ARTICLE IN PRESS

Transportation Research Part E xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

Determinants of port centrality in maritime container transportation

Yuhong Wang [a], Kevin Cullinane [b,*]

[a] Transport Research Institute, Edinburgh Napier University, Edinburgh, UK
[b] School of Business, Economics and Law, University of Gothenburg, Gothenburg, Sweden

ARTICLE INFO

Article history:
Received 21 September 2015
Received in revised form 30 March 2016
Accepted 11 April 2016
Available online xxxx

Keywords:
Port centrality
Degree
Closeness
Betweenness
Weighted network

ABSTRACT

This paper adapts Freeman's measures of degree, closeness and betweenness centrality and applies them to assessing: port centrality in relation to direct connectivity; accessibility to all ports in the network (direct and indirect routes) and; as an intermediary between other ports. An additional parameter added to the formulae ensures that the relative importance of available shipping capacity and foreland market coverage are also accounted for. Validation of this adapted measure is provided by the results obtained from an empirical application. These reveal that foreland market coverage exerts a particularly strong influence on a port's demand and closeness centrality.

1. Introduction

Centrality is a fundamental concept in network analysis, and is often utilized as an indicator for assessing the relative importance and/or influence of a vertex within a graph. It has now been widely applied in various disciplines including communication system (Burgess, 1968; Pitts, 1979; Hagen et al., 1997), transport infrastructure (Holme, 2003; Guimerá et al., 2005; Paul, 2011), social science (Cohn and Marriott, 1958; Granovetter, 1974; Valente and Foreman, 1998) and so on.

The application of the centrality concept in maritime container transportation, in particular to the port sector, has already been addressed in the literature. Fleming and Hayuth (1994) first introduced port centrality as a locational attribute indicative of the strategic role of each port within a transportation system. It was defined as the locational advantage within the market area the port serves. In other words, if the port is located in the midst, rather than being on the periphery, of a large hinterland, then the more central port has an advantage in attracting extra traffic generated from that hinterland. For example, Shanghai versus Xiamen in Eastern China and Antwerp versus Le Havre with respect to the North-West European market.

An additional indicator termed 'intermediacy' was also developed by Fleming and Hayuth (1994) in order to represent the natural geographical 'in betweenness' of a port in connecting more than one foreland markets. As claimed in their study, intermediate ports can attract extra traffic if they are favoured by carriers as connecting hubs or relay points in the system. Typical examples are the ports of Hong Kong or Singapore, which are strategically located in favourable intermediate positions along major sea trade routes. From a practical perspective, according to network theory, intermediacy might be viewed as an extension of node/port centrality from a local effect to a more global scale within the network/maritime transportation system, namely 'betweenness centrality' (Freeman, 1979; Freeman et al., 1991).

* Corresponding author.
E-mail address: kevin.cullinane@gu.se (K. Cullinane).

http://dx.doi.org/10.1016/j.tre.2016.04.002
1366-5545/© 2016 Elsevier Ltd. All rights reserved.

Please cite this article in press as: Wang, Y., Cullinane, K. Determinants of port centrality in maritime container transportation. Transport. Res. Part E (2016), http://dx.doi.org/10.1016/j.tre.2016.04.002

The concept of port centrality has greatly facilitated practical research related to port development and inter-port relationship issues. For example, the feature of port 'betweenness centrality' has been utilized by McCalla (2008) in identifying the potential of developing Kingston port as a regional hub serving the Caribbean Basin. Wang and Cullinane (2008) examined the relationship between the competitiveness of a port and its accessibility to the foreland market, where the latter refers to the potential or opportunity for the transportation of containerised cargo through the port and is called node centrality within the context of network theory. Ducruet et al. (2010), Ducruet and Notteboom (2012) and Laxe et al. (2012) all provide further evidence of the effectiveness of port centrality in determining a port hierarchy and in indicating all the attributes underpinning it. Port centrality represents a port's ability to attract both cargo traffic from its hinterland area and liner shipping services from its foreland market. In other words, port centrality may be viewed as a spatial quality within the market arena the port serves, and hence indicates how ports are strategically located within the container transportation system.

A major shortcoming of existing port centrality studies is that there is little or no comprehensive quantitative benchmarking available for empirical assessments. This is because most previous research is either based solely on qualitative comparisons, or utilizes adopted measures developed in social network analysis, but with limited consideration of the 'directed' and 'weighted' network features of maritime container transportation. In practice, this may lead to the drawing of inappropriate conclusions because: (a) some measures are initially designed for a binary network only (e.g. Freeman's three node centrality measures); (b) the network adjacency matrix becomes asymmetric when service direction is accounted for and, more importantly; (c) the node centrality of a weighted network should be assessed on the basis of a combined consideration of the relative importance of both edge weights and the number of edges associated with the nodes (Opsahl et al., 2010).

This paper aims to develop a unified framework for the mensuration of port centrality. A set of criteria in applying centrality assessments will be identified on the basis of the characteristics of maritime container traffic flow movements. Secondly, measures of port centrality are proposed to assess the relative importance of individual ports across three key dimensions: being physically connected to others, being directly and indirectly accessible to others, and being the intermediary (i.e. for transhipment) between others. As a consequence, the centrality metrics of degree, closeness, and betweenness are correspondingly adapted by giving due consideration to both connection strength (i.e. available capacity) between pairs of ports and the number of direct foreland connections available to ports. By so doing, a centrality index will be helpful in revealing how individual ports are competitively positioned within the maritime container transportation system, with each component showing the contributions to the index.

The overriding intended contribution of this work is to improve the applicability of centrality measurement within the context of the maritime container shipping industry. An enhanced assessment process is presented, based on multiple perspectives into how each port is competitively positioned against each other within the system of interest. As such, port centrality assessment need no longer be limited to simple individual indicators to address a port's position within its surrounding system. In developing this enhanced port centrality assessment process, two important technical developments are introduced that account for (a) foreland market coverage in port centrality assessment, and (b) the relative influence of foreland market coverage in each centrality assessment.

Following this introduction, Section 2 provides a brief review of the centrality metrics developed in previous studies, and identifies their applicability to this research. Section 3 deals with the theoretical framework and methodology employed. Section 4 comes with an empirical application to a sample network consisting of 39 major container ports on the East–West trade route. Finally, the implications of the research findings and some conclusions are drawn in Section 5.

2. Measures of centrality and applications to container ports

Centrality is one of the most studied concepts in social network analysis. From binary to directed and weighted social networks, numerous indices to measure node centrality (i.e. to identify which node is more 'central' than others) have been developed on the basis of various implicit assumptions about the manner in which flows move through networks (Borgatti, 2005).

These measures might be generally classified into four basic categories relating to different perspectives on defining 'centrality'. In the simplest and the most intuitive case, the number of direct connections associated with a node reflects its importance within a network. Degree-based centrality, introduced by Shaw (1954) and generalized by Garrison (1960), Nieminen (1973) and others, is a standard representative approach. This interpretation, however, does not take into account any indirect links. The second view of node centrality is based on the concept of control of communication, in that a node in the most central position in a network would 'spread' (e.g. information, container cargoes, etc.) throughout the entire network in minimum time (Bavelas, 1948). As developed by Bavelas (1950), Beauchamp (1965), Sabidussi (1966) and Rogers (1974), a representative of this approach is closeness-based centrality, which is determined by the sum of the distance (i.e. the length of the shortest-path from one to another) from all other nodes. The third view of node centrality is also related to the control of communication, but in a somewhat different way; when a node is located strategically on the communication path linking pairs of other nodes, then the node under consideration is deemed to be central (Bavelas, 1948; Shaw, 1954). The most well-known representative of this approach is betweenness-based centrality, which measures the extent to which a particular node lies between other nodes in a network (Freeman, 1977). A node tends to be more powerful if it is on the shortest paths connecting many node-pairs, as it may be in a position to broker or mediate connections between pairs.