Journal of Transport Geography 56 (2016) 53–61

Contents lists available at ScienceDirect

Journal of Transport Geography

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

Spatial coverage index for assessing national and regional transportation infrastructures

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ARTICLE INFO

Article history:
Received 22 June 2014
Received in revised form 21 June 2016
Accepted 16 August 2016
Available online xxxx

Keywords:
Transportation system spatial coverage
Spatial indicators
Infrastructure and service spatial coverage
GIS
National and regional indicators

ABSTRACT

Development of the transportation planning process at various decision levels (strategic, tactical, and operational) has strengthened the need for specific indicators as the basis for decision-making. Within the decision-making structure, however, the most popular indicators for national and regional analysis (i.e., extension, density) are still based on a legacy of limited technology and data availability. Growth in spatial of technologies, such as GIS, and reliable georeferenced databases can support new approaches to analyzing those indicators that shed light on infrastructure and service availability frameworks. This paper synthesizes and expands the former Roadway Coverage Index (RCI) as a Transport Spatial Coverage Index (TSCI) based on the concepts and characteristics of specific indicators, using the currently available tools, and taking into account network spatial behavior. Based on its structure, the TSCI is more robust and reliable than other approaches (network extension, spatial density, and population density), and it also has sound and convenient features for planners and decision makers towards national and regional infrastructure planning.

1. Introduction

Latin America historically has struggled to meet the demands of the intra- and international connectivity necessary to strengthen economic links at multiple scales. A broad understanding exists of the region's transport infrastructure weaknesses and of the level of investment needed to connect local, national, and regional economies more effectively to the global system (Keeling, 2013; Ramirez, 2014). Organizations like the Initiative for the Integration of the Regional Infrastructure of South America (IIRSA, 2012) have focused specifically on these regional connections, comprehending countries with strategic physical geography, expanding economy, and rapidly growing global trade relationships (Scholvin and Malamud, 2014) Latin transport planners and infrastructure strategists have enjoyed some notable successes in recent years, with urban rapid transit, port redevelopment, and rural road construction driven by the goals of various national plans for logistics and transportation (Gregoire, 2011). Additionally, infrastructure investments represent an important driver for significant capital flux in current globalized world - e.g. large Chinese $50bi investment fund for financing Brazilian infrastructure reported in the international media by Canes and Chagas (2015).

A significant challenge for national- and regional-level transport planners is determining the most important indicators that shape the infrastructure planning process. When dealing with planning frameworks, decisions should be based on meaningful measures of transport data called 'indicators' (Morris et al., 1979; Segnestam, 2002; FCM, 2002; OECD, 2003; Magalhães, 2004; BRASIL, 2007a). Indicators are entry level elements for the decision-making process, and they serve as the basis for policies, goals, programs, plans, and procedures. Therefore, they must address the information needs of the stakeholders involved, which are often limited just to basic data availability.

Although focused on the concept of 'accessibility', Morris et al. (1979) established an important methodological step for dealing with prospective indicators: how to choose appropriate indicators for evaluation. In other words, before choosing any measure, one has to specify a set of criteria to represent adequately the concept one aims to develop. An example of how this has unfolded is the Result-Oriented (Outcome) Indicators System for Transportation Planning elaborated for the Brazilian Ministry of Transportation (BRASIL, 2007a, 2007b; Magalhães et al., 2007; Silveira et al., 2008). The main advance of this approach is that it advocates not only that a set of standards has to be defined, but also that standardization of survey procedures is required. It also established a full, decoupled results-oriented set of relevant measures, all organized into three categories: mobility, efficacy of transportation, and efficiency of transportation (BRASIL, 2007a; Magalhães et al., 2007).

In terms of representing transportation systems through indicators, a common feature has been to highlight the spatial coverage of a transportation system. The most used measures are Network Length and Network Density, and they have been broadly used at both international and intra-national scales. In Australia, for example, the CGC (2006) used Network Length, Density, and Network Density by population as a comparative parameter for assessing accessibility in each Australian state. A similar application of such measures is found in a study by India's

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http://dx.doi.org/10.1016/j.jtrangeo.2016.08.015
0966-6923/

Ministry of Transport and Highways (Government of India, 2012), where Network Length and density measures were used for both international comparisons and comparisons between Indian states. The same measures were also used by the OECD (2012) in comparing the evolution of transportation networks in different countries.

Despite its simplicity and popularity as spatial transportation coverage indicators, Network Length and Density (and any other network length-based measure) show incongruences when confronted with the spatiality of both transportation systems and territories. For example, they may attribute zero value where such a measure would not be adequate. Such incongruences are called the "All-or-Nothing Problem", and are caused by how computation works for each indicator. Remarkably, this problem has been overlooked in the majority of the studies on transportation indicators.

The development of analysis tools, such as Business Intelligence - BI, Geographic Business Inteligence - GEOBI, Geographic Information Systems - GIS, and Global GeoDatabases – GEODB, opens new perspectives to spatially conceived transportation indicators and also the possibility for cross-national comparisons (International Steering Committee for Global Mapping, 2014).

The idea behind the proposed measure was first outlined by Magalhães (2004) as a research side-result. Since then, there have been a couple of well-directed and interesting applications of the index, though restricted to roadways and referred to as IC_{Rodo} (Índice de Cobertura Espacial), or RCI – Roadway Coverage Index. Examples of such are Pinto (2011) and the recently published research paper from Rodrigues da Silva et al. (2014). It is important to stress that, apart from the original document in Portuguese, no other research paper has focused on the theory and method behind the RCI.

This paper aims to present the foundations and methods behind TSCI (as an expansion of RCI), and to advocate it as an alternative to Network Length and Density as measurements of regional-level transportation network spatial coverage not affected by the All-or-Nothing problem. As demonstrated, this indicator is robust and spatially conceived and it can be applied to different modes and geographical aggregations (countries, states, municipalities, or any other area). It also takes advantage of the increasing availability of worldwide geographical databases on transport infrastructure. The paper also aims to demonstrate the use of the proposed indicator for diagnosing the spatial coverage of both roadway and railway networks to support National-level infrastructure investment decisions.

2. What are good indicators?

The term 'indicator' is broadly referred to in many diverse planning environments, be they academic, professional, public, or private. This is mostly due to the popularization of the strategic planning process, which involves different decision levels (strategic, tactical, and operational), and information management, which aims to deliver the correct information where it is needed, to who needs it, and when it is needed.

Indicators are representative, concise, and easy-to-understand parameters that are used to represent the main characteristics of a given object under analysis (CEROI, 2004). Indicators can also be understood as variables derived from a very scientific configuration yet invested with additional meaning to reflect a social concern or issue, so as to insert them more coherently into the decision-making process (MMA – Espanha *apud* Royuela, 2001).

Royuela (2001) proscribed the functions of indicators as: (*i*) to provide information on the problems to be addressed; (*ii*) to support the development of policies and definition of priorities and key-issues; (*iii*) to allow the monitoring of defined actions, especially those of integration; and (*iv*) to be a tool for sharing and spreading information to every level and agent.

However, not every "measure" is worthy of being called an "indicator." The Organization for Economic Co-operation and Development (OECD, 2002) proposed that good indicators must comply with the following requirements (Table 1):

Table 1
Requirements for good indicators.
Source: Adapted from OECD, (2002).

1. Policy relevance and utility	1.1. Representativity
	1.2. Simplicity
	1.3. Responsive to changes
	1.4. Provide base for comparison
	1.5. Broad scope
	1.6. Existence of reference values
2. Analytical soundness	2.1. Scientific basis
	2.2. Based on international standards and consensus
	2.3. Usable in economic, forecast models and information systems
3. Measurability	3.1. Feasibility - time and resources
	3.2. Properly documented
	3.3. Regularly updated

Morris et al. (1979) have gone further, detailing each requirement an indicator should comply with in order to be a good measurement for a particular feature. On what concerns the spatial coverage (or availability) of a transportation network, akin to Morris et al. (1979), the Brazilian Ministry of Transportation (Brasil, 2007b) has set the following criteria, and these are used as a reference for this paper:

- To reflect different levels of spatial coverage (or availability), depending on the proximity to a system's access points;
- To allow aggregation by mode of transportation;
- To allow aggregation by passenger or cargo;
- To allow temporal aggregation;
- To be georeferenced.

3. Transport network spatial influence, spatial coverage measures, and the All-or-Nothing problem

Network Length and Density measures are easy to calculate by simple use of a spreadsheet. However, despite the advent of GIS systems, their computation methodology has stayed quite unchanged. It is important to note that the new technology and databases have given rise to new kinds of problems, including how to estimate the length of a network (Commonwealth of Grants Commission of the Australian Government, 2006). Also, it is in GIS environments that the "All-or-Nothing Problem" becomes evident.

3.1. The spatial dimension of a network

Taaffe et al. (1996) and Rodrigue et al. (2006) advocate that all modes of transportation develop different spatial behaviors, especially when their impact on the spatial organization of territory is analyzed. Mumford (1989) analyzed impacts of the road network on the development of urban areas and noted that they develop a linear pattern, forming an occupation buffer along all its length. This behavior is entirely different from that of port, airport, or railway networks, which tend to display a more concentric pattern. Fig. 1A shows the growth pattern of a human agglomeration along a road network (which resembles the development of the urban area based solely on roadways), while Fig. 1B illustrates a pattern based on concentric development (as it happens on cities influenced by railway stations, e.g.).

Thus, planners need an indicator that is capable of resembling this spatial behavior of transportation systems.