Mathematical Analysis on Topological Community Properties of the Liquefied Natural Gas Seaport Networks

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Abstract. The method analysis hub degree properties of Chinese Liquefied Natural Gas Seaport Networks is studied by the networks complexity theory in this paper. Furthermore, the Chinese liquefied natural gas seaport network hub degree is combined by actual shipping conditions. Especially, the degrees, weights characteristics and modular properties are mainly studied in Chinese Liquefied Natural Gas Seaport Networks. This research on Liquefied Natural Gas Seaport hub degree and weight characteristics can improve economic benefits. Here, we use information about the itineraries of liquefied natural gas seaports during the year 2010-2018 to construct a network of links between liquefied natural gas seaports. The network has several features that set it apart from other transportation networks are shown.

Introduction

Natural gas as an efficient, clean energy. Liquefied natural gas systems are a great importance to the development of our country. Furthermore, they are important indicators of its economic growth. Liquefied natural gas systems affect the industry, the people of the country, the national economy. During the past few years, complex network analysis has been used to study transportation systems. In this paper, we study the statistical properties of the liquefied natural gas seaport networks of China in which the nodes are ports and the links are passenger liners connecting the ports. Based on two different representation of network topology-the space L and space P, where in the space L two ports are considered to be connected if they are consecutive stops on a route of at least one ship while in the space P two seaports are connected when there is at least one ship which stops at both seaports, we explore scaling laws and correlations that may govern intrinsic features of LNG seaport networks. The research results show that the degree distribution in the space L follows a power law. Recently, China’s exports are expected to increase with LNG seaport construction destined for international economic markets. LNG seaports like Tianjin, Shanghai, Guangxi, Jiangsu, Zhejiang and Shen Zhen are predicted to join the ranks of the top 6 biggest LNG seaports of the China in terms of throughput. LNG trade volumes are predicted to rise from 2006 to 2018.

In this paper, we present an investigation of the Chinese liquefied natural gas seaport networks (CLNGSN). Recently, R. Guimerà, S. Mossa, A. Turtsci, and L. A. N. Amaral (2005) provided a brief review of the worldwide air transportation network. M. Barthélemy and A. Flammini (2006) discussed the worldwide air transportation network: anomalous centrality, community structure and cities’ global roles. Govert E. Bijwaard, Sabine Knapp (2009) Analysis of ship life cycles—The impact of economic cycles and ship inspections. Mak, Sheehy, and Toriki (2010) discussed the application of Passenger Vessel Services Act (PVSA) of 1886 to the US cruise ship industry. Taedong Lee, Hyun Jung Kim (2015) study the barriers of voyaging on the Northern Sea Route: A perspective from shipping Companies. Here, we consider the Chinese Liquefied Natural Gas Seaport Networks (CLNGSN), which comprises 18 sea ports in different locations. We have gathered the ship schedule information from the Internet. The nodes of the network are the ports and the edges are the lines connecting them along the route.

The rest of this paper is organized as follows. Section 2 gives the notation and problem description. Section 3 proposes complex properties, simulation and results of the Chinese liquefied natural gas seaport networks (CLNGSN). Furthermore, the numerical experiments based on the...
Chinese liquefied natural gas seaport networks (CLNGSN) are carried out. Finally, the conclusion is given in Section 4.

Notation and Problem Description

The Chinese Liquefied Natural Gas Seaport Networks

We will implement different scenarios by considering different A. We assume the Chinese liquefied natural gas seaport networks (CLNGSN) considered in this paper are built, owned and operated by citizens of country A. The set of seaports, which can be further classified into two disjoint subsets: the set of hub seaports denoted by PC and the set of feeder seaports PF. The maritime cabotage legislations in liner H& S shipping network design can be simply described by introducing an indicator for each pair of seaport i and port j ($i,j \in P$). If ships of country A are allowed to directly transport containers from seaport $i$ to seaport $j$; $c_{ij}$ is equal to 1; otherwise $c_{ij}$ is 0 of Chinese liquefied natural gas seaport networks (CLNGSN).

The Directed Network of the Entire LNG Fleet

The directed network of the entire LNG fleet is noticeably asymmetric, with 76% of all linked pairs of seaports being connected only in one direction. Still, the vast majority of seaports belongs to one single strongly connected component, i.e. for any two seaports in this component there are routes in both directions, though possibly visiting different intermediate ports. The routes are intriguingly short: only few steps in the network are needed to get from one port to another. The shortest path length between two seaports is the minimum number of nonstop connections one must take to travel between origin and destination.

The community structure of CLNGSN can be symbolized by an asymmetrical weight matrix $W$ whose weight element $W_{ij}$ is the number of LNG transport liners traveling from seaport $i$ to seaport $j$. We should note that the weight element $W_{ij}$ includes the contribution from the direct ship transportation between the nodes $i$ and $j$ without middle stops.

The weights $W_{ij}$ denotes the link $(i,j)$ when the LNG demand flow, and $w_{ij}$ assumed randomly in the range $[0,1]$ for each link in our simulations.

First, we employ $k$ to denote the degree of a given node $i$ for directed CLNGSN to represent the undirected degree of the CLNGSN in the same network topology. The degree of seaport $i$ stand for number of seaports. The CLNGSN consists of nodes representing seaports and links between two nodes exists if they are consecutive stops on the route. The node degree $k$ in this topology is just the number of different ship routes one can take from a given seaport. An edge between two nodes means that there is a ship schedule traveling between them. From which one can arrive at seaport $i$ and the number of seaports that can be reached from seaport $i$, respectively. Using the weighted matrix, we can write these quantities as follows:

$$k_i = C_{i,j}w_{ij}$$  \hspace{1cm} (1)

and

$$S_i = aibj\sum_{j=1}^{J}w_{ij}d_{ij}$$  \hspace{1cm} (2)

Where $C_{i,j}$ is a unit step function, and $a$ and $b$ are coefficients, which takes 1 for $x>0$ and 0 otherwise. If $d_{ij}$ is the distance between ports $i$ and $j$, the decline in mutual interaction is expressed in terms of a distance deterrence function $S_i = aibj\sum_{j=1}^{J}w_{ij}d_{ij}$.

Similarly, we can also obtain the above equations. As the CLNGSN network is a directed connected network with 18 nodes, we report the size of the giant strongly component defined. We find that the strongly connected component, i.e., every pair of seaports is connected in both
directions, comprises 18 seaports. The sizes of the component are found to be 18. This indicates that the corresponding adjacency matrix for the network is almost symmetrical. Next, we consider the LNG demand flow of the weighted CLNGSN networks. We define the total LNG demand flow coming into node $i$ as the strength.

The large amount of LNG demand flow in both spaces suggests that database is highly redundant in its topological structure; i.e., most connections between pairs of ports are represented by more than one ship. This makes the analysis of network topology reliable.

**Simulation and Results**

In our simulations, the network topologies considered here are lattice networks as the example of regular networks, random networks generated by Chinese liquefied natural gas seaport networks (CLNGSN) model (The rewiring probability is 0.1 here). The average degree $<k>$ of the four networks is $<k> = 5$ (i.e., $m = 3$), as it resembles typical crossroads. The size of the generated network varies from 60 to 100. All the resulting data is averaged more than 10 realizations.

A common measure for investigating the performance of Chinese liquefied natural gas seaport networks (CLNGSN) can be characterized. Numerically investigating the Chinese liquefied natural gas seaport networks (CLNGSN) demand flows assignments over three ship types (container ships) topologies, it suggests that both the assignment strategy of Chinese liquefied natural gas seaport networks (CLNGSN) and the topology work significantly on container and LNG demand flows (the node degree) distribution, as shown in Fig.2.

![Figure 1. The relationship of weight in the Chinese liquefied natural gas seaport networks from the year 2006 to 2018 (CLNGSN).](image1)

![Figure 2. The relationship of demand strength for the Chinese liquefied natural gas seaport networks from 2006 to 2018.](image2)

The Fig.1 shows the relationship of weights of CLNGSN networks from the year 2006 to 2018. In the Fig.1, the vertical axis represents the weights and the horizontal axis, the year of the act-size. The solid cycles denote the empirical data.
The Fig. 2 shows the distribution of accumulative demand strength for CLNGSN from the year of 2006 to 2018. In the Fig.2, the vertical axis represents the weights, and the horizontal axis, a certain number of the years (from 2006 to 2018). The solid cycles denote the empirical data. The solid line the least-square fitting.

Study of Chinese LNG seaport networks have triggered tremendous interest in recent years. One of the salient features of Chinese LNG networks is the presence of communities, or groups of densely connected nodes. community detection can not only help to understand the topological structure of Chinese LNG networks, but also provide new techniques for real applications, such as data mining. We show that the LNG seaport network has several features that set it apart from other transportation networks. In particular, LNG seaport network has the community feature. The network of all ship movements possesses a heavy-tailed distribution for the connectivity of seaports and for the LNG loads transported on the links with systematic differences. It is found that geographical constraint plays an important role in the network topology of STNC. We also study the traffic flow of STNC based on the weighted network representation, and demonstrate the weight distribution can be described by power law or exponential function depending on the assumed definition of network topology.

![Figure 3](image1.png)

Figure 3. The relationship of weight w and P(w) in the Chinese liquefied natural gas community seaport networks from the year 2006 to 2018.

![Figure 4](image2.png)

Figure 4. The relationship of strength s and P(s) in the Chinese liquefied natural gas seaport networks from the year 2006 to 2018.

In conclusion, we have analyzed the statistical properties of Chinese liquefied natural gas community seaport networks. We explore scaling laws and correlations that may govern intrinsic features of such network. The topological properties, including the clustering distribution, degree distribution, the shortest path length, centrality and betweenness prosperities are studied in the space L and P respectively. The degree distribution of the Chinese liquefied natural gas community seaport networks follow a power law or truncated power law depending on the network topology.
definition. The degrees are negatively correlated in the space $L$ while positively correlated in the space $P$, which can be confirmed by the measured values of degree correlation coefficient. Large scale behavior is observed in the topologies but it is much more distinct in the space $P$ and the hierarchical structure of LNG community seaport network is also deduced from the behavior of the LNG community seaport networks. The relative large value of the average path length compared to the randomized version of LNG community seaport indicates that the geographical constraint is strong in the case of our LNG seaport community networks.

Summary

In conclusion, we have analyzed the statistical properties of Chinese liquefied natural gas seaport networks. We explore scaling laws and correlations that may govern intrinsic features of such network. The topological properties, including the degree distribution, weight and strength are studied. Our results indicate that nodes with high memberships play a central role in these networks. Furthermore, our investigations revealed interesting differences between the two types of networks concerning the dependence of the centrality measures on the relative out-degree of module members (the ratio of out-degree versus number of all nearest neighbors within the modules).

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References


