Traffic Flow Management in the Presence of Uncertainty

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Project Team

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Overview

- Ruminations on Uncertainty
- Introduction to Traffic Flow Management (TFM)
- Research Overview
- Uncertainty in TFM Demand Predictions
- Visualizing and Applying Uncertainty
- Impact of Uncertainty on Decision-Making

On Managing Uncertainty

- “The message is that there are no "knowns." There are things that we know that we know. There are known unknowns. That is to say there are things that we now know we don't know. But there are also unknown unknowns. There are things we don't know we don't know. So when we do the best we can and pull all this information together, and we then say well, that's basically what we see as the situation, that is really only the known knowns and the known unknowns. And each year, we discover a few more of those unknown unknowns...”
  - Donald Rumsfeld, June 2003

Background: En Route Traffic Flow Management (TFM) in the U.S.

- Primary mission is to balance demand for air traffic services with available system capacity
- Ensure the maximum efficient utilization of the National Airspace System (NAS)
- Allocate air traffic flows to capacity constrained NAS resources (airports, coordination fixes, air traffic control sectors)
- Support FAA and safety responsibilities by maintaining traffic flows within levels that can be safely managed by sector air traffic controllers

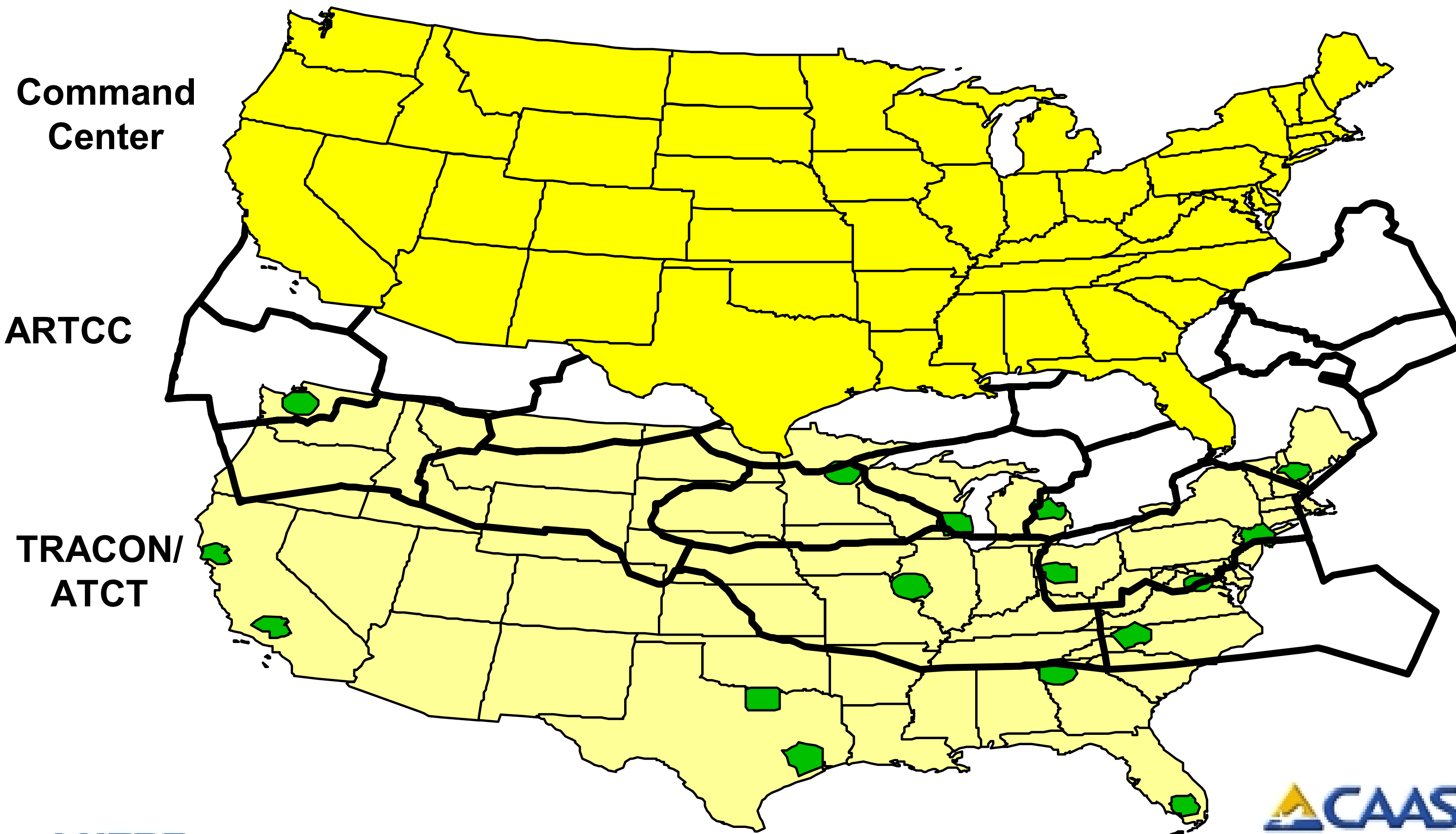
Traffic Flow Management Initiatives

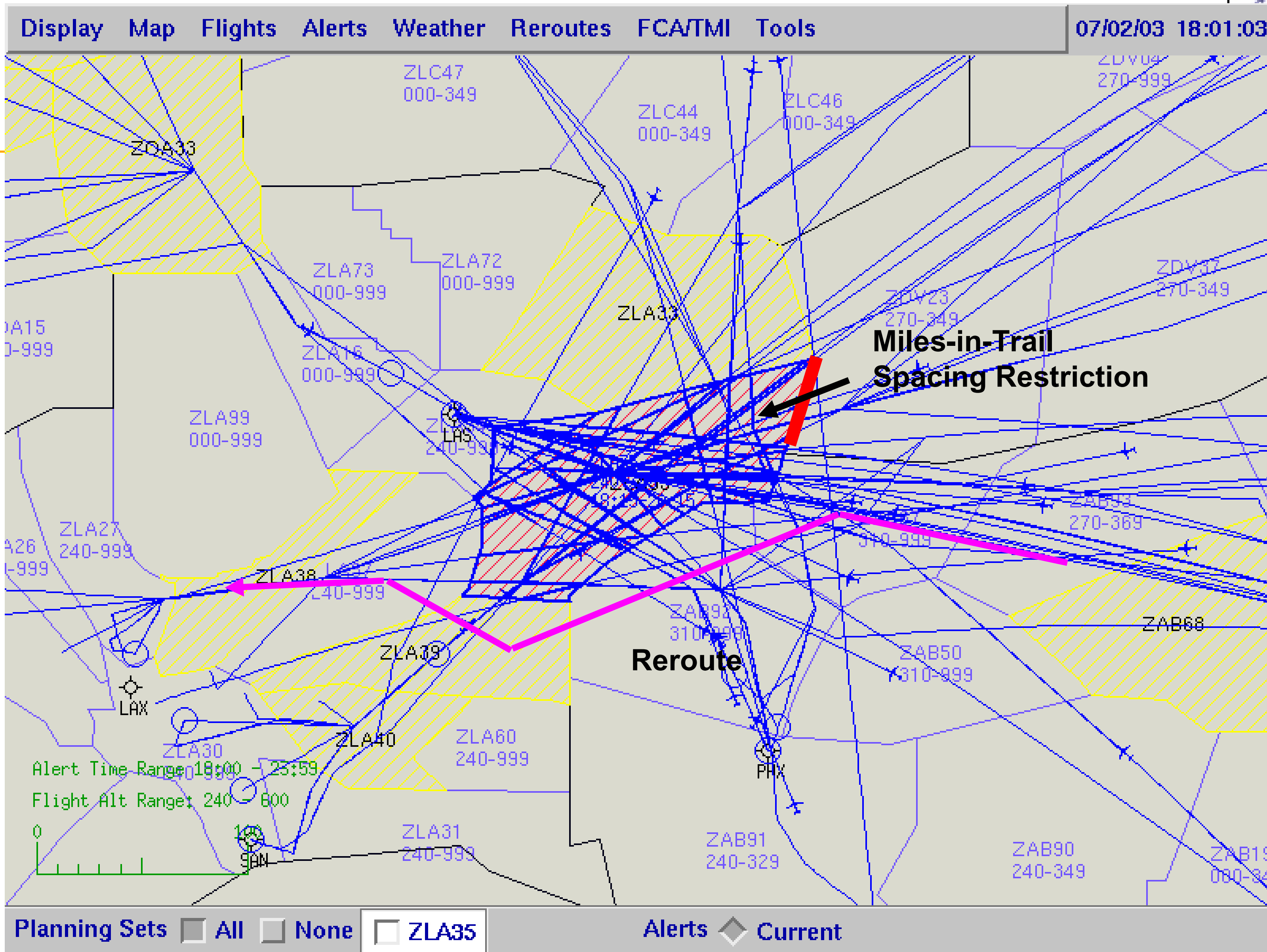
- Altitude restrictions
- Metering
  - Miles-in-Trail
  - Minutes-in-Trail
- Speed control
- Fix balancing
  - Arrival
  - Departure
- Airborne holding
- Rerouting
- Sequencing Programs
  - Departure Sequencing Program (DSP)
  - En route Sequencing Program (ESP)
  - Arrival Sequencing Program (ASP)
- Ground Delay Programs
- Ground Stop

Flow Management Structure: National to Local Facilities

Facility Level	General Characteristics
Air Traffic Control System Command Center (ATCSCC/Command Center)	• One of a kind facility within the FAA system • Responsible for system-wide coordination and planning • Primary focal point for interaction with air carriers and other NAS users • Enhanced Traffic Management System (ETMS) workstations with other automation support tools • Staffed with National Operations Managers, Supervisors, Traffic Management Specialists
En Route Air Route Traffic Control Center (ARTCC)	• Traffic Management Unit (TMU) at each of the 20 CONUS ARTCCs • Responsible for monitoring and planning of local flows • Coordinates with adjacent ARTCCs, underlying TRACONs, and Command Center • ETMS workstation and Host Computer-based automation tools • Staffed with 4-7 Traffic Management Coordinators
Terminal Radar Approach Control Facility (TRACON)	• TMUs in only 28 of the 192 TRACONs • Responsible for monitoring and planning of local (airport arrival and departure) flows • Coordinates with overlying ARTCC(s), underlying Tower(s), and Command Center • ETMS workstations with ARTS-based automation tools • Staffed with 1-4 Traffic Management Coordinators
Airport Traffic Control Tower (ATCT)	• Traffic Management Coordinators at only 5 of the FAA's approximately 400 ATCTs • Responsible for monitoring and planning of local (airport) traffic flows • Coordinates with overlying TRACON(s) and ARTCC(s) • ETMS workstations with ARTS-based automation tools • Staffed with 1 – 2 Traffic Management Coordinators, or duties are performed by ATCT supervisors, controllers, or collocated TRACON Traffic Management Coordinators

Geographical Areas of Responsibility





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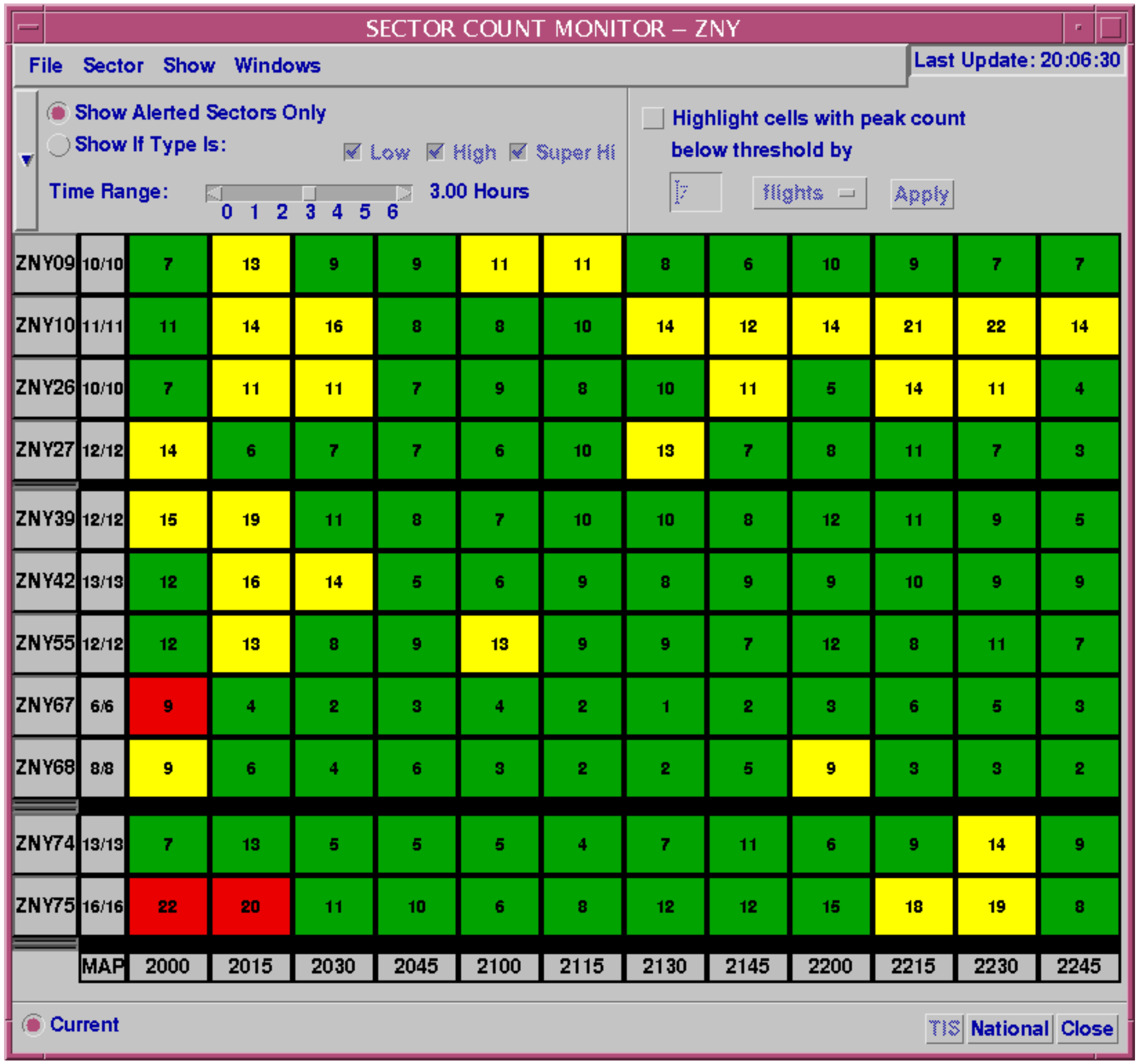
Tools for TFM: Sector Count Monitor



Sector	MAP	2000	2015	2030	2045	2100	2115	2130	2145	2200	2215	2230	2245
ZNY09	10/10	7	13	9	9	11	11	8	6	10	9	7	7
ZNY10	11/11	11	14	16	8	8	10	14	12	14	21	22	14
ZNY26	10/10	7	11	11	7	9	8	10	11	5	14	11	4
ZNY27	12/12	14	6	7	7	6	10	13	7	8	11	7	3
ZNY39	12/12	15	19	11	8	7	10	10	8	12	11	9	5
ZNY42	13/13	12	16	14	5	6	9	8	9	9	10	9	9
ZNY55	12/12	12	13	8	9	13	9	9	7	12	8	11	7
ZNY67	6/6	9	4	2	3	4	2	1	2	3	6	5	3
ZNY68	8/8	9	6	4	6	3	2	2	5	9	3	3	2
ZNY74	13/13	7	13	5	5	5	4	7	11	6	9	14	9
ZNY75	16/16	22	20	11	10	6	8	12	12	15	18	19	8

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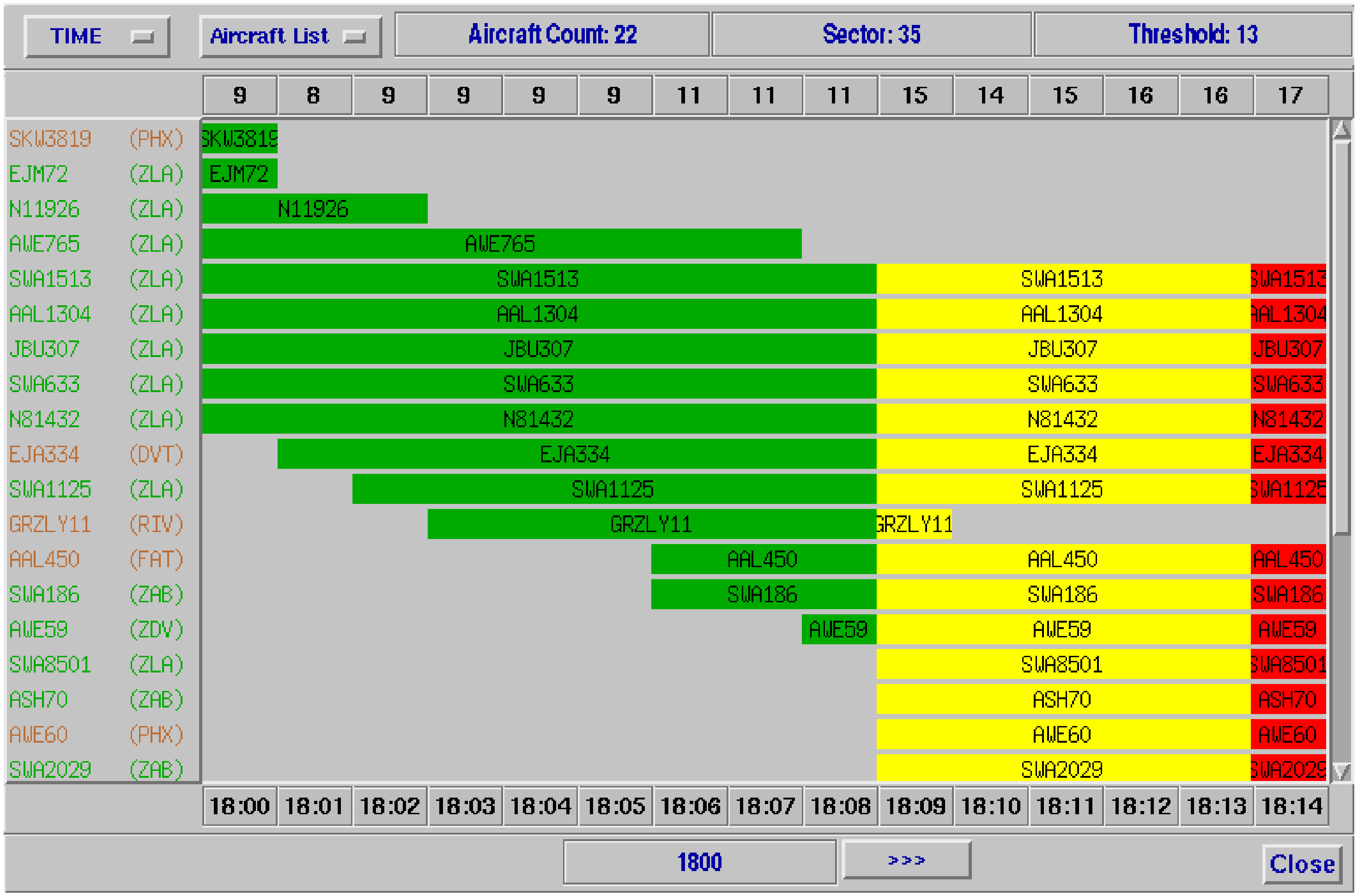
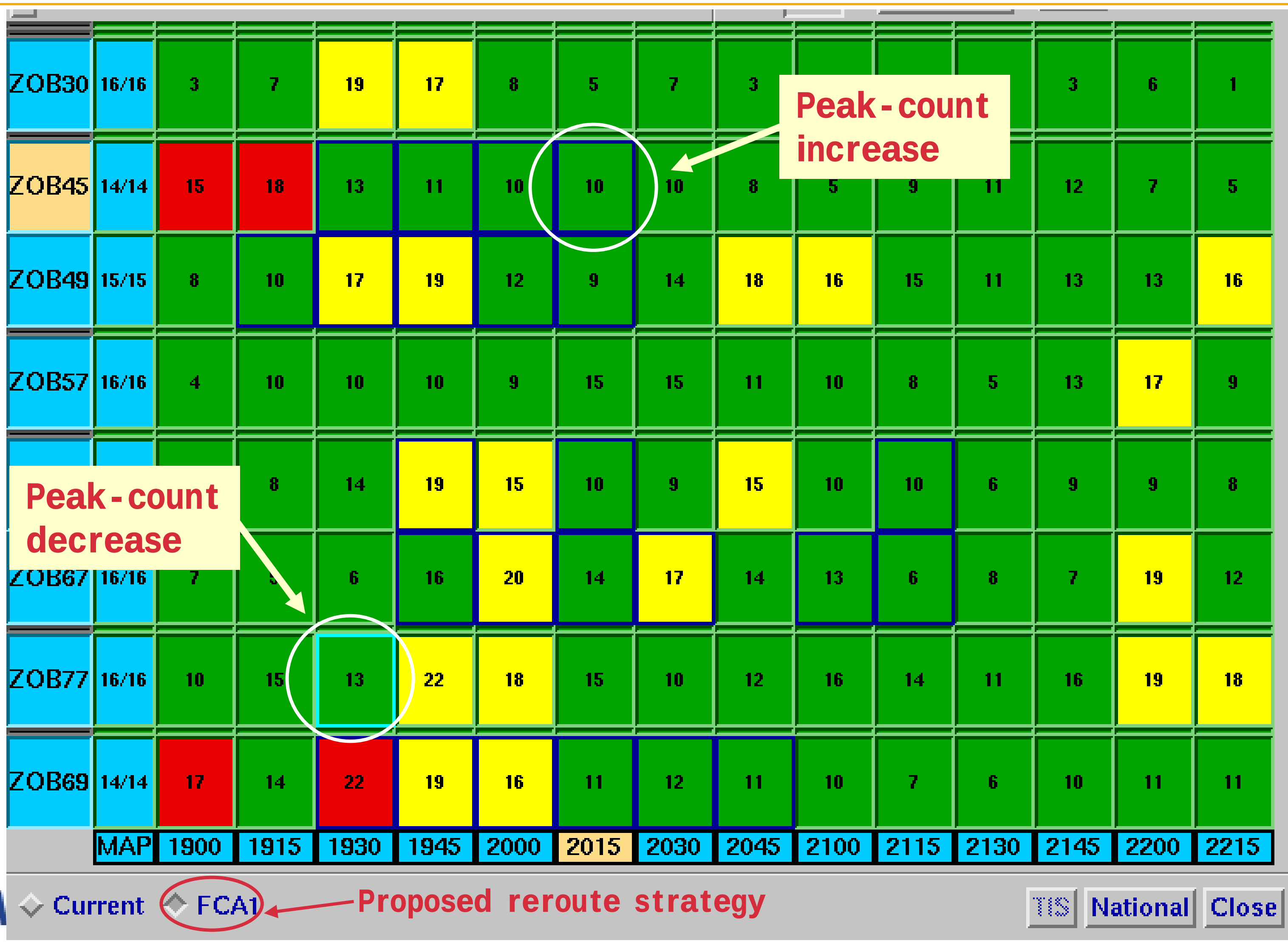
Tools for TFM: Time-in-Sector Display



Sector Impact of Rerouting



	MAP	1900	1915	1930	1945	2000	2015	2030	2045	2100	2115	2130	2145	2200	2215
ZOB30	16/16	3	7	19	17	8	5	7	3	[illegible]	[illegible]	[illegible]	3	6	1
ZOB45	14/14	15	18	13	11	10	10	10	8	5	9	11	12	7	5
ZOB49	15/15	8	10	17	19	12	9	14	18	16	15	11	13	13	16
ZOB57	16/16	4	10	10	10	9	15	15	11	10	8	5	13	17	9
[illegible]	[illegible]	[illegible]	8	14	19	15	10	9	15	10	10	6	9	9	8
ZOB67	16/16	7	5	6	16	20	14	17	14	13	6	8	7	19	12
ZOB77	16/16	10	15	13	22	18	15	10	12	16	14	11	16	19	18
ZOB69	14/14	17	14	22	19	16	11	12	11	10	7	6	10	11	11

Uncertainty in TFM

- TFM is about balancing demand for airspace and airport resources with the capacity of those resources
- Demand prediction is key to achieving balance
- However, at TFM timeframes (30 minutes to several hours), predictions are quite uncertain
  - Traffic management coordinators (TMCs) know this, but uncertainty is not quantified
  - Result: highly conservative decision-making
- If this uncertainty is known, then formal risk management techniques can be applied to improve decision-making

Research Question and Goals

- Research question:
  - Can prediction uncertainties be quantified, presented, and applied effectively to improve operational decision-making?
- Quantify uncertainty in TFM demand predictions
  - How accurate are present-day predictions and alerts?
  - What are the primary components of uncertainty, and what are the significant explanatory variables?
- Propose probabilistic TFM decision support techniques
  - Visualization methods for uncertain predictive information
  - Decision rules, automation aids to improve TFM decision-making in the presence of uncertainty

What is En Route TFM Demand? (1)

- Current metric: Peak Sector IAC over 15 minute period (ETMS Monitor/Alert) compared with threshold (MAP)
  - Uncertainty measure: Yellow vs. Red alerts
- If predictions are made at t_0 of demand at t_p, sector demand is the number of aircraft in the sector at t_p <u>assuming</u>:
  - Aircraft intent is accurately reflected by current flight plan information at t_0
  - No TFM or ATC actions will be applied to those flights between t_0 and t_p
  - No queing

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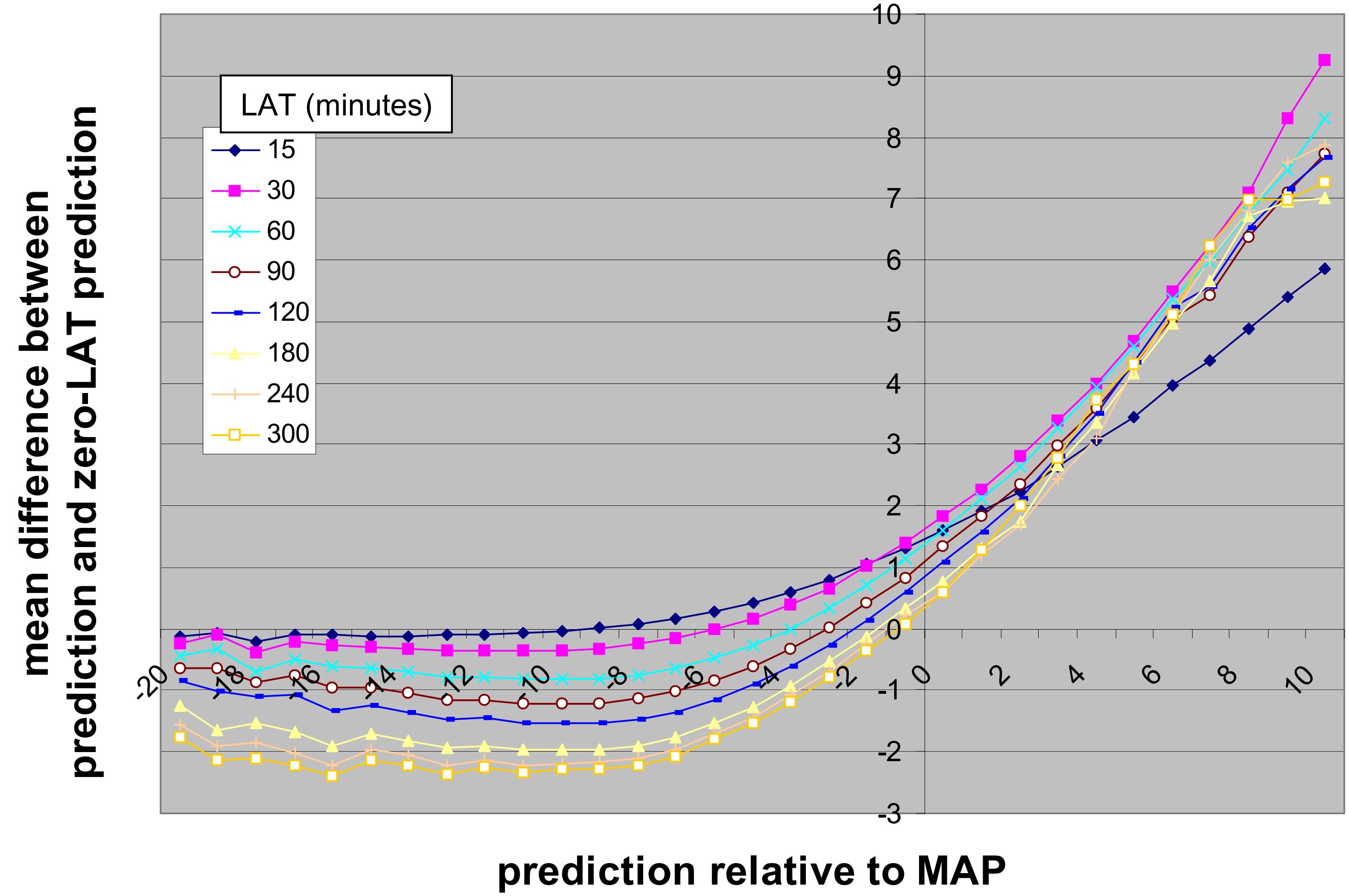
What is En Route TFM Demand? (2)

- This is done to provide decision-making information, not to predict the actual sector loading that will occur.
  – I (a TMC) want to know that 30 airplanes currently plan to use a sector an hour from now so I can take effective action…
  – …so a prediction of 30 is “accurate”, even though TFM or ATC will prevent 30 IAC from occurring even if I do nothing.
- Implication: actual sector loading, when at or near MAP, will reflect TFM/ATC actions and cannot be directly used to evaluate prediction error

Measurement of Demand Prediction Uncertainty

- Some research has used a simulation approach
  - Synthetic traffic can be used to create interesting conditions without effect of TFM/ATC actions
  - Simulate effects of changes in intent knowledge, etc.
  - Difficult and expensive to construct and validate a simulation that spans an interesting set of conditions
- Alternate method: use actual data, but select situations where TFM/ATC actions are not significant
  - Hypothesis: when predicted peak count is sufficiently fewer than the MAP, no action will be taken to manage demand
- Data source: 286 days of recorded peak count predictions for 754 NAS sectors, 0 to 6 hour LAT
  - Use zero-LAT predictions as proxy for actual peak count

Bias in Prediction Differences



Data Selection and Analysis

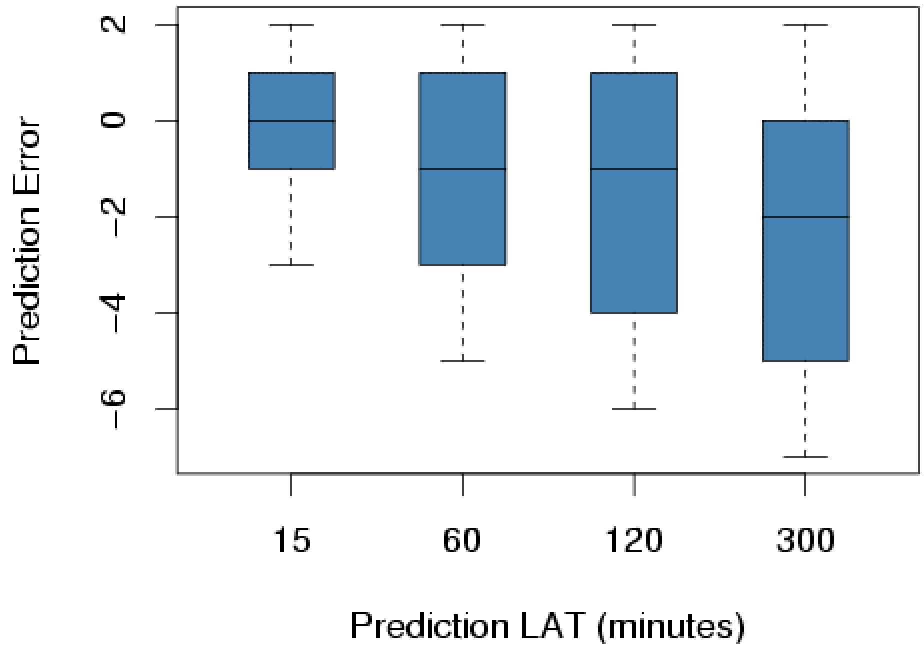
- Chose subset of the data where predicted peaks were less than (MAP – 6)
  – 350 million data points remain, only one-eighth were dropped
  – Assuming hypotheses are correct, prediction error was directly calculated as (predicted peak – zero-LAT peak)
- Categorized 754 NAS sectors by primary traffic operation
  – Departure, Arrival, En Route, Mixed
- Resulting distributions were characterized and plotted by many ways and under several conditions
  – Sector type, prediction, day-of-week, etc.
- Probabilities for alerting under various conditions were derived from these distributions

Factors Affecting Demand Predictions

Category	Class	Values
Airspace	Sector	Individual Sector (754 total) Altitude Class (Low, High, Super High) Primary Traffic Type (Departures, Arrivals, En Route, Mixed)
	ARTCC	Individually (21 total)
Time	Day	Day of week
	Time-of-Day	Hour of day, local time
	Time-of-Year	Season
Prediction	LAT	15 minute intervals, 0 to 6 hours
	Value	Absolute number or relative to MAP
Weather	Severe WX	Location (in sector, near sector, none)
	Jet Stream	Location, direction, strength

Prediction Error Quartiles: Mixed Sectors

- Features:
  - Increased spread at higher LAT
  - Under-prediction at higher LAT
  - Relatively large uncertainty magnitude



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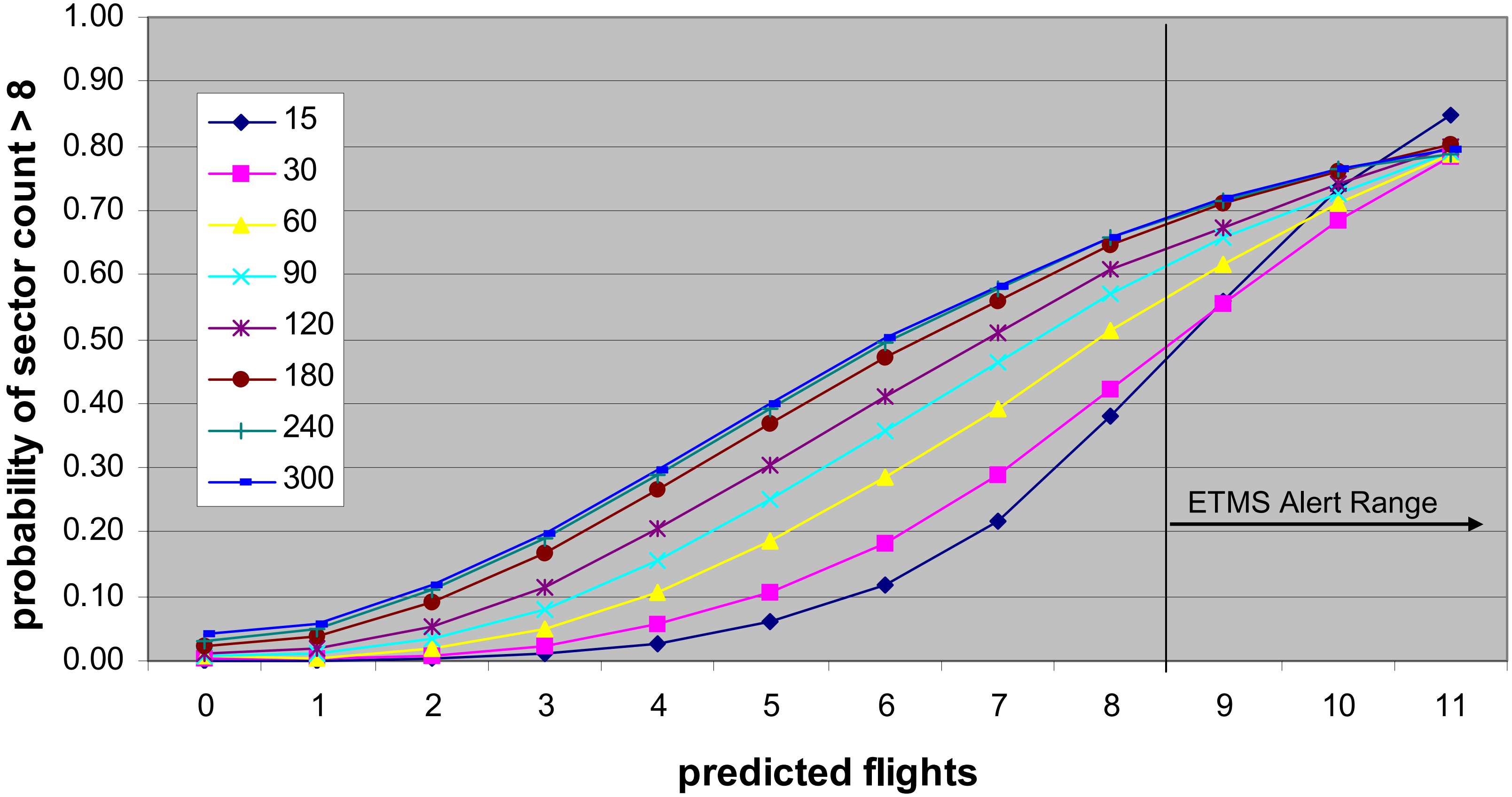
Evaluating Demand Uncertainty: Alert Probabilities – Based on Peak IAC

Mixed sectors: probability of exceeding 8 flights, conditioned on prediction value and look-ahead time



Applications

- This approach provides insight into present-day demand prediction uncertainty
  - Needs to be extended to higher-traffic situations
  - Does not provide a way to model uncertainty changes
- Results can be used to evaluate quality of information used in current traffic management operations
  - Develop new alerting, visualization methods
  - Support basic decision analysis
  - Guidance in adjusting procedures to account for uncertainty
- A synthetic traffic (simulation) approach is needed to do alternatives analysis

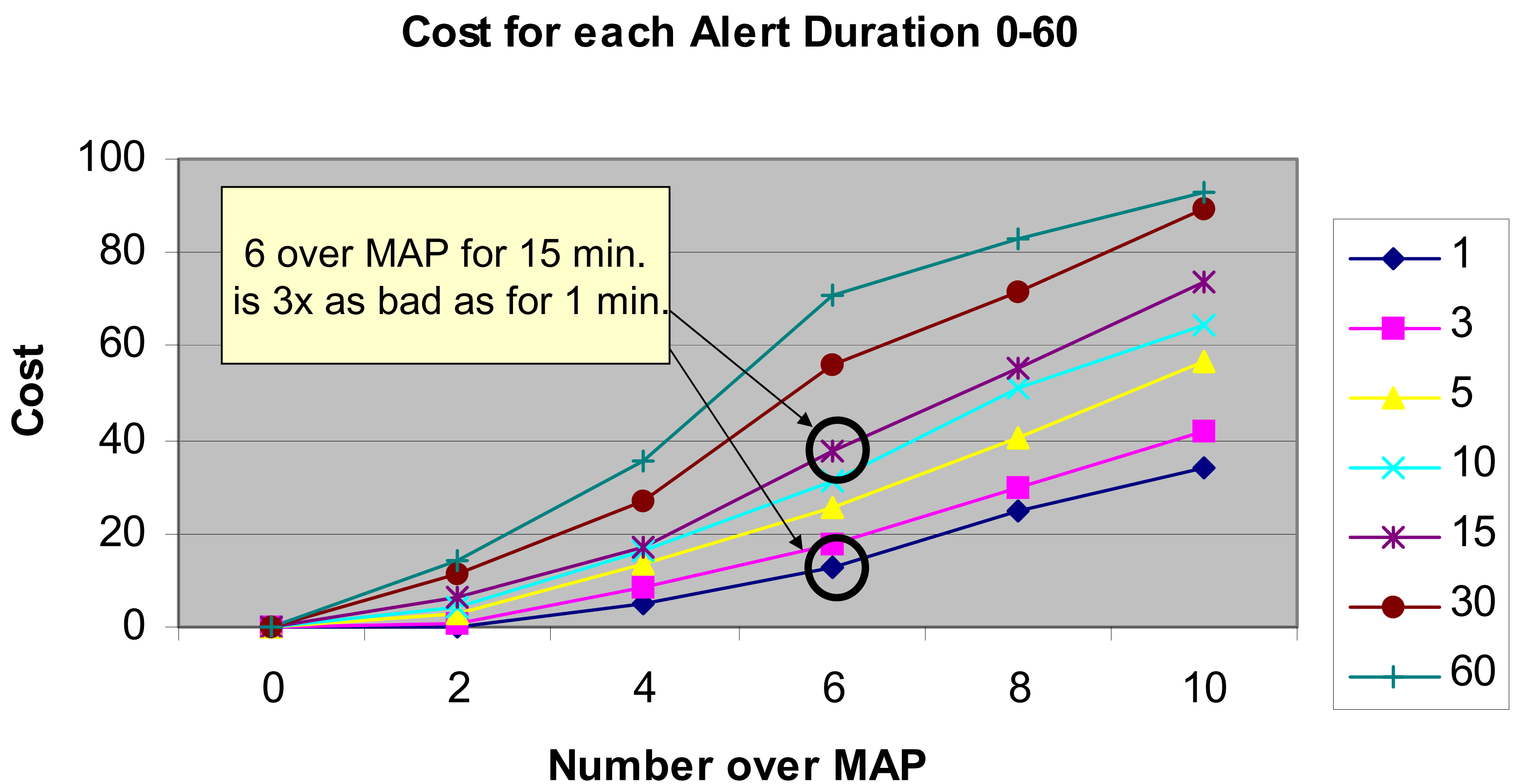
Visualizing and Applying Demand Uncertainty

- Sector alerts are used to flag *potential* problems; TMCs must explore further to identify and rank *real* problems.
  - Perceived prediction uncertainty is a key factor, but perceptions are not very good
- Can TMCs use and trust probabilistic information?
  - How should probability-based information be presented?
  - How do operational procedures change to take advantage of probability-based predictions?
    - Simplistic: inhibit actions until problems are more certain
    - "Hedge your bets": reduce traffic flows toward likely problem areas, play for the best expected value
  - Can probability-based automation aids improve decision-making, and would they be accepted and trusted?

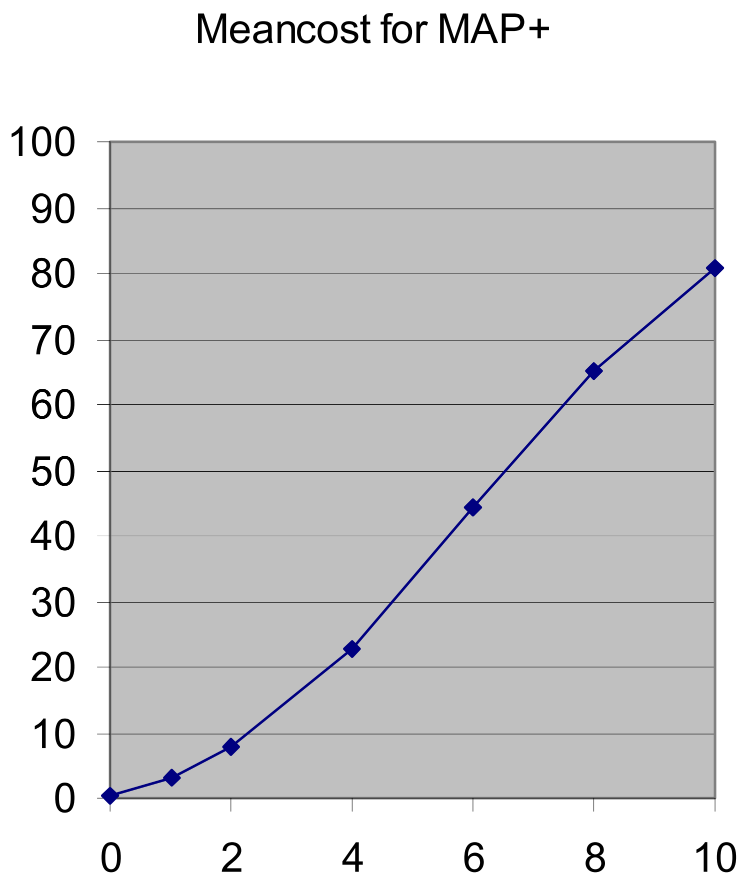
Interview with Operational Experts

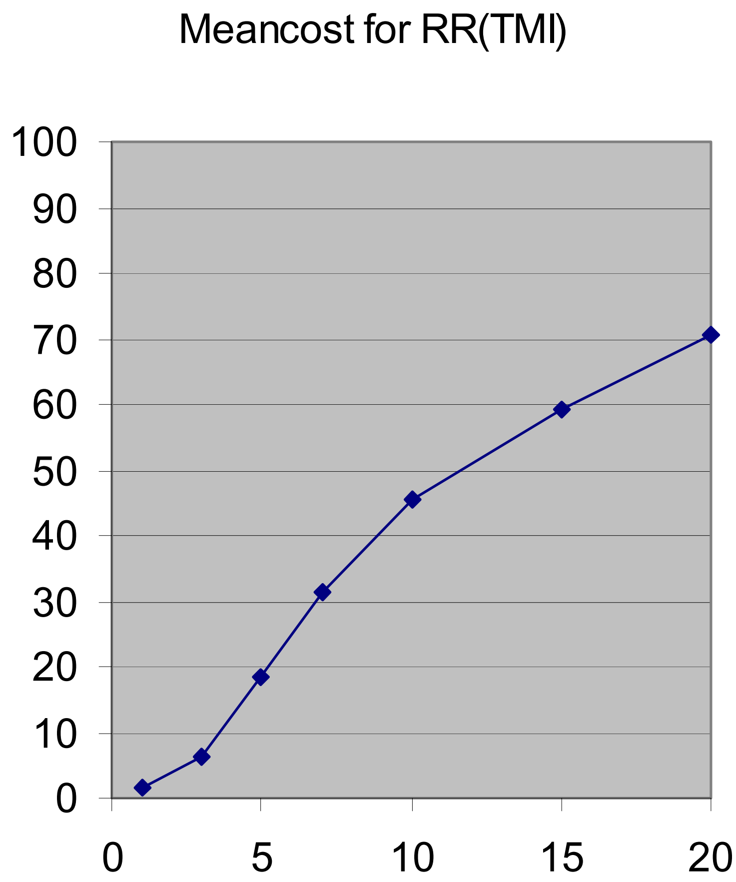
- Ten CAASD domain specialists participated
- Specific topics:
  - Subjective, relative “costs” of excess sector loading and traffic management initiatives
  - Information needs and candidate display methods
  - Relative importance of alert magnitude vs. duration
- Free-form discussion

Relative Cost: Alert Magnitude vs. Duration



Subjective Cost Functions: Exceeding MAP vs. Affecting Flights





Presentation of Uncertainty Information

- Desirable display attributes:
  - Range in peak sector counts
  - Range in alert start time
  - Color coding based on probability of MAP exceedance, severity, duration
- Unclear results on preferences for raw probability density function display: “love it or hate it”
- Disagreement on specifics of presenting route type information
- Flight specific information not as crucial (drilldown only)

Design Principles for Situation Awareness and Decision Support

- Endsley's model of Situation Awareness (SA):
  - Level 1: **Perception** of elements in the environment
  - Level 2: **Comprehension** of their meaning
  - Level 3: **Projection** of their state into the future
- Data presentation should directly support higher level SA needs
- Minimize mental transformations needed to convert raw data to operationally relevant knowledge
- Support concurrent multiple goals
- Co-locate information to support a particular goal

Probabilistic Sector Count Monitor: Ranges via Confidence Intervals

- Purpose of alerts, values is to assist identification of situations that require further analysis … does this work better?

	12:00	12:15	12:30
ZDV69 10/10	10-12	6-9	7-11
ZDV15 12/12	12-13	9-11	8-10
ZDV14 9/9	5-6	7-8	9-10

Best Guess
Range

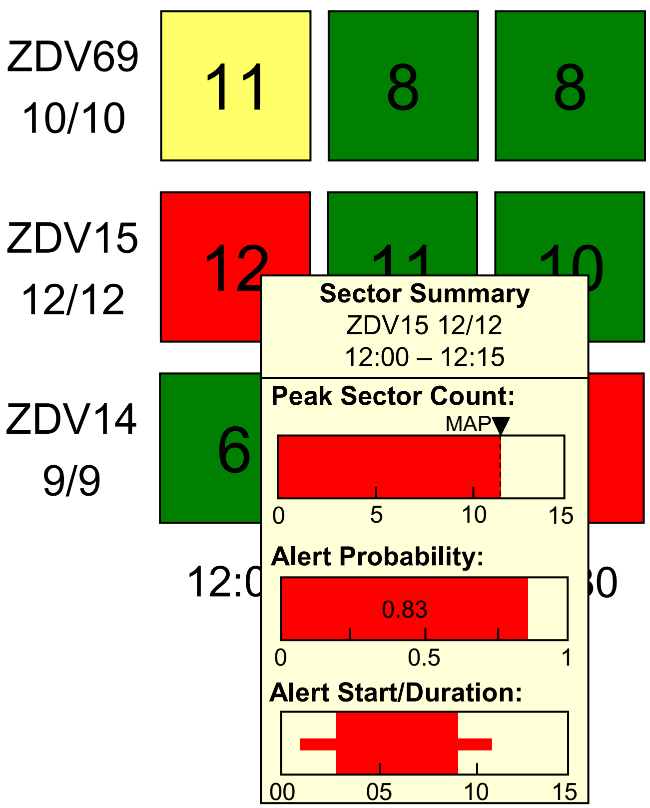
p(exceedance) 0.75

0.5 p(exceedance) < 0.75

p(exceedance) < 0.5

Probabilistic Sector Count Monitor: "Best Guess" plus Drilldown

- How about this one?

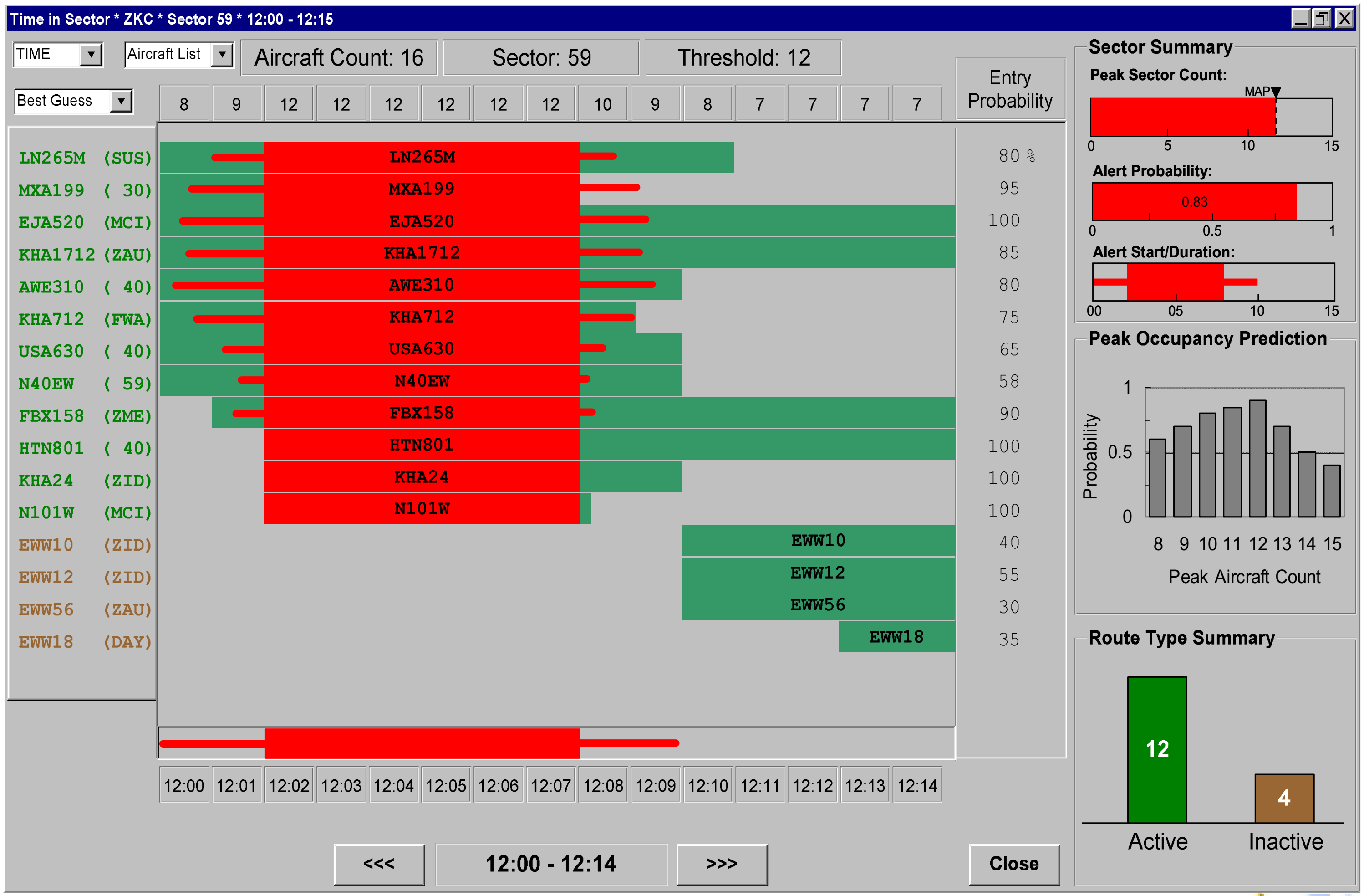


p(exceedance) 0.75

0.5 p(exceedance) < 0.75

p(exceedance) < 0.5

Probabilistic Time-in-Sector Display Concept



Decision Analysis

- Given an explicitly defined congestion management goal and estimated uncertainties, there is a "right answer."
  - The goal requires a mathematical representation of traffic management policy, balancing throughput vs. safety
  - This is done individually by TMCs today, we have started quantifying it
- Formal decision analysis can be applied to develop more uniform and effective decision-making strategies
  - For both procedural and automation-suggested solutions
  - Derive decision rules and methods for automation support
  - Link visualization work to effective decision-making
- First try: Single-sector congestion, single decision point

Probabilistic TFM Decision Support: Next Steps

- Test displays, decision heuristics in realistic settings
- Develop decision analysis model for operational situations
- Progress requires advanced modeling of NAS uncertainty
  – Realistic environment for HITL work
  – Operationally-relevant situations for decision analysis
  – “Variable uncertainty” to evaluate changes in prediction knowledge
- Design simulation model to support this work
- Design evaluation methodology and improved probabilistic displays for HITL experiment

For More Information

- Craig Wanke, Principal Investigator: cwanke@mitre.org

- Wanke, C., Callaham, M., Greenbaum, D., Masalonis, A. (2003) “Measuring Uncertainty in Airspace Demand Predictions for Traffic Flow Management Applications,” *Presented at the 2003 Guidance, Navigation, and Control Conference*.

Questions?

The day Heisenberg mailed out his Uncertainty Principle.