Comparative Study of Formal Public Transport Network and Informal Public Transport Network of Nagpur, India

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Abstract. In the developing countries along with formal public transport network (FPTN), informal public transport network (IPTN) also plays an integral role by achieving high public transport ridership. IPTN caters effectively to the user’s expectations and appears to be highly integrated with urban fabric. IPTN either complements or compete with the existing FPTN, even though due credit is not given to IPTN and considered as unlawful entities. Efficiency and robustness of transport network is based on topological structure of network. To summarize which network is more efficient and robust, the study tests the network parameters of formal Public Transport Network and Informal Public Transport Network of Nagpur (India). A topological measure of network structure has tested based on elementary concepts of graph theory. We explore the network structure and their properties. The practical significance of the network parameters was then analysed. In the IPTN the degree of small-worldliness is smaller, as compared to FPTN, indicative of IPTN being more robust as compared to FPTN. This study provides an approach to understand the efficiency of an Informal public transport network in combination with Formal public transport network. The article identifies the importance of Informal public transport network to improve the Complementarity with the formal public transport network. Integrating formal and informal transportation network into a hybrid network has the potential to induce the desired relationships amongst FPTN and IPTN, i.e. competing or complimenting nature to improve the overall efficiency of FPTN.

1. Introduction

In developing countries along with formal public transport network (FPTN), informal public transport network (IPTN) also plays an integral role by achieving high public transport ridership. IPTN caters effectively to the user’s expectations and appears to be highly integrated with urban fabric. IPTN provides frequent, convenient, flexible, decentralized, adaptable and affordable services [1] [2]. IPTN either complements by filling the gap left by existing FPTN or compete with the existing FPTN. Inspite of its role, IPTN is not given due credit and considered as unlawful.

Efficiency and robustness of transport network is based on topological structure of network. To summarize which network is more efficient and robust, the study tests the network parameters for formal Public Transport Network and Informal Public Transport Network of Nagpur (India). Links and nodes of FPTN and IPTN for Nagpur at city level is first mapped. Overlapping of FPTN and IPTN along with high intensity IPTN route and Medium intensity IPTN route are marked in the map. (Figure 1). City level, functions like major commercial markets, traditional market, agricultural produce market, major medical institutes and hospital, IT parks, formal transport hubs are also marked with dotted circle (Figure 2 & 3). A topological measure of network structure has been tested based on
elementary concepts of graph theory. Graph theory relies on several measures and indices that assess the efficiency of transportation. The practical significance of the network parameters was then analysed.

![Figure 1. FPTN, IPTN of Nagpur.](image1)

![Figure 2. Connectivity Measures of FPTN, Nagpur.](image2)

![Figure 3. Connectivity Measures of IPTN, Nagpur.](image3)
2. Network measures and indices, and their significance

Pre-defined network measures and indices by various scientists, like Network diameter, Mean path-length, Small-world network, Degree centrality, Betweenness centrality and Closeness centrality of networks are calculated at global level based on identified number of nodes, link and their topography (Table 1).

### Table 1. Characteristics and the calculated results of the FPTN and IPTN.

| Measures                  | Computed values for FPTN | Computed values for IPTN | Observation                                      |
|---------------------------|--------------------------|--------------------------|--------------------------------------------------|
| Number of nodes (N)       | 91                       | 382                      | 1: 4.198, FPTN : IPTN nodes ratio                |
| Number of Links (E)       | 126                      | 631                      | 1: 2.856, FPTN : IPTN links ratio                |
| Mean path-length (L)      | 6.518                    | 10.896                   | Mean path-length of FPTN is small                |
| Network Diameter (D)      | 15                       | 25                       | Network diameter of FPTN is small                |
| Small-world effect (SWI)  | 0.189                    | 0.130                    | Both FPTN and IPTN values reflect the absence of small-worldliness. |

2.1. Network Diameter (D)
The length of the shortest path between the most distanced nodes of a graph is termed as network diameter. It measures the extent of a graph and the topological length between two nodes [5]. The higher diameter, the less linked a network tends to be. IPTN have a large diameter as compared to FPTN (Table 1). Comparing the network diameter to the number of total links, diameter of FPTN is 0.119 (15/126) times to the total number of links and diameter of IPTN is 0.039 (25/631) times to the total number of links. Network diameter of IPTN is approximately three times smaller compared to network diameter of FPTN.

2.2. Mean path-length (L)
Measure of efficiency that is the average number of stops needed to reach two distant nodes in the graph [5]. The lower the result, the more efficient the network in providing ease of circulation. Mean-path length of FPTN is small compared to IPTN (Table 1). But comparing the mean-path length to the number of total links, mean-path length of FPTN is 0.051 (6.518/126) times of the total number of links and mean-path length of IPTN is 0.017 (10.896/631) times of the total number of links. Mean path-length of IPTN is approximately three times smaller compared to mean path-length of FPTN.

2.3. Small-world Index (SWI)
The Small-world is quite efficient in relating acquaintances of what connects the parts of the network that would be otherwise away [3]. Value of Small-world index Ranges from 0 to 1, value close to 1 reflect small-worldliness. Robustness is inversely proportional to the small-world effect [4]. It means that lower the small-world effect, the network tends to be more robust. Both the networks, FPTN and IPTN values reflect the absence of small-worldliness, but SWI value of IPTN is smaller than that of FPTN. Hence, IPTN tend to be more Robust Compared to FPTN and is highly integrated with urban form.

2.4. Centrality measures
A Visibility Graph Analysis (VGA) of a network analyse the different centrality measures by using depthmapX [8]. An axial analysis in VGA tells about movement flows in your network that test: Degree Centrality (connectivity), Betweenness centrality (Choice) and Closeness centrality (Integration) at a global scale.

2.4.1. Connectivity (Degree Centrality). Degree used to characterize the local features of the network. The degree centrality can be used to judge the key links in the network. For any link on the public transport network, the degree centrality reflects the number links that are directly connect to that link.
Most links have about three to four adjacent links, and a few key links have a higher degree centrality. Links with high degree centrality corresponds to the city's key sites and major transfer sites.

![Degree Centrality - FPTN](image)

**Figure 4.** Connectivity Measures of FPTN, Nagpur.

![Degree Centrality - IPTN](image)

**Figure 5.** Connectivity Measures of IPTN, Nagpur.

In FPTN links with degree centrality 4 are high number followed by 3; while in IPTN also links with degree centrality 4 are high in number flowed by 5 and 3(Figure 4 & 5). The key links of IPTN with a high degree of centrality are located and corresponds to major functions of the urban environment (Figure 2 & 3).

2.4.2. Choice (Betweenness centrality). Describes the influence of the links in the network on the transmission of commuters, and belongs to the global features of the network. This index is based on the idea that a link is central if it lies between many other nodes, in the sense that it is traversed by many of the shortest path connecting couples of nodes [7]. The larger the index, the more the number of the shortest path between any two nodes passing through that link in the network.

In FPTN, choice value ranges 2439.01 and above combinedly holds 16.57% of total number of links. While, in IPTN choice value ranges from 2548.01 and above combinedly hold 58.78 % of total number of links (Table 2 and 3). Few links with high choice value are common in both FPTN and IPTN (Figure 6 & 7).
Figure 6. Choice Measures of FPTN, Nagpur.

Figure 7. Choice Measures of IPTN, Nagpur.

Figure 8. Integration Measures of FPTN, Nagpur.

Figure 9. Integration Measures of IPTN, Nagpur.

Table 2. Choice value range of FPTN, Nagpur.

| Choice Value Range of FPTN | Percentage |
|---------------------------|------------|
| Above 3130.01             | 7.10       |
| 2439.01-3130              | 9.47       |
| 1748.01-2439              | 7.69       |
| 1056.01-1748              | 8.88       |
| 365.01-1056               | 20.71      |
| 365 and below             | 46.15      |
| Total percentage          | 100.00     |

Table 3. Choice value range of IPTN, Nagpur.

| Choice Value Range of IPTN | Percentage |
|---------------------------|------------|
| Above 32006.01            | 9.46       |
| 24641.01-32006            | 2.70       |
| 17277.01-24641            | 12.70      |
| 9912.01-17277             | 5.81       |
| 2548.01-9912              | 28.11      |
| 2548 and below            | 41.22      |
| Total percentage          | 100.00     |

Integration (Closeness centrality). It describes the average depth of a link to all other links in the network. The links of a network can be ranked from the most integrated to the most segregated. Closeness centrality values in the public transport network measures to what extent a certain link is near all the other links in a system along the shortest path. High closeness will have many connections within a short distance while low closeness will have few connections at short distance [6].

In FPTN high integration value of top range start from 69.01. While, in IPTN top value of bottom range is 193 (Table 4, 5). In FPTN very few links are of high integration value because of sparse
network structure, where as in IPTN, because of its dense structure most of the links are of high integration value (Figure 8 & 9).

| Sr. no | Year | FPTN Route Length in Km | IPTN Route Length in Km | Total Route Length in Km | % Share of FPTN to total Route length | % Share of IPTN to total Route length | Proportionate Share of FPTN | Proportionate Share of IPTN |
|--------|------|-------------------------|-------------------------|--------------------------|-------------------------------------|-------------------------------------|-----------------------------|----------------------------|
| 1      | 1972 | 78.89                   | 182.76                  | 261.65                   | 30.15 %                             | 69.85 %                             | 1                           | 2.32                      |
| 2      | 1987 | 99.70                   | 211.57                  | 311.27                   | 32.03 %                             | 67.97 %                             | 1                           | 2.12                      |
| 3      | 2002 | 151.1                   | 306.73                  | 457.87                   | 33.01 %                             | 66.99 %                             | 1                           | 2.03                      |
| 4      | 2017 | 186.3                   | 368.23                  | 554.57                   | 33.60 %                             | 66.40 %                             | 1                           | 1.98                      |

3. Discussions
IPTN have a large diameter and mean path-length as compared to FPTN due to the presence of many intermediate stops between two distant nodes. Structure of FPTN is sparse as it covers mostly trunk routes of a city. While, owing to flexible and market driven nature of IPTN, structure formed is dense and well integrated with city fabric. Dense nature of IPTN complements the FPTN, first in term of...
route (by filing the gaps left by FPTN) and secondly by increasing capacity (handling the ridership demand).

Robustness of network is linked with dense clustering of links is observed in IPTN over FPTN. Due to its flexible and dense nature, IPTN work efficiently even if few links or nodes are damaged/ blocked. Fixed route system of FPTN hardly permits minor deviation from the route. Dense structure of network permits number of link to connect together, high degree centrality is result of such connections. IPTN formed of such many high degree centrality links serves in major functions area of city because of its market driven nature.

Common high betweenness centrality links in both FPTN and IPTN are indicative of competition for space and ridership. High betweenness value mean, it connects any two-distance nodes through shortest path transverse by many commuters, always in high demand. Inadequacy or less frequency of operators on FPTN might have generated apt condition to flourish IPTN. It means, IPTN complement FPTN by taking care of capacity. A high betweenness values means highly integrated network structure. IPTN consist of such highly connected dense structure, resultant of high degree of centrality. Higher the density of high degree centrality link in a network, network tends to be highly integrated.

Efficiency of Public transport networks are of prime importance for the functioning of cities. Apart from FPTN, the role of IPTN to provide commuting services cannot be ruled out in most of the developing countries as FPTN may not suffice. The co-existence of FPTN and IPTN are of competing or complimenting in nature. The 90.54% overlap of FPTN with IPTN is very high denoting the high interconnectedness and interdependency between FPTN and IPTN. Looking at wide-spread, efficient and robust nature of IPTN over FPTN based on network measures and indices, and overlapping of FPTN with high intensity IPTN route indicate the scope of integration to achieve the complimenting relationship. The complimenting relationship if achieved amongst FPTN and IPTN can enhance the efficiency of the PTN in cities. Considering FPTN, IPTN together as a hybrid system, although is challenging, but does has benefits for efficient functioning of public transport network.

4. Conclusions
The article identifies the importance of Informal public transport network to improve the Complementarity with the formal public transport network. Integrating formal and informal transportation network into a hybrid network has the potential to induce the desired relationships amongst FPTN and IPTN, i.e. competing or complimenting nature to improve the overall efficiency of FPTN.

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