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# Inter-district urban bus flow in Madrid. Network study.

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**Abstract.** Madrid city has a population of 3,254,950 on a extension of 60,683 hectares and an urban bus network with 220 lines and 4,635 nodes. Madrid has also 21 administrative districts. Districts are administrative regions into which subdivide the city to distribute and manage the exercise of civil or political rights, public functions, and services.

In this paper we use the Network Theory [1] to study the urban bus network of Madrid, where the nodes of the network represent districts and the weight of a link between two nodes corresponding to the number of urban buses working between them in a day. We describe the relationship of urban bus flow between two districts and their population.

We also study the statistical properties of the urban bus network as a multilayer network [2], where each layer corresponds to a specific type of interaction between stops (shelter, line and operational center).

*Keywords:* Multilayer Network, Inter-District flow,Network Theory
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## 1. Introduction

We study the urban bus network of Madrid as a multilayer network and identify the relationship between traffic and population in each district.

## 2. Studying the urban bus network of Madrid

The urban bus network of Madrid has 4,635 nodes, 78 stops, 5 operational centers and 220 lines. It can be modelled as a multilayer network with the following features: fully interconnected, no-diagonal, layer-coupled, no categorical, $Li$ (set of layers)= 3, and $d$ (number of aspects) = 1. Different topological parameters are calculated.

We study the relationship between population and number of urban buses departing from each district. This relationship can be defined as:

$$T_{ij} = f(P_i, P_j, C_{i,j}) \tag{1}$$

Where:

$T_{ij}$ is the traffic from $i$ to $j$ district,

$P_i$ is the population of district $i$,

$P_j$ is the population of district $j$,

$C_{i,j}$ is the displacement cost between $i$ and $j$ districts.

Fig 1 shows $T_{ij}$ as function $P_i$.

We analyzed the dependence of the weight on the population and distance. The relation between the number of urban buses operating in a district and its population showed different features to that between the weight of a link between two districts and their population. This phenomenon would not happen, if the urban bus network would have a homogeneous structure.

We also found that the mean degree $k_{mm}$ of neighbor nodes which are connected to a node of degree k, $k_{nn}$ decreases as k increases, therefore the urban bus network is disassortative network. This means that a district with a small number of urban bus lines preferentially attaches to a district with a large number of bus lines.

## 3. Conclusions

We characterize the urban bus network as a multilayer network and model the relation traffic between districts.

## References

[1] M. E. J. Newman, *The structure and function of complex networks*, SIAM Review 45,(2003).

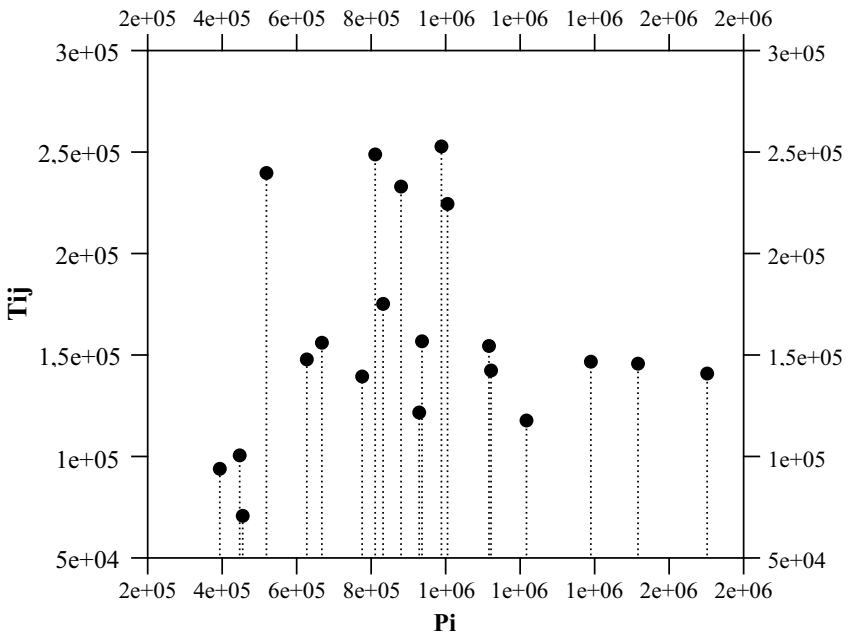


Figure 1: Flow of urban bus from $i$ to $j$ district ($T_i j$) as function of the Population in district $i$ ($P_i$)

[2] M. Kivel et al. *Multilayer Network*, Cornell University Library,(2013).