Tabula Peutingeriana. A network analysis of the Cursus Publicus

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abstract

In the present work we analyse the network structure of the Roman Cursus Publicus, as described in the Tabula Peutingeriana: in particular, we compare the road system of four macro geographical areas (Italy, Europe, Asia, Africa) by looking at the statistical distribution of the lengths of the paths between adjacent cities, and by applying some standard network measures, as the degree, the reach centrality and the k-local-bridge. An attempt was also made to understand the role of the symbols that appear in the map, as attached to the labels of some stations. Our study reveal a very centralized and heterogeneous road structure, with a viability sensibly dependent to the geographical areas.

Figure 1: Tabula Peutingeriana (detail): the Italian peninsula

1 Talbert's Database and network reconstruction

In 2010 Richard J. A. Talbert, professor of History Department of North Carolina, published his studies about the Tabula Peutingeriana, a medieval copy of an ancient Roman map that shows the roads of the Cursus Publicus as it was between the IV and V century: his work contains the record and the comment of any single segment in the map, including in particular the complete list of the labels that appear in correspondence to the stations of the map, and the lengths of the roads. Moreover, the symbols of the map are catalogued: in fact many of the labelled town are enriched by different symbolic drawings (see figure 1). Usually it is the same symbol that is repeated in many places, and some studies have been done in order to understand their meaning: in [3] is suggested that they represent station for (sosta) , while in [4] is conjectured that they served just as a reference for the travellers. We will return to this debate later (section 5).

The Talbert's database available on the web [6]. In the present work we used the Talbert's dataset to recreate the network, and we used UCINET [7] and pajek [8] to perform our main analysis: some preliminary remarks are needed.

First, it need to be taken into account that the Tabula Peutingeriana doesn't comprehend the road maps of Spain and Great Britain.

Moreover, since our measurements require as input a connected network, we decided to analyse only the largest connected component (sometimes called the *principal component*) of the Cursus Publicus. For this purpose, we decided to add one reasonable connection, from Costantinopoli to the near Chrisopolis, throught the Bosforo. This choice allow us to work with a large connected road network (add percentage of vertexes***) that only excludes few isolated road nets, as for instance the ones of the islands.

Eventually, we obtain the network that we adopted for our studies: the total number of its stations (the vertexes of our network) is 2670, of which 511 have an attached symbol, and the number of road connections is 5872. This network is binary, which means that the edges are not weighted; for example, one could have weighted them with the length of the corresponding connection in Roman miles. We didn't do that because we are more interested in the geometric structure of the network: so, for us, the distance between two stations will be measured in terms of the smallest number of stations that one has to pass through to go from one to the other (see figure 2 for the egonet of Rome). A statistical analysis of the length of the road is postponed in section 4.

Our goal is to study the network skills of the Cursus Publicus as a whole, compared with how it varies through different geographical areas. We can say, broadly speaking, that our 0-hypothesis is that the network is "homogeneous", which means that the whole network and the "local" ones share the same "structure". In particular, we distinguished four macro areas: the Italian peninsula, the remaining part of Europe up to the Bosporus, the North Africa up to Suez canal, and the remaining regions of the Middle East. For simplicity, in the following we will refer to them as: Italy, Europe, Africa, Asia. In figure 3 the reconstructed net of the Tabula Peutingeriana is represented.

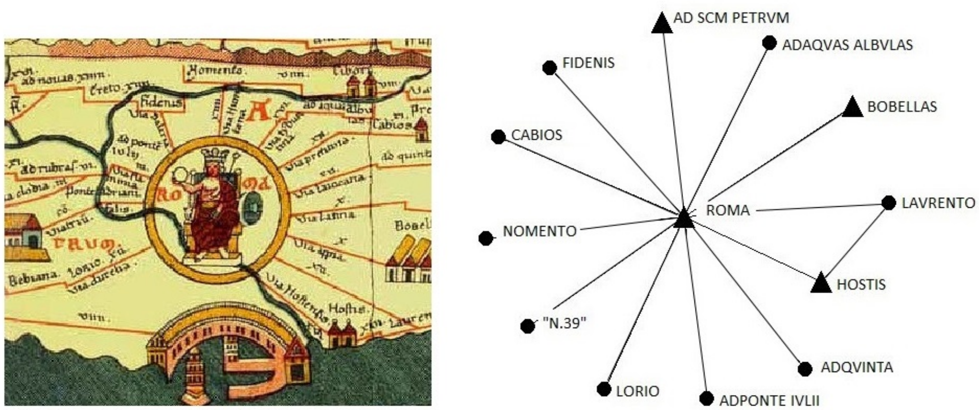

Figure 2: Rome's egonet. The egonet of a vertex is the subnetwork that contains that vertex and all the verteces that are at distance 1 from it, plus the edges among them. Here the triangle represent a station with a symbol, otherwise a simple dot is drown.

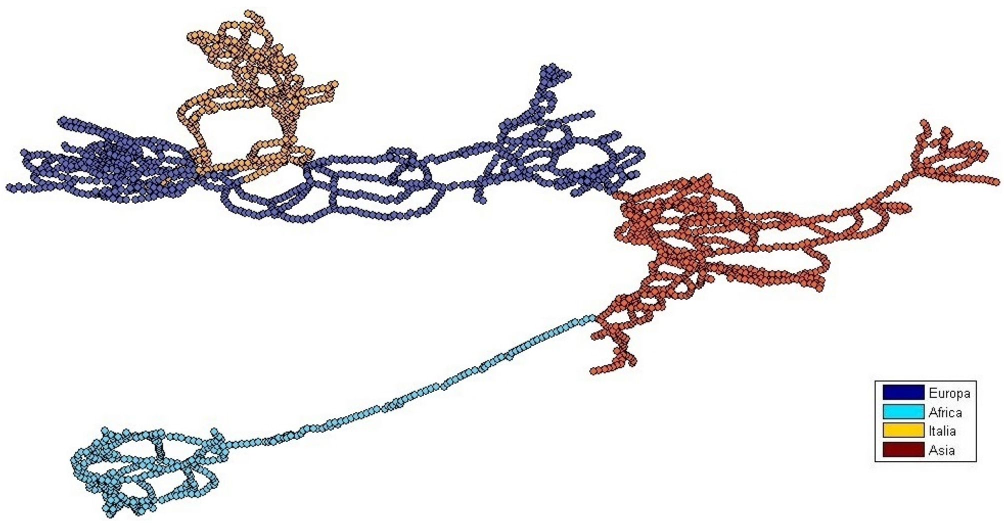

Figure 3: The reconstructed net of the Tabula Peutingeriana. The vertexes are coloured according to the geographical area they belong to.

2 Degree and reach-centrality: measuring the speed of the network

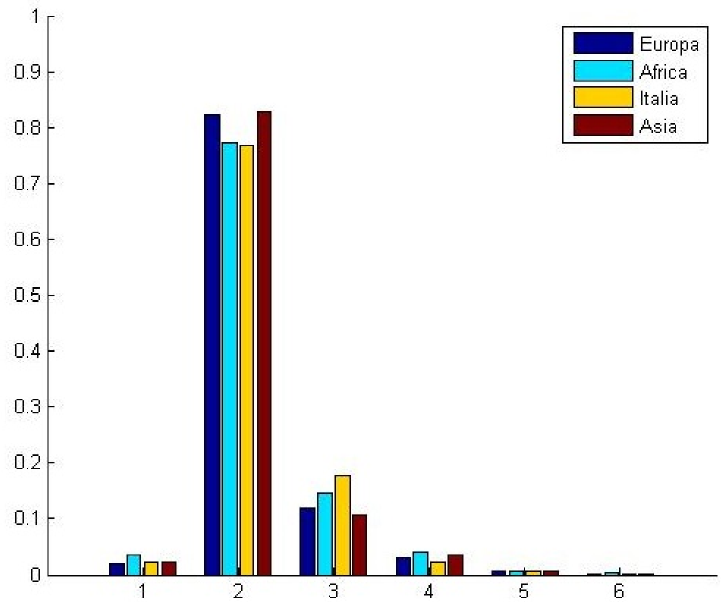

Figure 4: Degree distribution in the geo-areas: on the x-axis we have the value of the degree, on the y-axis the corresponding frequency. For graphical reasons, we excluded the degree of Rome, which is 12; however, it is the only exception, since in the map it's the only station with degree larger than 6.

The *degree* of a vertex is simply the number of edges attached to it. We computed the average value over all the vertexes belonging to a same geo-area and we plotted the distribution in figure 4.

First, we observe that the 80,67 % of the stations in the Cursus Publicus has degree 2. This is not surprising and it doesn't mean that the network has a simple structure (this usually happens also in our contemporary train networks.) What indeed was quite surprising, is seeing that the distribution of the degrees tends to be very homogeneous through the different geo-areas, as we may notice in figure 4. The only remarkable exception is the present of a station with 12 connections: but this doesn't surprise so much since we are talking about Rome and, as Italians say, "all the roads will lead you to Rome". This fact reveal that Romans did pay attention to the structure of the road system they were building.

But the average degree is a very superficial measurement: in fact it only "sees" up to distance 1 from a given vertex. So, to get a deeper insight in the actual structure of the network, we choose to measure the *reach centrality*: From a given vertex, we count the number of different vertexes that can be reached in k steps or less, and we divide this quantity by k; finally, we sum the values we obtain for every k to obtain the reach centrality of the vertex. In table 2 we show some statistics about the average reach centrality in the different geo-areas. We observe that the values of Italy and Europe are slightly above the average and present a strong continuity between each others; On the contrary, the African network shows the lowest average value.

We want to point out that, in a sense, the reach centrality capture the speed of a traveller along the network: in fact it counts the proportion of places that can be reached within a certain time (here interpreted as the number of steps).

	Europa	Africa	Italia	Asia	CursusPublicus
Media	58,75	39,273	58,302	55,719	55,004
Varianza	7,444	3,061	7,138	11,152	10,57

Table 1: Mean and variance of the reach-centrality over the geo-areas and in the whole Cursus Publicus.

3 Local bridges and the robustness of the network

In network analysis, a *bridge* between two vertexes is an edge that, if deleted, disconnects the network, which means in particular that there isn't any more a path that connects these two vertexes; analogously, a *k-local bridge* is an edge between two vertexes that, if deleted, increases by k the distance between them.

In our setting, the k-local bridge informs us of the importance of a connection: if k is very high, we won't have reasonable alternatives than crossing it if we are travelling along that direction. Since so far we dealt with measurements at the vertex level, we wish to encode the information of the k-local bridges in the vertexes instead than in the edges; this is possible thanks to the following simple construction: first, we create a square matrix $\mathbf{A}$ such that the element at position ij is il the value of the k-local bridge between the nodes i and j if these vertexes are adjacent, and 0 otherwise (in the case where the deletion of the edge disconnects the net, we put the maximal possible value, that is the total number of nodes, since we do not want to deal with infinite quantities). Now, for every i, we compute the average of all the values of the i row: this value will tell us how much is the average cost (in term of steps in the network) a traveller will pay if a certain station is eliminated in the network.

Now, the more this quantity is high, the more a station is strategical in the road system; if we want to built a "good" road network, we should then try to keep this quantity to be as small as possible for every vertex, such that there will be always a good alternative trajectory to reach one point from another. If we compute the average of this quantity among all vertexes in a geo-area, then it quantifies the robustness of the network in that area, how well it can avoid the risk of congestion in the traffic and deal with temporary damages in the stations or in the road connections.

In table 4 we show our results: the values obtained for the different geo-areas allow us to rank quite clearly the networks as follows: the Italian one is the more robust, followed by the European one, by the Asian one and finally, at a considerable distance, by the African one. In fact, the high value

	Europa	Africa	Italia	Asia	CursusPublicus
Media	234,456	670,826	148,23	378,298	324,396
Varianza	698,252	1109,823	546,92	884,404	821,595

Table 2: media e varianza della distribuzione dei klocal-bridges

of the average k-local bridge in the African net could have been predicted by just seeing the shape of this network, in which there is a very long queue of subsequent bridges (see figure 5).

We end this chapter by showing a graphic that encodes together the informations we obtained about the average reach-centrality and the average k-local bridges in the geo-areas (figure 6). The Italian and the European network form together the most efficient and robust road systems, since they both maximize the reach-centrality, while keeping the k-local bridge reasonably low.

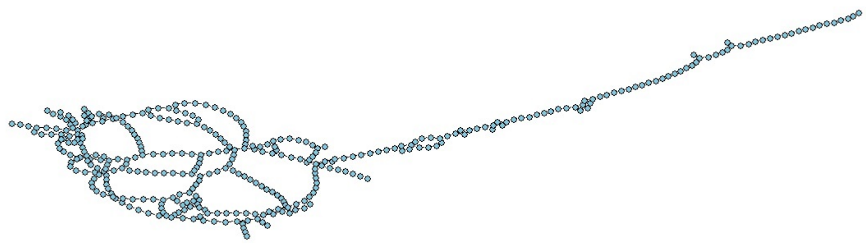

Figure 5: sottorete africana. Nella parte destra si vede una lunga sequenza di bridges, tratti di strada la cui eliminazione sconnette la rete: questo debole collegamento era l'unico -via terra- tra Africa e Asia.

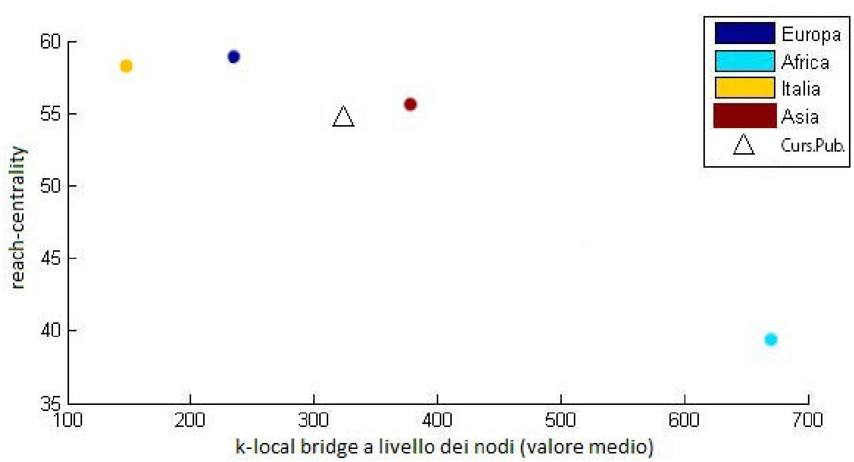

Figure 6: k-local bridge (x-axis) vs reach centrality (y-axis). The Italian and the European network form together the most efficient and robust road systems, since they both maximize the reach-centrality, while keeping the k-local bridge reasonably low.

4 Distribution of the road lengths

We conclude our work with the statistical analysis of the roads length. In fact these quantities are reported in the map, in Roman miles. Unfortunately, 250 roads (near the 4% of the total) have been left unlabelled by the cartographer.

In figure 7 the occurrence distribution of the roads length is shown: most of the roads are of 12 miles, while the frequency of longer connections deceases (polinomially??**parameter).

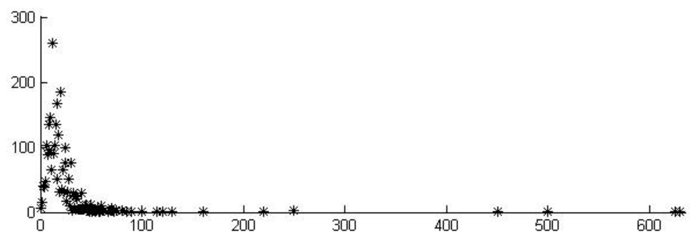

Figure 7: Occurrence distribution of the road lengths. The lengths are measured in Roman miles in the x-axis, while the occurrences are represented in the y-axis.

(controllare la misura: l'ho fatta senza considerare i tratti aggiunti a mano?)

In table 3 we present the average value and the variance over the whole Cursus Publicus and over the different geo-areas. What we observe, is that, in Asia the roads are considerably longer than in the other areas. Of course the length of the roads is also the distance between subsequent stations: this highlight that travelling along the Asian roads must have been harder, requiring, for instance, more food resources to be carried.

In must be noticed that the African network, which suffers of many disadvantages as we pointed out by the analysis of the previous sections, has almost the same average value of road length as the European one.

	Europa	Africa	Italia	Asia	CursusPublicus
Media	16,318	16,988	12,615	24,842	18,339
Varianza	9,688	11,915	8,296	40,146	24,147

Table 3: sono presentate, per ciascuna area geografica e per l'intera rete, media e varianza della distribuzione delle lunghezze dei tratti stradali.

5 What statistics can tell us about the "symbols"

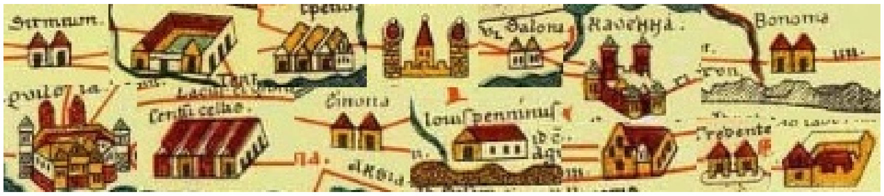

Figure 8: Some of the symbols that appear in the map. On the top right you can see Ravenna and Bononia.

As we briefly mentioned in section 1, in the map appear some symbolic figures attached to many of the stations (see figure 8 for some of the symbols). Many attempt to understand their role and meaning have been done (see e.g. [3] and [4]). To make it as simple as possible, there are two possibilities: either they tell us something about the role of a station in the viability by highlighting its importance in the Cursus Publicus, or not. The second hypothesis cannot be rejected a priori, since maybe these symbols have been pictured to describe a kind of feature of a city which is irrelevant for the viability (e.g. if it is a big city or not, a rich one, etc...) or simply for decorating the map. We start our analysis by taking a look at table 4, where the proportion of the symbols among the stations of every geo-area is shown, we notice that in the Italian network more than a quarter of the stations have got a symbol, almost the double that the value in the African one: this sparsity seems to indicate that the symbols are not there just for decorating the map, but it can hardly tell us more about the meaning of the symbols. In [4] Bosio suggests that the symbols represent the presence of a

	Europa	Africa	Italia	Asia	CursusPublicus
Percentuale	18,28 %	13,17 %	25,15 %	19,2 %	19,14 %

Table 4: Percentage of the stations with an attached symbol in the different geo-areas and in the whole Cursus Publicus.

station of ***, and in [3] it is hypothesized that they represent key places in the planning of a route. If one of these were the case, then we would expect the symbols to be located in correspondence to stations with a higher degree (for example, a degree greater than 2, which is the most frequent in the map). In fact a high degree station is a strategic point in a road map, from which one can go to different directions; and for the same reason, it is a station which is more likely to be visited often by different travellers and, for this reason, that needs to be more (fornita di vettovaglie.) We then decided to measure the correlation between the degree of the vertexes of the whole network and the presence of symbol and we obtained $\rho_{xy} = 0,3979$. This value suggests a *moderate correlation* (i.e. $0,3 \leq \rho_{xy} \leq 0,7$). This means, in practice, that it is more likely that, picking a station with high degree, there will also be a symbol attached to it.

This result seems to confirm that the symbols in the map have a meaning which is related to the viability in the Cursus Publicus.

Conclusions

Our analysis reveal the Cursus Publicus, as represented in the Tabula Peutingeriana, to be a quite inhomogeneous network; its structure, more developed in Europe, becomes weaker and slower the as we approach the boarders of the Empire, with very negligible interest in the local transport system of the extra-European areas.

In particular, the African road network looks inefficient and slow, and it is also weakly connected with the rest of the Empire. The Asian one seems more compatible with the characteristics of the Italian and European road networks, but still the analysis of the road length shows that the stations are more and more sporadic, as we approach the eastern border of the Roman Empire. On the other hand, the Italian and European road map, according to our measurements, present a remarkable homogeneity in terms of structure, and they form together the most efficient network. The main difference is the value of the k-local bridge, that indicate a smaller risk of congestion in the Italian network.

Finally, we remark that the percentage of "symbols" is larger among the Italian stations than in the other geo-areas; also they appear to be positive correlated with the degree of the vertexes. This seems to confirm the hypothesis that these symbols are not just decorations, but rather they indicate a particular role of these station in the network; however, what was exactly this role, still remains unclear.

References

[1] Lemcke L., *Imperial transportation and communication from the third to the late fourth century: the golden age of the Cursus Publicus.* UWSpace, 2013.

[2] Van Tilburg C. *Traffic and congestion in the Roman Empire.* Routledge, 2006.

[3] Levi A., Levi M., *Itineraria picta. Contributo allo studio della Tabula Peutingeriana.* L'erma di Bretschneider, 1967.

[4] Bosio L., *La Tabula Peutingeriana. Una descrizione pittorica del mondo.* Maggioli ed., 1983.

[5] Brotton J., *A history of the World in twelve maps.* Penguin, 2013.

[6] Talbert's database at http://www.cambridge.org/us/talbert/

[7] Borgatti, S.P., Everett, M.G. and Freeman, L.C. 2002. Ucinet for Windows: Software for Social Network Analysis. Harvard, MA: Analytic Technologies.

[8] V. Batagelj, A. Mrvar: Pajek - Program for Large Network Analysis. Connections 21(1998)2, 47-57.