Comparing and Clustering Ensemble Forecast Members to Support Strategic Planning in Air Traffic Flow Management

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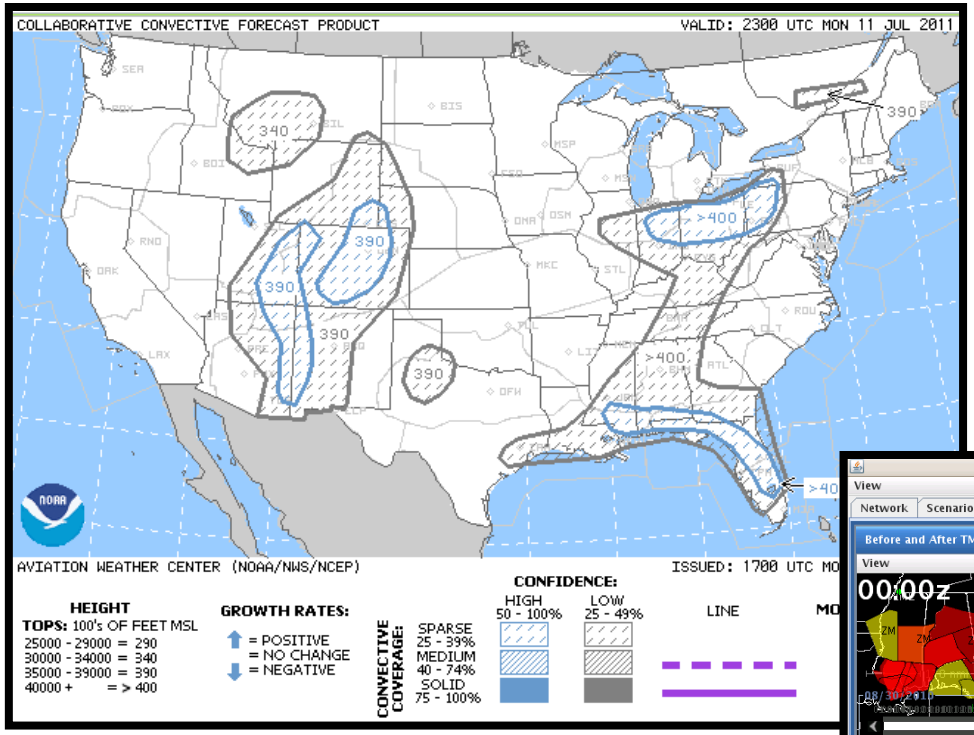
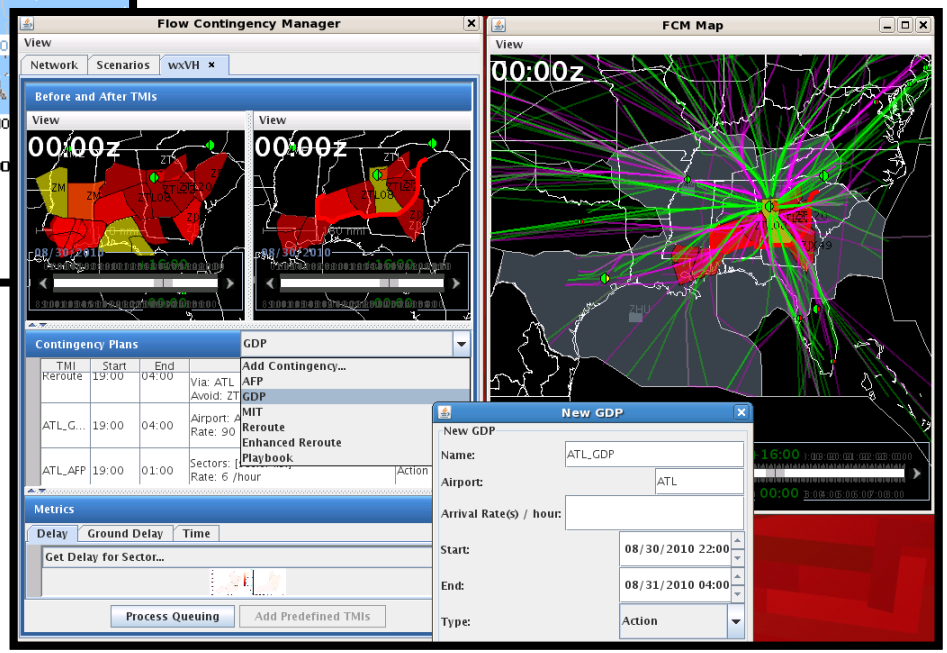
What is Flow Contingency Management?





Weather uncertainty creates *a range of TFM impacts*

Mitigation planning requires *a small number of scenarios*

The FCM decision support tool (DST) aims to provide a *scientific* methodology for strategic TFM decision-making

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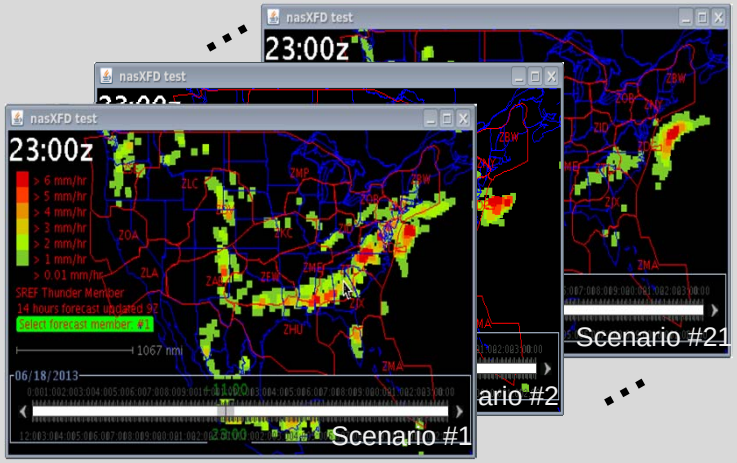
Research Framework

21 Weather Impact Scenarios



Scenario Clustering Methodology

Formulation of Impact Metrics
- Simulation Delays

Evaluation of Scenarios
- Spatiotemporal Aggregation Method

Development of Clustering Algorithm
- A Modified Spectral Clustering Algorithm

Selection of Representative Scenarios
- Development of Representativity Index

Representative Scenarios

Rep. Scenario 1
High impact over ZOB and ZAU

Rep. Scenario 2
High impact on NY terminal airspace

Rep. Scenario 3
Medium impact on ORD arrivals

Rep. Scenario 4
Low impact

Intended use; not included in this study.

Traffic Management Initiatives

Plan 1
AFP on A05, GDPs on NY Airports

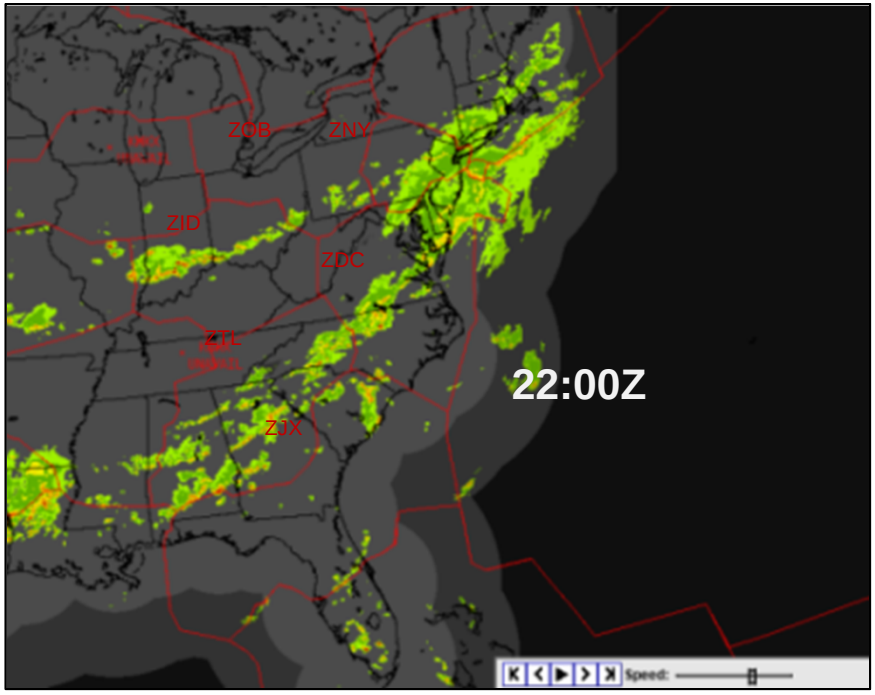
Plan 2
GDPs on NY Airports

Plan 3
GDP on ORD

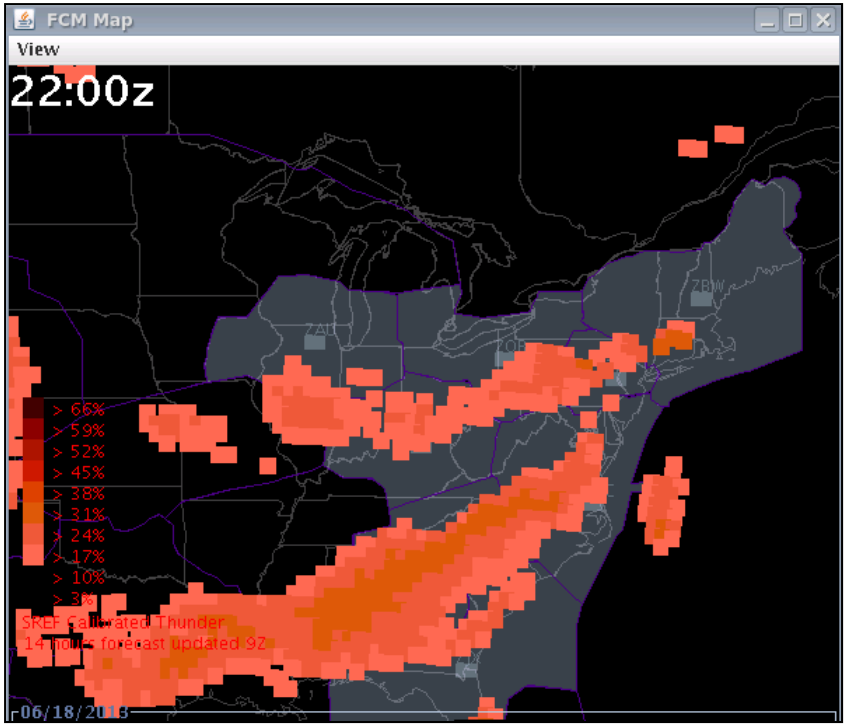
Plan 4
Do Nothing

Data Source – June 18, 2013

Historical Weather (CIWS)



SREF 9Z Forecast
(Calibrated Thunderstorm)



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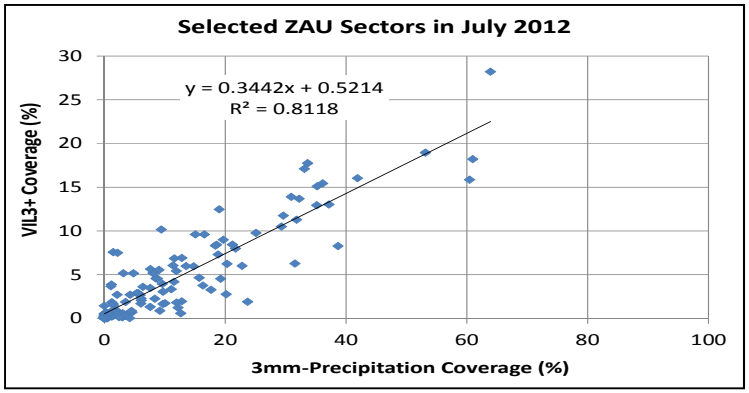
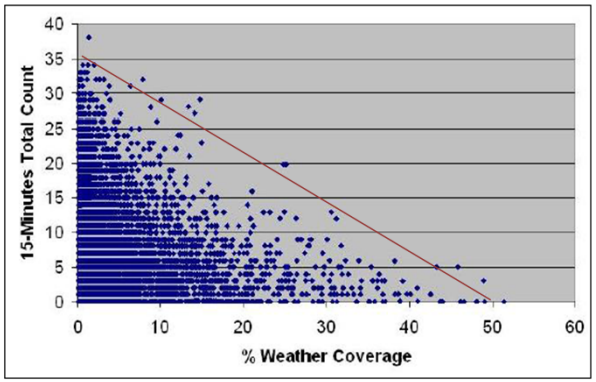
Estimating Capacity Loss

- **ATC Sector (Airspace) Capacity Reduction**
  - SREF Hourly Precipitation →VIL3+ Coverage → Capacity Reduction Rate





Source: Song, et al (2009)

- **Airport Capacity Reduction**
  - SREF Hourly Precipitation →Reflectivity (dBZ)→ Capacity Reduction Rate

dBZ	Description	Reduction Rate
Below 30	Light	0 %
30 ~ 40	Moderate	20 %
40 ~ 50	Heavy	40 %
Above 50	Extreme	60 %

Assumed for this study.

More sophisticated model under development

Forthcoming in ATIO 2014 Conference.

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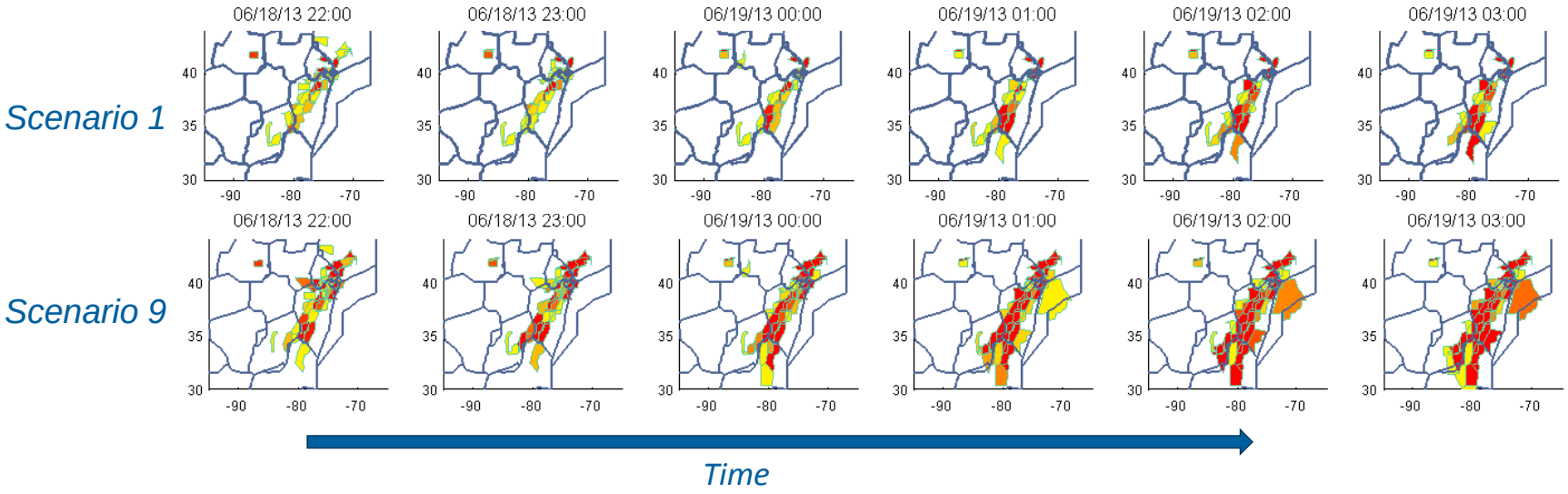
FCM Simulation Delays of Northeast Airspace

A few selected scenarios …



- **To facilitate scenario comparison, we have proposed metrics for aggregating spatiotemporal delays:**
  - Spatial Delay Metric:
    - Summation of delays weighted by sectors' geographical adjacency
  - Temporal Delay Metric:
    - Summation of delays weighted by temporal adjacency

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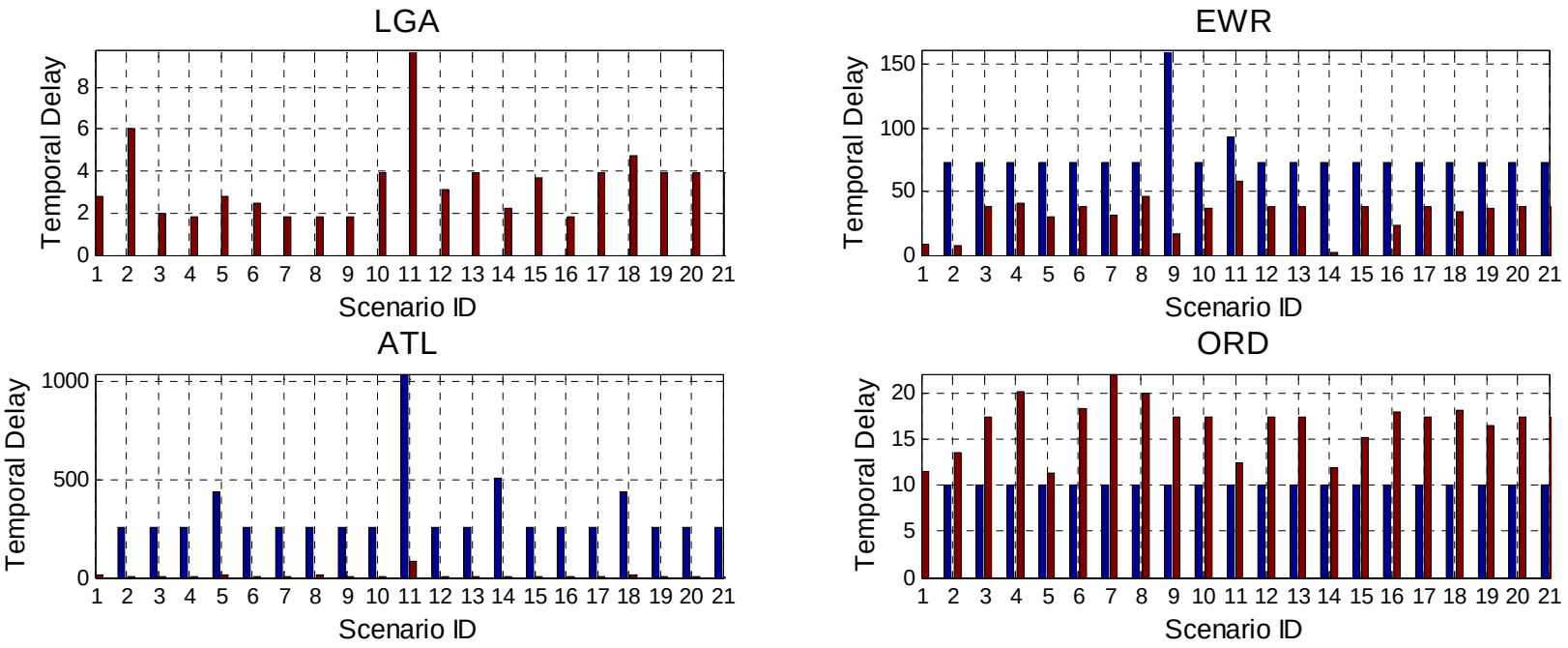
FCM Simulation Delays of Four Key Airports

Blue for delay at departure node; Red for delay at arrival node.



- **Significant delay variation can be seen in four airports.**
- **Five temporal delay metrics are calculated:**
  - LGA's arrival delay, EWR's departure delay, EWR's arrival delay, ATL's departure delay, and ORD's arrival delay.

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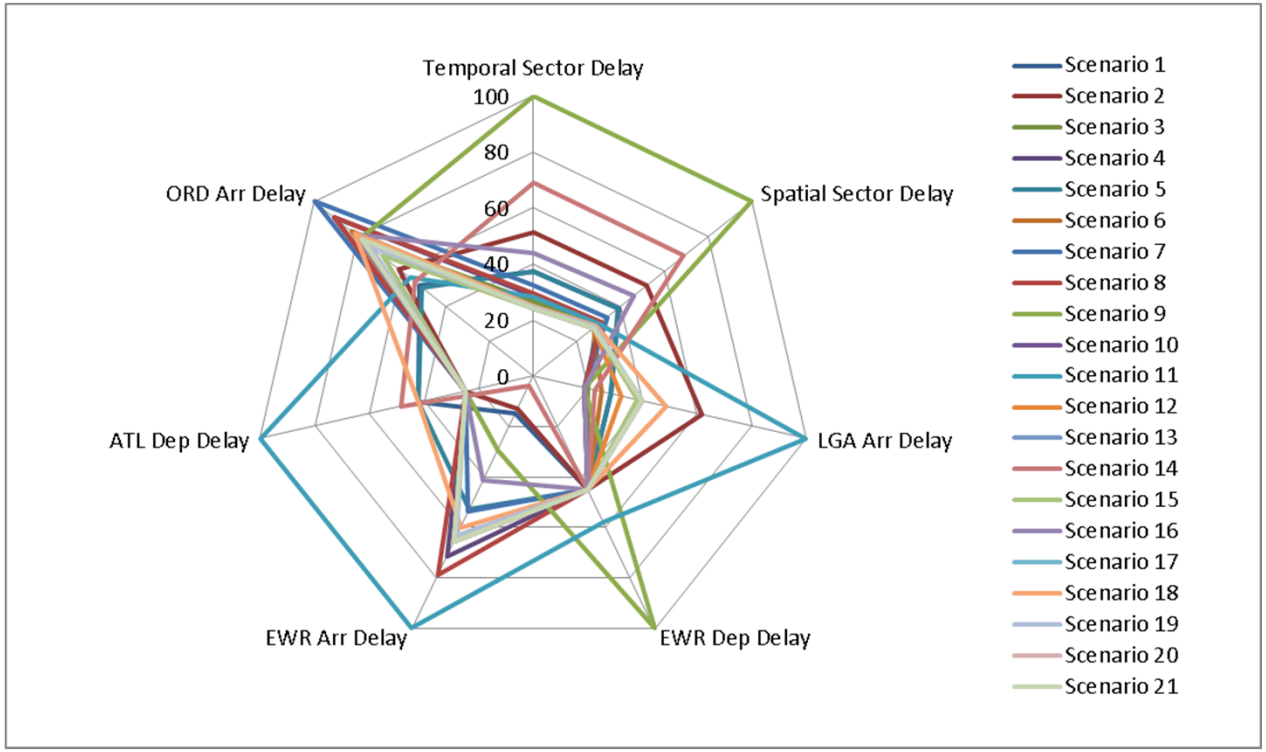
Impact Scenario Evaluation

- Each weather-impact scenario is evaluated with 2 sector delay metrics and 5 airport delay metrics.
- Metric values are normalized for display and clustering purposes.



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Clustering Algorithm & Representative Selection

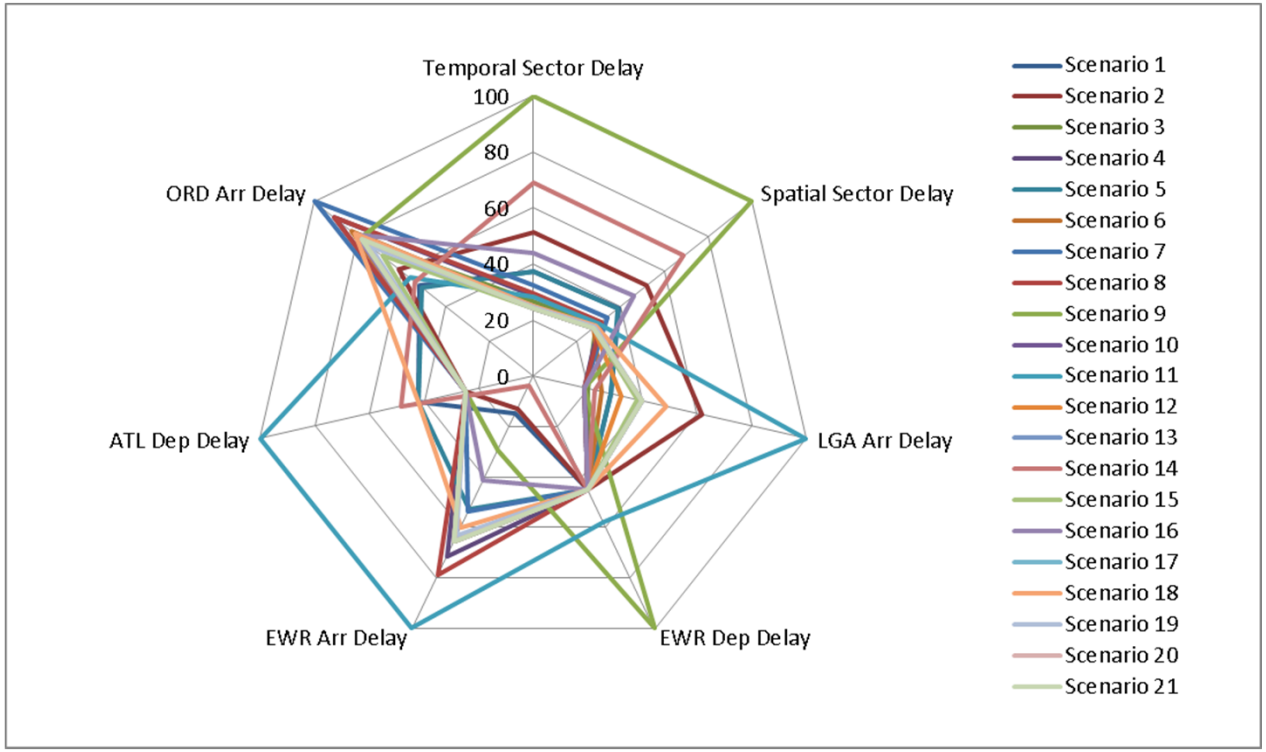
- **A recursive version of Spectral Clustering algorithm is adapted:**
  - Bipartition scenarios iteratively until convergence criteria are reached.
  - No need for pre-specifying/justifying the number of resulting clusters.
  - Parameters of convergence criteria are scale-free.
- **Representativity index (*RI*) is introduced:**

$$RI_i = \frac{\text{Average similarity metrics from the scenarios of all other clusters}}{\text{Average similarity metrics from the scenarios in its own cluster}}$$

  - A representative scenario of a cluster is defined as the one with the smallest *RI*.

Without Clustering

- Before running the clustering algorithm, there are 21 scenarios…



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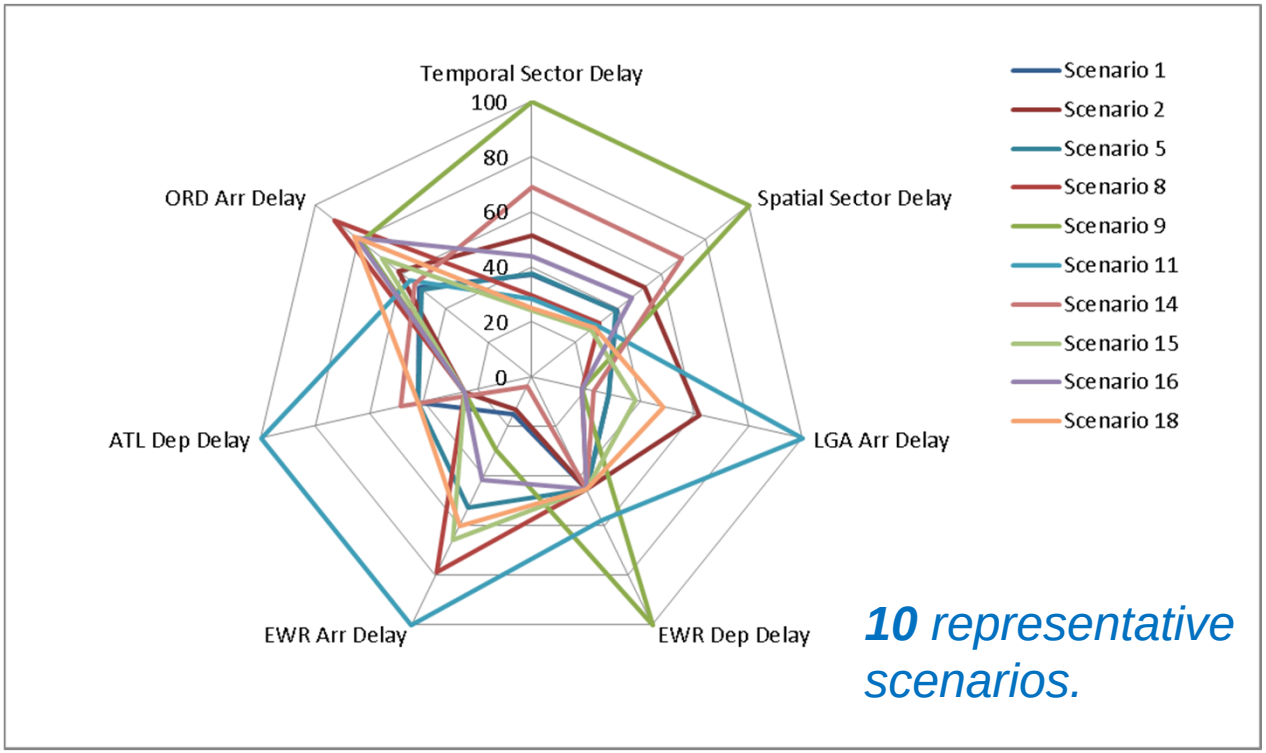
Clustering Results

***Legend**: Number for Scenario ID; color for cluster; boldfaced font for representative.*

S/A = 1

2	**9**	**11**	**14**	**16**	4	7	**8**	**1**	**5**	3	6	10	12	13	**15**	17	19	20	21	**18**

Sector to Airport Delay weighting factor



***10** representative scenarios.*

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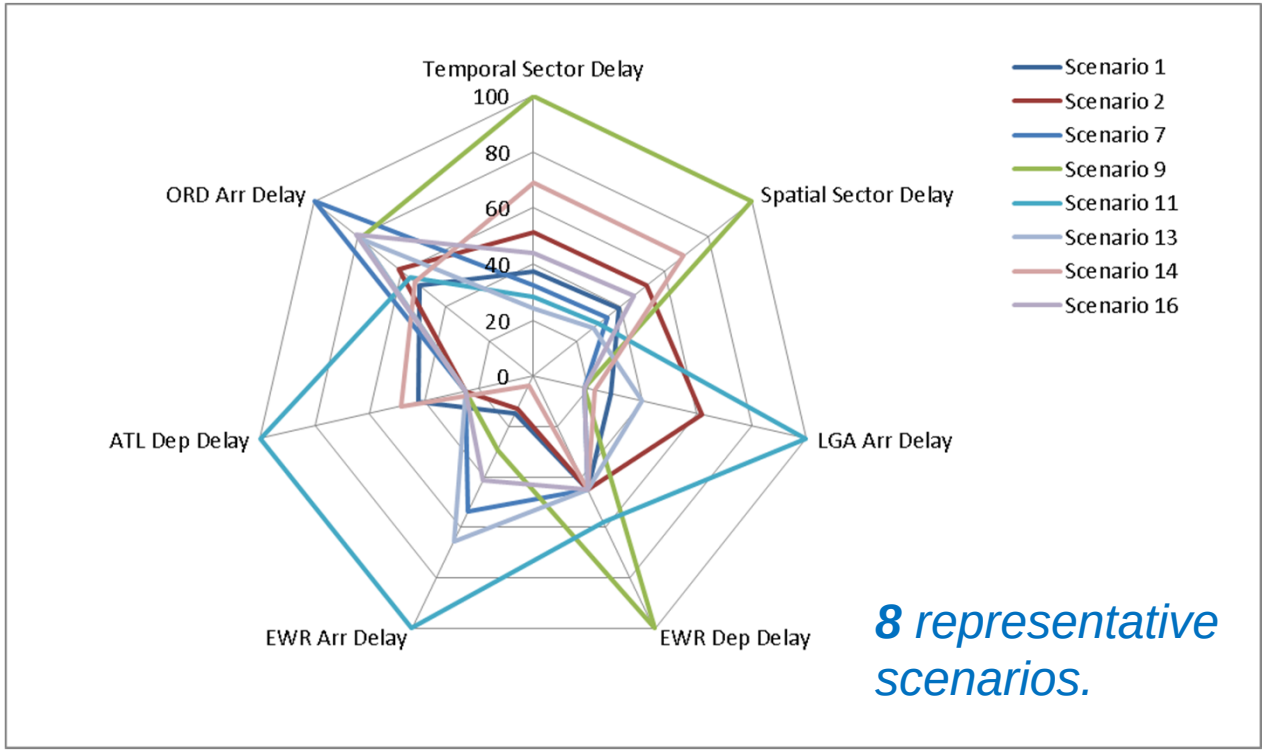
Clustering Results (2/2)

Legend: *Number for Scenario ID; color for cluster; boldfaced font for representative.*

S/A = 8

2	**9**	**11**	**14**	**16**	4	**7**	8	**1**	5	3	6	10	12	**13**	15	17	18	19	20	21

Sector to Airport Delay weighting factor



***8** representative scenarios.*

Weighting more on sector delays results in fewer clusters as differences in airport delays become less significant.

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Sensitivity of Sector-Airport Delay Tradeoff

***Legend**: Number for Scenario ID; color for cluster; boldfaced font for representative.*

S/A = 1

2	**9**	**11**	**14**	**16**	4	7	**8**	**1**	**5**	3	6	10	12	13	**15**	17	19	20	21	**18**

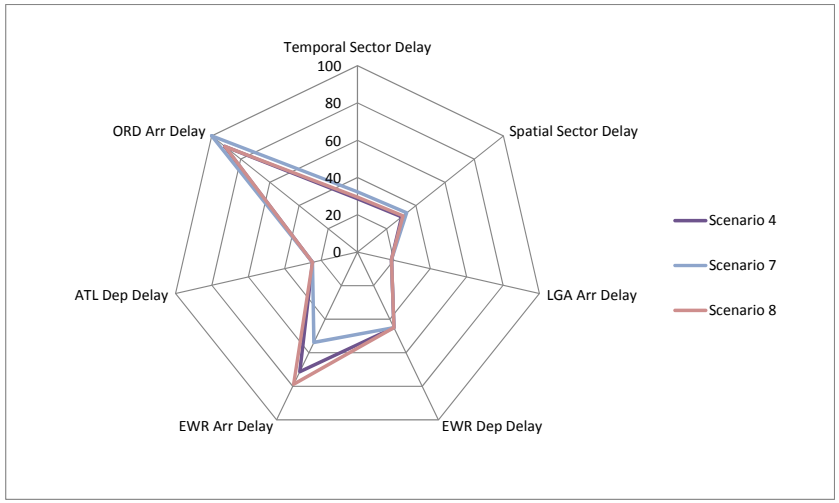
Change Representative.

Change Representative.

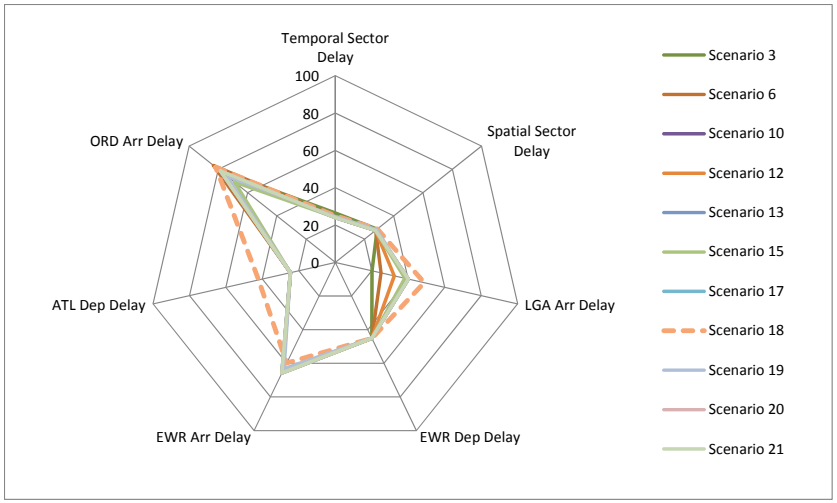
Change Group.

S/A = 2

2	**9**	**11**	**14**	**16**	4	**7**	8	**1**	**5**	3	6	10	12	**13**	15	17	19	20	21	18



Representative changed from 8 to 7.



Representative changed from 15 to 13 after Scenario 18 joined the cluster.

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Summary & Future Work

- **The ensemble members from the Short Range Ensemble Forecast product can be used to represent as a wide range of deterministic weather scenarios for FCM.**
- **The aggregation method for spatiotemporal data facilitates numerical comparison among scenarios.**
- **A representativity index (*RI*) is proposed for subjectively selecting representative scenarios after clustering.**
- **Sector and airport delays are incorporated into the proposed clustering approach, but the tradeoff between the two delay categories may influence the clustering results.**
- **Future work:**
  - Improve impact modeling for airport capacity.
  - Examine the performance of the clustering results with the traffic management initiatives designed for the representative scenarios.
  - Define and analyze more sample days for fine-tuning model parameters.

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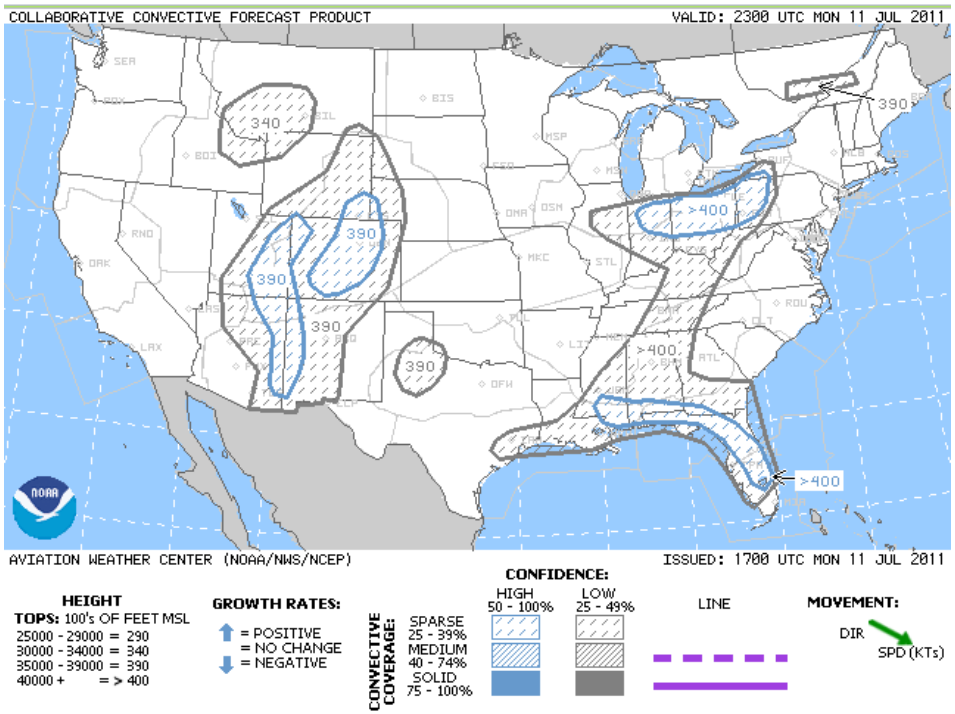
Strategic Planning in Today's Operation

Hours in advance, we know that there will be serious convective weather …

What is the range of possible weather scenarios, and how likely are these scenarios to occur?

What does the range of TFM impacts look like?

What options will we have available to alleviate congestion, and when do we have to act?



This is currently done by multi-stakeholder teleconference, with limited analytical information and few useful strategy assessment tools.

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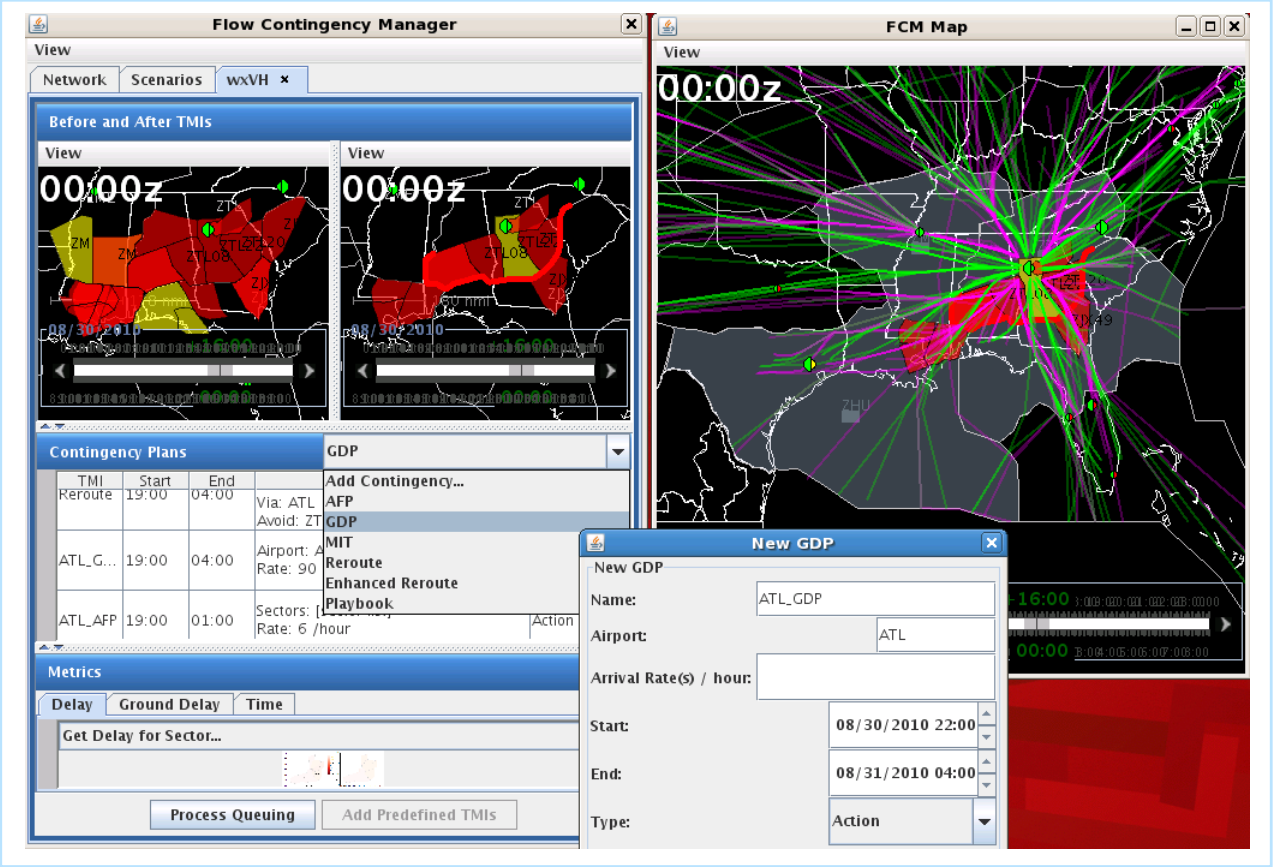
What is Flow Contingency Management?

The FCM decision support tool aims to provides a *scientific* methodology for strategic TFM decision-making

Developing a common understanding of the problem for stakeholders

Providing a quantitative analysis of potential plans *prior* to implementation

Enabling fact-based discussions for strategic planning development



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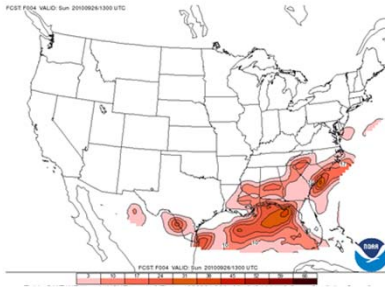
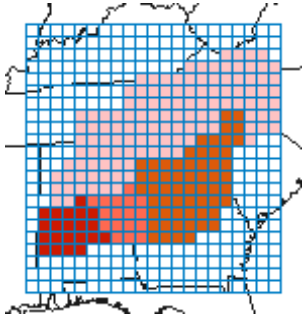
How does FCM work?

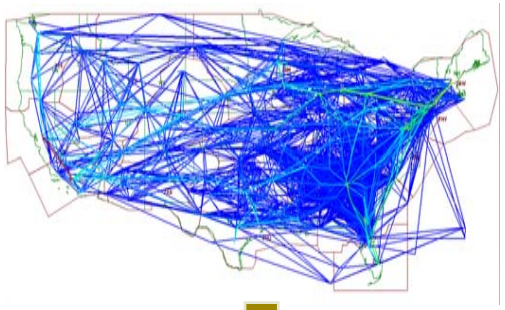
Weather forecast shows potential for convective activity



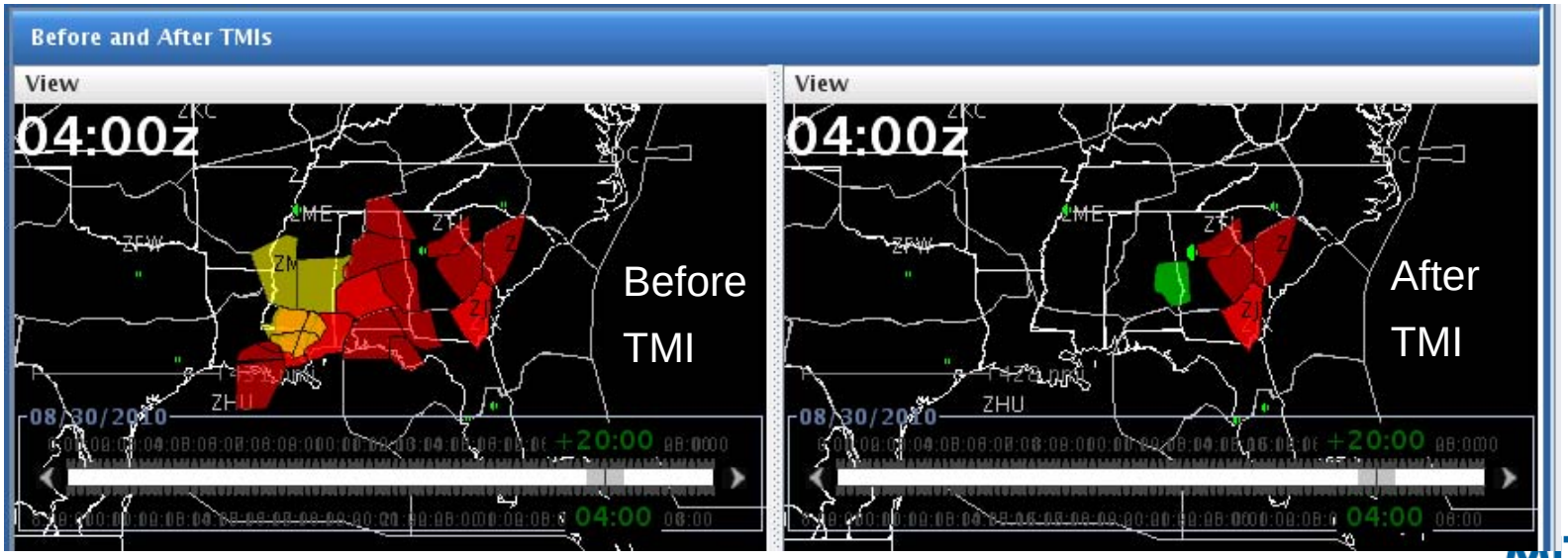
Translate into prediction of capacity impact



Simulation computes impact on demand across network



Interface provides details of impact and enables what-if planning of Traffic Management Initiatives (TMI)



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