International Journal of Students' Research in Technology & Management
eISSN: 2321-2543, Vol 6, No 1, 2018, pp 18-29
https://doi.org/10.18510/ijsrtm.2018.614

# BENCHMARKING FOR ACCESSIBILITY AND CONNECTIVITY OF INDIAN AIRPORTS

**[1]Amal Jose, [2]Sewa Ram**
[1] PhD Research Scholar, [2]Professor, Department of Transport Planning,
School of Planning and Architecture, New Delhi, India
ar.amaljose@gmail.com, drsewaram@gmail.com

Article History: Received on 10th January, Revised on 2nd March, Published on 10th April 2018

***Abstract***

**Purpose of the study:** Since 2015, International aviation sector has witnessed an exceptional transformation of Indian air transport with a growth rate of 15-20%. It is also predicted to maintain a similar trend for not less than 4-5 years. However, transporting 400-500 million people a year with the existing facilities and infrastructure will inversely affect the sector. Thus we require an efficient and well-equipped airport network throughout the country to cater the needs of the future demand. Benchmarks are said to be the vital part of every planning standards and processes.

**Methodology:** Study focuses on 109 airports of India (including upcoming airports in UDAN) and covers a critical evaluation of airport to airport connection as well as airport accessibility to and fro. This paper analyses all the benchmarking parameters, namely 'indicators', those influence connectivity and accessibility of these airports.

**Main Findings:** Using statistical tools, it evaluates the existing air network, makes a comparative investigation and models the entire network to frame individual and overall benchmarks. Based on these benchmarks, study recommends adopting few strategies for the next 5 years to address the increasing demand.

**Implications:** Study brings about a healthy competition among airports to resolve their shortcomings. It can boost up demand shift from other modes to air transport.

**Applications of this study:** The methodology may be followed to set Benchmarks of any networks based on the relevant parameters.

**Novelty/Originality of this study:** Airports in India are given different indices and ranks on the connectivity and accessibility parameters, so that their performance is analysed in the global network.

***Keywords: Connectivity; Accessibility; Benchmarks; indicators; Index***

## INTRODUCTION

Aviation is one of the fastest growing Industries in the world where fast mobility becomes extremely important on a daily basis. In 2015, 3.57 Billion passengers were carried by airlines throughout the world where 270 million passengers were added since 2014 (ATAG Report, 2016). Indira Gandhi International airport New Delhi stands at 21st position as on 2016 with an annual passenger traffic of 55.6 million where Mumbai has 44.7 million occupying 29th position. New Delhi has seen a tremendous growth of 21% in its passenger traffic in 2015-16 (AAI Report, 2017).

According to IATA's 20 year passenger forecast on India, the air traffic predicted towards 2015-16 was 190 million where it had already reached 223 million. In 2025-26, the total passengers in Indian airports are predicted to be 278 million (IATA Report, 2017). But, at the current average growth of 5.1% (Asia-Pacific region), it is projected to hit 365 million in 2030. It might shoot up to 460-480 million at 7.5% growth and 575 million at 10% rate. In 2035, it is predicted to transport 442 million passengers, however, prediction at current trends leads to 600 million, 800 million+ at 7.5% and crosses 1 billion mark at 10% growth.

Indian Aviation Industry will have to witness a huge transformation when passenger traffic increases to 2 to 3 folds in another 5-10 years. The existing system and infrastructure will not cater the needs of such a huge hike in demand in a short span of time. In this context, Indian Airports need to establish their own benchmarks and standards to cop up with the requirements. In spite of that, they necessitate to have wider and broader networks within India and International levels.

## LITERATURE REVIEW

The study majorly focusses on the connectivity and accessibility to and from airports, airside and landside, by evaluating the important parameters of both. Connectivity, here, deals with only airport to airport links where ground/land connectivity is not considered. However, accessibility parameter defines the airside access as well as ground access so that overall benchmarks are appraised.

### 1. Connectivity

The International Civil Aviation Organization (ICAO) defines it as an indicator of a network's concentration and its ability to move passengers from their origin to their destination seamlessly (ICAO, 2013). The connectivity is represented by the number of destinations or the number of direct flights offered by an airport. Connectivity is the relative location of an object to the destination centres. There are many different levels of hierarchy to connectivity. The connectivity of a network may be defined as the degree of completeness of the links between nodes (Bamford & Robinson, 1978). Guimerà defined the Betweenness of airport 'i' as the number of shortest path lengths (SPL) where airport 'i' is an intermediate node. Betweenness expresses the centrality of the airport (Guimera et al, 2007).

**2. Accessibility**

Accessibility is defined as people's ability to reach goods, services and activities (Litman, 2017). Accessibility also refers to the measure of the capacity of a location to be reached by, or to reach different locations. Therefore, the capacity and the arrangement of transport infrastructure are key elements in the determination of accessibility (Rodrigue et al, 2016). In air transportation, accessibility refers to the ease of reaching different destinations/airports. It increases upon the centrality of the airports and vice-versa.

Accessibility can be of two ways, access system and access modes (Hoel & Shriner, 1998). Road and Rail are the most prominent access systems to connect airports whereas cars, taxi, bikes, van, bus are road based modes and metro, mono rail, light rail, pods, and high speed train are rail based. As of now, water based access modes have not been used at any of the airports.

Accessibility here refers to the reachability in all the forms, as air side and landside. If the airport is not well accessible by road or rail, there is no significance of the airport being connected to other hubs airports and cities. Likewise, providing a good road or rail connection to airport doesn't make any travellers to use the airport if there are no or less flights, direct or indirect, to the desired airports. Thus, the study focuses on the significance of land and air accessibility to assess the combined effect of these parameters.

**3. Models**

Since 1978, different countries have started following the Hub and Spoke model of connecting airports into their network. Hub-and-spoke networks (HS) allow the hub-airline to maximize the number of connected city pairs given a certain number of flights by means of spatial and temporal concentration of the network (Burghouwt, 2007). Guillaume Burghouwt and Renato Redondi assessed 12 models from the past studies and compared the outcomes of them in an extensive manner (Burghouwt & Redondi, 2009). It was found that the indicators and the methodology used are different from one another, but study brought about a comparative view on understanding each models.

This paper aims to review all the models related to connectivity and accessibility of airports and outline the best performing models into the Indian network. The primarily chosen parameters for the connectivity and accessibility of Indian airports are travel time and number of connections between any two pairs of airports. These are further detailed into sub-parameters and analysed separately for better results. Two major models used for connectivity among Indian airports are 'shortest path length' and 'quickest time' models. For the purpose of land accessibility, reliability model has been used taking 'travel time' as the base parameter.

**3.1. Shortest Path Length Model**

The shortest path length (SPL) is the minimum number of flights that one needs to take to get from any city to any other city. In graph theory, the shortest path is the problem of finding a path between two nodes (airports) in a graph such that the sum of the weights of its constituent edges is minimized (Wilson, 1996). However, Graph theory was applicable in planar networks, whereas, airport network is generally a non-planar system. The equations were modified to prerequisite

The Connectivity Index of an airport is the average shortest path lengths (SPL) from a particular airport to other airports in the network. Accessibility Index is defined as the connection in terms of the equivalent number of one-step connections. The result of the model generates connectivity index and accessibility index of the airports. These results can be used to evaluate the different classes of airports as well as the extent to which the airports are connected. The connectedness and accessibility are also linked in most of the cases when number of connections is concerned (Malighetti, 2008). The equations for CI and AI are given below.

$$\text{Connectivity Index } (\mathbf{CI}) = \sum_{n=1,\, i\neq j}^{j} \frac{\boldsymbol{SPLij}}{\boldsymbol{N-1}}$$

$$\text{Connectivity Index } (\mathbf{CI}) = \sum_{n=1,\, i\neq j}^{j} \frac{\boldsymbol{SPLij}}{\boldsymbol{N-1}}$$

N represents the total number of airports in the network,

SPLij is the shortest path length, in terms of number of connections, from airport i to airport j. (A direct flight from i to j, SPL=1, indirect flight with 1 stop, SPL=2, indirect flight with 2 stops, SPL=3 and so on)

Closer the C.I. values to 1 and higher the value of A.I., better the airports are.

**3.2. Quickest Time Model**

The quickest Path Length (QPL) or Quickest Time Problem is the minimum travel time that one needs to take to get from any city to any other city in the world with minimum number of interchanges (Malighetti, 2008). In graph theory, the quickest path problem is the problem of finding a path between two nodes (airports) in a graph such that the sum of the travel time of its constituent edges is minimized (Wilson, 1996). The problem of the quickest path may be tackled by applying the time-dependent minimum path approach (average minimum travel time including waiting time at intermediate airports). The average travel time is indexed with unit in minutes which is converted to a weighted factor in the detailed analysis.

When the travel time between two airports in India exceeds 25 hours, it has been modelled as maximum value of 1500 (minutes). For international OD pairs, maximum travel time is set at 2000 (minutes).

$$\text{Connectivity Index} = 1 + \frac{\sum_{n=1,\, i\neq j}^{j} \frac{QPLij}{N-1}}{Avg\ \sum_{n=1,\, i\neq j}^{j} \frac{QPLij}{N-1}}$$

$$\text{Accessibility Index} = \sum_{n=1,\, i\neq j}^{j} \frac{60}{QPLij}$$

N represents the total number of airports in the network,

QPLij is the total travel time including layover at all intermediate airports, from airport i to airport j.

Closer the C.I. values to 1 and higher the value of A.I., better the airports are.

### 3.3. Reliability Model

The concept of reliability is developed as the probability that a trip between a given origin and destination pair can be made successfully within a given time interval and specified level of service (Asakura & Masuo, 1991). Reliability is defined as the probability that a component or system will perform a required function for a given period of time when used under stated operating conditions (Lyman, 2007).

The calculation of reliability involves generation of different indices based on various travel time (Elefteriadou & Cui, 2005). Generally, three types for indices are defined to investigate reliability of a system or mode. They are namely, Travel time index (TTI), Buffer time index (BTI) and Planning time index (PTI).

Travel time index can be defined as the ratio of the peak hour travel time to the free flow time (WSDOT Report, 2001). Buffer time is defined as the difference between the 95th percentile travel time and the average travel time (Chen, 2010)[18]. BTI is the relation of this time difference over average travel time. Planning time index assesses the travel time of a mode throughout the day or week irrespective of peak and non-peak hours (Racca & Brown, 2012). Thus, PTI is 95th travel time upon free flow time (MoRTH Draft, 2010).

Free flow speed can be defined as the desired average speed adopted by the driver when not restricted by other vehicles in the stream under given set of road conditions (Rao & Rao, 2014) (Barabasi & Albert, 1999). Free flow time (FFT) is the time taken by a mode in a free flow condition (Bagler, 2008).

Closer the PTI values to 1, better the airports are.

## METHODOLOGY

Literature study was followed by data collection and surveys which were conducted during January-March 2017. Primary data included travel time and speed survey. Secondary data were collected from AAI, IATA, DIAL, Google maps, different State Road transport Corporation websites and Rail websites. The data was analysed in Excel and MATLAB whereas map raster was done through Photoshop. Detailed methodology is given below as a flow chart in **Figure 1.**

Primary phase of methodology was to create Indian Airport network from the available airport and flight data with Airport Authority of India. All the parameters attributed to airport connectivity and accessibility was chosen initially, where only relevant ones were selected as indicators used in the model. They were classified in 3 types as network, air connectivity and land accessibility parameters. Travel time attributed to air and landside accessibility whereas no. of connections was considered only in airside connectivity. *Indices were generated** for all airports in the categories of network, air and landside. These indices were converted into unitary weighted index, ranging from 0 to 1 and highest index being 1. There were total of 22 subcategories of indices belonging to 3 major categories mentioned above. Cumulative indices of all airports were calculated by summation of all individual weighted values and ranked them accordingly. Later they were clustered in different classes to find the benchmarks for each class. Using these findings, a new airport network of India is prepared.

*The methodology for the calculation of indices was mentioned in the literature review part of the paper.

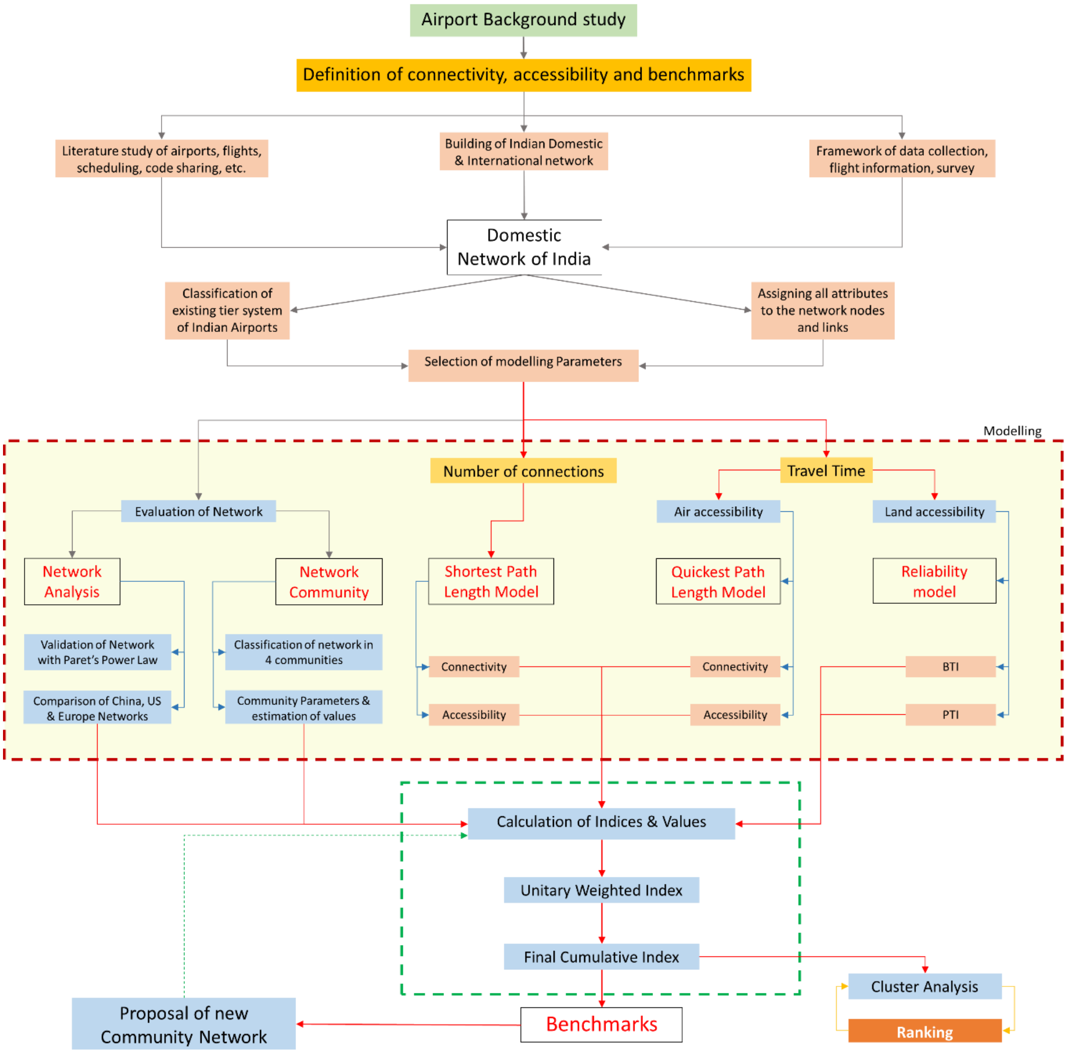


**Figure 1: Methodology of the study**

**Data Collection:** Study has aimed at data collection from 109 airports (including Tier I, II, III, & UDAN) for the development of the models. Out of which, 73 have been considered for QPL model and 60 for Reliability model. However, only 20 airports are assessed for the public transport reliability study due to the unavailability of data. A detailed evaluation of reliability of public transport is conducted in 6 metro airports namely New Delhi, Mumbai, Kolkata, Chennai, Bangalore and Hyderabad. The various parameters like, distance to the city centre, speed of car, speed of Public transport, etc. are also analysed for generating the indices. Map representing existing airports in India are shown in **Figure 2**.

Primary surveys for SPL and QPL were collected through the official schedules of all airlines given in the website of AAI and others. For SPL, direct and connecting flights data were used. QPL survey calculated net travel time to reach one airport to another, including waiting time at one or more airports if any. Survey for Reliability model was done through online sources where 24 hours' traffic data is collected by using google maps. Approximately 80-100 samples are gathered in the private mode (car) as well as public modes. The bus system and metro/urban rail have been segregated in public transportation for metro airports of which Bangalore and Hyderabad were excluded due to unavailability of fully-fledged metro/urban rail services.

 


**Figure 2: Airport network of India**

## NETWORK ANALYSIS

### 1. Community Structure

In the air network analysis, community structure is studied to understand the interrelationships between the airports in different regions or communities. Network Community is a group of airports having located in a specific geographic region, reflecting a strong local connectivity among each other, with one or more hubs and the rest spokes. We can characterize the role of each city or airport in the air transportation network based on its pattern of intra-community and intercommunity connections. Indian domestic network is classified into 4 communities and the values of degree, K, Average K, Z score, Participation coefficient and community Index are calculated. Degree of an airport is the number of airports connected to it by a direct flight. K value represents the degree of an airport in its community. Z-score is the ratio of 'difference between K value and Average K' and Standard deviation of all K values in the community. Participation coefficient indicates the extent of participation/ connectivity of an airport to the other communities (Guimera, 2007).

**Table 1: Community Structure in Indian Airports**

| Community | Major airports | Degree | K Value | Avg. K | Std. Dev. | Z-score | P.C. | Com. Index |
|---|---|---|---|---|---|---|---|---|
| New Delhi | New Delhi | 53 | 27 | 2.71 | 4.63 | 5.25 | 0.74 | 0.51 |
| Mumbai | Mumbai | 49 | 22 | 2.93 | 4.15 | 4.59 | 0.80 | 0.45 |
| Bangalore | Bangalore | 32 | 17 | 3.87 | 4.70 | 2.80 | 0.72 | 0.53 |
| | Hyderabad | 32 | 16 | 3.87 | 4.70 | 2.58 | 0.75 | 0.50 |
| | Chennai | 28 | 18 | 3.87 | 4.70 | 3.01 | 0.59 | 0.64 |
| Kolkata | Kolkata | 29 | 14 | 3.18 | 3.68 | 2.94 | 0.77 | 0.48 |
| | Guwahati | 15 | 10 | 3.18 | 3.68 | 1.86 | 0.56 | 0.67 |

Source: Survey Analysis

## 2. Network Structure

India has more than 250 airports/airstrips in the country but less than 100 have operational capability. The ambitious Ude Desh ka Aam Naagrik (UDAN) (Ministry of Civil Aviation, 2016) policy has laid path for many such regional airports to operate based on a metro/minor hub. This led to a sudden increase in the number of operational airports from 77 to 109. But most of them are awaiting the green signal from authority. This evaluation is based on Indian network in 2016 involving only 73 operational airports. Routing factor (RF) is the ratio of the actual flight distance to the direct flight distance between two airports, regardless of the type of connection.

**Table 2: Network structure of Indian Airports, 2016**

| No. of connections | No. of O-D pairs | % of O-D pairs | Average Great Circle distance (km) | Average RF | % of Flight Time | Average Waiting Time (min) | Average Speed (km/h) |
|---|---|---|---|---|---|---|---|
| 1 | 432 | 8.22% | 890 | 1 | 100.00% | NA | 475.5 |
| 2 | 3098 | 58.94% | 1399 | 1.16 | 24.68% | 458 | 137.7 |
| 3 | 1631 | 31.03% | 1925 | 1.25 | 16.45% | 919 | 106.2 |
| 4 | 87 | 1.66% | 2433 | 1.36 | 16.85% | 982 | 117.4 |
| 5 | 8 | 0.15% | 2649 | 1.54 | 15.10% | 1175 | 101.9 |
| | **5256** | | **1539** | **1.18** | **28.20%** | **573** | **155.23** |

Source: Survey Analysis

## 3. Degree Distribution

Degree is one of the measures of centrality of a node in the network. Degree of a network is the mean degree of all the airports in the network (Guimera, 2007). Degree symbolizes the importance of a node in the network – the larger the degree, the more important it is. Since Indian Domestic Network is a small network, we analyse the cumulative degree distribution, P (> k), whose scaling exponent ɤcum is related to that of P (k) = ɤcum +1. We find that the cumulative degree distribution of Airport Network of India follows a power law (Barabasi & Albert, 1999) (Bagler, 2008).

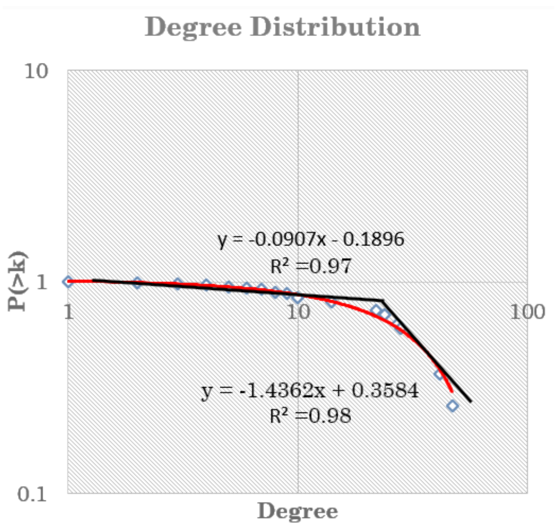


**Figure 3: Degree distribution of Indian airport network**

The degree 'k' is scaled by the average degree 'z' of the network. Cumulative degree distribution is plotted against degree of airports in Double logarithmic scale which shows power law fit highlighted by the small world networks (Guimera et al, 2005). The slope of the graph determines the rate of decay of the degree distribution. The higher the value of decay, the better the network is. Slope α1 & α2 determine the efficiency of the network.

It is evident that α1= -0.0907 and α2= -1.4362 which are comparatively slow slopes. Thus it says that the rate of decay is slow but it behaves like a scale free small world network (Bagler, 2008) (Li & Cai, 2004).

 

### 4. Clustering coefficient

Clustering coefficient (Ci) of a node is defined as the ratio of number of links shared by its neighbouring nodes to the maximum number of possible links among them. In other words, Ci is the probability that two nodes are linked to each other given that they are both connected to i.

$$Avg.\ Clustering\ Coefficient,\ \boldsymbol{C} = \frac{\mathbf{1}}{\boldsymbol{N}}\sum_{i=1}^{N} \boldsymbol{Ci}$$

Average clustering coefficient of Indian airport network in 2016 was 0.50, whereas in 2007, China, U.S. and Europe had 0.49, 0.45 and 0.38 respectively (Paleari et al, 2010). As the network size increases, the clustering coefficient decreases. But clustering coefficient increases upon the increase in connections within the network.

## FINDINGS / RESULTS

**Shortest Path length:** New Delhi (1.52) is the most connected airport in India in the domestic level followed by Mumbai (1.56), Hyderabad (1.71), Kolkata (1.74), Bangalore (1.76) and Chennai (1.79). For the international connectivity, only those airports which are already connected by Indian airports are taken into consideration. New Delhi again ranks first with C.I. of 1.25 followed by Mumbai (1.43), Chennai (1.74), Bangalore (1.80), and Cochin (1.80).

In accessibility parameter, New Delhi has the highest accessibility Index of 80.33 leaving behind Mumbai (78.33), Hyderabad (69.83), Kolkata (68.67), Bangalore (68.75) & Chennai (67.25).

**Quickest Time:** The time problem results are also similar to SPL model except few of the airports are more connected in terms of travel time taken to reach. New Delhi tops the list with a connectivity Index of 1.25 tailed by Mumbai (1.29), Hyderabad (1.38), Bangalore (1.39), Chennai (1.40), and Kolkata (1.41). Indore (1.71) emerges as one of the most connected airport among domestic sector.

New Delhi has the highest Accessibility Index of 35.75 trailed by Mumbai (33.51), Hyderabad (27.98), Bangalore (27.04), Kolkata (25.34), and Chennai (25.10).

**Reliability:** Hyderabad again becomes the most reliable metro airport with an index of 1.79 followed by Bangalore and Mumbai with 2.01 and 2.03 respectively. Mumbai's suburban network proves to be the better reliable mode in the city. New Delhi comes at $4^{th}$ with highly reliable metro network but poor circuit factor. Kolkata and Chennai ranks last at $5^{th}$ and $6^{th}$ respectively making bus as well as suburban rail systems least reliable among metro cities.

The model results for 6 metro airports are given in Table 3. Other airports were also evaluated in the study, but excluded from the table.

**Table 3: Model results**

| SN. | Airports | SPL Model | | QPL Model | | Reliability Model (PTI) | |
|---|---|---|---|---|---|---|---|
| | | C.I. | A.I. | C.I. | A.I. | Private | P.T. |
| 1 | New Delhi | 1.52 | 80.33 | 1.25 | 35.75 | 2.40 | 2.29 |
| 2 | Mumbai | 1.56 | 78.33 | 1.29 | 33.51 | 2.28 | 2.03 |
| 3 | Hyderabad | 1.71 | 69.83 | 1.38 | 27.98 | 1.65 | 1.79 |
| 4 | Bangalore | 1.76 | 68.75 | 1.39 | 27.04 | 1.79 | 2.01 |
| 5 | Chennai | 1.79 | 67.25 | 1.40 | 25.10 | 2.63 | 2.75 |
| 6 | Kolkata | 1.74 | 68.67 | 1.43 | 25.34 | 2.61 | 2.50 |

Source: Survey Analysis

## BENCHMARKING

Dean and Yunus states the essence of benchmarking is the process of identifying the highest standards of excellence for products, services, or processes, and then making the improvements necessary to reach those standards, commonly called "best practices" (Elmuti & Kathawala, 1997). Airport benchmarking is an advantage for the operation and management of airport. Airport managers compare significant indicators or the whole performance parameters with potential competitors or best-practice airports to develop new strategies. In order to improve the use of benchmarking and provide a valuable instrument for airport authorities, governments, regulators and other stakeholders, academic research continuously aims to enhance quantitative methods and models to assess the individual and overall performance of airports.

**Procedure:** Network benchmarks are derived from the comparative study conducted on Indian network with China, U.S. and Europe networks. The various network indicators are separately evaluated and benchmarking values are chosen from the best performing ones.

Parametric benchmarks are set for individual as well as different classes of airports from the models. The benchmarking values are selected upon the highest value of total index in each category.

Overall benchmark is a single value which is set on the different classes or tiers of airports based on the selected parameters for the respective class.

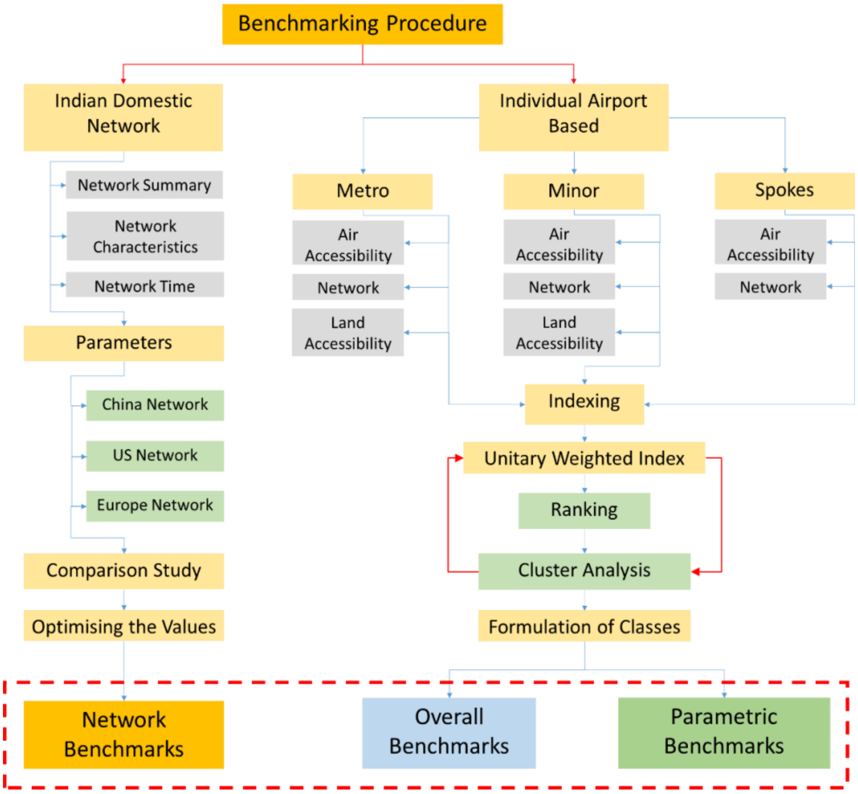


**Figure 4: Benchmarking Procedure for the study**

**Indexing & Ranking:** Study assessed 22 indicators on different classes of airports, each indicator weighted equally with maximum weightage of 1, to generate a unitary weighted Index (UWI). Cumulative Index is obtained by the linear summation of all weighted indices of the matrix. The range of cumulative index varies from 0-22. The highest index was recorded for New Delhi with 18.40 and least by Gorakhpur (3.30). Among Minor hubs, Goa has the maximum index of 12.70.

| Hierarchy | No. | Airport | CI (SPL) | | AI (SPL) | | CI (QPL) | | AI (QPL) | | Z-score | Part. Coeff. | Degree | Cluster. Coeff. | BTI (car) | PTI (car) | BTI (bus) | PTI (bus) | BTI (rail) | PTI (rail) | Distance | Speed (car) | Speed (bus) | Speed (rail) | Cum. Index | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dom | Inter | Dom | Inter | Dom | Inter | Dom | Inter | | | | | | | | | | | | | | | | |
| Metro Hub | 1 | New Delhi | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 0.740 | 1.000 | 0.098 | 0.64 | 0.387 | 0.95 | 0.638 | 0.970 | 0.774 | 0.880 | 0.654 | 0.668 | 1.000 | 18.40 | 1 |
| | 2 | Mumbai | 0.976 | 0.869 | 0.975 | 0.893 | 0.969 | 0.930 | 0.937 | 0.791 | 0.893 | 0.798 | 0.925 | 0.108 | 0.76 | 0.537 | 0.94 | 0.708 | 0.911 | 1.000 | 0.800 | 0.660 | 0.739 | 0.846 | 17.97 | 2 |
| | 3 | Chennai | 0.850 | 0.717 | 0.837 | 0.719 | 0.889 | 0.877 | 0.702 | 0.697 | 0.634 | 0.587 | 0.528 | 0.208 | 0.83 | 0.540 | 0.97 | 0.423 | 0.957 | 0.894 | 0.600 | 0.619 | 0.432 | 0.780 | 15.28 | 1 |
| | 4 | Kolkata | 0.872 | 0.683 | 0.855 | 0.680 | 0.875 | 0.842 | 0.709 | 0.724 | 0.623 | 0.767 | 0.547 | 0.209 | 0.77 | 0.393 | 0.90 | 0.538 | 0.925 | 0.804 | 0.640 | 0.475 | 0.598 | 0.618 | 15.04 | 2 |
| | 5 | Hyderabad | 0.886 | 0.683 | 0.869 | 0.675 | 0.903 | 0.849 | 0.783 | 0.817 | 0.564 | 0.750 | 0.604 | 0.211 | 0.88 | 0.846 | 0.92 | 0.942 | 0.000 | 0.000 | 0.694 | 0.891 | 1.000 | 0.000 | 14.76 | 3 |
| | 6 | Bangalore | 0.863 | 0.694 | 0.856 | 0.691 | 0.896 | 0.853 | 0.756 | 0.662 | 0.599 | 0.718 | 0.604 | 0.224 | 0.84 | 0.901 | 0.92 | 0.942 | 0.000 | 0.000 | 0.714 | 1.000 | 0.824 | 0.000 | 14.55 | 4 |
| Minor Hub | 1 | Goa | 0.745 | 0.652 | 0.702 | 0.625 | 0.805 | 0.780 | 0.467 | 0.548 | 0.183 | 0.802 | 0.170 | 0.917 | 0.91 | 0.919 | 0.92 | 0.635 | | | 0.962 | 0.953 | | | 12.70 | 1 |
| | 2 | Cochin | 0.707 | 0.694 | 0.677 | 0.686 | 0.740 | 0.837 | 0.474 | 0.608 | 0.215 | 0.556 | 0.170 | 0.639 | 0.87 | 0.796 | 0.90 | 1.000 | | | 0.610 | 0.862 | | | 12.04 | 2 |
| | 3 | Lucknow | 0.719 | 0.642 | 0.677 | 0.609 | 0.752 | 0.811 | 0.449 | 0.500 | 0.152 | 0.816 | 0.151 | 0.679 | 0.76 | 0.608 | 0.93 | 0.552 | | | 0.880 | 0.721 | | | 11.41 | 3 |
| | 4 | Ahmedabad | 0.770 | 0.647 | 0.742 | 0.617 | 0.836 | 0.835 | 0.494 | 0.471 | 0.341 | 0.716 | 0.283 | 0.400 | 0.91 | 0.839 | 0.92 | 0.416 | | | 0.440 | 0.870 | | | 11.55 | 4 |
| | 5 | Guwahati | 0.752 | 0.593 | 0.727 | 0.551 | 0.710 | 0.629 | 0.545 | 0.306 | 0.445 | 0.556 | 0.283 | 0.281 | 0.78 | 0.657 | 1.00 | 0.605 | | | 0.880 | 0.765 | | | 11.07 | 5 |
| | 6 | Jaipur | 0.749 | 0.642 | 0.704 | 0.609 | 0.756 | 0.811 | 0.463 | 0.523 | 0.222 | 0.826 | 0.226 | 0.500 | 0.83 | 0.578 | 0.92 | 0.383 | | | 0.320 | 0.647 | | | 10.70 | 6 |
| | 7 | Nagpur | 0.692 | 0.628 | 0.659 | 0.584 | 0.707 | 0.759 | 0.378 | 0.507 | 0.183 | 0.673 | 0.132 | 0.952 | 0.87 | 0.601 | 0.83 | 0.388 | | | 0.500 | 0.647 | | | 10.69 | 7 |
| | 8 | Pune | 0.770 | 0.628 | 0.742 | 0.584 | 0.813 | 0.782 | 0.554 | 0.427 | 0.302 | 0.782 | 0.283 | 0.567 | 0.81 | 0.510 | 0.62 | 0.509 | | | 0.400 | 0.581 | | | 10.66 | 8 |
| | 9 | Coimbatore | 0.692 | 0.601 | 0.650 | 0.556 | 0.718 | 0.629 | 0.397 | 0.306 | 0.111 | 0.640 | 0.094 | 1.000 | 0.87 | 0.604 | 0.65 | 0.573 | | | 0.660 | 0.653 | | | 10.40 | 9 |
| | 10 | Bhubaneswar | 0.732 | 0.606 | 0.702 | 0.559 | 0.724 | 0.629 | 0.382 | 0.306 | 0.215 | 0.702 | 0.208 | 0.373 | 0.87 | 0.535 | 0.84 | 0.378 | | | 0.760 | 0.577 | | | 10.10 | 10 |
| | 11 | Indore | 0.686 | 0.555 | 0.659 | 0.523 | 0.728 | 0.629 | 0.430 | 0.306 | 0.183 | 0.750 | 0.151 | 0.893 | 0.85 | 0.444 | 0.71 | 0.265 | | | 0.520 | 0.488 | | | 9.77 | 11 |
| | 12 | Srinagar | 0.651 | 0.585 | 0.623 | 0.545 | 0.601 | 0.629 | 0.313 | 0.306 | 0.187 | 0.556 | 0.113 | 0.567 | 0.99 | 0.907 | 0.00 | 0.000 | | | 0.560 | 0.872 | | | 9.01 | 12 |

**Figure 5: Airport Indexing and Ranking (sample)**

**Cluster analysis:** Cluster analysis divides data into groups (clusters) that are meaningful, useful or both (Tan et al, 2004). It is the task of grouping a set of values in such a way that values in the same group (called a cluster) have similar characteristics to each other than to those in other groups. It is an efficient tool which is used for data analysis in different fields of research. The univariate clustering was used in the study due to single variance classified data.

International Journal of Students' Research in Technology & Management
eISSN: 2321-2543, Vol 6, No 1, 2018, pp 18-29
https://doi.org/10.18510/ijsrtm.2018.614

Here, in the cluster analysis, Cumulative index of every airport is clustered with respect to its own cumulative index (univariate clustering) to identify the classes among them. The appropriate number of classes can be retrieved by trial and error method with certain number of classes. Cluster analysis was performed for classes 3, 4, 5 & 6 in this study. It was evident that network has 6 classes since the results were recurring after 6.

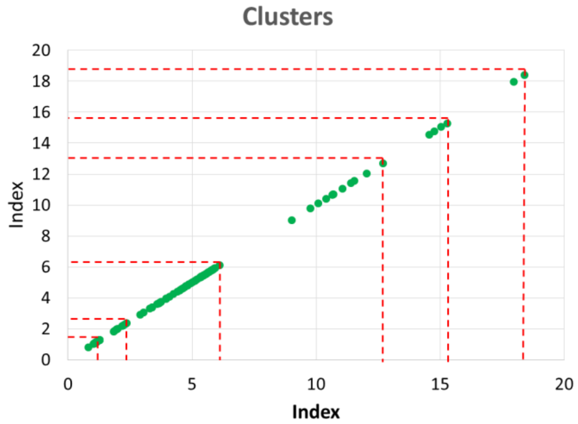


**Figure 6: Cluster analysis**

From the cluster analysis results, each class has been given specific names, first 4 being Hubs and rest spokes. Cluster-wise variance and centroid information are also mentioned along with each class. According to the analysis, the class 1 or Mega Hubs, New Delhi and Mumbai are to be upgraded to another Tier/class/category. Study recommends 4 classes of Hubs instead of 2-hub Tier system in India, hence validating the Hub and Spoke model. The classes 1 to 6 are named as Mega Hub, Metro Hub, Minor Hub, Regional Hub or Link, Major spoke and minor spoke respectively.

**Table 4: Benchmarks in the network level**

| **Criteria/Class** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|
| *Class Name* | Mega Hub | Metro Hub | Minor Hub | Regional Hub | Major Spoke | Minor Spoke |
| *Number of Airports* | 2 | 4 | 12 | 36 | 21 | 34 |
| *Range* | >17.0 | 13.0-17.0 | 9.0-13.0 | 4.75-9.0 | 2.9-4.75 | <2.9 |
| *Within-class variance* | 0.094 | 0.101 | 1.008 | 0.124 | 0.285 | 0.190 |
| *Minimum distance to centroid* | 0.217 | 0.134 | 0.137 | 0.001 | 0.056 | 0.127 |
| *Average distance to centroid* | 0.217 | 0.251 | 0.759 | 0.285 | 0.445 | 0.360 |
| *Maximum distance to centroid* | 0.217 | 0.369 | 1.858 | 0.703 | 0.972 | 0.972 |

Source: Survey Analysis

**Network Benchmarks:** They are based on the network analysis on Indian airport network. In addition to the appreciation of Indian network, the study has carried out a comparative investigation on Chinese, American and European networks comprehensively. This has been incorporated in setting the benchmarking level of each and every category.

**Table 5: Benchmarks on the Network level**

| **No.** | **Benchmarking Parameter** | **Values** | **No.** | **Benchmarking Parameter** | **Values** |
|---|---|---|---|---|---|
| 1 | Konig number | 5 | 10 | Average SPL | 10% |
| 2 | Percentage of direct flights | 10% | 11 | Clustering coefficient (Measured) | 0.40 |
| 3 | Average direct flight distance | 750 km | 12 | Clustering coefficient (Random) | 0.07 |
| 4 | Individual routing factor | 1.25 | 13 | Degree distribution decay (α1) | -0.60 |
| 5 | Avg. Network routing factor | 1.1 | 14 | Degree distribution decay (α2) | -3.00 |
| 6 | Avg. distance b/w Airport pairs | | 15 | Average time duration | 90 min. |
| | *A. Metro-Metro* | *1200 Km* | 16 | Minimum % of flight time | 50% |
| | *B. Metro-Minor* | *1000 Km* | 17 | Average direct flight distance | 750 km |
| | *C. Minor-Minor* | *700 Kms* | 18 | Average waiting time (1 layover) | 100 min. |
| 7 | Average frequency | 4 flights/route | 19 | Average waiting time (2+ layovers) | 300 min. |
| 8 | Percent of Intra-network routes | 75% | 20 | Minimum average speed of flights | 200 km/h |
| 9 | Average degree | 10 | 21 | Average time duration | 90 min. |

Source: Survey Analysis

International Journal of Students' Research in Technology & Management
eISSN: 2321-2543, Vol 6, No 1, 2018, pp 18-29
https://doi.org/10.18510/ijsrtm.2018.614

**STRATEGIES**

**1. Hub and Spoke Model**

The concept of hub and spoke in airport transportation management is comparatively weak in Indian airports excluding few metro airports. If the community base is strong with the presence of metro hubs or minor hubs, regional hubs and spokes along with intra-connections among them, system can generate an efficient domestic network.

The current 4 communities (New Delhi, Mumbai, Hyderabad-Chennai-Bangalore, and Kolkata-Guwahati) in the domestic network in India is re-projected to 10 communities to serve the purpose. The new booming regions to have more air connectivity and demand centre for air travel are Uttar Pradesh, Gujarat, Maharashtra, Punjab and North-East. The proposal consists of 212 airports in India by 2022 including the existing airports.

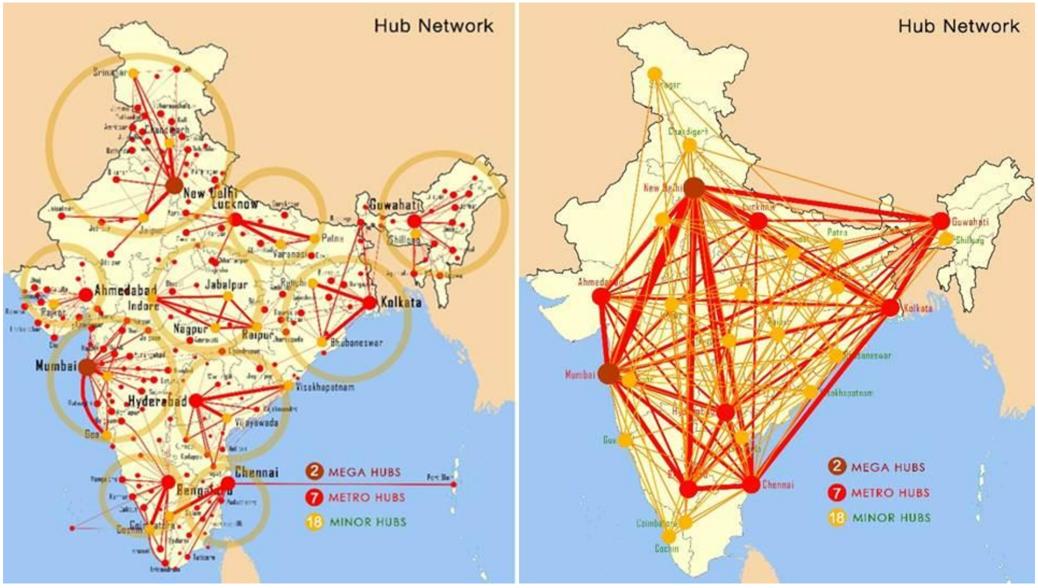


**Figure 7: Intra-community and inter-community system of airport network (Tentative)**

The current Indian HUBs are connected to each other with less than 30% of the existing airports pairs. To improve this, the new HUB system with 4 classes and more interactions will serve the purpose up to 56-60% of their existing connections.

1 The mega Hub with a daily frequency of 50-60 flights are to be operated to transport a total of 15,000-20,000 passengers in both directions.
2 The metro hubs are to be connected with 100% inter-connections among them with different frequencies w.r.t. the emerging passenger demand.
3 The metro-minor hubs flights are connected up to 50% of its total connections where it is advisable to achieve 75% of their routes inter-connected.
4 Not all minor airports are to be connected each other due to less demand and to rationalize the hub activity in a hierarchal system. However 25% of the OD pairs are to be connected to each other to reduce more intermediate hubs.
5 Regional hubs or Links are those sub-hubs within a community connecting its minor and metro hubs.

**2. New class system**

The current Indian airports are categorized into 3 tiers of 6 metro hubs (Tier 1), 12 minor hubs (Tier 2) and rest of the airports (Tier 3). After the expansions of the various hubs, the new class system needs to be established having 6 classes as given below.

Class I: Mega HUBs (New Delhi & Mumbai: 50+ connections)
Class II: Metro HUBs (6 airports: 30-50 connections)
Class III: Minor HUBs (18 airports: 10-30 connections)
Class IV: Regional Hubs or Link (20-30 airports having 3 or more connections)
Class V: Major spokes (30-40 airports connecting 2-3 hubs)
Class VI: Minor spokes (rest of the 120+ airports with minimum 1 route)

 

**3. Alternate airports for saturated Metro HUBs**

The major airports like New Delhi and Mumbai have reached their saturation levels in the passenger and airline traffic according to their existing capacity. It won't be able to perform further operations in the nearest future when the demand increases 15-20% every year. Even airports like Bengaluru, Hyderabad, Chennai and Kolkata are about to reach their saturation levels during the peak hours and peak seasons. Taking this in consideration, second airport proposal in these cities are essential in the nearest future. For Delhi and Mumbai, the proposals are already on the approval/implementation stage, whereas others can be identified after the locational preferences.

**4. High speed Land accessibility corridors**

The major issues with airports are not the inter-airport connectivity but their existing land accessibility provisions. The reachability to and from airports is an important parameter on the utilization of airports. It can be either on a city level or a regional level.

**Regional connectivity:** The maximum distance/time to reach an airport in European standard is 150 kms or 90 minutes by car whichever is better. If the current Indian airports, regardless of tier systems, are taken as nodal points of air travel, it makes an average of 250 kms (4-6 hours) by road. This is very high in terms of the accessibility to airports. Average speed in Indian roads is 40-50 km/h in highways and 25-30 km/h in hills whereas rail system offers up to 60-70 km/hour. Either, airport links are to be classified as expressways with access controls and design speed up to 120 km/hour, or more airports are to be proposed to reduce the distance to 100-150 kms. Efficiency and speed of rail corridors with a speed more than 100 km/h are to be proposed alongside.

**Urban Connectivity:** The average distance to the airport from city center is found out to be 25 kms for metro cities, 16 kms for medium sized cities and 12 kms for small cities up to 5 lakhs population (Comparison of Major European and US airports). Regardless of the strategic location of the airport in the city, the airport links are to be connected via high speed road/rail corridors.

When it comes to metro cities with 5 million plus population, the airport link becomes more significant. All the major demand centers/districts are to be connected with both road and rail based rapid transport system. As an example, Airport Express line of Delhi Metro is connected with an access time less than 25 minutes from New Delhi. However, it creates limitation for the travelers from other regions of NCR and other nearby states to reach airport. Likewise in road system, an outer ring road, either elevated or dedicated fast corridor should be proposed to tackle the accessibility issues. The alternative airports within the same city need to be connected by a dedicated transit corridor.

## CONCLUSION

This study aims to set benchmarks for the existing airports in India and evaluate their ability to upgrade into 'Hubs' of air transport. The recommendations and strategies put forward by the study make a vision for Indian Airport network 2022. A 6-Class system needs to be established replacing the currently prevailed Tier system to envisage a world-class network. Airports need to connect both urban and rural India satisfying the urge of equitable and inclusive transport. UDAN policy by Govt. of India ensures the rural towns of the country to be part of fast mobility. Moreover, all the hub airports need more access modes which are cheaper, faster and available for all classes of people. Initiatives to bring upon more private fliers into the market can boost the connectivity of all cities in India. In this way, we can make a dynamic demand shift from fully loaded passenger trains to flights, thus achieving the objectives of fast mobility.

Although the benchmarks were set based on 22 indicators, study can be enhanced by adding rest of the influential parameters, whichever is applicable, to make it more comprehensive. It is suggested to use an alternate index weightage system with respect to the impact of each parameter on connectivity and accessibility. Similar methodology may also be adopted to evaluate other networks like road, rail and water.

## REFERENCES

1. Air Transport Action Group, 2016. *Aviation benefits beyond borders*, Geneva: ATAG.
2. Airport Authority of India, 2017. *Annexure IIIA*, New Delhi: AAI.
3. International Air Transport Association, 2017. *20 Year Passenger Forecast.* [Online]
   Available at: http://www.iata.org/publications/store/Pages/20-year-passenger-forecast.aspx [Accessed 02 January 2017].
4. International Civil Aviation Organization, 2013. *Enhancement of Air Transport Connectivity and Facilitation.* Montréal, s.n.
5. Bamford & Robinson, 1978. *Geography of transport*, Plymouth: Macdonald & Evans.
6. Guimera, R., Sales-Pardo, M. & Amaral, L. A., 2007. Classes of complex networks definedby role-to-role connectivity profiles. *Nature Physics*, pp. 3(1):63-69.
7. Litman, T., 2017. *Evaluating Accessibility for Transport Planning*, Victoria: Victoria Transport Policy Institute.

8. Rodrigue, J.-P., Comtois, C. & Slack, B., 2016. *The Geography of Transport Systems.* 4th ed. New York: Routledge.
9. Hoel, L. A. & Shriner, H. W., 1998. *Evaluating improvements in landsilde access for Airports,* Virginia: Department of Transportation & The University of Virginia.
10. Burghouwt, G., 2007. Airline Network Development in Europe and its Implications for Airport Planning. *Aldershot.*
11. Burghouwt, G. & Redondi, R., 2009. Connectivity in air transport networks: models, measures and applications.
12. Wilson, R. J., 1996. *Introduction to Graph Theory.* 4 ed. Essex: s.n.
13. Malighetti, P., Paleari, S. & Redondi, R., 2008. Connectivity of the European airport network: "Self-help hubbing" and business implications. *Journal of Air Transport Management,* 2(15), pp. 53-65. https://doi.org/10.1016/j.jairtraman.2007.10.003
14. Asakura, Y. & Masuo, K., 1991. *Road network reliability caused by daily fluctuation of traffic flow.* Briton, s.n., p. pp. 73–84.
15. Lyman, K., 2007. Travel Time Reliability in Regional Transportation Planning.
16. Elefteriadou, L. & Cui, X., 2005. *Review of Definitions of Travel Time Reliability,* s.l.: s.n.
17. WSDOT, 2001. *Travel Time Reliability,* Texas: Department of Transportation.
18. Chen, M., 2010. *Travel time based congestion measures,* Kentuky: Department of Transportation.
19. Racca, D. P. & Brown, D. T., 2012. *Study and Calculation of Travel Time Reliability Measures,* Delaware: Delaware Department of Transportation.
20. Sekhar, R. C., E., M., B., K. & S., G., 2013. *Analysis of travel time reliability of an urban corridor using micro simulation techniques,* New Delhi: Current Science.
21. Ministry of Road and Highways, 2010. *Highway Capacity Manual: Draft,* New Delhi: MoRTH.
22. Department of Transportation, 2000. *Highway Capacity manual,* Washington D.C.: Transportation Research Board.
23. Rao, A. M. & Rao, R. K., 2014. Free Speed Modeling for Urban Arterials - A Case Study on Delhi. *Transportation Engineering,* 30 October, pp. 111-119.
24. Ministry of Civil Aviation, 2016. Ude Desh Ka Aam Naagrik : Civil Aviation Ministry's Regional Connectivity Scheme "UDAN". [Online] Available at: http://pib.nic.in/newsite/PrintRelease.aspx?relid=151850 [Accessed 5 March 2017].
25. Barabasi, A.-L. & Albert, R., 1999. Emergence of Scaling in Random networks. *Science,* Volume 286, p. 509. https://doi.org/10.1126/science.286.5439.509
26. Bagler, G., 2008. Analysis of the Airport Network of India as a complex weighted network. *Physica A,* 387(12), pp. 2972-2980. https://doi.org/10.1016/j.physa.2008.01.077
27. Guimera, R., Mossa, S., Turtschi, A. & Amaral, L., 2005. The worldwide air transportation network: Anomalous centrality, community structure,and cities' global roles. Proceedings of the National Academy of Sciences of the United States of America, 102(22), pp. 7794-7799. https://doi.org/10.1073/pnas.0407994102
28. Li, W. & Cai, X., 2004. Statistical analysis of airport network of China. *Phys. Rev. E,* 69(4), p. 046106. https://doi.org/10.1103/PhysRevE.69.046106
29. Paleari, S., Redondi, R. & Malighetti, P., 2010. A comparative study of airport connectivity in China, Europe and US: which network provides the best service to passengers?. *Transportation Research Part E Logistics and Transportation Review.* https://doi.org/10.1016/j.tre.2009.08.003
30. Elmuti, D. & Kathawala, Y., 1997. An overview of benchmarking process: a tool for continuous improvement and competitive advantage. In: *Benchmarking for Quality Management & Technology.* Bingley: Emerald Group Publishing, pp. 229-243. https://doi.org/10.1108/14635779710195087
31. Tan, Steinbach & Kumar, 2004. *Cluster Analysis: Basic Concepts.* Minnesota: DM Book.