Network Based Comparison of Indian Railways and Airways

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Abstract. We compare the Indian railways and domestic airways using network analysis approach. The analysis also compares different characteristics of the networks with a previous work and notes the change in the networks over a decade. In a populous country like India with an ever increasing GDP, more and more people are gaining the facility of choosing one mode of travel over the other. Here we have compared these two networks, by building a *merger* network. The need for such type of network arises as the order of both networks are different. This newly formed network can be used in identifying new routes and adding more flights on some of the popular routes in India.

Keywords: Transportation networks · Railway network · Airways network · Network analysis

1 Introduction

Transportation Systems are the backbone of the economy of a country. It drives the economy of the country as the foundation of tourism industry, aids in efficient mobility of goods and movement of people. Network analysis has been known as a widely applied tool to understand the structure and characteristics of public-transit systems across various countries. There exist some unique features in transportation networks like limited network sizes, slow rate of change in structures, bidirectional and weighted links with marginally varying frequency, which makes them different from other type of networks.

Transportation networks such as railways and airways network are very popular among public-transit systems. There are several general differences in the railways and airways network. For example, in the airways network, each airport is fairly independent. Whereas, In the railways network many smaller stations are present in between two main stations. Although being the two most popular mode for commuting, owing to this kind of differences in the structure of airways and railways networks, it becomes even more interesting to compare these two type of networks.

Over recent years, complex network analysis has been used to analyze many transport networks such as Airport Network of China, World-wide airport networks, US airport network etc [1,2,4,5,7,8]. There are some common features

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which has been observed in almost all transport networks. For example, almost all the transportation networks studied till now exhibit the small world properties [2,4–6,8]. Whereas some features show significant variations among different transportation networks. For example degree distribution of Indian railways network and Chinese railways network shows exponential behaviour [1,4]; degree distribution of Indian airport network and US airport network shows power law behaviour [2,5]. In terms of combining different types of transport network, there have been studies utilising the multi-modal nature of combined network for several purposes (e.g. [18,19]). In the present work, we compare two modes of transport network instead of combining and analysing them as one.

Indian railways network is one of the cheapest, largest as well as busiest rail networks. Every section of the country whether student, employees, household people or businessman etc. all use the railway service for different purposes. Railways is considered as the lifeline of India as it offers $24 * 7$ services and countrywide connectivity. Railways Network of India is commonly depicted as the pillar of India's economy as it is the most durable, robust, efficient, economical and popular mode of long distance transportation. Indian civil aviation sector has also been expanding rapidly in recent times. Due to the recent active involvement of several low-cost private carriers, it is expanding at a faster pace and more people are choosing to travel by airways instead of railways.

Characteristics of railways as well as airways network have been studied individually but to the best of our knowledge, this is the first study which attempts to compare the two popular modes of transport (Airways and Railways) in Indian context. Due to a huge difference in the *order*, i.e., number of nodes in both type networks it becomes very difficult to effectively compare these two networks in Indian context. For example, an airport is not only used by the people of that particular city but also by the people of neighbouring cities. On the other hand, in the case of railway stations, almost every city has its own station. Here, we have done a thorough analysis of the two transport modes of India. To tackle the challenges in the comparison, we have proposed creation of a new type of network by merging the data of these two networks, which allows us to easily compare these networks.

The paper starts with a description of the creation of networks in Sect. 2. The data acquisition and representation chosen for different networks is explained in details in this section. Section 3 contains the result of analysis of different parameters of the networks obtained. We discuss in this section the interpretation of these results and their usefulness. Finally, Sect. 4 presents the discussion and conclusion of the present work.

2 Network Data

In this section, the creation of both the transport networks is discussed in detail. We have also detailed the network representation used in this paper. Finally, we also discuss the method of creation of the merger network.

2.1 Railways Network

There are two most common network representations of railways system. In the first one, railway stations are considered as the nodes and there exists an edge from an node i to another node j if there exists at least a single train which has scheduled halts on node i and at later point to node j. The obtained network is a directed and weighted network, where the weights on the edges represent the number of trains. As trains in India run with variety of frequency, we have aggregated the trains running in a week together. Thus, the weights on the edges represents the total number of trains in a week which have scheduled halts on node i and then on node j. Many previous studies on transportation network used this approach. Let us call this type of railways network as *S-Railways* Network. Checking some of the properties like resiliency is challenging in this type of representation which is tackled well by the another representation. This second representation of railways network also considers railway stations as nodes but here there exists an edge from an node i to another node j if there exists at least a single train which has scheduled halts on node i and next immediate halt to node j, i.e., node i and j are neighbours in the scheduled halts of at least a single train. The weight on the edge (i, j) represents the total number of trains presents in a week which have scheduled halts on node i and next immediate halt to node j. Let us say this type of railways network as *T-Railway* Network.

In this study, only express, mail and super-fast trains considered. Further only those stations are abstracted as nodes which are present as a halting station in the schedule of at least a train. The data was extracted from **etrain.info** in December 2019. From the collected trains data, we constructed the weighted S-Railway and T-Railway Networks.

The current Indian railways network comprises of 3441 stations(nodes) and 243368 links. The values of Average Shortest Path Length, Clustering Coefficient, Assortativity and Average Degree can be found in Table 1. The diameter of the S-Railways Network turns out to be 4, whereas the diameter of T-Railways Network turns out to 31. A reason for such change in diameter between two types of railway network is that S-Railways Network shows the connectivity of stations rather than the routes of the network. On comparing the current railways network with the network of a previous study of Indian Railways Network by Ghosh et al. [1] in 2011, we find that the railways network grew rapidly in this duration of time. There were only 3041 nodes and 181208 edges in that network which has reached to 3441 stations(nodes) and 243368 links in less than a decade. Most of the structural properties are coherent with the previous study, however, a few characteristics changed. Table 1 shows the changes in the various characteristics of the railways network from 2011 to 2020.

2.2 Airways Network

Airways Network, considered here, consists of domestic airports of India and airlines connecting them. The considered airways data in this paper includes flight schedule of all major domestic airlines in India along with few international airlines which gives services on domestic routes of India. The flight schedules are obtained from the official website of Directorate General of Civil Aviation in December 2019 (www.dgca.gov.in). A total of 12 airlines' schedules are taken into consideration namely Air Asia, Air India, Alliance Air, Deccan Air, Go Air, Heritage, Indigo, Pawan Hans, Spicejet, Star Air, Trujet, Vistara for forming this network. From the collected data, an Airways Network is formed in which nodes represent the airports and there is an edge from node i to node j if there exist at least one flight from node i to j in a week. The weights on the edges represent number of flights from node i to j in a week.

The current Indian Airways Network consist of 103 nodes and 908 links. The values of average shortest path length, average degree, clustering coefficient and assortativity can be found in Table 1. The diameter of the airways network turns out to be just 4 which is same as the diameter in the S-Railways network. On comparing the current airways network with the network of a previous study of Indian Airways Network by Bagler [2] in 2008, we realise that the airways network grew even more rapidly than the railways network in this duration of time. There were only 79 nodes and 442 edges in that network which has reached to 103 airports(nodes) and 908 links in approximately a decade. Most of the structural properties are coherent with the previous study, however, a few characteristics changed. Table 1 shows the changes in the various characteristics of the airways network from 2008 to 2020.

2.3 Merger Network

An effective comparison between the above two transportation networks was challenging due to a large variation in the order of the networks, i.e. the number of nodes in these networks. The creation of a network that can ease the comparison was essential. There are many ways to achieve this. In this paper we propose to compress the railways network to the order of the airways network. We do the following to get the *Merger* Network.

We collected the Latitude and Longitude coordinate of all the railway stations and all the airports from google map. Then we identified the nearest airport from each railway station. Afterwards, every railway station is mapped to the airport nearest to it. In this way, the railway stations for which the nearest airport is same, belong to the same set which corresponds to the airport. The nodes in the Merger Network represents a set of such railway stations and the nearest airport to all those railway stations. An edge exists between two nodes i and node j of the Merger Network, if there exists at least a single train connecting from at least one railway station in the set represented by node i to at least one railways station in the set represented by node j. The weights on the edges represent the total number of trains connecting two sets or nodes in a week. As train connectivity can be assumed as a notion of the quantity of commuters between regions, the edge-weights may be understood as commuting demand from one region to another region.

We got 103 nodes in the giant component of airways network but only 90 nodes in the giant connected component of the merger network. The rest of

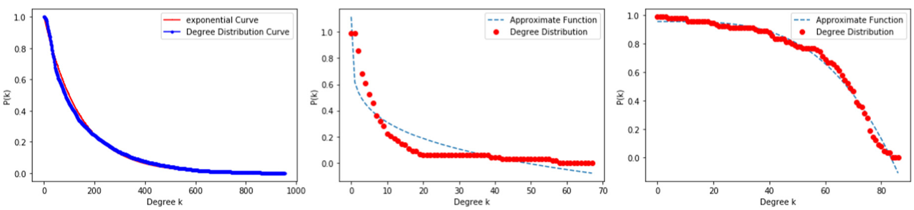
Table 1. Network Characteristics table

		Nodes	Links	ASPL	Clustering Coeff.	Assortativity	Ave. Degree
Railways Network	Saptarshi Ghosh et al. (2011)	3041	181208	2.53	0.733	0.0813	119.177
	Current Network	3441	243368	2.45	0.6927	0.045	141.45
Airways Network	Bagler (2008)	79	442	2.26	0.6574	−0.4	5.77
	Current Network	103	908	2.188	0.6630439	−0.47647	8.815
Merger Network		90	5618	1.30	0.847	−0.077	62.4

13 nodes were isolated. This is because of the airports which are located on islands or in hilly areas without any train connectivity for e.g. Port Blair Airport or all the nearby stations are nearer to some other airport. While the current airways network had only 908 edges, the merger network contains 5618 edges over smaller number of nodes than the airways network. It shows that the airways network is very sparse than the demanded connectivity. Table 1 shows various characteristics of the merger network.

3 Network Analysis

In this section, we summarise various structural properties of the three networks (S-Railway Network, Airways Network and Merger Network) using popular network analysis tools. The analysis is similar to the one done by Ghosh et al. [1] and Bagler [2]. As the edges are bi-direction between nodes with almost similar weight, we consider the out going edges in most of the analysis.



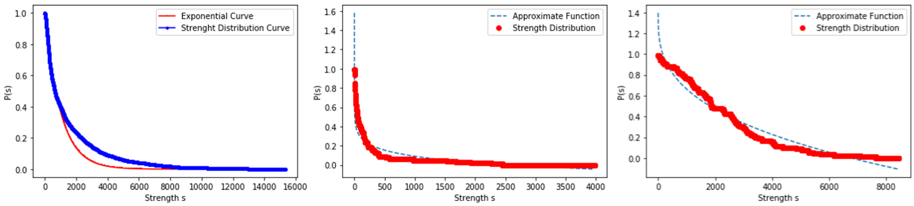
Railways Network Airways Network Merger Network

Fig. 1. Degree Distributions

3.1 Degree Distribution

Degree of a node i, is the total number of edges that are incident on the node i. In case of S-Railway Network, out degree of a node i represents the total number of stations which are reachable by a single train from node i. Cumulative Degree Distribution is defined as $D(k) = \sum_{i=k}^{\infty} d(i)$, Where d(i) $= n_k/N$, where n_k is the number of nodes having degree k and N is the total number of nodes in the network [14]. Cumulative degree distribution is used at place of simple degree distribution to avoid noise in the histogram [14]. Figure 1 shows the degree distribution of the three networks.

The cumulative degree distribution of Indian railways network still follows exponential decay as noted by Ghosh et al. [1]. The approximate fit for the curve of cumulative degree distribution turns out to be D(k) $\sim$ exp(-0.007k). The cumulative degree distribution of the Indian Airways Network still follows power law as noted by Bagler [2]. It is approximated by a power law curve with a scaling exponent y = 1.11 in $P(k) \sim k^{-y}$. The degree distribution of Merger Network is characterized by a power function with a scaling exponent 0.95.



Railways Network Airways Network Merger Network

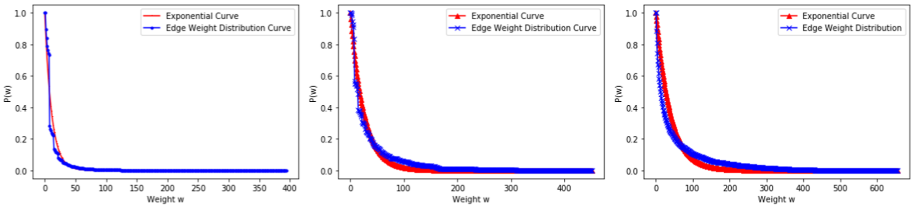
Fig. 2. Strength Distributions

3.2 Strength Distribution

The strength of a node i is defined as sum of the weights on the edges incident at i [1]. Strength at a node indicates the availability of transportation from that node. It can be understood as the weighted degree. The considered networks have weights on the edges, therefore, it is a good idea to study the strength distribution. It depicts the information about the traffic dynamics. The cumulative strength distribution [14] is defined as $S(k) = \sum_{i=k}^{\infty} s(i)$. Fig. 2 shows the cumulative strength distribution of the three networks. The cumulative strength distribution S(k) of the railways network is observed to be an exponentially decaying distribution with scaling $a = 0.001$ in the approximate fitting $S(k)\ exp(-ak)$. The Strength Distribution of the airways network and merger network follows power law with a scaling exponent y = 1.57 and 1.39 respectively.

3.3 Edge Weight Distribution

The weights on edges in networks represents the total number of trains/flights between two stations/airports in a week. Figure 3 shows the Edge Weight Distribution of the three Networks. The cumulative edge weight distribution of railways, airways and merger network follows exponential decay. The approximate fit for the curves of cumulative edge weight distribution turns out to be EW(e) $\sim$ exp(-0.09e), EW(e) $\sim$ exp(-0.04e) and EW(e) $\sim$ exp(-0.025e) respectively.

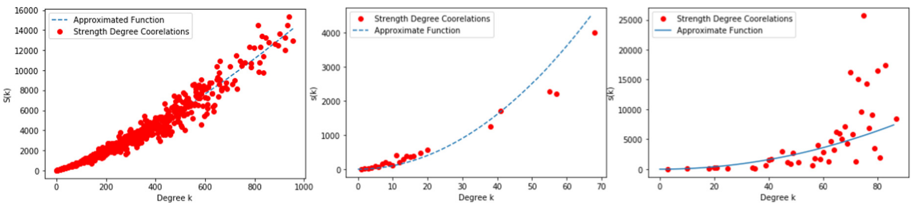


Railways Network Airways Network Merger Network

Fig. 3. Edge Weight Distributions

3.4 Strength Degree Correlations

The correlations between the degree and strength of a node may be used to understand the relationship between these two topological properties [1]. Figure 4 shows the strength degree correlations of the three networks. The plots for all the three networks follow power law. The approximate fit for the three curves of strength degree correlations turns out to be S(k) $\sim k^{1.39}$, S(k) $\sim k^2$ and S(k) $\sim$ k^2 respectively.

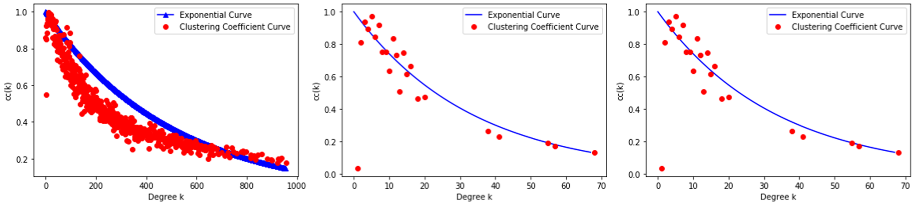


Railways Network Airways Network Merger Network

Fig. 4. Strength Degree Correlations

3.5 Average Clustering

Clustering coefficient of a node i is calculated using the following formula $cc_i = \frac{2t(i)}{d(i)(d(i)-1)}$ where $t(i)$ denotes the number of triangles on i [17]. In order to understand the distribution of clustering coefficient of nodes over the whole network, we plot the average clustering coefficient of nodes of degree k against k and summarize in Fig. 5. The plots for all the three networks seems to follow exponential decay. The approximate fit is cc(k) $\sim$ exp(-ak), where a = 0.002, 0.029 and 0.003 respectively for railways, airways and merger network.

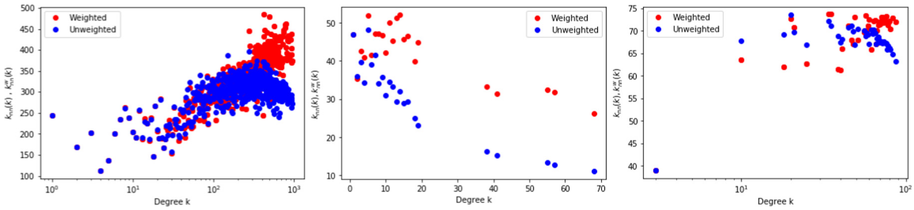


Railways Network Airways Network Merger Network

Fig. 5. Average Clustering of nodes having degree k

3.6 Assortativity

Assortativity is the phenomenon of nodes connecting with nodes of similar degree. The opposite phenomenon is called Disassortativity [15]. For checking this property we use similar formulations as used in [1]. Figure 6 shows the plot of average degree of nearest neighbors of degree k against k for the railways, airways and merger network.



Railways Network Airways Network Merger Network

Fig. 6. Assortativity: average degree of nearest neighbors of nodes having degree k (both unweighted and weighted).

The plot for railway network exhibit that the relationship can not be predict as assortative or disassortative in case of unweighted version but if we look at the strength, the assortative behaviour of the network is seen. In case of airways network, it is observed that for small values of degree, airways network shows no specific assortative or disassortative nature but for large values of degree, it is clearly showing the disassortative nature. The disassortative nature of airways network can be explained by the fact that many large degree airports are connected to low degree airports. The plots for merger network in case of unweighted degree shows disassortative behaviour (as in case of Airways Network) and in case of strength, it shows assortative behaviour (as in case of Railways Network). Hence it is concluded that the topology of Merger Network is Disassortative, but if we consider the traffic dynamics then it is assortative.

3.7 Degree and Betweenness Centrality

Degree Centrality is a measure of the number of links a node has. In Railways Network HWH(Howrah Junction) has the highest degree centrality among all other railway stations. In Airways Network DEL(Delhi) has the highest degree centrality among all other airports. In Merger Network DEL(Delhi) has the highest degree centrality among all other nodes.

Betweenness centrality is a measure of the dominance of the node on the flow of information between each pair of nodes, assuming that information flows mainly along the shortest paths. In Railways Network HWH(Howrah Junction) has the highest Betweenness centrality. In Airways Network DEL(Delhi) has the highest betweenness centrality. In Merger Network, GAU(Guwahati) has the highest Betweenness centrality.

3.8 Resiliency

Resiliency of networks are studied in terms of how much the graph has to change in order to make some property of network vanish. Higher the amount of change, stronger the network posses that property. An important property of transport network is connectivity. In case of natural calamity, disruption in transportation network is normal. Using resiliency, we study how much disruption will make the transportation network disconnected. We consider connectivity property in all three types of networks. We find out the least number of nodes whose removal will make the network disconnected (both strongly and weakly). The approach for checking network resilience against connectivity is that we check for connectivity by removing every node one by one. If network doesn't get disconnected by this then remove pairs of every two nodes one by one and check for connectivity and so on until the network gets disconnected.

Railways Network is not strongly connected. It can be attributed to three trains Chhattisgarh Express(18237, CSMT DHI Express (11057) and KOAA PNBE Express (13131) which follows different routes on to and fro journey. On the other hand the railways network is weakly connected. Therefore, we discuss the resiliency of the railways network against weakly connected property. Using the above-mentioned approach, we get the following stations in the railways network which are dependent on a single railway station in the network.

Atari (ATT) is connected only with Delhi junction(DLI). Munabao (MBF) is connected only with Bhagat Ki Kothi (BGKT). Petrapol (PTPL) is connected only with Kolkata (KOAA).

It is found out that the airways network is strongly connected. Hence, we can analyse its resiliency for both properties i.e. strongly connected and weakly connected. For strongly connected property, Agatti Island (AGX) has incoming flights from only Cochin Airport (COK), Lilabari Airport (IXI) has outgoing flights only to Kolkata Airport (CCU), Pasighat Airport (IXT) has incoming flights only from Guwahati Airport (GAU), and Khajuraho Airport (HJR) has outgoing flights only to Varanasi Airport (VNS).

For weakly connected case, Adampur Airport(AIP), Bikaner Airport(BKB), Pathankot Airport(IXP) and Ludhiana Airport(LUH) are connected only with Delhi Airport (DEL), Dimapur Airport(DMU), Pakyong Airport(PYG) and Shillong Airport(SHL) are connected only with Kolkata Airport (CCU), Tezpur airport(TEZ) is connected only with Guwahati Airport(GAU), Mundra airport(MDA) is connected only with Ahemdabad airport(AMD), Bhuj Airport(BHJ) and Jamnagar airport(JGA) are connected only with Bombay airport(BOM), and Salem Airport(SXV) is connected only with Chennai Airport(MAA).

The merger network is also strongly connected. Hence, we analyse its resiliency for strongly connected as well as weakly connected property. The merger network lost its weakly connected property if at least 3 nodes are removed from the network. Those 3 nodes are GAU(Guwahati), TEZ(Tezpur), IXI(Lilabari). Removing these nodes makes the node IXT(Pasighat) disconnected from the network.

3.9 Edge-Based Comparison Between Airways Network and Merger Network

In this section we identify the major differences between the airways and merger network based on the edges and edge weights. If some edges are present in the airways network but not in the merger network, it is inferred that although two regions are directly connected by flights but there is no direct rail connectivity. It might be due to very long distance between two regions or due to geographical locations not suitable for railway lines. The top ten such pairs are mentioned in Table 2. If some edges are present in the merger network but not in the airways network, it is inferred that although two regions are directly connected by rail but there is no direct air-connectivity. Such pairs which have high weights on the edges in the merger network but are not adjacent in airways network are the best options for new flight routes. This is because yet no flights have been started on these routes and these regions have very good rail connectivity expressing the heavy demand of commuting. There are several such edges as the density of merger network is very high in comparison to the airways network. We have mentioned top 10 such pairs which are at least 118 Kms (the minimum distance between two airports with a direct connectivity) distance apart in Table 2.

Table 2. Regions between which direct flight connectivity is available but direct train connectivity is not available and vise-versa. The top 10 routes of each type are summarized below.

S.N.	**Present in Airways but not in Merger Network**		**Present in Merge but not in Airways Network**	
	Route	**# Flights/Week**	**Route**	**# Trains/Week**
1	Ahemdabad(AMD) ⟺ Nashik(ISK)	13	Kolkata(CCU) ⟺ Durgapur(RDP)	635
2	Amritsar(ATQ) ⟺ Bangalore(BLR)	7	Indore(IDR) ⟺ Varanasi(VNS)	624
3	Amritsar(ATQ) ⟺ Hyderabad(HYD)	7	Delhi(DEL) ⟺ Agra(AGR)	600
4	Bangalore(BLR) ⟺ Amritsar(ATQ)	7	Indore(IDR) ⟺ Bhopal(BHO)	595
5	Kolkata(CCU) ⟺ Lilabari(IXI)	6	Varanasi(VNS) ⟺ Allahabad(IXD)	506
6	Kannur(CNN) ⟺ Hubli(HBX)	7	Gwalior(GWL) ⟺ Agra(AGR)	448
7	Goa(GOI) ⟺ Lucknow(LKO)	7	Indore(IDR) ⟺ Allahabad(IXD)	426
8	Nagpur(NAG) ⟺ Goa(GOI)	14	Durgapur(RDP) ⟺ Patna(PAT)	419
9	Hyderabad(HYD) ⟺ Agartala(IXA)	4	Kadapa(CDP) ⟺ Vidyanagar(VDY)	412
10	Amritsar(ATQ) ⟺ Nanded(NDC)	2	Gaya(GAY) ⟺ Durgapur(RDP)	411

Next, we compare the edge weights between two airports in airways network denoting the current number of flights and the weights between the region covered by those two airports in the merger network representing the demand of connectivity and commuting fulfilled by the rail mode. It has been observed that between some regions, there are more flights than trains whereas between some regions there are more trains than flights. The top ten node pairs with high and low ratio has been summarized in the Table 3. Node pairs with very high trains to flight ratio helps identifying the airports and corresponding regions between which although there are air connectivity but it is relatively very low in comparison to the rail connectivity and demand of commuting. Adding more flights on these routes will turnout to be profitable than routes with lower trains to flights ratio. Node pairs with very low trains to flight connectivity are those which have large number of flights between them and yet due to distance or geography, relatively very small number of trains are operating between those node pairs.

Table 3. Regions between which the ratio of train connectivity and flight connectivity is very high and low. The pairs representing routes with top 10 high and low trains to flights ratio are summarized below.

S.N.	**Very high ratio of trains to flight**		**Very low ratio of trains to flight**	
	Route	**Ratio**	**Route**	**Ratio**
1	Delhi(DEL) ⟺ Gwalior(GWL)	140.33	Chennai(MAA) ⟺ Goa(GOI)	0.037
2	Delhi(DEL) ⟺ Ludhiana(LUH)	82.75	Guwahati(GAU) ⟺ Hyderabad(HYD)	0.042
3	Pantnagar(PGH) ⟺ Delhi(DEL)	80.25	Bangalore(BLR) ⟺ Jaipur(JAI)	0.05
4	Gwalior(GWL) ⟺ Indore(IDR)	73.33	Agartala(IXA) ⟺ Kolkata(CCU)	0.076
5	Varanasi(VNS) ⟺ Agra(AGR)	57	Goa(GOI) ⟺ Hyderabad(HYD)	0.082
6	Jalgoan(JLG) ⟺ Mumbai(BOM)	55.2	Bangalore(BLR) ⟺ Delhi(DEL)	0.093
7	Kolhapur(KLH) ⟺ Mumbai(BOM)	53.6	Guwahati(GAU) ⟺ Ahemdabad(AMD)	0.1
8	Dehradun(DED) ⟺ Pantnagar(PGH)	51.5	Bangalore(BLR) ⟺ Lucknow(LKO)	0.125
9	Kanpur(KNU) ⟺ Delhi(DEL)	51.14	Shirdi(SAG) ⟺ Chennai(MAA)	0.143
10	Agra(AGR) ⟺ Jaipur(JAI)	49.25	Jaisalmer(JSA) ⟺ Bangalore(BLR)	0.143

4 Discussion and Conclusion

In this paper, Indian railways and airways network have been studied as complex weighted network. It has been noted that both networks grew bigger in size, yet the basic topological properties remains almost unchanged over the last decade. Network Resilience against connectivity has been studied for both the network. In order to compare the railways traffic and airways connectivity between two regions of the country, we created a new network based on the two networks. After comparing the new merger network with the current airways network, It has been noticed that few regions have much better rail connectivity than the air connectivity and vice versa. This newly formed network can be very helpful in identifying new routes and adding more flights on some of the routes. Combination of merger and airways network forms a two-layer network and using network analysis tools for multi-layer networks may deliver better analysis. A different direction for further analysis could be considering multi-modal transport with better and complicated merger to closely reflect the real-world scenarios. A similar type of analysis for other countries is another open direction.

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