Studying transport networks using centrality measures: The Case of Tunisian Sahel Region

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As the urban population continues to grow, the transport network must keep pace with this development and cope with the increased inflows of people as well as the new interactions that may occur in different parts of the city (Hong et al. (2019)). This situation paved the way for more resilient decision-making systems to adapt to the increasing passenger flows that accompany cities' urban expansion. As it may be ineffective to change the built environment already present in urban cities, attention has been focused on improving current transport options, using a multimodal approach (Daniel et al. (2020)).

Following this logic, knowing the characteristics of the existing transport networks and grasping the central hub with great influence on the whole region seems to be an effective tool to adequately adapt the current transport system and improve its spatial connectivity (Hong et al(2019)). Graph-based measures, in particular network centrality analysis, have been employed to investigate this issue and capture the most relevant locations for further improvements in travel networks, in addition to identifying the existing spatial interaction between cities (Asgari et al. (2013), Tan et al (2016), Zhao et al (2016), Han & Liu (2018), Yang et al (2019)). Among the key measures of network centrality, the degree centrality presents an important tool to identify the critical nodes in a network: the more central the node, the more efficient the transportation network, and may be interpreted as the number of incidental links to a node (Tan et al. (2016), Yang et al. (2019)).

In general, there are three-degree centrality indicators: the in-degree centrality (the inflow into a city), the out-degree centrality (the outflow from a city), and the net degree of centrality (the net change between cities). Another measure used in this context is betweenness centrality, which highlights the relative importance of nodes serving as intermediaries in a network and their impact on its efficiency (Tan et al. (2016), Daniel et al. (2020)). This index is defined as follows:

$$C_B(v) = \sum_{s \neq v \neq t \in v} \frac{\sigma_{st}(v)}{\sigma_{st}} \quad (1)$$

Where σ_{st}, represents the total number of the shortest paths from the city s to city t, $\sigma_{st}(v)$ is the number of paths passing through the city v, and V represents the set of all the cities in the network.

These two metrics are considered spatial node qualities that indicate the strategic locations within a transport network (K. Fleming & Hayuth (1994)). In fact, identifying influential nodes in complex networks such as urban cities is essential as they guide improvements that have major impacts on people's lives (Curado et al., (2020)).

Therefore, the aim of this paper is to identify the regions with major influence on the transport network of the Tunisian Sahel, and be among the first milestones for future research on the centrality of network analysis in the Tunisian context. The main idea is to identify critical regions whose reliability level has a major impact on the whole transport system of the Sahel and be able to point out opportunities for improvement.

To achieve our goal, in 2019 a traffic survey was conducted and managed for all three governorates of Tunisia's Sahel: Sousse, Monastir and Mahdia. Data collection was based on a stratified sampling technique of 2021 respondents aged 15 and older, depending on the gender, age and spatial distribution of this sample (governorates and delegations), over a period of one and a half months and only during working hours. A travel database of 7329 daily trips was created to show the passenger flow that occurs daily for different modes of transport. Our analysis firstly focuses on the external links of our field of study and then emphasizes the links between different geographical entities that make up the Tunisian Sahel region at delegation level (40 delegations). The two previously mentioned measures of centrality were introduced to identify, in the first phase, the delegations with net passenger inflow (degree centrality) and then to identify those that serve as a bridge between different parts of the Sahel and have an impact on passenger flow. We used UCINET 6 software to calculate these centrality indices in their normalized form between 0 and 1. In addition to these two measures, we use an interaction intensity index (Equation 2) adapted from the work of Han & Liu (2018) to analyze the spatial interaction particularly between the delegations with higher betweenness centrality and the rest of the region.

$$I_{ij} = P_{ij} + P_{ji} \quad (2)$$

Were I_{ij} represent the interaction intensity between delegation i and j, P_{ij} is the incoming flow from delegation i to j, and P_{ji} is the incoming flow from delegation j to i.

The results obtained were then compared to those of the traditional gravity model to demonstrate its reliability in network analysis. The formulation of the gravity model was also adopted from the work of Han & Liu (2018) as follows:

$$I_{ij} = \frac{\sqrt{Pop_i * Pop_j}}{D_{ij}^2} \quad (3)$$

Where I_{ij} represents the interaction intensity between delegation i and j, Pop represents the population of delegation i and j, and D_{ij} is the Euclidean distance between delegation i and j.

The first analysis of the external passenger flows of the Sahel shows 10 main interactions, mainly with governorates along the Tunisian coast. In terms of centrality measures, the governorate of Sousse represents the most attractive city and has more influence as major intermediate node through which 43% of the total river in the Sahel flows. The values obtained show an important spatial hierarchy between the three governorates of the study region, to the detriment of the southern part with little territorial development (Mahdia).

At a finer spatial scale, only eight out of 40 delegations showed a net passenger inflow (positive net degree), particularly in the Sousse governorate, the most populous. The main geographic entities attracting more passengers from other Sahel delegations were Bouficha, Sousse Jawhara (in Sousse) and Chebba (in Mahdia). When examining the betweenness centrality, it was found that the Medina of Sousse has the higher betweenness centrality (34,627) and tends to have more impact on the Sahel as more passengers flow through it. In the second row, we observe Monastir (9,829) and Mahdia (8,075). However, these three delegations represent the centers of the three governorates and the improvements they can make in these three entities can be so limited as they are congested areas.

In contrast, Esouassi (6,572), Sousse Riadh (4,368), Sousse sidi Abdelhamid (3,857), Moknine (3,571) and Msaken (3,162) may represent critical locations where improvements in transportation supply may represent a benefit for the whole region under consideration of the delegations associated with these areas. Despite the fact that Bouficha and Chebba represent the higher value of passenger flow, these two delegations have zero intermediate centrality. However, due to their strategic location at the extreme ends of the Sahel, which connects the north and south to the rest of the country, these sites could represent potential areas for a multimodal transport hub. This point represents the first axis to further improve this research, which can be articulated around improving betweenness centrality measures by integrating the characteristics and topological importance of delegations to have a more informative tool for decision-making.

As with the centrality measures, an uneven intensity of interaction between different delegations was observed, giving more weight to the northern areas of the Sahel region. Furthermore, the results of our analysis are consistent with most of the literature, which has found the traditional gravity model to be less reliable and less informative for urban interaction because it is based on statistical data that cannot agree with what actually happens between cities.

Some implications can be gleaned from our study as follows. Firstly, the improvement of transport infrastructure, especially in locations that act as intermediate hubs and with high and even low centrality, seems to be a necessity to strengthen the connections between different parts of the region. And this is where the importance of spatial interaction analysis becomes clear. Second, the spatial variability found between the three governorates of Tunisia's Sahel highlighted the low ranking of Mahdia, which also has the highest poverty rate at 21.1% compared to Sousse and Monastir. Given this situation, it seems important to rethink urban planning in these three geographical entities in an integrated way, both spatially with projects that cover the entire Sahel, and complementary through the anticipation of behaviors and flows, in order to be able to establish an equitable system able to balance these historically homogeneous spatial units.

In addition to the limit, mentioned above, according to the betweenness centrality, our study still needs further improvements. In fact, expanding this research may include, first, using a larger database and opting for a space-time analysis. Furthermore, extending the study period and using a finer spatial scale including delegation sectors can further improve our analysis by considering the chronological events that can occur and affect the daily passenger flow, and have a deeper photograph of the socio-economic characteristics of locations, which can be integrated into the spatial interaction analysis.