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A measure of regional influence with the analytic network process

Reza Banai [a,*], Tina Wakolbinger [b,1]

[a] University of Memphis, Graduate Program in City and Regional Planning, School of Urban Affairs and Public Policy, 217 McCord Hall, Memphis, TN 38152, USA
[b] WU (Vienna University of Economics and Business), Institute for Transport and Logistics Management, Nordbergstraße 15, 1090 Vienna, Austria

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ABSTRACT

The metropolitan region is commonly defined by a socio-spatial network of urban nodes that are linked in territory and function. Such a network is differentiated by size and dominance of the linked nodes, characterized by physical or virtual flows of a wide-ranging variety. The analytic network process (ANP) is a multi-criteria analytic method that measures the influence or dominance of the nodes in a network with feedback. We illustrate how ANP determines county rank as a measure of influence in a metropolitan statistical area (MSA) defined by its interrelated socio-economic and spatial elements qualitatively and quantitatively. We compare the ANP results to similar measures of regional influence in the literature.

1. Introduction

The spatial organization of the metropolitan region is a subject of conceptual and methodological research in urban studies. Albeit with a variation in nomenclature such as conurbation, megalopolis, polycentric metropolis, mega-region, from the classic [26] and near-classic [28] to the contemporary [16,30] and [47], the concepts of a metropolitan region commonly render an image of a socio-spatial network of urban nodes that are linked in territory and function (see also [25,29,68]). Furthermore, the polycentric metropolitan region is characterized by a variety of "flows" in a network of communication, information, trade, and commuting among nodal activity centers [17,18,30,47].

Concomitantly, systems analytic methods have found plausible applications to regions, particularly with an emphasis on concepts of networks or systems from the near-classic "systems of cities" to the contemporary networks of flows [8–11,21,30,39,44,45,47,48]. Markov chains, graphs, networks, and spatial interaction are among the methods and techniques which measure a variety of "flows" in the region.

The analytical foundation of regional analysis is credited to Isard [33] with an introduction to regional science. A wide variety of methods of regional analysis are now commonly applied to the investigation of regions and increasingly used in conjunction with geographical information or decision-support systems [38,64,65]. The "quantitative revolution" that stirred the fields of regional geography and regional planning into "analysis" [3], however, also contributed to the qualitative vs. quantitative, and analysis vs. synthesis chasms in urban and regional studies. Multicriteria methods responded to the quantitative vs. qualitative gap in planning and regional science as the methods of operational research expanded from single objective to multiple objective optimizations [34,38,41,43,64]. However, the movement of these fields into "analysis" contradicted the holistic concept of the region as a system (synthesis) (see also [1,2,9]). The notion of a system or network that regions connote reveals the strengths and vulnerabilities of analytic methods.

The analytic network process (ANP) [51,54,55] is a systems methodology that surmounts shortcomings of traditional quantitative methods while capturing systemic characteristics of regions, thought of as networks of linked urban nodes. ANP is a multi-criteria analysis method that is effectively used when data are mixed tangibles and intangibles, which also characterizes the socio-economic and spatial features of regions [22,23,38,42,43,51,52,64].

In this paper, we highlight ANP features with an application to regional analysis. The paper is structured as follows. The ANP and related systems analytic techniques are briefly compared for methodological and conceptual strengths and limits. A case

* Corresponding author. Tel.: +1 901 678 4559; fax: +1 901 678 4162.
E-mail addresses: rbanai@memphis.edu (R. Banai), tina.wakolbinger@wu.ac.at (T. Wakolbinger).
URL: https://umdrive.memphis.edu/rbanai/www/index.html
[1] Tel.: +43 (1) 313 36 5828; fax: +43 (1) 313 36 90 5828. www.wu.ac.at.

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application of ANP in a metropolitan region is then presented. ANP is used to determine a measure of influence for counties in the MSA region.[2] Results are compared to other measures used in the literature to measure regional influence.

2. An analytic network process (ANP) approach to regional analysis

In the literature on regional studies, regions are defined as spatial units which are unified by a diverse set of interrelated physical, cultural, social, and economic features [21,48]. Regions have nodes or centers that are hierarchically differentiated in influence and they are linked in a network with variable magnitude of dominance. Regions exhibit properties of "open systems," which are defined endogenously by features that are "site-specific" or unique to the region but also defined exogenously by factors that explain the interaction of the region as a system with still other systems.

Defined this way, regions have unique as well as universal features, which imply the utility of both inductive and deductive systems, as well as methods of systems analysis which are accountable to diverse sets of interrelated physical, social, and economic qualitative and quantitative factors. Owing to the "flexible" concept of the region and the variable size or spatial extent, the region plays havoc with officially defined standard areal units of data collection, which limits regional analysis. The (network) structure of a region is measured by "flows" of all kinds - information, communication, commuting, migration, flows of goods, services, and the like between pairs of cities as nodes of a regional network with interaction. The greater the interaction, the denser is the regional network structure. The observations of the flows are used to determine hierarchically the relative dominance of nodes as linked urban centers within a regional "system of cities" see also [10]. A variety of techniques are used to "map" the physical, social and economic features of the region that determine proximity, contiguity, and population density. "Centrality" in the region is determined by methods that classify cities within a "system of cities" with rank-size rule [11,15]. Cluster analysis, factor analysis, multivariate analysis, graph theory, and Markov chain method are systems concepts [14,19,20,44,45,47]. These systems analytic methods are among the techniques of regional analysis. Graph theory and Markov chain methods are noted as approaches that identify regions as a system with diverse social and economic features [48].

However, the following conceptual and methodological issues are revealed in the analysis of the region as an urban system. Regions are unified by a diverse set of interrelated physical, cultural, and economic features *organizationally*, as well as identified *instrumentally* with a functional role in the national or global economic system (see also [25,31]). Organizational and instrumental systems elements require differentiation in the method of regional analysis. The organizational features are weighted so as to define regions uniquely. The relative weights of the features (or criteria) differ by region. These weights are not captured by graph theoretic approaches that classify regions as systems with nodes and links and undifferentiated weights. Furthermore, links between pairs of nodes commonly have bi-directional flows. Hence, nodes and links as elements of a regional system are better modeled as dynamic systems with feedback rather than static linear systems. The dynamic features can be approached with Markov chains. However, the matrix of the transitional probability that depicts the future state of the regional system requires "countable" inputs as data (relative frequency-probability) which are constrained by the availability of flows data. Qualitative data that play an essential role are not captured. This recalls Einstein's aphorism, "Not everything that counts can be counted, and not everything that can be counted counts" in regional systems.

The analytic network process ANP—the general, nonlinear form of the analytic hierarchy process (AHP) [50]—is well suited for the region with its "messy," multiple interrelated features and in the face of limited data. For an exposition of the contrasting features including the linear form of AHP vs. nonlinear ANP, see [54,56].[3] ANP provides a network structure that characterizes a variety of two-way "flows" in the region. The network is determined by the structure of its interrelated, clustered elements. The weights of the elements within and between clusters indicate the outcome of dependency and feedback in the network. These weights are determined by means of paired comparisons of elements that are gauged for logical consistency and by rating-scale functions that are akin to membership functional values of fuzzy sets [6,54]. The overall weights of the clustered elements thus indicate a measure of network influence. While methods like MIMIC [35], the weighted sum of principal components using a normalized eigenvector for the weights and Sheaf coefficients [32,36] derive weights of individual indicators through statistical analysis of quantitative data, they are derived based on a pairwise comparison using quantitative and qualitative information in the ANP. The facility to handle mixed data type and sources of information in a unified framework (network) is a property of the ANP akin to "metadata" analytic methods and "data fusion" techniques that are emerging in the multidisciplinary literature [61,70]. Arguably, ANP facilitates integrated analysis and synthesis of the urban system without methodological (statistical) restrictions of data fusion (e.g., Dampster-Shafer theory-based), particularly in dealing with multiplicity, variability, and uncertainty in planning and decision making. This facility is particularly desirable at the metropolitan regional scale which epitomizes the problem of availability and reliability of data from hybrid sources.

3. Case application

To highlight the plausibility of ANP in regional analysis, we provide an illustration. We use the ANP to determine a measure of influence or dominance of the counties in the MSA region. The Metropolitan Statistical Area (MSA) contains Memphis, which is the largest urban core in Shelby County with seven other contiguous counties, denoted by Tri-State MSA Counties (Fig. 1). We chose the MSA region because, as defined further below, it is a standard classification of the metropolitan region as a socio-economic spatial system.

The analytic network process (ANP) allows us to address fundamental MSA regional questions. For example, how do the (eight) MSA counties as a group (or cluster) enhance the economic base or quality of life of the region? Or vice versa, how does the economic

[2] The title of our paper recalls an earlier paper by [49] titled "A Measure of World Influence." The AHP— the forerunner of ANP – estimates of a country's influence are compared with several other indicators, including GNP, net imports, military expenditures and the like.

[3] The architecture of ANP is akin to "agent-based" methods that similarly allow for micro-level, "fine-grain," high resolution behavioral and spatial analysis, compared to statistical methods that are more suited for the large scale, aggregate-level, low resolution spatial analysis [37,65]. The popularity of multi-criteria analysis methods that use AHP/ANP in combination with Geographical Information Systems (GIS) that provide high resolution parcel-level analysis of urban and regional form compared to statistical methods at the low resolution, zonal level of aggregation is evidence of this facility in spatial analysis [22,23,38,65,67,69].