Supply-Chain-Focused Measures of Centrality and Spread in Metropolitan Areas

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The Port of NY in the Early XX Century

Early 1900s

1920's

Nowadays

Source: (National Archives Catalog, 1942); (Maureen, 2005); (Port Authority of New York and New Jersey,2019)

What's the issue?

Source: Port Authority of New York and New Jersey (2019)

Transporting the cargo across the Hudson River may have created NYC billions of dollars in congestion

Freight Efficient Land Use … a Goal…

- Freight-Efficient Land Use (FELU): The one that minimize the social cost, both private and external costs, produced by supply chain activity

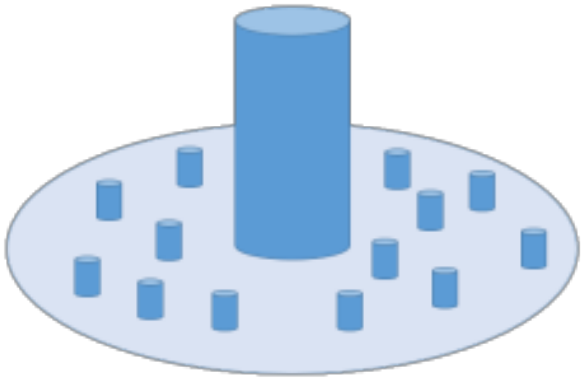
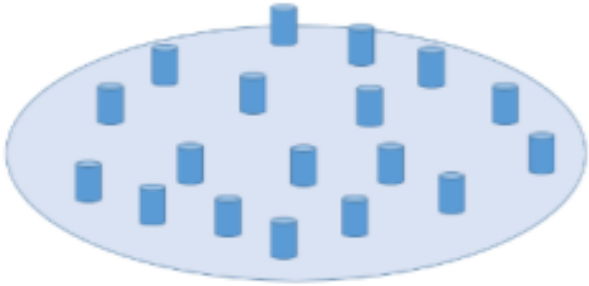
- Accounting for:

  - Impacts on supply chains
    → Network effects must be considered

  - Impacts on communities (externalities)
    → External effects during the journey
    → External effects at nodes

Characterizing Metropolitan Statistical Areas (MSAs) based on Urban Form

- MSAs are described using the following urban forms

Urban Structure	Monocentric	Polycentric	Disperse
Schematic			
Density	High at core	High at multiple cores	Depends
Spread	Concentrated at a single center	Distributed concentration at multiple centers	Relatively equally distributed
Centrality	Near to the center	Near to the multiple centers	None

Source: Adapted from Anas et al. (1998), Tsai (2005), and Meijers and Burger (2010)

- Measures of centrality and spread are essential to gain insight into the efficiency of logistical activity

Understanding the Local Conditions

- For FELUs, it is crucial to have a solid understanding of the importance, extent and geographic patterns of freight activity

- Two different analyses were done for 6 MSAs in the US
  1. Identification of economic pole(s)
  2. Spatial separation between supply chain stages

- The MSAs represent three different sizes
  - Large regions (more than 10 million inhabitants): NYC and Los Angeles
  - Medium regions (between 2 and 10 million inhabitants): Washington and Houston
  - Small regions (less than 1.5 million inhabitants): Albany and New Orleans

Identification of Economic Pole(s)

- Three different measures were used to identify the centrality of each MSA
  - Employment
  - Employment density
  - Interaction index: measure based on a simplified gravity model
- Each measure identifies urban centers in different ways and therefore do not always isolate the same centers
  - Employment → identifies large establishments and employment centers
  - Employment density → indicates where employment is concentrated
  - Interaction index → quantifies the interconnectedness within the MSA

Identification of Economic Pole(s): Interaction index

- The index considers intra-industry connections as the key determinant of centrality
- The economic center is influenced by the efficiency of the transportation systems that connects the areas to other parts of the metropolitan area

$$Interaction\ Index\ at\ Location\ \mathrm{i} = \sum_{j} \frac{E_i^k \cdot E_j^k}{C_{ij}}$$

Where:

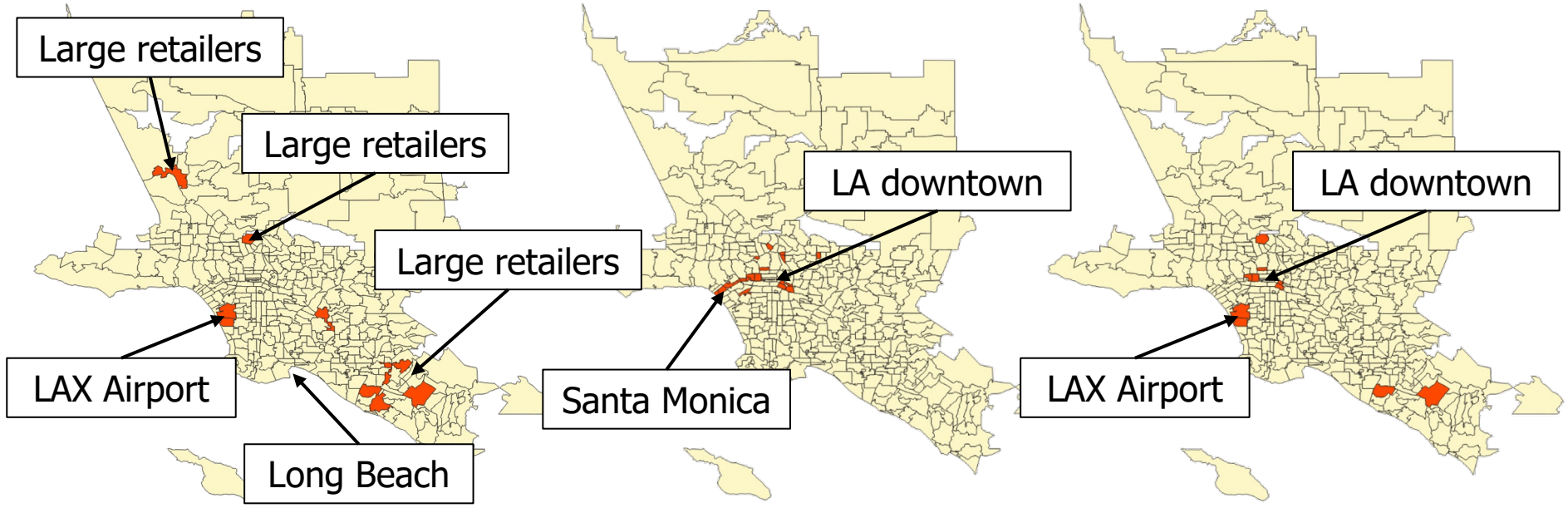
E_i^k and E_j^k are the employment of origin *i* and destination *j* in industry *k*

C_{ij} is the impedance between *i* and *j*

k is the industry sector

The larger the employment at *i* and *j*, the larger the index
The larger the separation C_{ij}, the smaller the index

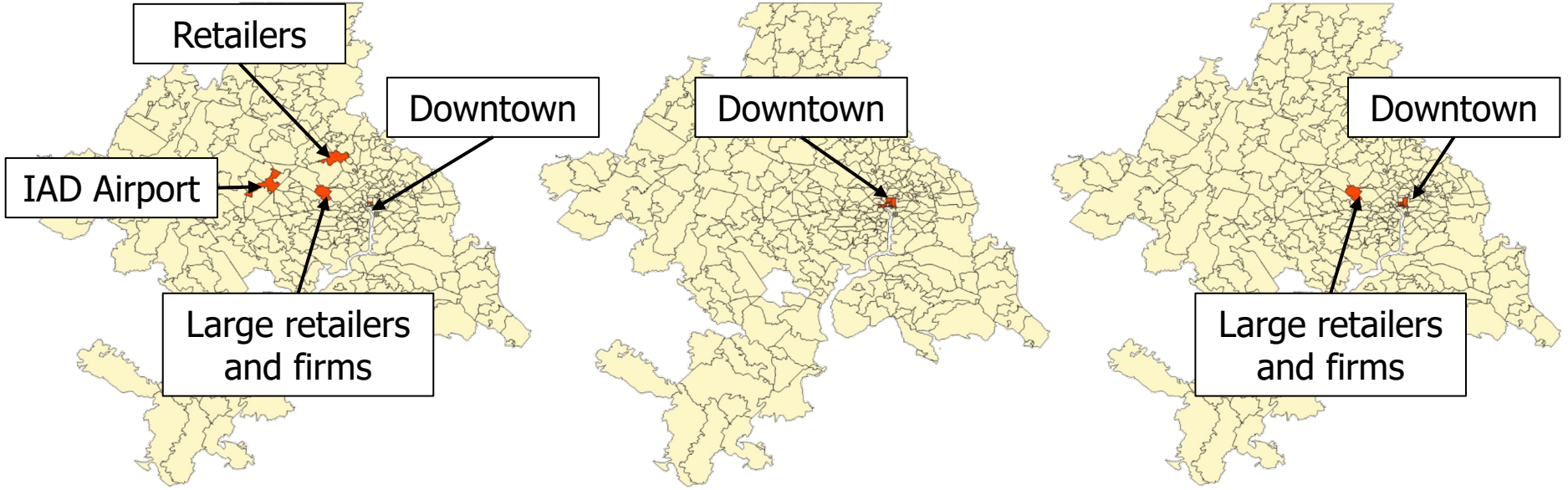
Identification of Economic Center: Los Angeles, CA



Employment **Density** **Interaction Index**

	Employment	Density	Interaction Index
No. of ZIP Codes	9 out of 385	20 out of 385	11 out of 385
Area	100.0 mi^2 (1.9%)	26.1 mi^2 (0.5%)	62.1 mi^2 (1.2%)
Average Distance	34.4 miles	15.2 miles	20.7 miles

Identification of Economic Center: Washington, DC

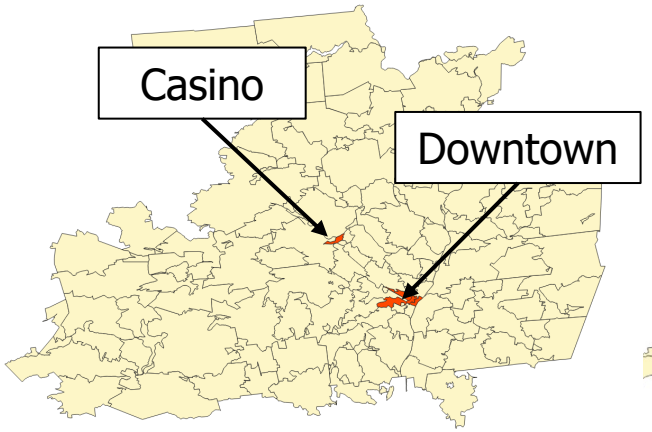


Employment **Density** **Interaction Index**

	Employment	Density	Interaction Index
No. of ZIP Codes	5 out of 349	7 out of 349	6 out of 349
Area	56.0 mi^2 (0.8%)	6.3 mi^2 (0.1%)	16.4 mi^2 (0.2%)
Average Distance	16.4 miles	1.7 miles	4.9 miles

Identification of Economic Center: Albany, NY

Employment



Density

Interaction Index

	Employment	Density	Interaction Index
No. of ZIP Codes	1 out of 127	5 out of 127	1 out of 127
Area	15.9 mi^2 (0.5%)	10.0 mi^2 (0.3%)	15.9 mi^2 (0.5%)
Average Distance	N/A	8.0 miles	N/A

Spatial Separation Between Supply Chain Stages

- Metric to compare a weighted physical distance between establishments for MSAs
  - The metric will be weighted by the estimated number of trips between key industry pairs from a trip distribution model

$$\overline{D_{ij}^{kl}} = \frac{T_{ij}^{kl} * C_{ij}}{\sum_{i}^{N}\sum_{j}^{N} T_{ij}^{kl}} \qquad \theta^{kl} = \sum_{i}^{N}\sum_{j}^{N} \overline{D_{ij}^{kl}}$$

T_{ij}^{kl} = Establishments between zones i and j between industry sectors k and l

C_{ij} = Distance between origin i and destination j

$\overline{D_{ij}^{kl}}$ = Weighted distance between zones i and j between industry sectors k and l

θ^{kl} = Total weighted average distance between industry sectors k and l

Measure of Spread: Results

			Albany	New Orleans	DC	Houston	LA	NYC
Population 2015			881,551	1,263,526	6,091,560	6,664,187	13,283,824	20,118,063
Area (sq mi)			3,480.05	3,779.38	6,764.25	10,914.38	5,384.11	6,926.38
Square Root of Area (mi)			58.99	61.48	82.25	104.47	73.38	83.22
Distance between Industry Sectors								
Manufacturing	to	Warehouses*	23.033	23.356	33.531	27.678	28.147	32.655
Warehouses*	to	Retail	21.291	22.338	31.315	28.566	29.786	31.858
Warehouses*	to	Accom + Food	21.142	21.114	29.879	28.462	29.437	31.598
Warehouses*	to	Warehouses*	20.657	22.999	31.536	26.626	27.978	30.644
Manufacturing	to	Manufacturing	25.203	23.544	35.418	28.644	28.276	34.554
Manufacturing	to	Retail	23.594	22.415	33.386	29.569	29.868	33.869
Manufacturing	to	Accom + Food	23.475	21.133	32.030	29.480	29.515	33.637
Average			22.628	22.414	32.442	28.432	29.001	32.688
FIS	to	FIS	22.727	21.864	34.153	30.903	29.454	34.747
SIS	to	SIS	20.425	19.917	27.476	28.395	30.834	33.155
FIS Average Distance / Square Root of Area			**38.52%**	**35.57%**	**41.53%**	**29.58%**	**40.14%**	**41.75%**

*Referred to all establishments that function as a warehouse or storage facility, covered in NAICS 42, 484, and 493.

Max

Min

Final Remarks

- Three measures of centrality were proposed; each with their own advantages and unique theoretical backgrounds, so they complement each other
  - Interaction index method is unique given that it considers intra-industry connections as the key determinant of centrality
- The spread of freight activity was measured by the weighted distance between key industry sectors in the supply chain
  - Commonalities were found among the six MSAs despite their differences in size and population
  - The average weighted distance between FIS establishments is larger than SIS establishments

Final Remarks (II)

- The metrics of centrality and spread highlight the importance of considering simultaneously the urban economy of the MSAs, transportation network and supply chain efficiency
- The proposed indices can assist transportation and land-use planners to examine how by changing land-use policies the supply chain could become more compact
  - It is necessary to examine the interplay between supply chain efficiency, land-use policy, and freight activity

Thanks