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Bus network structure and mobility pattern: A monocentric analytical approach on a grid street layout

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A B S T R A C T

This study discusses which transit network structure is the best option to serve urban mobility. As a consequence of the evolution of urban form, cities have undergone a process of dispersion of their activities that has caused a change in mobility needs in the last few decades. Mobility networks and services should progressively adapt to the new demand patterns, especially the bus transit network, which has more flexibility to absorb the changes. We compare four base transit network structures: a radial scheme, a direct trip-based network, and a transfer-based system by means of either a complete grid or a hybrid structure. An analytical model is used to estimate the behavior of these structures for idealized monocentric mobility patterns with several degrees of concentration. The purpose is to determine the right range of situations for the applicability of each bus transit structure, and to determine guidelines about the transit network planning process. It turns out that the best structure is not always the same, and depends on the mobility spatial pattern. A radial network is the best alternative in very concentrated cities; however, a direct trip-based system is more suitable for intermediate degrees of dispersion. A transfer-based structure is the best option when the activities are more decentralized. Nevertheless, the decentralization degree that justifies a specific transit structure is not constant. This degree depends on the characteristics of the city, transport technology and users.

1. Introduction

Transportation has a relevant impact on the economy and also is a key issue with regard to social, political and environmental aspects. The economic competitiveness of a city and its social equity might be determined by its transport supply. The convenience of transit systems versus cars in urban areas is clearly accepted. However, a good design of these transit systems is essential to guarantee their efficiency and effectiveness in order to satisfy mobility necessities. Among the different aspects that one can consider for a well-designed transit network, its network structure stands out, i.e., how the different transit lines that compose the system are arranged over the city. This structure should be the most suitable with regard to transit system cost and level of service to satisfy urban mobility patterns.

These urban mobility patterns have been evolving at the same time as urban spatial structures. Rodrigue et al., (2006) summarized this evolution in three phases: the first is a highly centralized scenario, where the major part of

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Nomenclature

H	Headway [h]
s	Stop spacing [km]
d	Swath width or swath-corridor spacing in a direct trip-based network structure [km]
α	Parameter defining the central grid in a hybrid network structure
Z	Total system cost [h/p-h]
C_A	Agency cost [h/p-h]
C_U	User cost [h/p-h]
L	Infrastructure length [km]
V	Kilometers traveled per vehicle and hour [veh-km/h]
M	Number of vehicles working per hour [veh-h/h]
A	Average access time per trip [h]
W	Average waiting time per trip [h]
T	Average in-vehicle time per trip [h]
e_T	Average number of transfers per trip
O	Vehicle occupancy in the most loaded points of the network [p/veh]
ϕ	Demand decentralization degree
f_d	Factor of densities between central and peripheral areas
ρ	Portion of generated demand at central area
Λ	Demand during the rush hour [p/h]
λ	Average hourly demand [p/h]
D	Length of the side of the square that represents the city [km]
μ	Value of time [€/h]
δ	Equivalent penalty distance per transfer [km]
v_{FFS}	Speed without considering spent time at stops [km/h]
w	Pedestrian speed [km/h]
$€_i$	Unit agency cost, where i=L, V or M [€/km-h; €/veh-km; €/veh-h]
C	Vehicle capacity [p/veh]
τ	Dwell time per stop [h]
τ'	Boarding (and alighting) time per passenger [h]
w_i	Time perception weight, where i=A, W, T or t
H_s	Cut-off headway between types of service [h]
h_s	Safety waiting time [h]
f_s	Home waiting time factor
ε_H	Parameter defining the type of service operation in a direct trip-based network structure
SF	Occupancy safety factor

activities takes place in a central business district (CBD) or city center; the second is an intermediate phase, when some of these activities start to scatter over adjacent areas of the CBD; and the final phase is a dispersed urban form, where a high number of activities is relocated in new peripheral areas far away from the CBD. Anas et al., (1998) presented a similar evolution of the city in the last two centuries from a centralized to a decentralized scenario due to changes in technology, telecommunications and transportation. From the so-called *nineteenth century city*, characterized by a compact core surrounded by residential areas, CBDs have expanded. At first, activities from the center spread outward around it; afterwards, new poles of activities appear, forming subcenters or, on a metropolitan scale, edge cities. Initially, these new poles have a clustered form, and with time, they also reach a scenario of dispersion.

American cities' forms have been studied in a more exhaustive way than European or Asian cities. Lee (2007) identified three distinctive patterns in American urban areas: (i) monocentric cities, where the urban core remains stable and its decentralization takes place in its adjacent areas; (ii) polycentric cities, where those activities that are decentralized are concentrated in suburban centers at the same time; and (iii) dispersed cities, characterized by the absence of a clear structure, where decentralized activities from the CBD are not regrouped in other centers. The most generalized pattern for European cities is the first of these patterns, since traditional city centers remain the most significant pole of activities, and new poles are usually dependent on them.

On the other hand, Bertaud (2004) summarized the global trend in the evolution of urban spatial structures in two types of cities: a monocentric city where the traditional CBD was still predominant, although it progressively expanded, and a polycentric city where no predominant centers existed. In addition, the author suggested that the monocentric structure was predominant even in polycentric cities. Perfect polycentrism, as an agglomeration of autonomous urban villages that conform a large city, does not exist in the real world. New poles of demand attracted trips from everywhere in the city, but these were less relevant than the traditional CBD, forming the mono-polycentric model defined in Bertaud (2004). Craig and Ng (2001) showed the decreasing slope of the employment densities from the CBD to the periphery. The decreasing