Characterization of Traffic and Structure in the US Airport Network

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Motivation

- **Applications:**
  - **management/planning of air traffic system, impact of air traffic emissions on environment, connection with economic activity, vulnerabilities...**
- **Prior modeling efforts:**
  - **Aggregate models of traffic time dynamics (e.g. 20 CONUS centers)**
  - **Structural analysis of aggregate properties (week – years) airport networks**
- **Current work:**
  - **Re-examination of aggregate properties**
  - **Analysis of temporal characteristics of US airport network**
  - **Employing data provided by the FAA Traffic Flow Management System, via the Aircraft Situational Display to Industry data stream**

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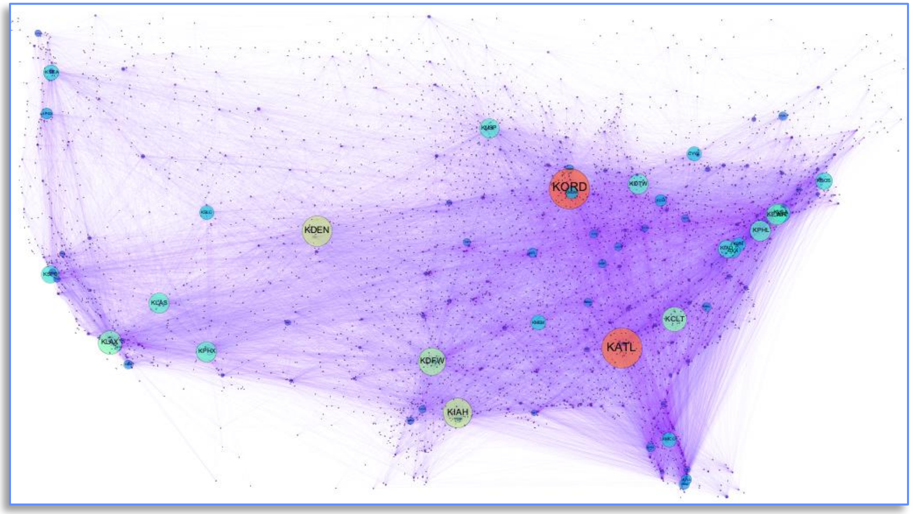
Analysis & Modeling Approach

- **Analysis of undirected weighted graphs**
- **Structural characteristics**
  - **degree/weight distributions**
  - **clustering coefficient**
  - **vertex strength**
- **Temporal characteristics**
  - **aggregate metrics: flight count, edge count**
  - **n-lag difference graphs**
  - **correlation**
- **Spectral analysis**



$$G_n \quad : \quad \text{Daily Graph}$$

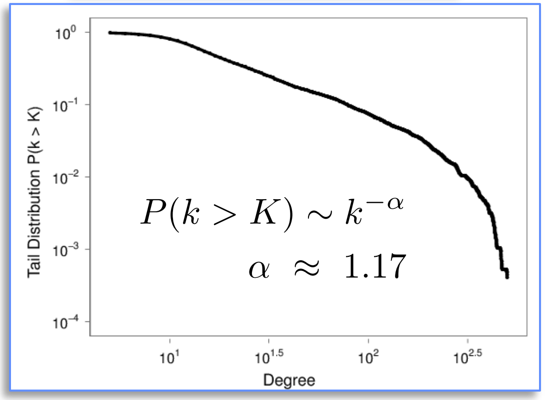
$$\bar{G}_{\cup}(\bar{E}_{\cup}, \bar{V}_{\cup}) \quad : \quad \text{Union Graph}$$

$$\bar{E}_{\cup} = \bigcup_{n=0}^{N-1} E_n, \quad \bar{V}_{\cup} = \bigcup_{n=0}^{N-1} V_n$$

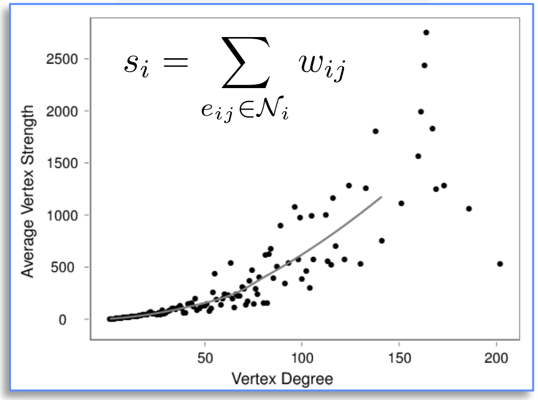
$$\bar{w}_k = \frac{1}{N} \sum_{n=0}^{N-1} \hat{w}_{k,n}$$

Structural Characteristics

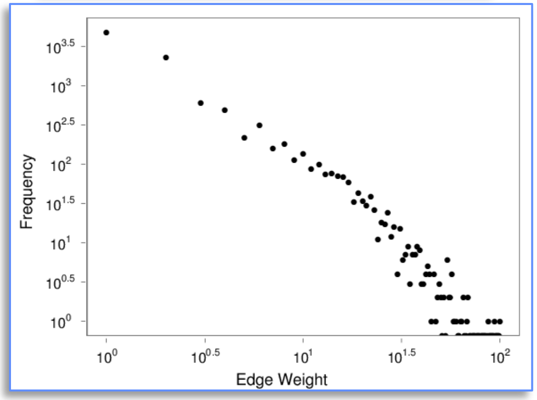
Degree Distribution



Vertex strength



Edge weight histogram



- **Power law vertex degree distribution – “scale-free” property**
  - **Hub-spoke topology also a characteristic of other airport networks**

- **Exponential relation between vertex strength and degree**
  - **Higher degree airports carry higher than average traffic**

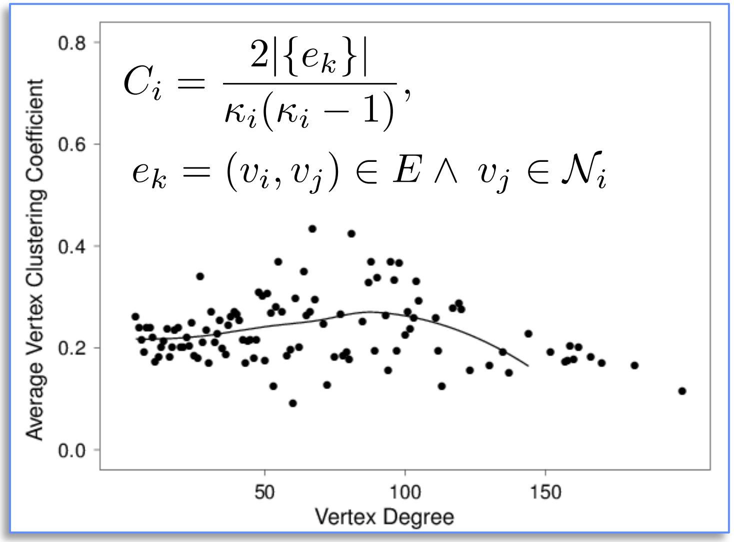
Structural characteristics consistent with findings of previous studies

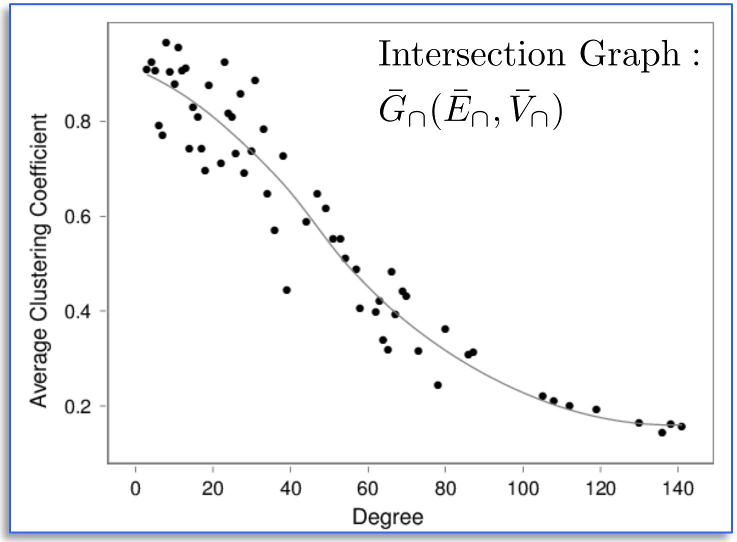
Structural Characteristics
(Clustering Coefficient)

- **Previous studies have found low degree airports to exhibit a high degree of interconnect**

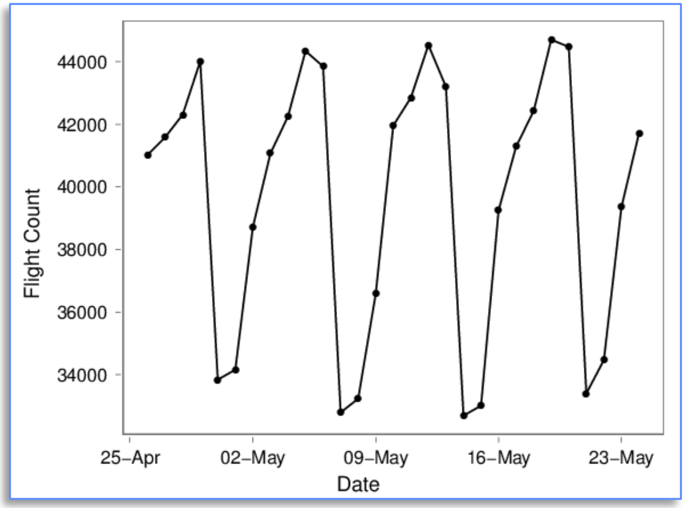
- **To the "contrary", this analysis has found the local clustering coefficient to be low, and appears uniform with degree**

- **Clustering coefficient for intersection graph is similar to previous studies**
  - ***Previous studies possibly limited to using scheduled flight data***

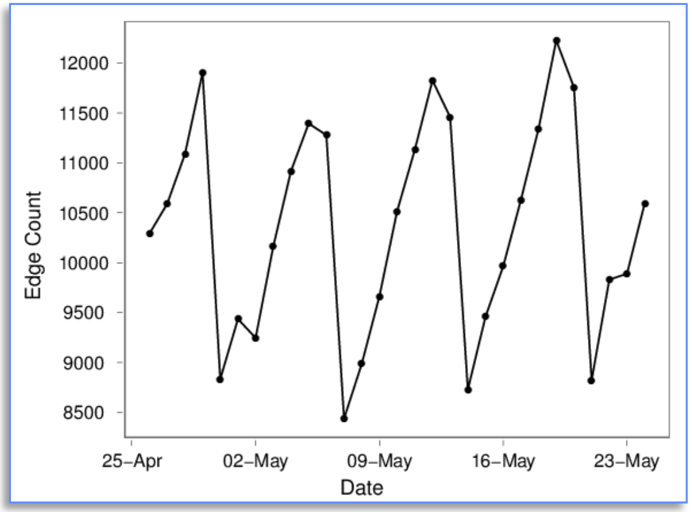




Temporal Characteristics
(Aggregate Properties)



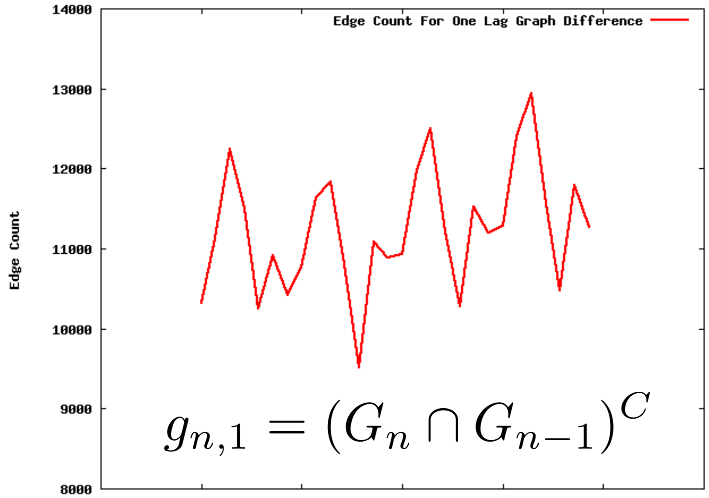
Daily Flight Count



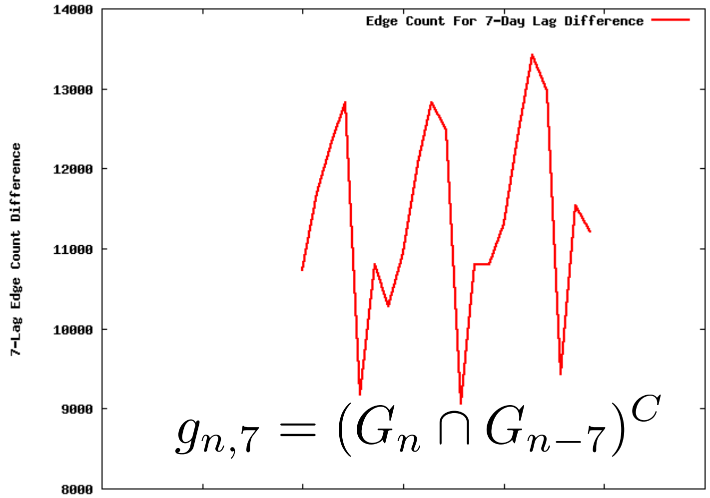
Daily Edge Count

- **Flight and edge counts exhibit *week-duration* periodicity**
- **However, the aggregate edge count masks more complex underlying dynamics**

Temporal Characteristics
(Difference Graph Properties)



1-day Lag Edge Counts



7-day Lag Edge Counts

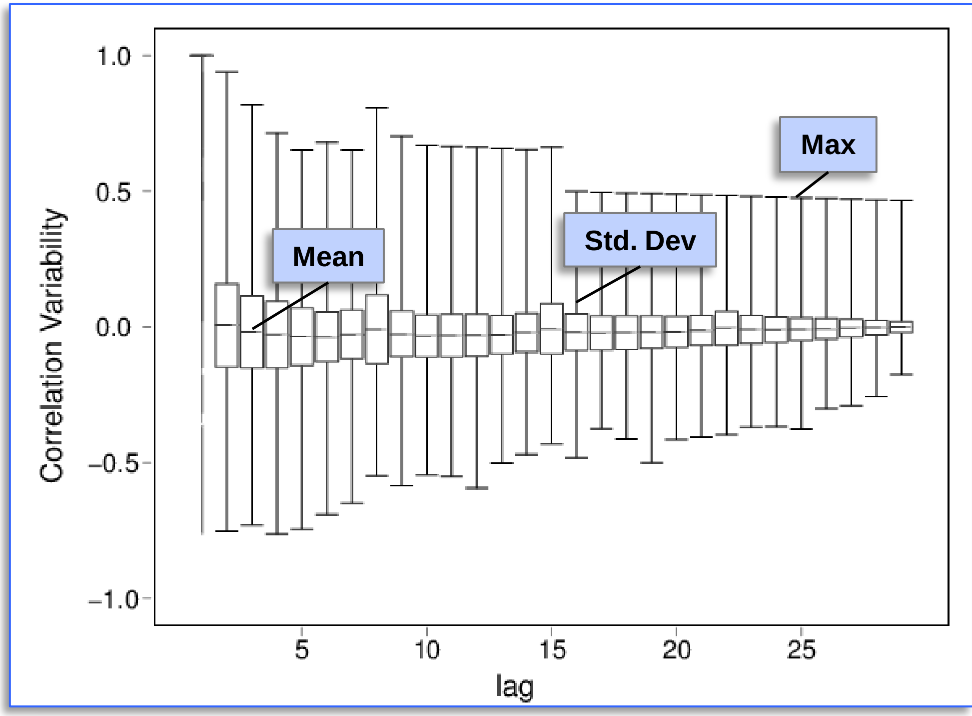
- **Uncommon edge counts between adjacent days same order as daily edge counts**
  - **A significant portion of traffic from one day to next is between new airport pairs**
- **Weekly periodic trend is removable by 7-day lag intersection**
  - **A significant portion of traffic does NOT follow a weekly trend**

Temporal Characteristics
(Time Correlation)

- **Correlation of edge time series**

$$R_{\tilde{w}_k,\tilde{w}_k}(n) = \frac{1}{N-1}\sum_{m=0}^{N-1}\tilde{w}_{k,m}\tilde{w}_{k,m+n}$$

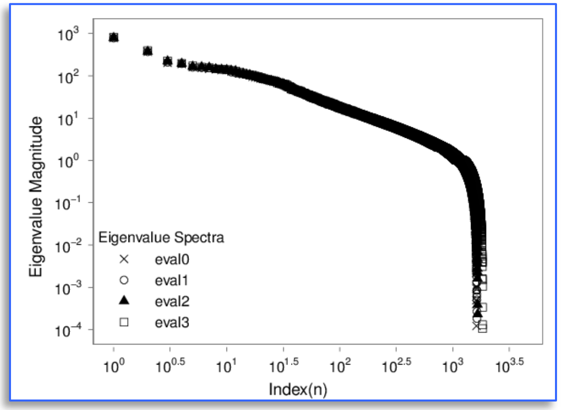
- **Plot shows:**
  - **Average, standard deviation, and maximum correlations**
- **Aggregate or maximum value suggest a high degree of correlation between days**
- **However underlying edge dynamics are in fact *NOT* well correlated**



Spectral Analysis

- **Eigenvalue spectrum shows power law decay**
- **High degree of correlation in leading eigenvectors**
- **Suggests low rank models are feasible for time series prediction**

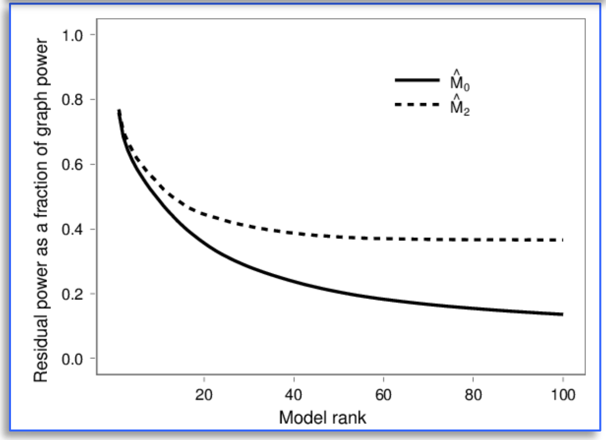
Eigenvalue Spectrum



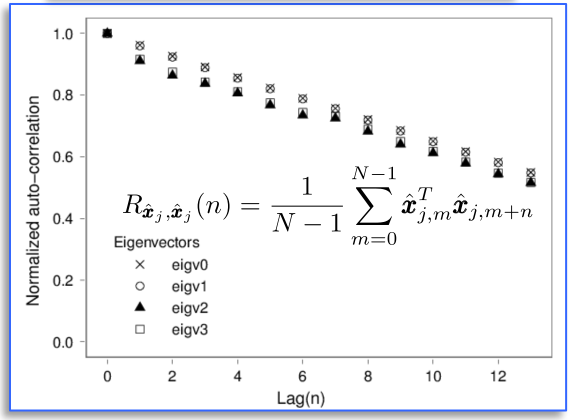
$$\hat{A}_n = \sum_{j=0}^{|\hat{V}_n|-1} \hat{\lambda}_{j,n} \hat{Q}_{j,n}$$

$$\hat{M}_n \approx \sum_{j=0}^{J-1} \hat{\lambda}_{j,n} \hat{Q}_{j,0}$$

Spectral Model Residual Power



Eigenvector Correlation



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Conclusions

- Network analysis of inter-city traffic using FAA's traffic flow management data stream
- Found daily graph clustering properties to differ from previously reported results (due to limits of those data sets)
- Quantified temporally complex behavior, which contains a significant non-weekly trend
- Spectral analysis:
  – Dominant eigenvectors are quasi-stationary
  – Low rank spectral models capture bulk of daily network power
  – Preliminary analysis suggests utility of model in forecasting