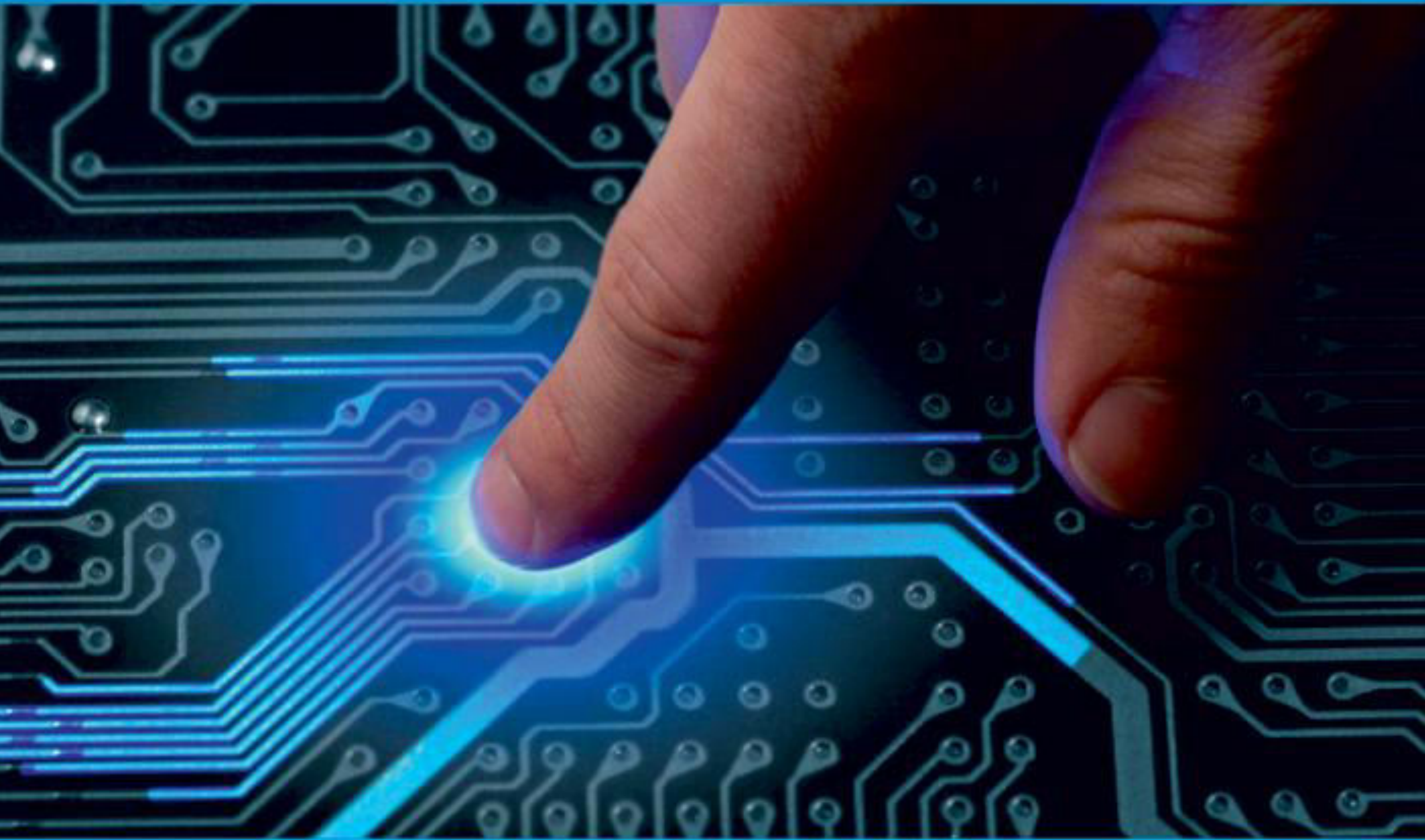
IJIRCCE

e-ISSN: 2320-9801 | p-ISSN: 2320-9798



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING

Volume 9, Issue 6, June 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.542

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

A Survey on the Effects of Topological Properties in Road, Metro and Air Transportation Network Sutilizing Graph Theory Approach

Pooja Chakrabarthy, Asish Mukhopadhyay

MSc Student, Dept. of Computer Science, University of Windsor, Ontario, Canada

Professor, Dept. of Computer Science, University of Windsor,Ontario, Canada

ABSTRACT: In this paper,weillustrate thestructural properties of transportation network as a complex network basedon graph theory approach,where road junctions, metro stations, and airports are considered as "nodes" and an existing connection between a pair of nodes is said to be connected by an "edge". We introduce topological properties of small world network model and compare it with random and regular network models to carry out research on road, metro and air network in urban transportation system. Statistical measures are computed, and results shows that road and air network forms small world network and exhibits properties different from regular and random networks. Our study is on various categories of real-world transport systems which offersconclusions to assist decision-makingfor public transportation engineers. This paper provides a novel approach for transit planners to improve the performance of the existing transportation systems.

KEYWORDS: Complex Networks; Small World Network; Graphs; Topological Properties; Transportation Networks

I. INTRODUCTION

In order to studyvarious complex systems, a lot of real-world problems can be observed as network. Large networks have been used to model various types of phenomena, especiallyphenomena having to do with many heavily inter-connected entities, in different fieldsof science. A network is a set of entities(nodes or vertices) with connections(links or edges) that can exist between pairs of nodes. The entities can be people, protein, companies, locations, and animals and the relationships might include anything which links these entities. The connection between entities is called network diagrams or can also be called as network graphs. The representation of the network graphs is called the network topology which is used to analyse how various nodes, devices, and connections on your network are arranged to each other. Some of the topological properties include degree of a network, shortest path, transitivity and centralities. Exploring the properties can better explain the structure and function of the network. Many of the real-world networks are large and have millions of nodes and edges. To study them, it is helpful to use mathematical models to identify the structural patterns and correlations within a network. Models for networks give insight about the properties of real-world networks and help as a foundation for understanding the interactions within the networks. Analyzing andinterpreting large real time data is challenging. Small average path length and high connectivity aretwo properties that are present in most real-world networks.Motivated by local clustering and connectivityof large real-world graphs, we are interested to study the small world propertiesand how is it significant in large complex networks in real world. In the next section weshall discuss some related previous work. In section 3 we present the different methods and algorithms. Here, we study thestructure and properties of different graphs. We also study the algorithms to generatedifferent graph models. Then we will explore small world properties of transportationnetworks and compare with equivalent random and regular graphs. In section 4 wetested the algorithms on rapid urban transportation system and produced the results for Road, Metro and Air network so as to analyze and study the properties in large variety of network.

International Journal of Innovative Research in Computer and Communication Engineering

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

II. LITERATURE SURVEY

Understanding the transportation network is crucial as itis a fast and effective way to transport goods and services across the country.

A. Small World Networks

Watts and Strogatz (WS)[1] introduced a new network model named small-world network, which is highly clustered like regular networks, and highly connected like random networks. They used the six degrees phenomenon principle which was first studied by the social psychologist Milgram[2] and popularly known as six degrees of separation (Fig. 1). Through an experiment of passing letters among strangers with minimum information given to all the people participating in the experiment, he found that it took an average of six steps for the letter to get from one stranger to another. He thus concluded that two randomly chosen individuals in a human social contact network are connected by a small chain of intermediate acquaintances.

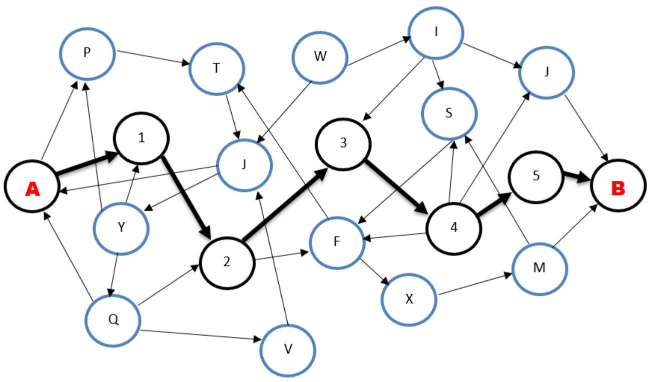


Fig.1. Six degrees of separation (by Milgram, 1967)

The small world model has been actively applied to the various fields of networks research due to resulting network topology with features such as smaller average transmission delay and more robust network connectivity. They proposed a specific construction of small-world model by randomly rewiring the edges (Fig. 2). Rewiring means shifting one end of the edges and attaching it to a randomly chosen node with probability p. With varying p, the model's structural properties can be considered through the two key characteristics: the average path length, l (p), and the clustering coefficient, cc (p). Small-world networks lie in the intermediate region between p = 0, when the network is still regular, and p = 1, when the network is similar to a random network. Small average path length and high transitivity are two properties that are present in most real-world networks. The standard random network model possesses only the small average path length property. On the contrary, regular network models have high transitivity.

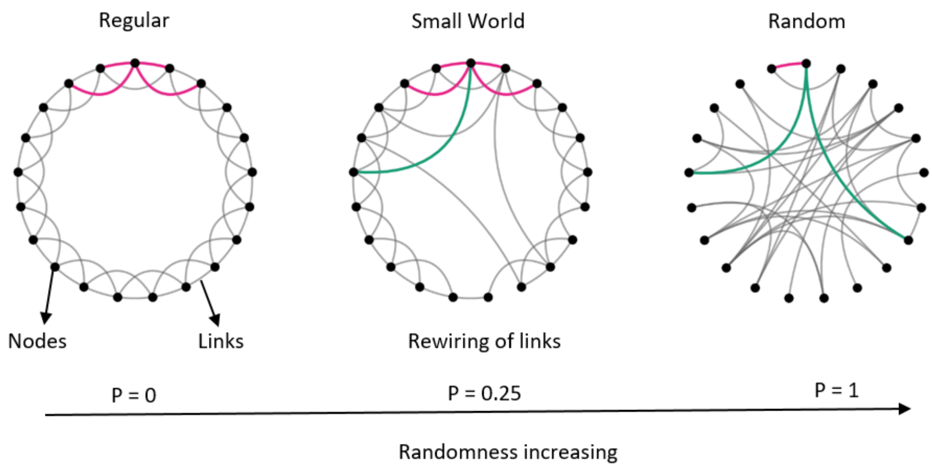


Fig.2. Regular, random vs small world networks (generated from Watts and Strogatz 1998)

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

WS combined these two properties in one network model called Small-world networks by analogy with the social psychologist Milgram's experiment, popularly known as six degrees of separation. Their paper was published in Nature June 1998 and ranks at 6 among highly cited papers in Physics. This paper has received 2,700 citations between January 1, 1998 and August 31, 2008. Kleinberg's [3] explained small world properties similar to Watts and Strogatz but with slight differences. Kleinberg used two-dimensional n x n grid of vertices to represent the network (Fig. 3), and several long-range connection edges were added and not rewired.

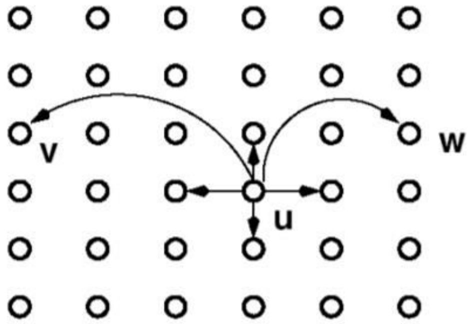


Fig.3. Kleinberg's small world model (2004)

Once the edges are added, the probability of connecting two random vertices, v and w is proportional to 1/d(v, w)q, where q is considered as the clustering coefficient. Kleinberg also introduces some theorems to quantify the decentralized algorithms delivery time. He proved that the delivery time needed for a Milgram's letter to reach from one node to another node is not always logarithmic, but it depends on other parameters as well. The new parameter was (α >=0) that considers the long-range connections and shows different time taken for various interval of time.

B. Topological Properties

In 2012, F Zaidi [4], introduced a model to generate small world network from random graphs. Initially, random network graph is generated and, then each node is then replaced with triads of different sizes (100 -1000) to increase the overall clustering coefficient of the network. The author placed an edge between two triads for every edge which, is replaced by the initial nodes in the random network. The final network thus obtained exhibits the two structural properties of a small world network. Additionally, the author also found the properties of community structures (clusters) with 17 nodes and 28 edges. Experiments showed that the generated networks exhibit clustered small world properties. H. Dai et. al[5], proposed a new ''rich-gets-richer'' rewiring rule. Here the selection of the vertex to be reconnected was considered in a different way than the WS paper. While reconnecting, they link a vertex that already has many connections and has a higher probability. D Wang et. al[6], presented a study on the effects of small world and scale free properties on hierarchical network. They constructed hierarchical self-similar fractal and found the average path length and clustering coefficient of large network. As a result, they found that average distance grows logarithmically with increasing order of networks. AG et. al[7], proposed a new procedure based on creating triangles in the regular network. The proposed algorithm reduces the average shortest path length and mitigates the loss of clustering coefficient leading to the typical behaviour of small world networks. The resulting network exhibits both characteristics of small world. J Alstott et. al [8], introduced edge rewiring method that create a highly clustered network with an existing random network without impacting other properties of networks like degree distribution and shortest path length. They used two algorithms, Swing towards best for global optimization and Swing away from worst for local optimization. Results showed that the network had high clustering and while rewiring the average path also decreased. Therefore, the authors claimed that their method constructs small world properties. M Boguna et al. [9], identified the homogenous and heterogeneous spatial networks that has three properties, i.e. sparsity, small world properties, clustering. Mozart B et al. [10], proposed a method to construct a Watts Strogatz network using a sample from a small-world network with symmetric degree distribution. Their method yields an estimated degree distribution which fits closely with that of a Watts Strogatz network and leads into accurate estimates of network metrics such as clustering coefficient and degree of separation. L. Luo et al. [11], reviewed the small world network parameters and found out how the parameters contributes to highest utility growth rate (UGR) in the economic system. Their experiments involved number of neighbours, rewiring probability and the number of redundant edges. The results showed that UGR can be increased only when neighbours are in the range between 2 to 18. Experiments also showed that the redundant edges prove to have advantages when the economic system challenges any random or deliberate attacks. Insoo Sohn [12], focused on the working method of small world algorithm. They studied about the random

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |
|| Volume 9, Issue 6, June 2021 ||
| DOI: 10.15680/IJIRCCE.2021.0906232 |

rewiring procedure and the important metrics for evaluating small world networks. Further, they provide the related issues in design and implementation of small world network. F Ma [13], proposed a new family of modular, generalized self-similar and non-planar graphs as network space with multiple hub-vertex. Various topological properties like degree distribution, the diameter, the clustering coefficient, the average path length was determined. Additionally, even the number of spanning trees of a complex network to different structural and dynamical properties, such as reliability, synchronization capability and diffusion properties was determined in this paper. Haifeng Du [14], considered average path length and average clustering coefficient to measure small world property. They introduced a genetic algorithm based on simulated annealing to enhance the diffusion efficiency of small-world phenomenon on benchmark networks. Latora et al. [15], presented a weighted graph to analyse small world characteristics on three real networks data i.e. neural network, communication network and transport network. They worked on efficiency of networks which can be defined as the inverse of the mean of the geodesic distance between the nodes. The efficiency calculates how fast an information can be transmitted from one node to another in a network. Firstly, they produced adjacency matrix (aij). Secondly, matrix for physical geographical distances (lij) was generated based on the triangle equality. Thirdly, they found the shortest path length (dij) i.e., the distance between nodes i and j from the aij and lij. Finally, from these results, the efficiency of the graphs was found. To identify the efficiency in small world, they considered unweighted graph with the total number of nodes in the network being, N = 1000 and k = 20 is rewired and global efficiency (Eglob) and local efficiency (Eloc) were evaluated.

C. Transportation Network

Anderson et. al[16], used weighted and unweighted network of a transportation network where nodes are the stations and a links are any number of routes connecting two nodes. Weighted networks were built using the geographical distances between two stations. They removed all the two-degree nodes from the representation to make the network simple and reduced. The authors applied their model to four different bus, airport, and metro transportation networks with around 50-1000 nodes. From the results, the authors found the degree distribution, path length distribution, connectivity distribution has small-world characteristics and, if a reduced network has a hierarchical structure, the initial network is a scale-free properties.

C Hong et. al[17], investigated the structural properties of multilayer networks in China. They merged 26 layers together, where each layer is an airline company. They compared major and low- cost airline layers to analyse their different contributions to the properties of the networks. The authors found that the Chinese network has a high clustering coefficient and short average path length, thus producing a small world property. W Wang et. al[18], conducted a study on the Chinese railway network, where rail stations are the nodes and edges denote the transit services which connects two stations. They analysed various properties of complex networks like cumulative degree distribution, degree correlation, correlation between in degree and out degree, betweenness centrality, assortativity coefficient of rail stations. The analysis results show that the Chinese network is a core-periphery structure which exhibits small-world properties. The core layer consist of 28 developed cities in china and the periphery layer consists of 227 other cities. C Wu and I Kim [19], introduced bike-sharing representation of five various bike-sharing network in the United States, Canada, and China. From the network representation, the authors deduced the network properties and their spacial autocorrelation to measure the degree of clustering. Some of the properties were degree of the nodes, clustering coefficient, Average path length, degree centrality, node centrality, betweenness centrality, closeness centrality. Results shows that degree centrality is positively related to the closeness centrality which means the stations have high accessibility. Also, the network representation showed that the bike-sharing networks have a small-world property. This implies that bike stations are having high clustering coefficient and bikes can be moved easily from one station to another. M Li and J Han [20], analysed the topological characteristics and network dynamics on four different models, i.e. rules network, random network, small world network and scale free network. They carried out an empirical study on road network, bus network and track network in urban transportation system. Based on the analysis the authors concluded that topological features of transportation network can be used to analyse the robustness of a network to prevent random attacks.

V Latora and M Marchiori [21], studied Boston's rail transit system and observed that network characteristics can be obtained while separately analysing subway networks were compared to those of the network combination of subway and buses. SiozosRousoulis L. et. al [22], proposed a methodology to study evolution of the U.S air transportation network to reduce terrorists attacks based on topological properties. The data comprises of flight data with origin, destination and number of people travelling. The nodes were considered as airports and the edges were denoted by connections between the air routes. If there was at least one airline route, the two airports were assumed to be connected. Different topological properties like centrality measures, network assortativity was evaluated. Results

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

showed a decline of shortest path length and the network had high connectivity. Addionally, node deletion method was applied to identify the network efficiency on targeted attacks.

Z.S.Yang et. al [23], proposes a topological analysis of around 417 transit lines based on a functional representation of network constructed from the urban transit system in Beijing. Here nodes represent the transit lines and edges represent convenience for passengers to transfer from one place to another. The statistical measures were computed, and topological properties were investigated to optimize the transit system. The properties were compared with random and regular network model which revealed that Beijing transit system exhibits small world property. J Li et. al [24], studied the characteristics and properties of bus and metro networks based on smart card data. Results reveal that bus network has small world characteristics and metro network is has strong connectivity. Next, they introduced PageRank algorithm to identify most influential nodes in the network to find out the distribution of the complex network. It was found that bus network has weekday community characteristic. Addionally, they used community detection algorithm to imply community structures based on modularity of Combo algorithm.

W Li et. al [25], proposed two networks and the experiments were conducted based on degree distribution and strength distribution.. Firstly, they considered weighted bus line network with 105 nodes and 2384 edges. The authors found the clustering coefficient to be 0.74 and the average shortest path length as 1.56. Secondly, the authors considered weighted unconnected bus station network with 887 nodes and 33659 edges. Results showed that average shortest path length is 2.212 and the clustering coefficient is 0.735. Both the networks have small-world phenomenon. Additionally, they also investigated on the robustness of the network to random and selective attacks. Results showed that the two networks were highly robust, and deletion of few nodes would not affect the connectivity of network.

III. METHODOLOGY

In this section, the small world network and its properties will be discussed and will be compared and contrasted with those of regular and random graphs of similar size. We shall also discuss algorithms for generating such graphs. A regular graph has a very deterministic edge connectivity. An example of a regular graph is a ring lattice G^L with n number of nodes, where each node having degree K is connected with $\frac{k}{2}$neighbours on each side. Note that GL has $\frac{nK}{2}$edges.

Algorithm 1 can be used to create such a regular graph structure (or almost regular graph structure when $\frac{nK}{2}$ is not an integer) with n number of nodes and M number of edges. It is due to this regularity, that the amount of local clustering is quite high compared to other graphs where the edges are more irregularity connected. The network average clustering coefficient for a ring lattice is given by $C = \frac{3(K-2)}{4(K-1)}$, as K-> ∞ and C -> ¾.

Algorithm 1: Regular graph generation

```
Input: n = number of nodes, m = number of edges
Output: Regular graph G_reg with n nodes and m edges
G_reg = (V, E), where V = {1, ··· , n} and E = φ
K = 2⌈m/n⌉
/* Creating a ring lattice with n nodes each having degree K     */
for every vertex v ∈ V do
    E = E ∪ {(v, (v + 1) mod n), (v, (v + 2) mod n)}
/* Removing extra edges sequentially                             */
v = 1
while |E| not equal to m do
    E = E\{(v, (v + 1) mod n)}
    if G = (V, E) is not connected then
        E = E ∪ {(v, (v + 1) mod n)}
    v = v + 1
```

Unlike regular graphs, the edge connectivity in a random graph is not deterministic.Every random graph can be considered as a sample from a probability distributiondefined on the space of graphs. A well-known graph random graph model, denoted byG(n, p), was proposed by Gilbert [26], where every pair of vertices are connected withprobability p. Any particular random graph follows Bin(N, p), where N = $\binom{n}{2}$, that is,the probability of a random graph with m edges is $p^m(1-p)^{N-m}$. Erdos and Renyi[27] proposed a very similar model, denoted by G(n,m), where the graphs withmedges follows a uniform distribution with probability given by $1/\binom{N}{m}$. The two modelsG(n, p)and G(n,m) are almost interchangeable if we choose m = Np. Note that inmodel G(n, p), theexpected number of edges a graph can have is [Np]. Consideringequivalence of two models, $p \approx \frac{2m}{n-1}\frac{1}{n}$. If m< $\frac{n-1}{2}$, which might be true in graphs withsmall number of edges, it is very unlike to have a connected random graph. To obtain aconnected random graph, we followed a two-step approach. In the first step we create auniform spanning tree with n vertices and n−1 edges, and in the next step we connectrest of the edges by choosing pair of vertices randomly as described in algorithm 2. It is evident from the expression of p that, when m is much closer to n compared to Nand n is considerably large, p ≈ 0. Consequently, the expected value of the networkaverage clustering coefficient, which can be shown to be equal to p turns out to be verysmall.

```
Algorithm 2: Random graph generation
  Input: n = number of nodes, m = number of edges
  Output: Random graph G_rand with n nodes and m edges
  G_rand = (V, E), where V = {1, ··· , n} and E = φ
  /* Creating a uniform spanning tree with n nodes and n − 1 edges following
     Wilson's random walk algorithm                                          */
  S = {1, ··· , n} and T = φ
  current_node = random node selected from V
  while S not empty do
      neighbor_node = random node selected from V
      if neighbor_node not in T then
          E = E ∪ {(current_node, neighbor_node)}
          S = S\{current_node}
          T = T ∪ {current_node}
          current_node = neighbor_node
  /* Adding rest of the m − n + 1 edges randomly                             */
  while |E| not equal to m do
      Randomly select two nodes (u, v) from V
      E = E ∪ {(u, v)}
```

Small world network, introduced by WS lies somewhere in themiddle of regular and random graphs. There are two main distinguishing characteristicsof this kind of graphs. Unlike regular graphs, every node ingraph can be reached fromevery other node in relatively small number of steps due to the presence of few longedges, resulting in a smaller separation among the nodes. On the other hand, thesegraphs have larger network average clustering coefficients compared to the randomgraph, as the neighborhood of every node has a higher likelihood ofbeing a clique.There are several ways to achieve small world characteristics by introducing regularityin a random graph or introducing randomness in a regular graph. Zaidi [4] haveintroduced cliques to increase the localclustering in a random graph to achieve this.On the other hand, WS transformed a regular graphinto asmall world network by means of random rewiring of edges, as presented in algorithm3.

```
Algorithm 3: Rewiring strategy I
  Input: Graph G = (V, E), probability p
  Output: G rewired as proposed by Watts and Strogatz (1998)
  for every v ∈ V do
      for every e_vw ∈ E where w ∈ N_v do
          Randomly choose a vertex u from V\N_v
          /* Add e_uv and remove e_vw with probability p                */
          Choose a random number r from Unif(0,1) distribution
          if r < p then
              E = (E ∪ {e_uv})\{e_vw}
              if G is not connected then
                  E = (E ∪ {e_vw})\{e_uv}
```

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

By connecting vertex u with some v $\notin N_u$ with probability p, a few long-range edges are introduced to create shortcuts within a graph, while removing an equal number ofconnections between v with N_v making the graph more irregular.For every node v,on average N_vp number of edges are rewired in this way, keeping the graph connected.Thus, pquantifies the randomness in a graph, with p = 0 indicating a regular latticeand p = 1 indicating a completely random graph.

IV. REAL-WORLD EMPIRICAL STUDY

A. Road Network

We have used Indian road network data and implemented the small world for four different cities.The dataset is taken from figshare repository which consists of humongous amount of real-worlddata. Each road network consists of millions of data. The dataset consists of X coordinate and Ycoordinate, which imply the UTM coordinates. From the UTM coordinates, the UTM zones of eachcities needs to be interpreted to find out the latitude and longitude of each location. The roadnetworks for Bengaluru and Kolkata and equivalent regular and random graphs based on algorithm1 and 2 have been displayed in figure 8. The results for the networks with 7246 nodesfor Bengaluru and 7840 for Kolkata have been presented in table 1 to show the pattern of thesmall world properties. We have worked on data from four different cities - Bengaluru,Kolkata, Delhi, and Chennai based on the largest connected components in the networks.The number of nodes considered have been reported along with the respectiveaverage shortest path length and network average clustering coefficients. The resultsshow that random networks have low average shortest path lengths and network averageclustering coefficient and regular networks have high average shortest path length andnetwork average clustering coefficient. Table 1 gives Road Network for Bengaluru with44.12960788 average path length and 0.02470749 clustering coefficient. When comparedwithRandom and Regular, results showed that average path length is 1019.528101 andclustering coefficient is 0.086044923 for regular. Whereas for Random it is 12.71167995and 0.000324537respectively. Thus, we can conclude that Bengaluru Road networkfollows small world pattern.Similarly, we analyzed the results for three other citiesnamely 1) Kolkata (Table 2); 2) Chennai (Table 3); and 3) Delhi (Table 4)and found that they follow small worldproperties as well.

Table 1: Experimental Results of Bengaluru.

City	**Bengaluru**	
Properties	Average Path Length	Clustering Coefficient
Regular Network	1019.528101	0.086044923
Road Network	44.12960788	0.02470749
Random Network	12.71167995	0.000324537

Table 2: Experimental Results of Kolkata.

City	**Kolkata**	
Properties	Average Path Length	Clustering Coefficient
Regular Network	948.5598709	0.111469627
Road Network	51.13700025	0.02017725
Random Network	11.37687838	0

Table 3: Experimental Results of Chennai.

City	**Chennai**	
Properties	Average Path Length	Clustering Coefficient
Regular Network	732.1600976	0.162148744
Road Network	35.32372148	0.03738457
Random Network	9.576695805	0.000129084

Table 4: Experimental Results of Delhi.

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

City	Delhi	
Properties	Average Path Length	Clustering Coefficient
Regular Network	675.7450857	0.141281099
Road Network	41.30730054	0.024631318
Random Network	9.999219813	0.000979399

Fig 4,5,6,7 shows the degree distribution of Bengaluru, Kolkata, Chennai, and Delhi respectively. We find that the most common degree of a vertex is 3, followed by degree 1, there are very few 4 and 2-degree nodes becauseaccording to our data, when the place is in two-wayroad, we have 2-degree nodes as we can travel from both directions. Naturally there will be few numbers with high degree nodes as four- or five-way roads are very less in real world, so the degree is less.

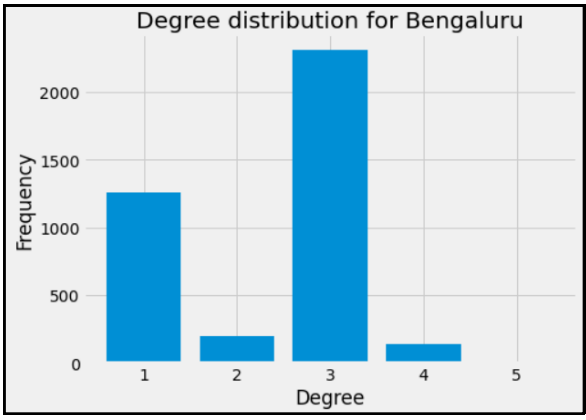


Fig.4.Degree Distribution of Bengaluru

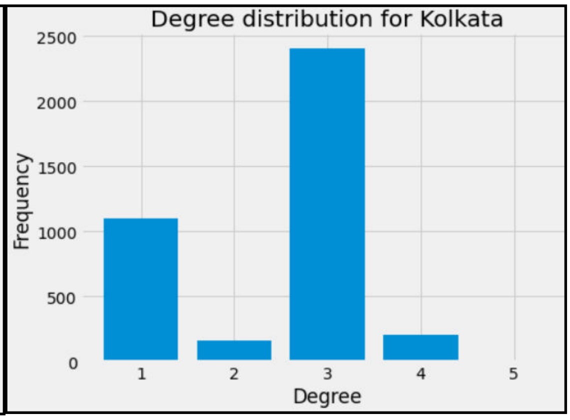


Fig.5. Degree Distribution of Kolkata

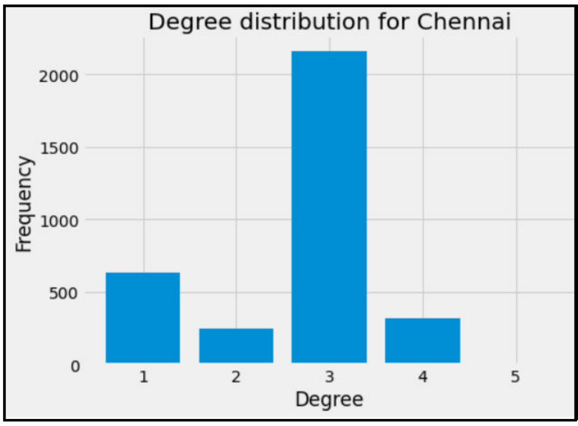


Fig.6. DegreeDistribution of Chennai

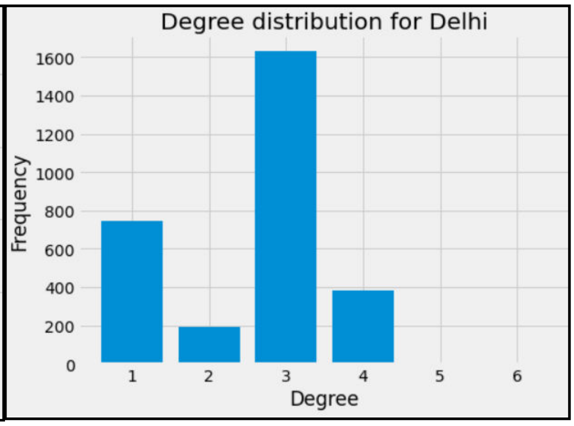


Fig.7. DegreeDistribution of Delhi

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

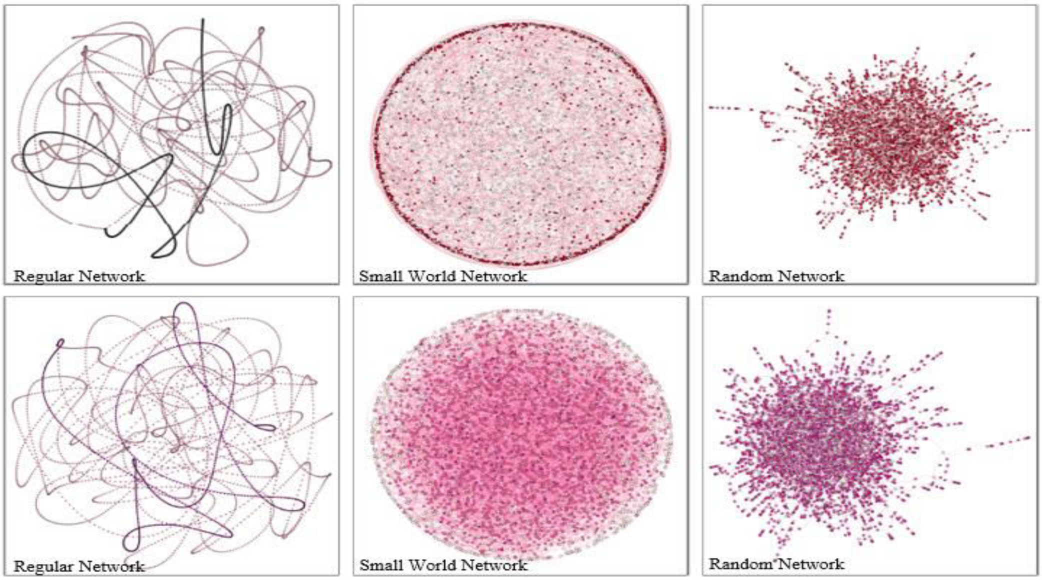


Fig.8.The top row represents the regular graph, road network and the random graphrespectively for Bengaluru, the bottom row represents the graphs for Kolkata.

B. Metro Network

Metro transit systems are composed of stations all linked by tracks; they are in essence physical networks. Metro networks, although being topologically simpler than many other networks, present some specific challenges, notably due to the existence of lines, as well as overlapping between the lines.By studying Delhi metro systems, we can effectively scrutinize transportation mediums and draw some conclusions on their characteristics. We have considered Delhi metro network for analysing small world characteristics, which has 261 Nodes and 274 Edges. We can see that Metro network do not exhibit small world properties. Table 5, shows that the clustering coefficient being zero, which means that the nodes are not densely connected and the average shortest path length being 21.03 which means to move from one place to another a person needs to visit at least 21 stops on an average. Hence, the results shows that metro network do not follow the small world phenomenon. The degree distribution of the metro network shows that the network has high number of 2-degree nodes while fewer number of high degree nodes.

Table 5: Experimental Results of Delhi Metro Network.

Properties	**Average Path Length**	**Clustering Coefficient**
Delhi Metro Network	21.03	0

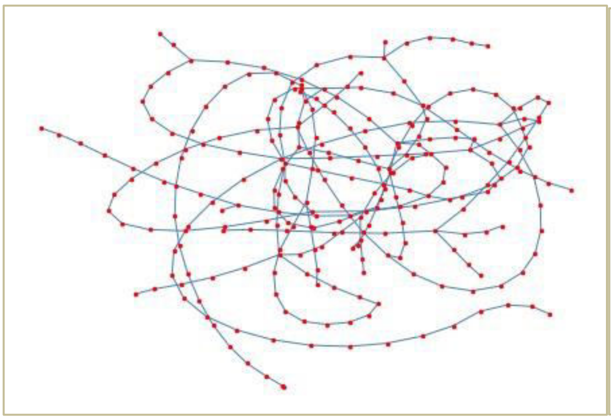


Fig. 9. Graph of Delhi Metro

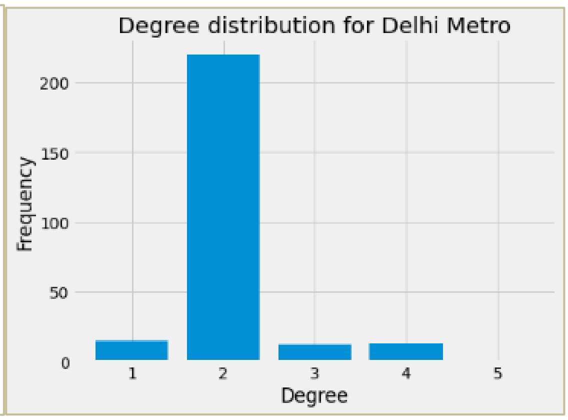


Fig. 10. Degree Distribution

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

C. Air Network

Air Transport Network is a network of air traffic between cities. The cities are represented by nodes and edges between two nodes represent that a direct flight exists from one city to the other, irrespective of the airports in the city. This network has attracted lots of researchers from the field of geography and transportation. The network is a simple, undirected graph which contains flight information from the year 2000. We have used the Open Flights/Airline Route Database. It Contains 59036 routes between 3209 airports on 531 airlines spanning the globe. We have considered air network with 3425 Nodes and 19,257 Edges. Different from metro networkresults,all the network features presented in table 6 confirms that air network has properties similar to small world characteristics. The average shortest path length is calculated to be 4.103, indicating that on a randomly chosen origin to destination path a traveler would need to visit about 4 airports on average. The clustering coefficient of the air network being 0.488 which is much larger than that of a random network and similar to regular network. This confirms the air network has a high probability of travelling with fewer stops or hops.

Figure 11 shows that there are few nodes with very high degree and most of the nodes are having very small degree which is clearly a small world pattern. Most common degree in this random network are 10,11and 12 and then it gradually decreases. The complex network analysis reveals that the air network can be classified as a scale- free small-world network and has a power law degree distribution.

Table 6: Experimental Results of Air Network.

Properties	Average Path Length	Clustering Coefficient
Regular Network	189.286	0.636
Air Network	4.103	0.488
Random Network	3.622	0.003

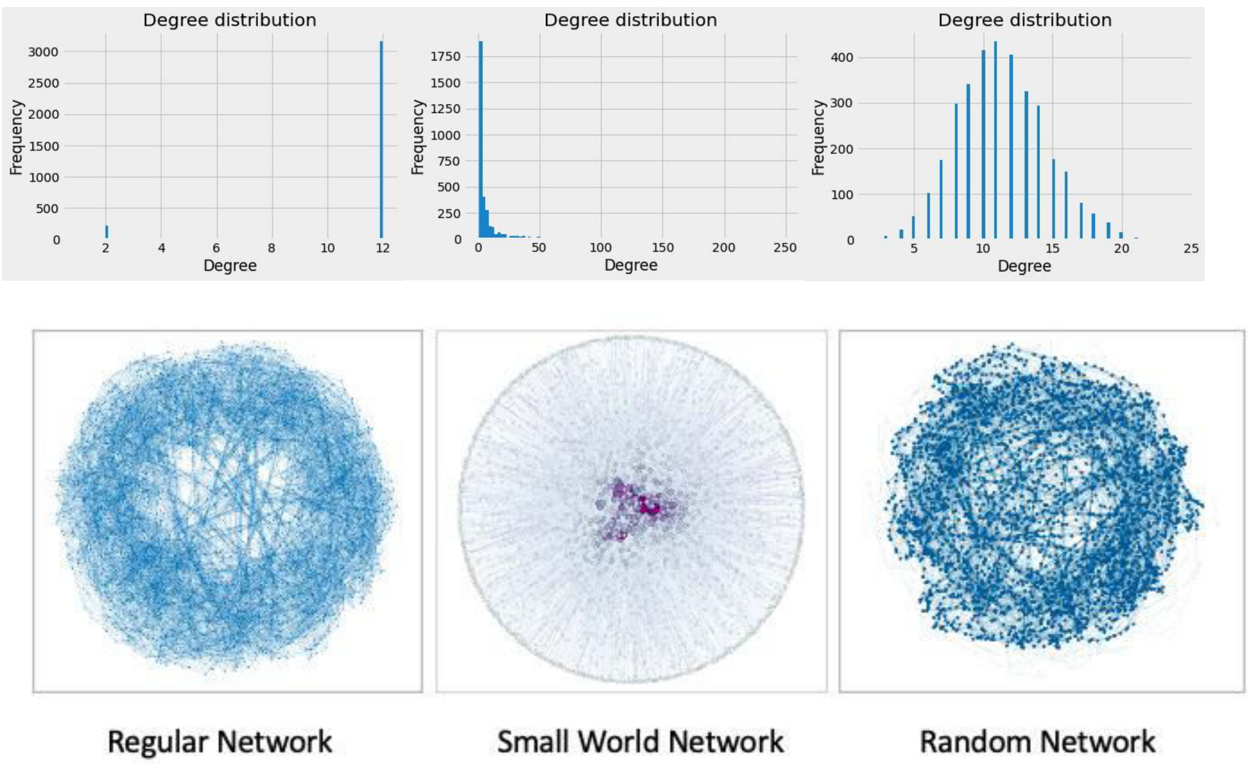


Fig. 11.The top row represents the degree distribution of regular, small world network and the random graphrespectively for global air network, the bottom row represents the graphs for the respective models.

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

V. Conclusion and Future Work

In summary,thetransportation network features studied using can be used to improve transportation planning and traffic management to provide effective way to transport goods and services across the countries. The three metrics studied in this paper are: clustering coefficient, degree distribution and average path length. The importance of these quantities has been first defined and emphasized by empirical studies of real-worldtransportation networks. Stimulated by the high clustering and small average path length observed in real-world networks, this paper presents a combination of analytical results, empirical work and simulations regarding small-world network models and their average path length.Road networkwith small average path length, and high clustering coefficient in a good agreement with the empirical study of real-world networks. However, they lack the scale-free degree distribution observed in real-world networks. Whereas the Delhi metro network does not exhibit small world properties. On the other hand,we also analyze the global air transportation network to better understand its large-scale characteristics. The air transportation network exhibits small-world characteristics. Moreover, an important finding is that, on average, travelers experience 4 transfers before reaching their destinations and they follow power law distribution.

In addition to analyzing the network features, the resilience capabilities can be studied in detail. Based on the analysis of the complex network theory, the dynamic analysis of the network can be carried out.The analysis of the topology of the traffic network, and the small world or scale-free characteristics of the traffic network can be analyzed.Such an analysis would be extremely beneficial to the transportation industry in achieving high efficiency when roads areunder constructions, unforeseen delays/cancellations or traffic congestions occurs. Likewise, we may consider the distance between airports for link weights. Finally, we may consider finer granularity of the time for seasonal analysis.

References

[1] D. Watts and S. Strogatz, "Collective dynamics of," *Nature*, vol. 393, no. 6684, pp. 440–442, 1998.
[2] Stanley Milgram, "The Small World Problem," *Electr. Commun.*, vol. 1, no. 1, pp. 61–67, 1967.
[3] J. Kleinberg, "The Small-World Phenomenon: An Algorithmic Perspective * STOC 2000 Portland Oregon USA," pp. 163–170, 1999.
[4] F. Zaidi, "Small world networks and clustered small world networks with random connectivity," *Soc. Netw. Anal. Min.*, vol. 3, no. 1, pp. 51–63, 2013.
[5] H. Dai, S. Gao, Y. Yang, and Z. Tang, "Effects of 'rich-gets-richer' rule on small-world networks," *Neurocomputing*, vol. 73, no. 10–12, pp. 2286–2289, 2010.
[6] D. Wang, Y. Xue, Q. Zhang, and M. I. N. Niu, "Scale-free and small-world properties of a special hierarchical network," *Fractals*, vol. 27, no. 2, 2019.
[7] A. G. Soriano-Sánchez and C. Posadas-Castillo, "Smart pattern to generate small–world networks," *Chaos, Solitons and Fractals*, vol. 114, pp. 415–422, 2018.
[8] J. Alstott, C. Klymko, P. B. Pyzza, and M. Radcliffe, "Local rewiring algorithms to increase clustering and grow a small world," *J. Complex Networks*, vol. 7, no. 4, pp. 564–584, 2019.
[9] M. Boguñá, D. Krioukov, P. Almagro, and M. Á. Serrano, "Small worlds and clustering in spatial networks," *Phys. Rev. Res.*, vol. 2, no. 2, pp. 1–10, 2020.
[10] M. B. C. Menezes, S. Kim, and R. Huang, "Constructing a Watts-Strogatz network from a small-world network with symmetric degree distribution," *PLoS One*, vol. 12, no. 6, pp. 1–9, 2017.
[11] L. Luo and J. Fang, "A study of how the Watts-Strogatz model relates to an economic system's utility," *Math. Probl. Eng.*, vol. 214, 2014.
[12] I. Sohn, "Modeling and implementing small world network," *2016 Int. Conf. Inf. Commun. Technol. Converg. ICTC 2016*, pp. 414–416, 2016.
[13] F. Ma and B. Yao, "A family of small-world network models built by complete graph and iteration-function," *Phys. A Stat. Mech. its Appl.*, vol. 492, pp. 2205–2219, 2018.
[14] H. Du, J. Fan, X. He, and M. W. Feldman, "A Genetic Simulated Annealing Algorithm to Optimize the Small-World Network Generating Process," *Complexity*, vol. 2018, 2018.
[15] V. Latora and M. Marchiori, "Efficient behavior of small-world networks," *Phys. Rev. Lett.*, vol. 87, no. 19, pp. 198701-1-198701–4, 2001.
[16] A. A. De Bona, M. de Oliveira Rosa, K. V. Ono Fonseca, and R. Lüders, "A reduced model for complex network analysis of public transportation systems," *Phys. A Stat. Mech. its Appl.*, vol. 567, p. 125715, 2021.
[17] C. Hong, J. Zhang, X. Bin Cao, and W. B. Du, "Structural properties of the Chinese air transportation multilayer network," *Chaos, Solitons and Fractals*, vol. 86, pp. 28–34, 2016.

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 7.542 |

|| Volume 9, Issue 6, June 2021 ||

| DOI: 10.15680/IJIRCCE.2021.0906232 |

[18] W. Wang *et al.*, "Analysis of the Chinese railway system as a complex network," *Chaos, Solitons and Fractals*, vol. 130, 2020.

[19] C. Wu and I. Kim, "Analyzing the structural properties of bike-sharing networks: Evidence from the United States, Canada, and China," *Transp. Res. Part A Policy Pract.*, vol. 140, no. August, pp. 52–71, 2020.

[20] M. Li and J. Han, "Complex Network Theory in Urban Traffic Network," vol. 123, no. Msmee, pp. 910–913, 2017.

[21] V. Latora and M. Marchiori, "Is the Boston subway a small-world network?," *Phys. A Stat. Mech. its Appl.*, vol. 314, no. 1–4, pp. 109–113, 2002.

[22] L. Siozos-Rousoulis, D. Robert, and W. Verbeke, "A study of the U.S. domestic air transportation network: temporal evolution of network topology and robustness from 2001 to 2016," *J. Transp. Secur.*, 2021.

[23] Z. Yang, H. Zhou, P. Gao, H. Chen, and N. Zhang, "The Topological Analysis of Urban Transit System as a Small-World Network," *Int. J. Comput. Intell. Syst.*, vol. 4, no. 6, pp. 1216–1223, 2011.

[24] J. Li, P. Zheng, and W. Zhang, "Identifying the spatial distribution of public transportation trips by node and community characteristics," *Transp. Plan. Technol.*, vol. 43, no. 3, pp. 325–340, 2020.

[25] L. N. Wang, K. Wang, and J. L. Shen, "Weighted complex networks in urban public transportation: Modeling and testing," *Phys. A Stat. Mech. its Appl.*, vol. 545, p. 123498, 2020.

[26] Gilbert, E. N. "Random Graphs," *The Annals of Mathematical Statistics, vol. 30(4*), 1959.

[27] Erdos, P. and A. Renyi. "On random graphs," *Publications Mathematics,vol. 21(1),* 1959

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING