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Spatio-temporal fluctuations in the global airport hierarchies

Tony H. Grubesic a,*, Timothy C. Matisziw b,c, Matthew A. Zook d

a Department of Geography, Indiana University, Bloomington, IN 47405, United States
b Department of Geography, University of Missouri–Columbia, Columbia, MO 65211–6170, United States
c Department of Civil and Environmental Engineering, University of Missouri–Columbia, Columbia, MO 65211–6170, United States
d Department of Geography, University of Kentucky, Lexington, KY 40506, United States

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ABSTRACT

The global air transportation network is responsible for moving millions of domestic and international passengers each year. Not surprisingly, relationships between airports vary widely, due to a myriad of geographic, economic, political and historical determinants. Further, given the dynamic nature of the many influences acting on the air transportation system, inter-airport relationships and the structure of the global air network as a whole are also constantly changing. The purpose of this paper is to explore such spatio-temporal variations in the structure of the global airport hierarchies. Here, we show how the concept of nodal regions can be applied to measure the extent of these variations. To facilitate this analysis, a database of nearly 900 airline carrier schedules and 4650 worldwide origins and destinations, representing a nearly complete record of commercial air travel over a six-year period, is examined. Given this dataset, nodal regions are derived for all airports represented. In general, results suggest that regions associated with individual airports are often relatively dynamic at the yearly as well as quarterly level. Los Angeles International Airport (LAX) is utilized as a local case-study to provide a detailed examination of these dynamics.

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1. Introduction

The global airline network is a massive system comprised of both passenger and freight components, serving thousands of airports and cities on all seven continents. That said, the global airline system remains a relatively tightly structured hierarchy (Grubesic et al., 2008), consisting of a small set of dominant airports which either serve as the origin, destination or mediator for the bulk of all traffic flows (Derudder et al., 2007a; Zook and Brunn, 2006; Smith and Timberlake, 2001).

The effects of air transport liberalization plays an interesting role in this framework. With an increased focus on free-market economics and a removal of regulatory controls over pricing, the global air passenger system has become relatively dynamic in structure. In the current operating environment, carriers are permitted to both enter and exit most markets at will (Goetz and Graham, 2004) and competition within the airline industry often forces carriers to operate with razor-thin profit margins, making them highly sensitive to exogenous factors such as fuel prices and consumer preferences (Dogantis, 2002). Further contributing to this dynamism is the ease at which inter-airport relationships can be changed since the linkages between airports require no physical infrastructure other than the airports themselves. As a result, shifts in both airline fares and markets served are common within this hierarchically organized system. For example, consider the recent 2008 bankruptcy of ATA Airlines. Once the tenth largest carrier in the United States, this is the second bankruptcy filing for ATA in four years. With ATA serving nearly 10,000 passengers per day and thirteen different destinations, the bankruptcy will have a significant impact and a distinct spatio-temporal footprint. From the standpoint of airport accessibility, there will be a significant reduction in seats (capacity) and flight frequency between Chicago Midway, Indianapolis and the other cities served by ATA should this gap in the airline market remain unserved.

This is just one example of how the global airline system is exposed to change. While some of these changes exhibit a degree of permanence (e.g. liberalization), others are more dynamic in nature (e.g. demand-based scheduling between airports). The purpose of this paper is to outline a method for examining the spatial and temporal changes in the air transportation system. Given the geographic extent and complexities of this system it is difficult to represent the global airline network and its airports in such a way to explore these types of changes. However, the concept of regions, nodal regions in particular, can provide one way of representing the structure of these types of complex networks. In this paper, a basic conceptual framework for assessing and monitoring...
spatio-temporal aspects of the global air transportation system based on the derivation of nodal regions for world airports is presented. To illustrate the utility of the proposed framework and method, we conduct an exploratory analysis of the temporal/seasonal shifts associated with the Los Angeles International Airport (LAX) region. Results suggest that airport regions are dynamic, with some airport regions exhibiting greater regional instability than others.

2. Globalization, air transport liberalization and Nodal regions

One of the more compelling aspects of air transport liberalization is its role in an increasingly globalized world-economy. Globalization is not easily defined, but the concept of an increasing geographical scale of economic, political, social and cultural interactions certainly provides a good point of departure (Janelle and Beuthe, 1997). Of particular consequence are the concepts of reterritorialization and the location of economic activity (Goetz and Graham, 2004). While scholars initially hypothesized that information and communication technologies (ICT) would largely replace face-to-face interaction and supplant many local economic/geographic advantages (Cairncross, 1997), this has yet to come to fruition (Grubesic and O’Kelly, 2001). Place and location still matter, although this is increasingly being influenced by relative location on a network (e.g. airline) as opposed to continuous geographic space (Zook and Brunn, 2006). Sheppard (2002) suggests that globalization and most of its current working conceptualizations of networks are incomplete, overstating the non-hierarchical nature of global flows and underemphasizing how the characteristics of places affect their standing. As a result, Sheppard (2002, 308) proposes the concept of positionality as a means to capture “the shifting, asymmetric, and path dependent ways in which the futures of places depend on their interdependencies with other places”. It is important to reiterate that place remains a fundamental component to all economic activity, regardless of an emerging globalized economic paradigm (Dicken, 1998). In particular, spatial relationships are crucial in determining a place’s role in a larger system such as the global air network. This is further reinforced by the emergence of a sub-national scale of economic integration and coordination, somewhere between a state and a locality (Goetz and Graham, 2004). In this context, the “reorganization of the world-economy around specific localities and city hinterlands depends on air transport and other communications industries” (Goetz and Graham, 2004, p. 267).

A consequence of airline liberalization is that patterns of positionality have become more unstable because carriers are increasingly sensitive to global economic shifts and other events that impact the air travel market. For example, consider the financial crisis in the airline industry caused by the events of September 11th, 2001 (Nolan et al., 2004). This was the beginning of a significant period of instability in the commercial air travel industry in North America and Europe – with impacts of this financial crisis still affecting carriers in late 2008. However, while 9/11 did little to impact markets in Asia and Australasia, severe acute respiratory syndrome (SARS) did (Goetz and Graham, 2004). In this context, while the geographic origins of these system impulses are varied, so are their impacts. As with any complex entity, even the smallest perturbation to a single carrier, airport or city can generate or amplify negative outcomes both within and between systems (Grubesic and Murray, 2006). What remains unclear is how the system responds to perturbations and how these responses manifest geographically. Can there be variations in airport dominance at the local, regional or international level? If so, what is the frequency of these changes? How do relationships between airports change? Which airports are most resistant to perturbations over time? Further, how permanent are changes in the geographic structure of the global air network and does the system attempt to revert to some preexisting state?

Considering the importance of global air transport to larger issues of globalization and economic geography, it is surprising that more research has not convincingly addressed the geographic manifestations of airport hierarchies. Specifically, if we are to better understand how the positionality of an airport within this complex networked system impacts reorganization of the world-economy around specific localities and city hinterlands (i.e. sub-national scale), more rigorous, empirical testing of airport hierarchies is needed. Granted, the work of Keeling (1995), Smith and Timberlake (2001), Zook and Brunn (2006), Guimera et al. (2005) and Derudder et al. (2007a,b) partially address these relationships, but many of these studies are hampered by incomplete geographic data, focus on metropolitan-level analysis (i.e. aggregations of airports) or are forced to provide a limited temporal snapshot of the network. Missing, is a comprehensive spatio-temporal analysis that integrates a wider temporal window using a complete spatial database of airports and their associated connections, flight capacities and frequency, thereby capturing the dynamics of this system, particularly in response to perturbations. While the work of Grubesic et al. (2008) offers a good starting point for such an analysis, its focus on a single time period provides little insight on temporal change within the global air system.

Given the enormous number of interacting airports in the world, summarizing these spatial relationships is challenging. What is needed is some way of organizing the data into functional units for analysis. One way of representing the spatial and functional relationships between airports is to classify airports into regions where all airports within an identified region share some degree of similarity with one another with respect to a set of attributes (e.g. flight frequency). Based on these derivations, changes in regional morphology can then be tracked through both time and space and the results analyzed. The concept of regions has a long history in geographical research (Whittlesey, 1954) and many types of regions exist as do methods for their delineation (see Noronha and Goodchild 1992). A type of region of particular relevancy to the study of airport relationships is the nodal region. Nodal regions are formed by the classification of locations or nodes within a system into regions of dominance based on the level of interaction existing between nodes (Nystuen and Dacey 1961). Each nodal region is hierarchically structured in terms of the dominance of nodes within the region. Thus, although the nodes are geographically referenced, the derivation of nodal regions is based purely on the level of interaction between nodes. In this respect, regions are not required to be spatially continuous and member nodes need not be contiguous. Given that airport relationships do not require spatial contiguity for interaction to exist, nodal regions represent a promising way of providing a regional organization for the global air network. More importantly, since air transportation is often hierarchically organized with sets of smaller airports feeding into larger hub airports, the concept of delineating nodal regions is highly relevant (Grubesic et al. 2008).
This type of hierarchical regionalization is not without precedence. In previous work, Reed (1970), Wacht (1974), Nader (1981), Chou (1993), Shaw and Ivy (1994), Bania et al. (1998), Bowen (2000), Zook and Brunn (2006), Grubesic and Zook (2007) and Reynolds-Feighan (2007) utilize basic graph theory, accessibility indices, statistical measures of concentration, or some combination thereof to hierarchically differentiate between cities and/or airports. However, none of these studies extend their analysis to a global scale or attempt to assess the stability of hierarchies through time. As a result, the true hierarchical position of airports in the global system can remain obscured. While several studies do examine the global air transportation network (Guimera and Amaral, 2004; Guimera et al., 2005), the data used for analysis are aggregated to cities and limited to one week of flight data. To address these issues, the concept of the nodal region is applied in this paper to delineate airport regions to facilitate assessment and monitoring of change in the global air transportation system.

3. Data and methods

A valuable source of high resolution data on spatial and temporal aspects of the global airline system is Innovata’s Schedule Reference Service (SRS) database. The SRS database contains information for 900 different airlines and their 10,935 associated airports in 4700 cities. This database represents approximately 99.9% of worldwide commercial passenger schedules for each tabulation quarter (IATA, 2007). An important aspect of these data is that they represent a “neutral” worldwide schedules database which conforms to global standards put forth by the IATA for data quality control. All elements of the schedule database are thoroughly checked for the accuracy of the IATA flight codes, flight duration, segment continuity and scheduled dates and times. As a result, these data represent an unbiased, globally complete source of airline schedules. More importantly, the inter-state and trans-state biases outlined by Derudder et al. (2005a,b, 2007a) are avoided.

Similar to other databases, information regarding route capacity is included. The SRS database reports the average number of seats per week between each scheduled airport pair. In addition, flight frequency is also included. Specifically, the SRS database reports the average number of flights per week, for each quarter, between each scheduled airport pair. In sum, the SRS information provides a micro-level temporal scale database, with global coverage, that includes functional measures of both capacity and frequency between airports. For this paper, quarterly SRS data from 2001–2006 will be used for an exploratory analysis of spatial-temporal change in the global air network.

3.1. Constructing airport regions

This paper utilizes the Nystuen–Dacey method (N–D method) (1961), for organizing airports into regions. As outlined in Section 2 and in Grubesic et al. (2008), this methodology assumes that a

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4 For more information on the N–D method, including issues associated with implementation and statistical tests, see Tinkler (1988).
A hierarchical network relationship exists among airports and that a region of dominance is associated with each airport. Such a region can consist of as few airports as one (e.g. no subdominant airports) or many hundreds of airports. The use of the N–D method represents a good alternative to some of the graph-theoretical based analyses for complex networks such as the community structure metrics based on airport centrality and betweenness (Guimera et al., 2005). For example, rather than simply focusing on the degree of a node (i.e. the number of direct connections an airport has to other nodes) and the supplementary metrics associated with nodal degree, the N–D method is able to incorporate levels of capacity (e.g. average seats or flight frequency) while still accounting for direct connections between airports. This allows for a more realistic portrayal of both airport connectivity and link importance, ultimately providing a more detailed picture of system hierarchies and communities. Furthermore, because actual itinerary information associated with origin-destination flows was not available for the SRS database, the value of calculating airport betweenness and centrality on a network would be questionable.

From a computational perspective, 10,935 interacting origin-destination airport pairs are utilized for analysis, yielding a matrix of $\binom{n}{2}$, or 119,563,290, potential interactions. While many of these airport pairs have no interaction between them, there are instances where airports interact with several hundred other airports. The actual number of interacting airport pairs varies slightly between quarters and years, but an average of ~38,000 are used for analysis during each quarter. To facilitate the analysis of nodal regions, the N–D method was programmed using Avenue in ArcView GIS. The computational time required to calculate nodal regions for the SRS data was approximately 30 min for each quarter. The resulting output consists of a hierarchical system with the following characteristics. Dominant airports are designated as “Tier 1” and subdominant airports are denoted “Tier m + 1”, where $m$ = tier of the airport to which the subdominant airport has its largest outflow. For the purpose of discussion, the concept of ordered

Fig. 2. LAX nodal region (Q1, 2001).

5 Recall that interaction between pairs of airports is detailed in the SRS database in the form of seats per week (capacity) or flights per week (frequency).

6 Computations were carried out with a windows-based, dual Xeon (3.2 GHz) machine with 3 GB or RAM.
dominance within these generated hierarchies is helpful. Ordered dominance refers to the ability of Tier $m + 1$ airports to exert dominance over lower-ordered airports. For example, while all airports belonging to the Tier 1 hierarchy are technically subdominant in this analytical framework, the largest total outflows of airports classified as Tier 3 or lower do not have a direct relationship to the Tier 1 airport. Instead, the largest outflow of Tier 3 airports is directed at Tier 2 airports. Similarly, the largest outflow of Tier 4 airports is directed at Tier 3 airports. Therefore, while Tier 1 airports directly dominate Tier 2 airports, they also indirectly dominate (i.e. ordered dominance) Tier 3 and lower airports. Given this logical framework, ordered dominance is tracked by tabulating where each airport has its largest outflow to any Tier $m + 1$ airports. Further, nodal regions for each airport can be defined by a simple accounting procedure that tracks these subdominant relationships. That is, given the hierarchical relationships among airports, a region can be defined for each airport that consists only of that airport and airports denoted as subdominant to it. One of the most compelling reasons for using this type of approach in classifying relationships between airports (or cities) is that “the nesting of cities defines the organization of networks of cities and the position of each city within the network” (Nystuen and Dacey, 1961, p. 32). Obviously, this is not meant to suggest that additional flows or relationships between other airports are absent; instead, we are simply attempting to identify the dominant relationship between these places and better establish a regional structure for comparison through time.

In the next section, we examine spatio-temporal hierarchical dynamics in the global airline system. Using Los Angeles International Airport as a case-study, its nodal region is tracked for six-years, by quarter, over a total of 24 observation periods. In an effort to put this into context, we also track shifts in the top 10 most dominant global airports and the size of their nodal regions for the same period.

4. Airport regions in time and space

The analysis in this section utilizes the average seats per week (SPW) measure in the SRS database as the measure of interaction between airports used in the N–D method. Again, this represents a metric corresponding to average capacity between airports for each quarter and is tabulated for direct flights between each interacting airport pair, of which there are approximately 38,000 for each observation period.

![Fig. 3. A logical representation of the Phoenix (PHX) nodal region.](image-url)
Fig. 1 displays a baseline analysis for the first quarter of 2001 and highlights the derived hierarchies for each airport in the study. The size of each graduated symbol corresponds to the number of directly or indirectly subdominant airports in each Tier 1 region. In this particular instance, LAX maintains the largest airport region, capturing 282 subdominant airports. The remaining top ten airports are also labeled, and include Chicago O’Hare (ORD) and Stockholm-Arlanda (ARN) among others.

To provide some perspective on the composition of these airport regions, Fig. 2 displays the region associated with LAX for Q1, 2001. In this instance, LAX (Tier 1) dominates 26 different Tier 2 airports, including Salt Lake City (SLC), Phoenix (PHX), San Francisco (SFO), Seattle-Tacoma (SEA), Portland (PDX) and Anchorage (ANC). To reiterate, all of these airports can be considered subdominant since they have their maximum outflow (seats per week) to LAX. It is also important to note that while these airports are subdominant to LAX, many of the Tier 2 airports maintain dominance over a large subset of lower-tier airports. For example, consider Fig. 3 which displays a logical network representation of PHX as the highest-order airport (Tier 2) and its associated subdominants. As denoted in Fig. 2, while PHX is subdominant to LAX, airports such as Tucson (TUS), Albuquerque (ABQ) and El Paso (ELP) are subdominant to PHX (Fig. 3). If one drills further down this hierarchy, ABQ is subdominant to PHX, but it also dominates Tier 4 airports such as Clovis, NM (Tier 4) – which ultimately dominates Hobbs, NM (Tier 5).

In a nutshell, this is how airport (nodal) regions are structured – displaying a relative complex array of dominant and subdominant relationships between airports. What is most interesting about the LAX region is the geographic extent of its domination. From New Mexico to Alaska to the South Pacific (Papeete), the spatial footprint of LAX is massive. It is also important to note that many other Tier 1 airports capture fairly large geographic regions, including Beijing (PEK) and Sydney (SYD).

4.1. A longitudinal view of the LAX region

Fig. 4 highlights an explicitly temporal, longitudinal view of the LAX region between Q1, 2001 and Q4, 2006. This chart displays the number of subdominant airports in the LAX region for each observation period at two different levels. In this chart, the line represents the number of airports directly and indirectly dominated by LAX when it is classified as a Tier 1 airport. The bars in the chart represents the number of airports directly and indirectly dominated by LAX when it is classified as a Tier 2 airport. As will be highlighted in this section, this distinction is an important one. First and foremost, there is a great deal of fluctuation in the number of subdominant airports within the LAX hierarchy between 2001 and 2006. There are also several important observation periods worth discussing. The first is Q4, 2001 where Phoenix (and several other airports) drop out of the LAX region. This change has significant geographic ramifications as can be observed by reconsidering Fig. 3. The loss of Phoenix as a Tier 2 airport in the LAX region also involves the loss of all airports that were directly and indirectly subdominant to PHX from the LAX region. This includes all Tier 4 and Tier 5 airports associated with ABQ. Needless to say, these losses have a major impact on the geographic extent of the LAX hierarchy. Further, these types of ordered geographic relationships in the generated airport regions are somewhat analogous to the spatial lags utilized for defining neighborhoods or proximity in geographic or network space. In this case, we observe fifth-order spatial effects with the loss of Hobbs, NM, because Hobbs represents a Tier 5 subdominant airport to LAX.

![Fig. 4. Subdominant nodes in the LAX region, 2001–2006.](image-url)
Q2, 2002 also reveals a dramatic shift in the LAX region. During this period, San Francisco and Seattle-Tacoma are no longer Tier 2 airports for LAX and this has a major impact on its spatial footprint. In previous quarters, Seattle was designated as a Tier 2 airport to Los Angeles and Anchorage was classified as Tier 3 airport, directly subdominant to SEA in the LAX hierarchy. Because Anchorage serves as the major connection point for all of the airports in Alaska, seventh-order spatial effects are observed for LAX with the change of SEA to Tier 1 status, independent of LAX. In other words, because Seattle becomes a Tier 1 airport, Anchorage is no longer indirectly subdominant to LAX. As a result, LAX not only loses its dominance over Anchorage, but also its dominance over all of ANC’s associated subdominant (Tier m + 1) airports for Q2, 2002 (Fig. 5). Even with these losses, however, LAX remains a Tier 1 airport.

By Q1, 2003, LAX is no longer a Tier 1 airport (Fig. 3). Instead, LAX is subdominant to Chicago O’Hare (ORD). This means that the largest outflow from LAX is to the larger (in terms of total flow) ORD. As a result, ORD inherits all airports that are directly or indirectly subdominant to LAX. Put more simply, the shift of LAX to a subdominant role does not preclude it from maintaining second-order and lower dominance over additional smaller airports (represented by the columns in Fig. 4). This is, after all, how ORD inherits these Tier 3 and lower airports from Los Angeles. For example, the maximum outflows for Oakland (OAK), Sacramento (SMF), Salt Lake City (SLC) and 13 other airports are still directly captured by LAX. This makes these Tier 3 airports and all of their subdominants (e.g. Tiers 4–6) part of the Tier 2 LAX hierarchy and indirectly subdominant to ORD (Tier 1). Therefore, although the graphic representation of the “bottoming out” of LAX as a Tier 1 airport in Fig. 4 is slightly misleading in terms of its relationship with all airports and its associated importance, the fact that it loses Tier 1 status is the most relevant interpretation of these data.

From a global perspective, minor compositional changes in the hierarchy of airports can also be observed for Q1 2003 (Fig. 5). For example, in addition to the loss of LAX within the top ten, Stockholm-Arlanda and Toronto also disappear in favor of alternative airports such as Copenhagen (CPH), Vancouver (YVR) and Seattle (SEA). Fig. 6 provides a graphical summary of the aggregate changes in Tier 1 dominance between Q1 2001 and Q3 2003. In addition to highlighting the precipitous decline in LAX’s Tier 1 dominance, Fig. 6 also reinforces the dramatic emergence of SEA as a top ten airport region. Also illustrated is the relatively large, positive increase in dominance for airports such as Dubai (DXB), an increasingly important passenger and cargo hub in the Middle East.

4.2. Summarizing airport trends

Given the relative dynamism associated with the LAX region, how do the longitudinal profiles of other airports compare? More importantly, how can one capture and summarize the general trends for Tier 1 airports? Fig. 7 highlights an exploratory approach for addressing both issues. Four major airports are displayed in Fig. 7: Sydney, Atlanta, Los Angeles and Phoenix. Both Sydney and Atlanta display a relatively stable number of subdominant
airports in their hierarchies through time. The composition of nodal regions for Los Angeles and Phoenix, however, fluctuate quite dramatically between 2001 and 2006. An effective approach for summarizing the overall trend for each airport is through the use of a polynomial trend line. In this instance, the ability for the curves to explain the longitudinal trends in Tier 1 region size ranges from 49.8% for Atlanta and 70.7% for Sydney. More importantly, the trend lines capture (and smooth) the quarterly fluctuations for each airport and enhance the interpretability of the results. The ability to capture these long-term trends is important. As mentioned previously, this type of approach can help smooth short-term fluctuations caused by standard operational changes in scheduling or routing. As a result, a more robust representation of airport hierarchies emerges. Second, the polynomial trend lines have the potential to be used predicatively. By extrapolating hierarchy sizes to future observation periods using the trend lines, a comparison between observed and predicted outcomes can be made. At the very least, this can provide analysts with an effective benchmark for predicting/examining changes in airport hierarchies. Perhaps more relevant to the presented case-study for LAX is the ability of the polynomial trend line to capture the precipitous decline of LAX Tier 1 dominance between 2001 and 2003. As noted previously, this decline in Tier 1 influence does not suggest that LAX has lost its importance in the global system. Even as a Tier 2 airport, Los Angeles still exerts second-order dominance for significant number of Tier 3 and lower airports. However, it is hypothesized that this somewhat chaotic profile is a result of three factors. First, the dynamics of the air passenger market, particularly at LAX during this time period, are important to consider. Fig. 8 displays the aggregate counts of passenger arrivals and departures for LAX between 2001 and 2006. The number of passengers passing through LAX was already at a six-year low by the end of 2002 and passenger traffic during 2003 was no better. In part, this reduction in traffic can be linked to the events of September 11th, 2001. Ito and Lee (2004) suggest that the impacts of the attacks generated a negative transitory shock of over 30% and an ongoing negative demand shock amounting to approximately 7.4% of pre-September 11 demand. This massive decrease in demand also fueled a major financial crisis in the aviation industry, with many carriers filing for Chapter 11 bankruptcy. Particularly salient to LAX was the December 2002 bankruptcy filing of United Airlines (UAL). In 2001, United Airlines maintained a dominant share of the passenger arrivals and departures at LAX (20.62%) (Fig. 9). Its nearest competitor was American Airlines, which maintained a 12.4% share. By the time UAL emerged from bankruptcy in early 2006, its share of the passenger market had fallen to 15.26% at LAX and both American Airlines (14.99%) and Southwest Airlines (12.71%) had virtually closed the competitive gap. Nearly simultaneous to the bankruptcy filing of United Airlines, the United States launched its invasion of Iraq and SARS emerged in Asia (March 2003). Although both events decreased the demand for international and domestic travel, they were particularly damaging for LAX because of its role as the premier gateway to Asia from the United States. For example, Oldham (2003) notes that
passenger loads originating in Japan, China, Thailand and Korea were off nearly 60% during early 2003, prompting many airlines to cut service to LAX.\(^8\)

A second factor that led to the precipitous decline in the dominance of LAX is that it interacts heavily with a handful of similarly dynamic airports, thus mimicking temporal/seasonal trends occurring at lower levels. Obviously, Phoenix (Fig. 3) is an excellent example of this dynamism – frequently entering and exiting the LAX hierarchy. In fact, the initial loss of Phoenix during Q4 2002 occurred because PHX became established as an independent Tier 1 airport. In this particular instance, this change was precipitated by a shift in maximum outflow from PHX to SAN (a smaller airport). Moreover, when airports that have relatively extensive subdominant structures (e.g. PHX) change hierarchies, the impacts for their old Tier 1 airports (e.g. LAX) are substantial. Third, it is suspected that airports which maintain a significant seasonal profile for airline capacities and flight frequencies also contribute to a dynamic profile in the upper tiers of the hierarchy. For example, many of LAX’s subdominant airports are vacation destinations in Mexico, the South Pacific and portions of the Rocky Mountain West. As a result, when major world events such as the Iraq war and SARS precipitate increased levels of traveler anxiety and uncertainty, leisure travel suffers (Floyd et al., 2003; Reisinger and Mavondo, 2005). Specifically, seasonal flows to warm-weather destinations during the winter and early spring surely have an impact on seating capacity to LAX. For instance, although destinations such as Los Cabos (SJD) and Guaymas (GYM) Mexico are present in the LAX hierarchy during Q1 and Q2 2001 (pre 9/11), they are completely absent during Q1 and Q2 2003 (post 9/11, Iraq war and SARS). Domestically, both Las Vegas (LAS) and Lake Havasu City (HII) displayed a similar pattern during the same time periods.

Obviously, while the polynomial trend lines do not specifically explain how or why such trends occur, they do provide a useful summary of general trends for each airport. As illustrated in this section, even a modest effort to disentangle the SRS data and the resulting airport hierarchies generated by the N–D method can provide a convincing forensic snapshot of events within the industry and their specific geographic outcomes.

4.3. A final global snapshot

In an effort to provide a final summary view of airport hierarchies, Table 1 documents the top ten Tier 1 airports, with respect to the number of subdominant airports in their region, for the first quarter (Q1) for 2001–2006. An important thematic element in this table is that airports such as London-Heathrow (LHR), Sydney

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\(^8\) Singapore Airlines cut four flights a week from LAX during March 2003 alone (Oldham, 2003).

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(SYD), Atlanta (ATL) and Beijing (PEK) are permanent fixtures in the top ten, consistently displaying large regional membership. Other airports, such as Bombay (BOM), Bangkok (BKK), Phoenix (PHX) and Stockholm-Arlanda (ARN) make only a single, temporary appearance in the top ten. Airports such as LAX and YYZ, however, display more temporally dynamic characteristics, often disappear-
ing and then reappearing from the list of top ten Tier 1 airports. More importantly, both the spatial composition and number of subdominant airports associated with LAX undergo significant and frequent changes, corresponding with LAX’s decline from the largest Tier 1 airport in the world during 2001, to being subdominant to ORD during 2003. While Table 1 does not capture all of the observation periods and all of the airports that had membership in the top ten, it does provide a good snapshot of the dynamic temporal nature of airport hierarchies.

5. Discussion and conclusion

There are several important results highlighted in Section 4 worth further discussion. First, airport nodal regions are subject to constant change. As mentioned previously, these dramatic changes in regional composition can be attributed to a wide variety of factors. For example, the recent and massive increase in fuel costs can motivate carriers to cut capacity on their least profitable routes, or perhaps eliminate those routes altogether. The ability to make these types of operational decisions, particularly in the United States, can be linked to deregulation of the airline industry. In a regulated environment, government entities (e.g. the Civil Aeronautics Board in the US) controlled route entry and exit of air carriers, regulated fares and awarded subsidies (Goetz and Sutton, 1997). As a result, even if a route was not profitable, many carriers still provided service because they were awarded subsidies to offset their losses. In a deregulated environment, these subsidies no longer exist and carriers make decisions regarding routes served and fares charged based on the competitive landscape and real financial constraints. Unlike many infrastructure systems, routes between airports are temporary, intangible manifestations of supply and demand relationships. Depending on global or domestic economic conditions and regional demand, these paths can appear, disappear, expand or contract. Simply put, links lack permanence in this system. These types of decisions are necessarily reflected in the hierarchies generated in this paper, encompassing macroeconomic trends (e.g. exchange rates), world events (e.g. the attacks of 9/11), technology (e.g. aircraft improvements), policy (Wacht, 1974) and consumer preferences.

What is most interesting about the detected regional dynamics is the degree of variability associated with these changes, particularly between airports. As noted previously, airports such as LAX have a much more dynamic temporal profile than airports like SYD. In previous work, Grubesic et al. (2008) noted that many of the largest airport regions are linked to locations that have a decidedly domestic operational focus. While airports such as Atlanta, Beijing, Toronto and Sydney do have international options available to passengers, the majority of their routes and passengers flows are domestic. That said, while LAX has a significant domestic component, many of its major carriers focus on the Pacific Rim, allowing LAX to serve as the major international gateway to these destinations. To put this in perspective, while the more domestically focused Sydney (SYD) airport has carriers/routes serving 31 different countries on five continents, the more internationally focused Los Angeles (LAX) airport has carriers/routes serving 54 countries on six continents. Further, over 6.5 million passenger arrivals and departures at LAX during 2006 were generated by smaller international carriers with a decidedly Pan-Asian focus (e.g. Qantas Airlines, Korean Airlines, Cathay Pacific Airways, etc.) (LAXWorld, 2008). Can the temporal dynamism be explained solely by international or domestic focus? Certainly not, this would make explaining airports such as London-Heathrow exceedingly difficult. However, route structures and the operational foci of carriers within an airport do play a role in the hierarchical composition of airport regions. Further, airports that maintain a decidedly international focus are also more exposed to global economic trends, health crises or other factors that may impact travel patterns. As noted in Section 2 (e.g. SARS), this is certainly the case for LAX.

A second important point is that the resulting impacts of changes to airport regions display spatially ordered effects. This is particularly relevant (although not limited) to Tier 1 airports when they lose Tier 2 or Tier 3 airports that maintain control over large geographic areas. This is probably best illustrated by the example of LAX losing SEA as a subdominant airport. Not only were all the cities in the state of Washington lost (all of which are subdominant to Seattle), LAX also lost Anchorage, which is dominant over all of the airports in Alaska. As noted in Section 4, this loss prompts seventh-order effects to the LAX hierarchy and drastically reduces its geographic footprint.

A third point worth mentioning is that the approach outlined in this paper has great potential as a forensic tool for analyzing the impacts of major global or local events on airport hierarchies. For example, one might be interested in tracking the impacts of
Hurricane Katrina on airport nodal regions in the southeastern US. Conversely, one might be interested in tracking the impact of Southwest Airlines on airport nodal regions when it enters a new market. The quarter-level SRS data combined with the N–D method provide an excellent opportunity for this type of forensic analysis.

In conclusion, the longitudinal spatial analysis of airport regions conducted in this paper highlights a variety of important aspects in the global airline system. Results suggest that airport regions are dynamic, with some airport regions exhibiting greater regional instability than others. While seats per week (SPW) (capacity) were the focus of this research effort, it is likely that flights per week (frequency) would yield different regional structures. Future work will incorporate a longitudinal comparison of both these measures. Finally, the ability to analyze a global database that does not suffer from any of the constraints associated with strictly international or regional databases is also an appealing aspect of this analysis, ultimately providing a more complete snapshot of global networks and their associated processes.

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