Characterization of Traffic and Structure in the US Airport Network

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CIDU 2012

25 October 2012

This work was sponsored by the Assistant Secretary of Defense (Research and Engineering) under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government.
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
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

\[ G_n : \text{Daily Graph} \]
\[ \bar{G}_U(\bar{E}_U, \bar{V}_U) : \text{Union Graph} \]
\[ \bar{E}_U = \bigcup_{n=0}^{N-1} E_n, \quad \bar{V}_U = \bigcup_{n=0}^{N-1} V_n \]
\[ \bar{w}_k = \frac{1}{N} \sum_{n=0}^{N-1} \hat{w}_{k,n} \]
Structural Characteristics

- 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)

- Flight and edge counts exhibit *week-duration* periodicity

- However, the aggregate edge count masks more complex underlying dynamics
Temporal Characteristics
(Difference Graph Properties)

- 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

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

- 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

\[ \hat{A}_n = \sum_{j=0}^{|\hat{V}_n|-1} \hat{\lambda}_{j,n} \hat{Q}_{j,n} \]
\[ \hat{M}_n \approx \sum_{j=0}^{J-1} \hat{\lambda}_{j,n} \hat{Q}_{j,0} \]
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