the assignment of the different trips to the network.

There is a small amount of international literature on the subject of the simultaneous assignment of private, public and cyclist traffic and the reflection upon user's behavior when choosing between these three available modes of transport.

Therefore, the aim of this research is to propose a cycling network optimization model by establishing the type of infrastructure required on each link, which will maximize number of cyclists and is subject to budgetary constraints. The methodology is applied to the city of Santander, which allows a sensitivity analysis to be performed as well as an evaluation of the cost increases resulting from improvements made to the network to provide a quality sustainable transport system. The resulting network is capable of reducing the conflict between motorized traffic and bicycles.

This article firstly presents a bi-level mathematical programming model, which is used to optimize the location of public bicycle docking stations. Its lower level is a modal split and assignment model capable of jointly simulating private and public transport and bicycle modes, considering the interactions between them (Romero, 2012). Secondly, the models developed are applied to the real case of Santander city, determining the optimum location of cycle paths and its typology. The article ends with a section that enumerates the most important conclusions reached.

2. Methodology

The outlined problem's structure perfectly satisfies the requirements of a bi-level mathematical programming model (Bard, 1998).

Bi-level programming constitutes one of the most important areas of overall system optimization. Currently there are countless problems associated with practical applications that take advantage of their own structural hierarchy to