Multiplex Network Analysis Public Transportation

Matteo Fasulo
Tecniche Informatiche per la gestione dei Dati
Libera Università Maria Santissima Assunta
Rome, Italy
info@matteofasulo.me

Matteo Sivoccia
Tecniche Informatiche per la gestione dei Dati
Libera Università Maria Santissima Assunta
Rome, Italy
m.sivoccia@lumsastud.it

Simone Flavio Paris
Tecniche Informatiche per la gestione dei Dati
Libera Università Maria Santissima Assunta
Rome, Italy
simone.flavio.paris@gmail.com

Lorenzo Bianchi
Tecniche Informatiche per la gestione dei Dati
Libera Università Maria Santissima Assunta
Rome, Italy
lorenzobianchi5082@gmail.com

***Abstract*—This paper contains the multimodal transport network of Ille-de-France (Paris) modelled with a multi-layer network structures. Each layer in the network represent a public transport network with last layer being the road layer. In order to connect two different transport layers, a spatial approach is proposed by making a new edge between two nodes on different layers. A set of nodes near point of interest is analysed to verify if the presence of a museum or a monument guarantees more centrality to those nodes.**

***Index Terms*—Multimodal transport networks, Multiplex Network, Transport Analysis**

I. INTRODUCTION

Public Transport Layer (PTN) contain multiple layers of traffic networks like: metro, train, road and tram network. The analysis of traffic flow in large metropolitan areas is often a challenging task. In the analyses of the PTN, complex graphs and networks are used with focus on spatial analysis of the network considering the individual transport level or the overall transport level. In this context, data has recently become an interesting source of information and analysis on mobility behaviour since it is difficult for city authorities to act on an unified view of mobility patterns. In the analyses made on PTNs, which use graph theory, the networks are represented as graphs with nodes representing the stops of means of transport such as trains and trams and edges representing the connection of the stops of the respective PTNs. Depending on the type of edge, the graph can be modelled in a space S, where there is an edge between two stops if they are consecutive. The majority of passengers use multiple transport nodes to reach their destination or even different transport layers and the interaction between network layers may lead to a better understanding of the entire network. In this paper we make a contribution to the research and analyses carried out on the transport structure of Ille-de-France (Paris).

II. RELATED WORK

Kivela et al. [1] introduced the representation and notation for the monoplex (mono-layer) networks, multiplex (multi-layer networks), interdependent networks, interconnecting networks, networks of networks, etc. Tomasini [2] also introduced measure for multi-layer analysis and Zanin [3] demonstrated that the results of the analysis of single projected layer might yield a biased understanding of the actual network by comparing with its multi-layer functional network counterpart.

III. MULTIPLEX NETWORKS

Recalling a graph G is a set of nodes V and edges E, $G = (V, E)$. Our work propose the spatial analysis by representing

$$G = (V(x, y), E) \tag{1}$$

with $V = n_i(x_i, y_i), x_i) = latitude, y_i = longitude$ and $E = e_{ij} \to (n_i(x_i, y_i), n_j(x_j, y_j)$. For instance we assume that a particular node is always identified with its latitude and longitude so $n_i(x_i, y_i)$ will be a unique value representing n_i. In transport network analysis the inspection of spatial embedding of nodes manifest locations in which two or more nodes are almost overlapped. In these specific cases, if d_{ij} (the distance between two nodes n_i and n_j) satisfy the condition

$$d_{ij} < d_{th} \tag{2}$$

then n_i and n_j will be connected with a *inter-layer edge*. Indeed our graph structure will be

$$G = (V(x, y), E, E_L) \tag{3}$$

with E_L being *inter-layer edges*. The distance d_{ij} is calculated with the Haversine formula [4] and d_{th} is set to be 455 m assuming that it is a walkable distance to reach a station. Considering the previous graph structure we define the multilayer network, M, as follows

$$M = (V_M, E_M, L) \tag{4}$$

$L = \{L_\alpha\}_{\alpha=1}^{d}$ is the set of layers with d dimensions. For $d = 1$ (single dimension), the network reduces to a mono-layer aspect. In this paper, $d = 4$ with an elementary layer and an additional layer. $E_M \subseteq V_M \times V_M$ is the edge set with bot *intra-layer* and *inter-layer* edges. Among all layers, the metro layer is considered the elementary layer since it is the most preferred transport mode in Ille-de-France. Another interesting aspect is that the transport network structure is a layer-disjoint multi-layer network so each node exists in at most one layer

$$(n_i)_\alpha, (n_i)_\beta \in V_M \Rightarrow \alpha = \beta \tag{5}$$

where a node is present either in layer α ($L_1 = \alpha$) or β ($L_2 = \beta$). The layer-disjoint property signify an important observation that there exists no edges between the layers in the actual network structure, and the layers are normally connected virtually (by a small walking distance) and not physically. In order to connect these layers we employ the method of spatial join with a radius of 455 m. The overlapped nodes in the 455 m region will be edge-connected and a weight attribute will be added to those edges. The weight attribute added is an estimation based on both distance between nodes and transfer speed (T_s) (i.e. walking speed to reach destination) plus a basic cost (for simplicity B_c) representing the mean time waiting the transportation vehicle. Hence the weight will be

$$w_{ij} = \frac{d_{ij}}{T_s} + B_c \tag{6}$$

with T_s set at 5 km/h (mean walking speed) and B_c set at 11 minutes. [5]

IV. Dataset description

The analysed dataset contains information about the public transport lines of Paris, by splitting them in four different layers: metro, train, tram, road.
The data are collected from different sources, like *OpenStreetMap* [6] (OSM) and *The National Institute of Geographic and Forest Information* [7] (IGN), a french public administrative establishment, and then gathered to perform the analysis. Table I has a summary of every layer with average degree and reference database.

The collection of data is grouped into a **GeoJSON** file containing both nodes and edges.

A. Nodes properties

Every node in the dataset has a *coordinate* attribute indicating *latitude* and *longitude* to identify node's position as well as a *layer's* attribute to identify its source.

B. Edges properties

Every edges has a name attribute (that could be road name, train line, subway line or metro line), direction indicating if the edge is directed (i.e. one way) or undirected (i.e. two way) and a layer attribute to identify its source. Among *intra-layer edges* there is also a *length* parameter that measure the distance between nodes of the edge itself. There is also a fifth layer named *crosslayer* that groups all the edges between nodes standing on different layer, the *inter-layer edges*.

C. GeoSON format

There are also information about the coordinates of the different transport hubs, that are of type *Point* for the nodes and type *LineString* for the edges.
The *Points* are lists in the format $[lat, lon]$ while *LineString* contain coordinates of both source and target node (i.e u and v) in the format $[[u_{lat}, u_{lon}], [v_{lat}, v_{lon}]]$
The latitude and the longitude format follows the standard coordinate system *WSG 84*.

D. Transport lines

- *Train* ⇒ RER A, RER B, RER C, RER D, RER E
- *Tram* ⇒ T1, T2, T3a, T3b, T4, T5, T7
- *Metro* ⇒ M1, M2, M3, M3bis, M4, M5, M6, M7, M8, M9, M10, M11, M12, M13, M14
- *Road* ⇒ A86, D1, D19, D9, D11, D17, D130, D14, etc

V. Analysis

Table I: Different transportation networks with their properties.

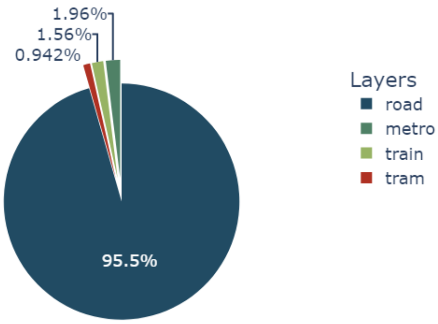
	Nodes	**Edges**	**Avg.Degree**	**Reference**
Metro	303	356	2.350	OSM
Train	241	244	2.025	OSM
Tram	144	140	1.944	OSM
Road	14804	22281	3.010	IGN

VI. Conclusions

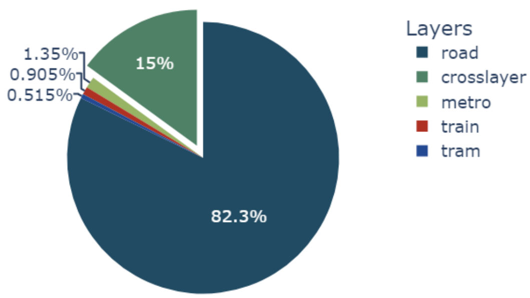
Compared to a normal graph representation, the multiplex graph representation offers a more specific way of analyse the transport network topology which not only helps in a realistic network analysis, but also takes into account an accurate representation of the network without ignoring inter-layer interactions. From this type of analysis it can be observed that the centrality of nodes differs significantly in the monolayer and multilayer analyses of the network. It therefore seems clear that is important to consider all aspects of the multimodal and multilayer network to understand the behaviour of an urban transport system and therefore to understand the effects of transport on other characteristics of interest. Although these studies are still very theoretical, they convincingly show that reasoning with only one mode of transport can be extremely misleading (i.e. leading to a biased view of the network) and therefore it is better to have a spatial multi-layer approach.

TABLE II: General measure of each layer

	Metro	Train	Tram
max_degree	8.00000	4.00000	3.00000
density	0.00778	0.00844	0.01360
shortest_path	12.20895	16.54604	20.73942
diameter	34.00000	47.00000	61.00000
avg_cluster	0.00881	0.00000	0.00000
transitivity	0.01863	0.00000	0.00000
bridges	115.00000	152.00000	140.00000
max_degree_centrality	0.02649	0.01667	0.02098
max_between_centrality	0.32723	0.22690	0.10411
max_eigen_centrality	0.34506	0.50485	0.50028



(a) Nodes distribution



(b) Edges distribution

Fig. 1: Nodes and edges distribution over layers

ACKNOWLEDGMENT

We have dedicated this to the achievement of a *Ille-de-France Multi-layer Public Transport Network Analysis*.

REFERENCES

[1] M. Kivelä, A. Arenas, M. Barthelemy, J. P. Gleeson, Y. Moreno, and M. A. Porter, ”Multilayer networks,” Journal of complex networks, vol. 2, no. 3, pp. 203–271, 2014.
[2] M. Tomasini, ”An introduction to multilayer networks,” BioComplex Laboratory, Florida Institute of Technology, Melbourne, USA, pp. 1–14, 2015.
[3] ”Can we neglect the multi-layer structure of functional networks?” Physica A: Statistical Mechanics and its Applications, vol.430, pp. 184–192, 2015.
[4] C. Veness, “Calculate distance and bearing between two latitude/longitude points using haversine formula in javascript,” Movable-Type Scripts, 2011.
[5] ”Waiting Time In Paris,”Moovit Website, [Online; accessed 21-May-2022].
[6] ”Open Street Map,”Open Street Map Website, [Online; accessed 21-May-2022].
[7] ”National Institute of Geographic and Forest Information,”IGN Website, [Online; accessed 21-May-2022].