The 3 M's of ATM

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Outline

- What was the NextGen dream?
- What is the NextGen reality?
- What were some of the issues?
- What are the 3 M's of ATM?
- How could we use the 3 M's?
- R&D Project Portfolio Optimization
- Key Research Questions

What was the NextGen dream?

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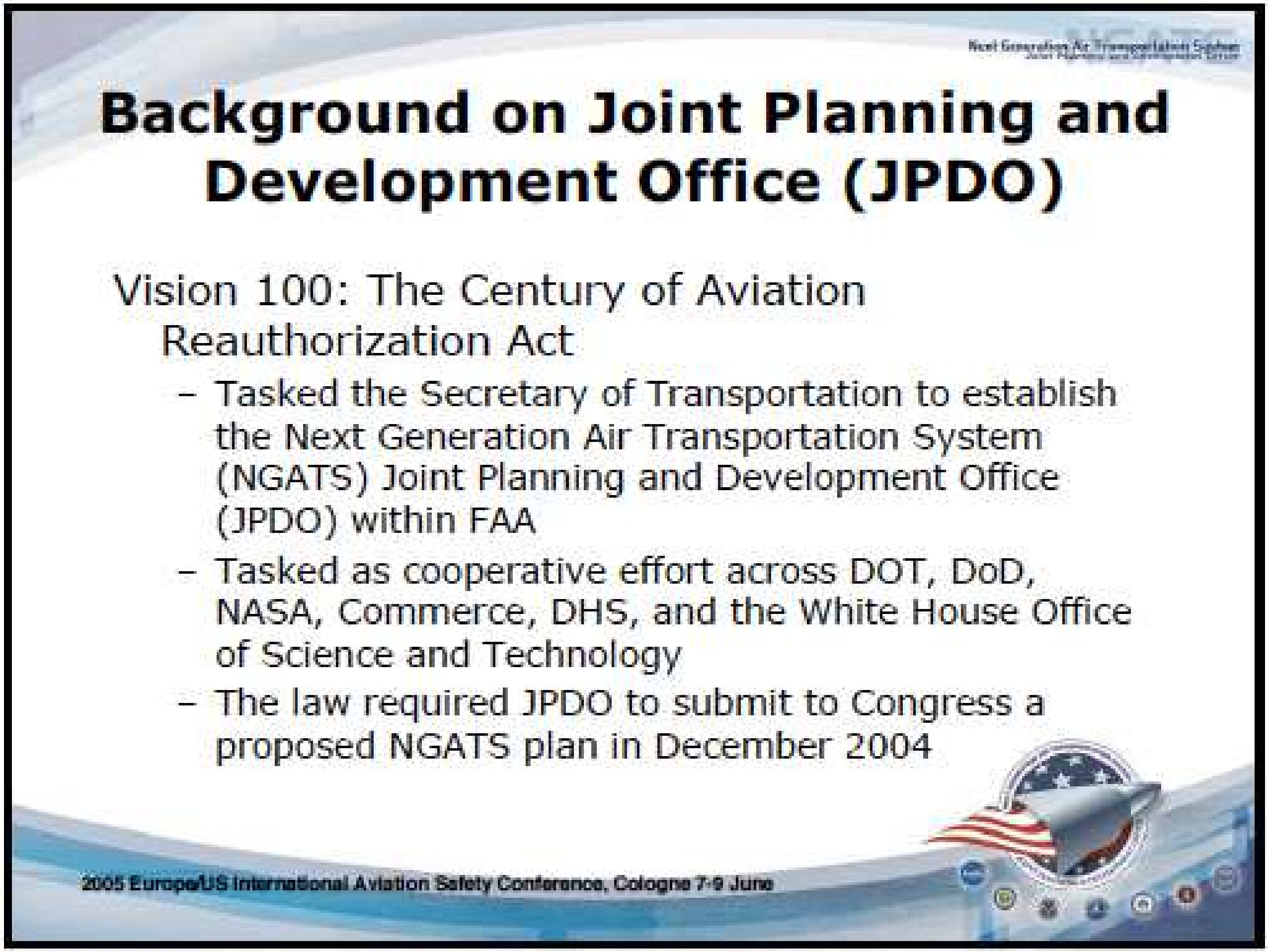

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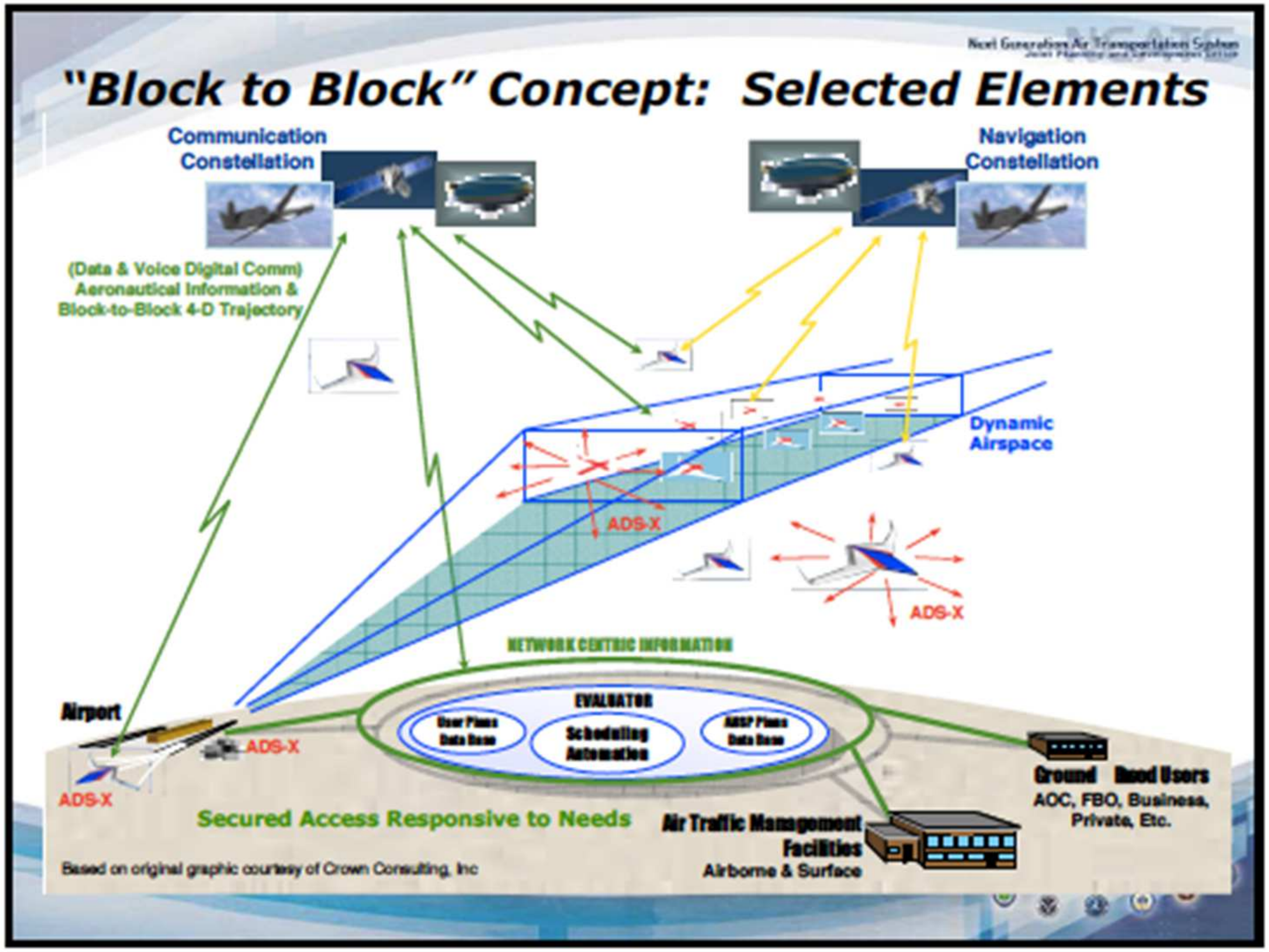

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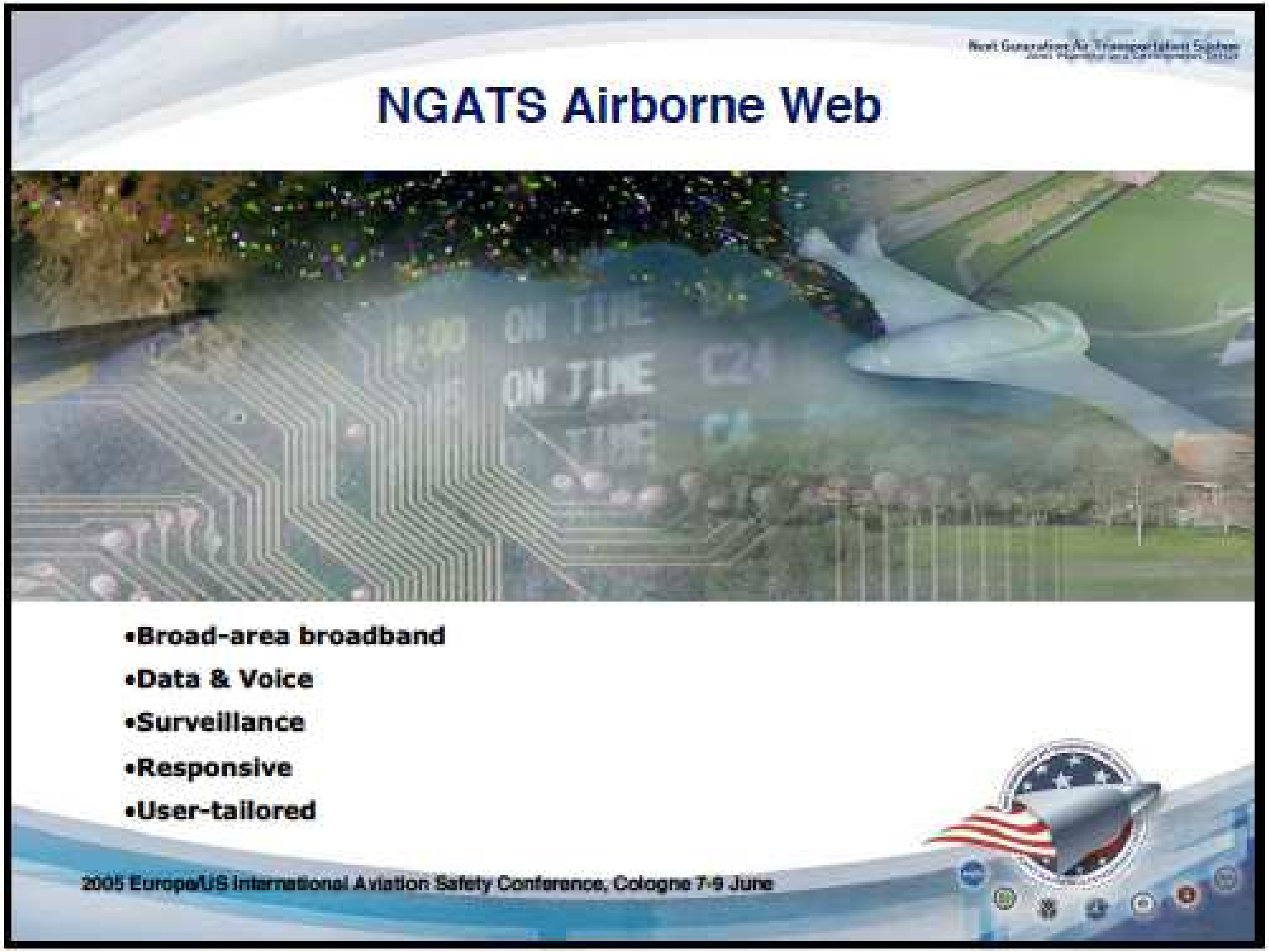

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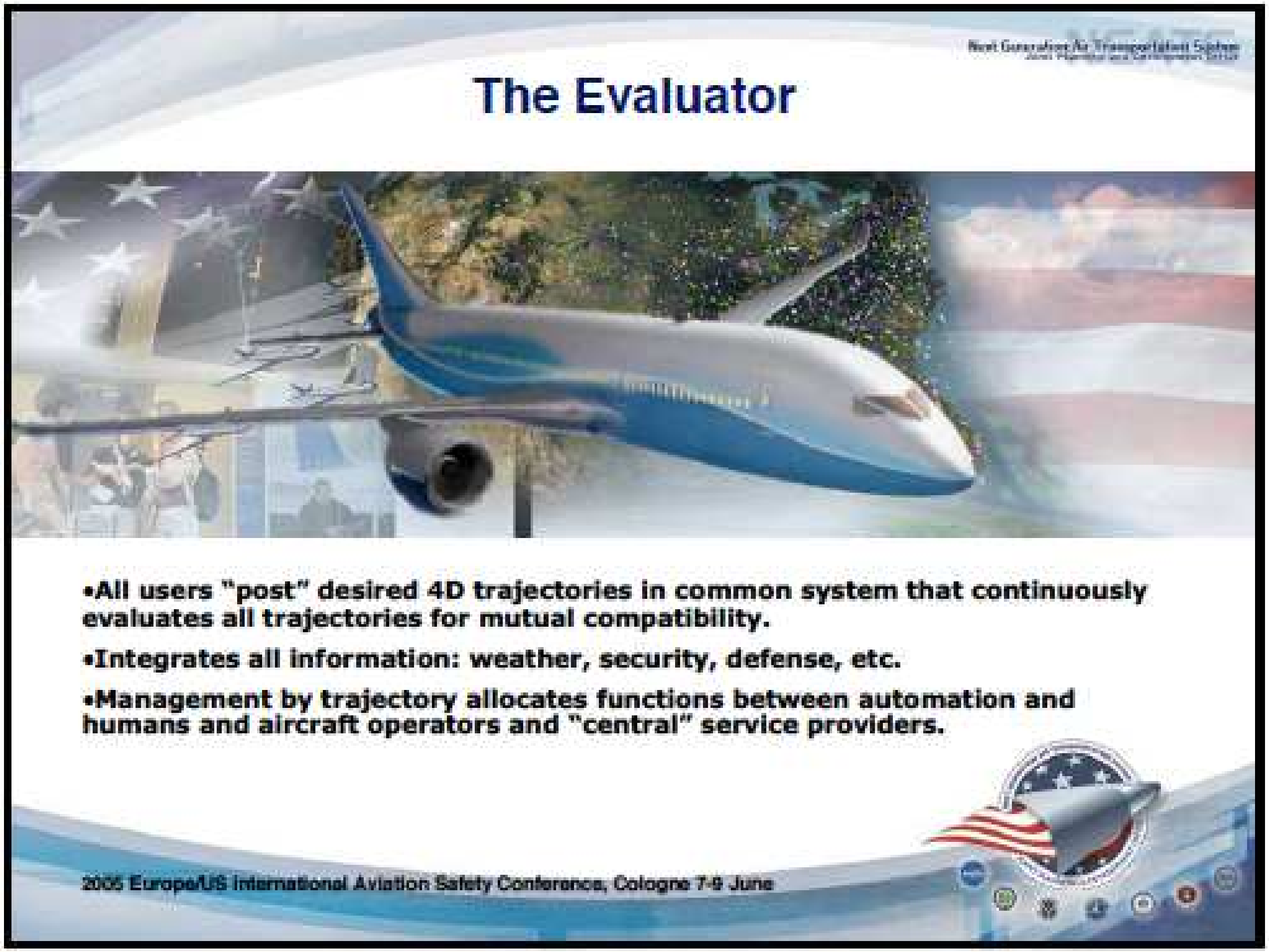

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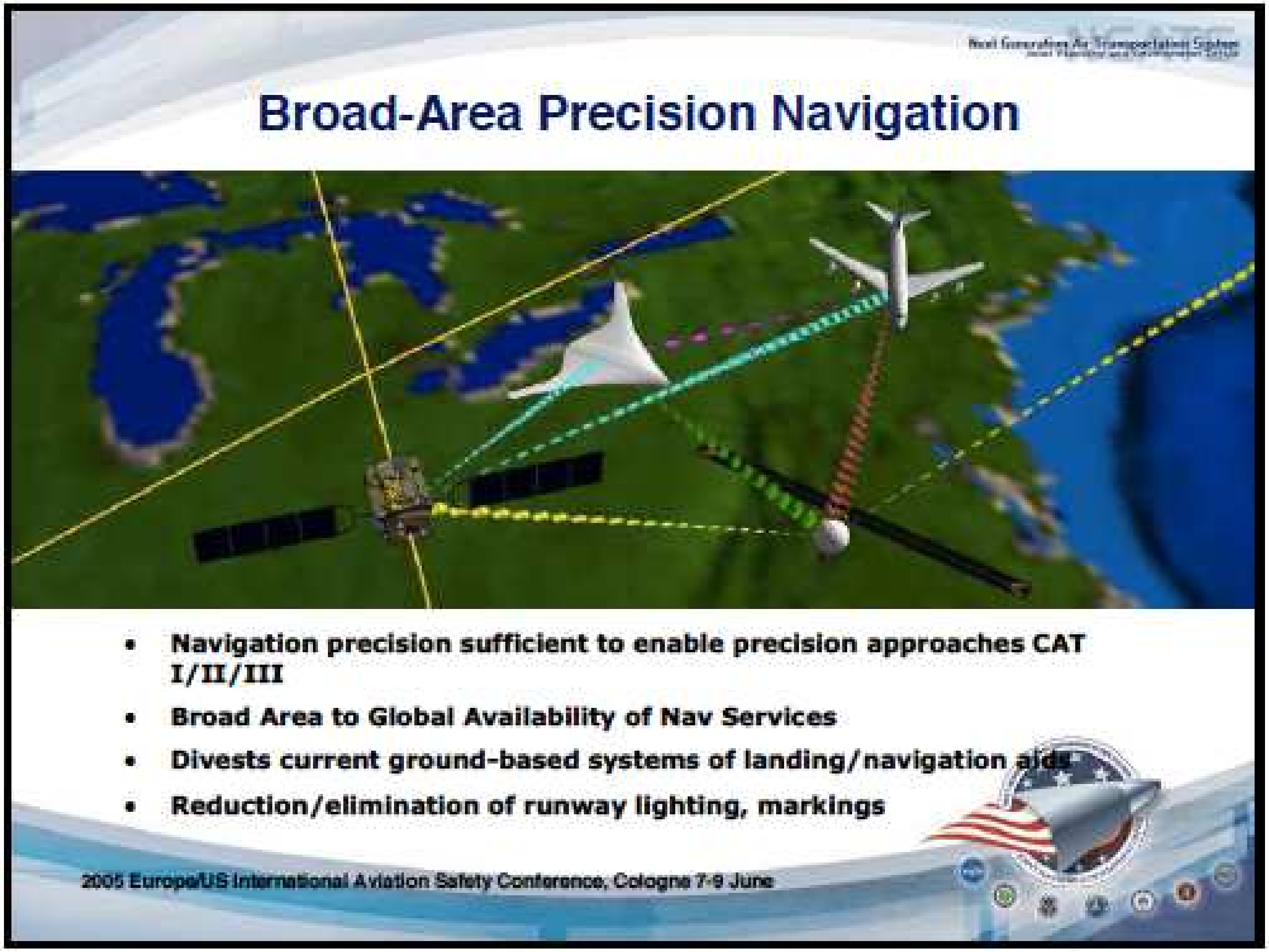

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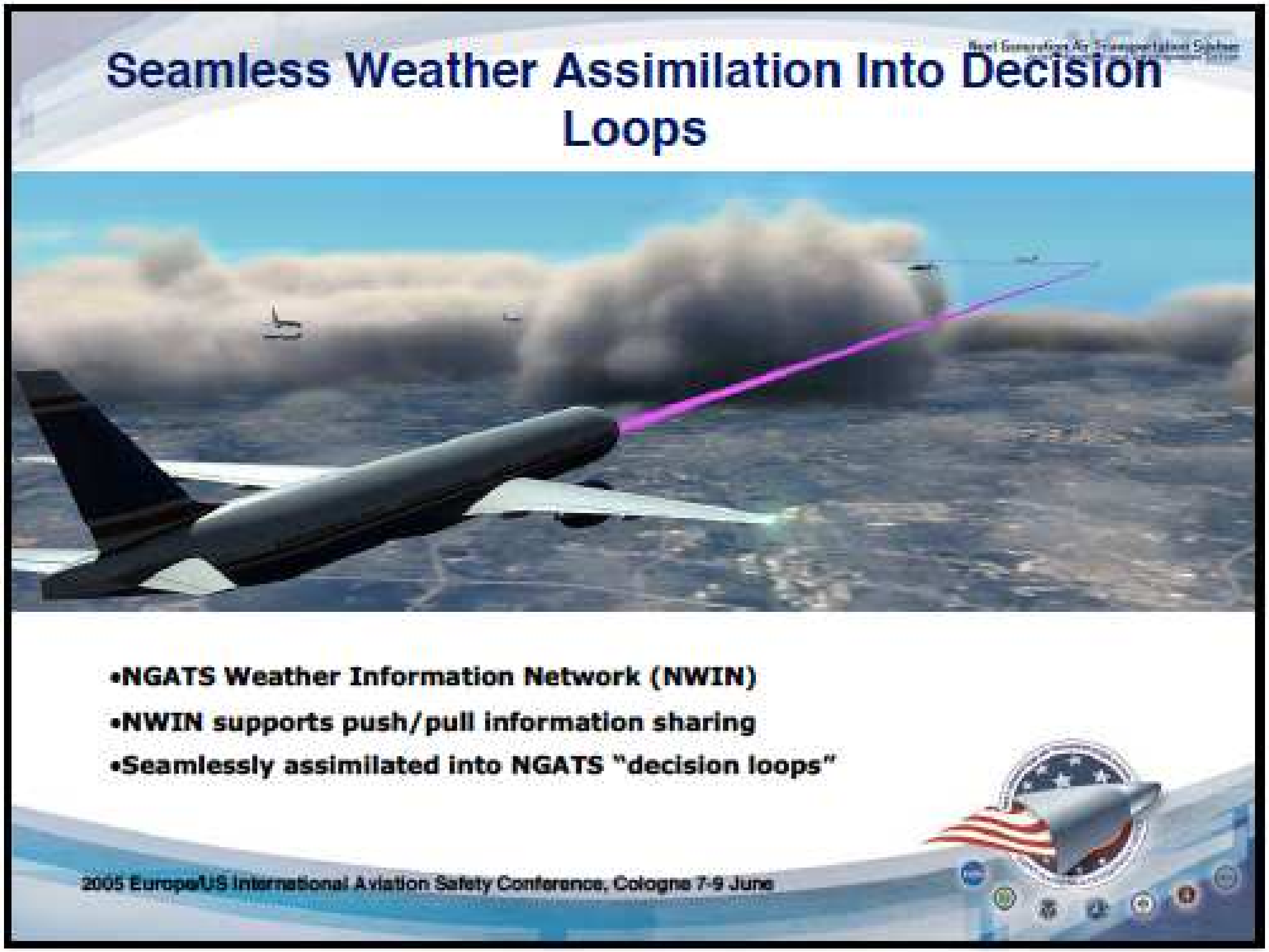

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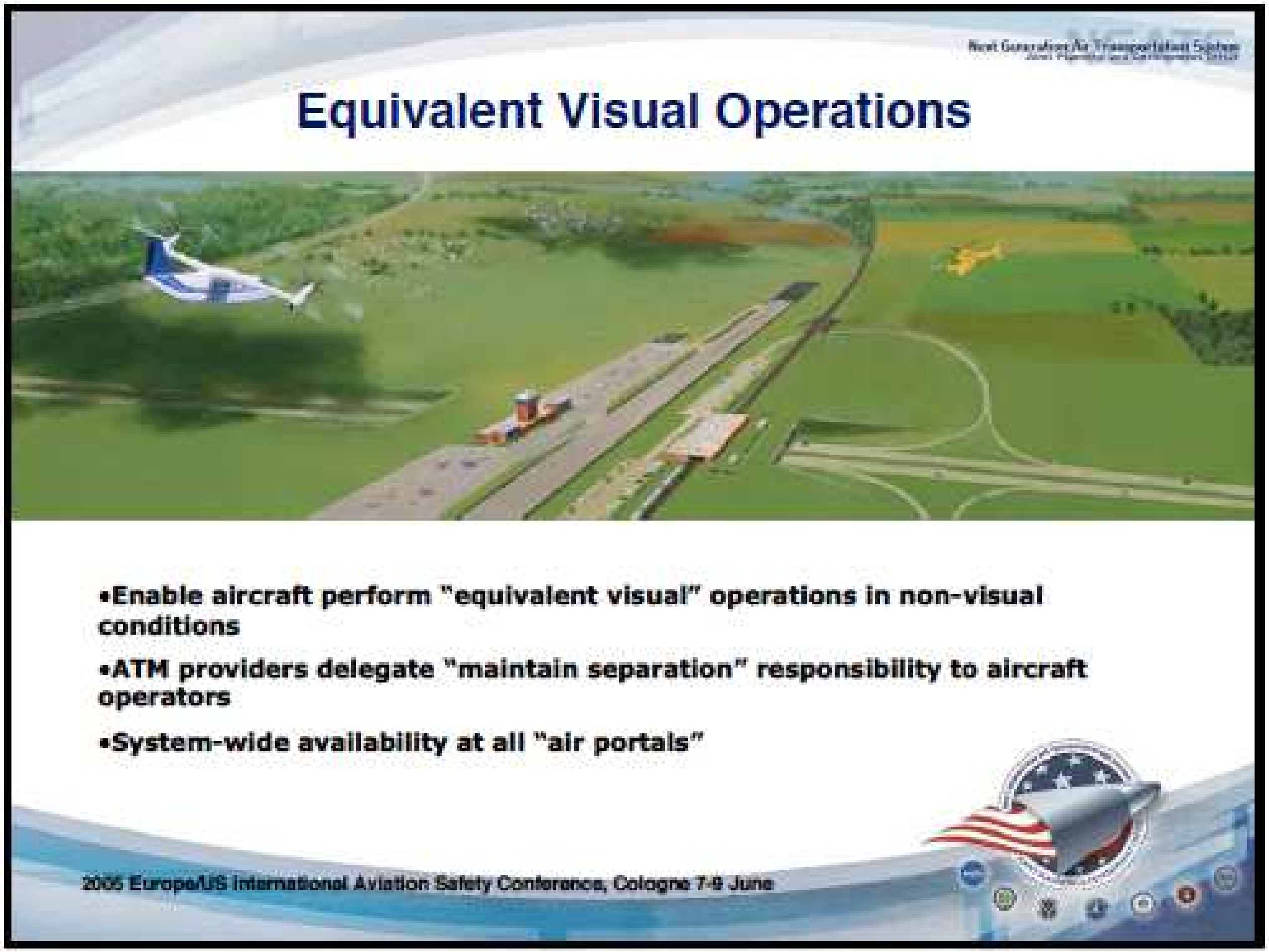

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What is the NextGen reality?

- According to the ad hoc committee chartered under the auspices of the National Research Council to…
  - Review the enterprise architecture, software development approach, safety and human factor design aspects of NextGen.

What is the NextGen reality?

- Findings:
  - Early JPDO documents stressed transformation, but NextGen of today is incremental (primarily refresh & modernization);
  - As a large-scale, software-intensive system, NextGen and the NAS will only benefit if ongoing maintenance of the NAS and its hardware and software systems are supported;
  - Enterprise Architecture supports and documents existing systems and business processes, but it is not an adequate technical foundation for steering NextGen's technical governance and managing the inevitable changes in technology and operations;

What is the NextGen reality?

- Findings (cont'd):
  - Current NAS system architecture is not well-developed; many opportunities to use the architecture in forward-looking ways have been foregone;
  - The risks to NextGen are not clearly articulated and quantified in order of importance, making it difficult to make sound decisions about how to prioritize effort and allocate resources.

What is the NextGen reality?

- Recommendations:
  - Reset expectations for NextGen;
    - Explicitly qualify the early transformational vision in a way that clearly articulates the new realities.
  - Grow a diverse architecture community with exemplary skills and collaboration;
  - Attract and retain top-tier engineering talent;
  - Prototype (experiment with) architectural governance approaches to make progress and maintain leadership;
  - Explicitly plan and fund for maintenance and modernization;

What is the NextGen reality?

- Recommendations (cont'd):
  - Quantify and prioritize risks and opportunities;
  - Make cybersecurity a focus of NextGen;
  - Exploit the opportunities of UAS to drive architectural improvements;
  - Integrate human factors expertise earlier and more often;
  - Make a better case before any more equipage mandates.
    - Most costs go to carriers; most benefits go to passengers; benefits lag costs significantly.

What is the NextGen reality?

- According to the ad hoc committee chartered under the auspices of the National Research Council to…
  - Review the (February 2014) FAA Research Plan on Methods and Procedures to Improve Confidence in and Timeliness of Certification of New Technologies into the National Airspace System.

What is the NextGen reality?

- Findings:
  - February 2014 Research Plan does not meet the requirements of the authorizing legislation, nor does it demonstrate how integration of aircraft, ground systems, and procedures will occur in the National Airspace System;
  - In best interest of the FAA that it describe and fully explain the steps that the FAA and aviation stakeholders are taking to expedite the realization of the NextGen capabilities;
  - All stakeholders would benefit substantially from the explanation of the end-to-end processes necessary to certify, approve, and implement advanced NextGen capabilities beyond the mid-term (i.e., 5-7 years).

What is the NextGen reality?

- Recommendations:
  - Create a comprehensive research plan that results in a documented approach that provides the full context for its certification and implementation of NextGen, including both ground and air elements, and the plan's relationship to the other activities and procedures required for certification and implementation into the National Airspace System;
  - Address software assurance issues associated with complex systems in order to ensure timeliness and confidence in the certification of new technologies into the National Airspace System;

What is the NextGen reality?

- Recommendations (cont'd):
  - Address cybersecurity as an integral part of the National Airspace System;
  - Include as a significant priority the improvement in the use of verification and validation of the overall system. The FAA research plan should demonstrate how the FAA is building upon the significant research in verification and validation being done by NASA and other government research labs, academia, and international research groups;
  - Benchmark the best practices of other organizations regarding certification that can contribute to the timely implementation of NextGen technologies and coordinate its research with other relevant organizations, particularly NASA.

A DAUNTING REALITY

What were some of the issues?

- GAO reports and a confidential (and unfiltered) survey of a few key NextGen stakeholders suggest:
  - Issues with structure of JPDO:
    - Chartered to plan and develop NextGen but not given the funding and budget authority to control development;
    - Spent time developing details that are in the purview of the development organization;
    - Not enough attention paid to financial and policy research and engineering;
    - Failure to recognize the continued importance of the environment as post-implementation issue.

What were some of the issues?

- Issues with structure of FAA:
  - No single person with skills and authority to oversee enterprise and systems engineering, research, programs and acquisitions;
  - Devolving research and acquisitions to operating units good for small, evolutionary improvements; but not so good when trying to plan and execute a major system-of-systems program and transformation;
  - Inadequate workforce planning, training and involvement for such a large system-of-systems development program, with the objective of transforming of a very complex, human-centric operating system.
- Issues with structure of NASA:
  - NextGen contributions hampered in the early days by NASA "pull back" from higher TRL research;
  - Disconnect between concepts and implementation constraints.

What were some of the issues?

- For example… As early as 2005, it was evident that the Evaluator (a.k.a. "Big Giant Head") approach to trajectory-based operations (TBO) was not tenable…
  - Uncertain operating environment…
    - Like a bus operating in traffic, aircraft could spend most of their time speeding up or slowing down to keep to their desired trajectory;
    - Changing airspeed to maintain planned groundspeed can put an aircraft in a position where it is unable to meet its ultimate RTA
  - If we consider uncertainties….
    - Huge stochastic programming problem due to large number of aircraft combinations, long duration of aircraft trajectories, and very large number of possible events and recourse actions.

What were some of the issues?

- However the originally proposed concept persisted even though there was a more pragmatic approach…
  - Break problem into "manageable" number of stages;
  - Solve a two-stage stochastic program within each stage;
    - Analogous to using "stage stops" for buses v. trying to schedule the precise times at each bus stop;
    - Consider the expected cost of any recourse that might have to be taken near the end of the stage.
  - Solve problem within a dynamic programming framework.
    - Derive end point (space and time) for each aircraft using airline scheduling objectives and ANSP throughput objectives;
    - Solution for given stage is handoff "target" for preceding stage.

What were some of the issues?

- Failure on the part of many stakeholders to…
  - Recognize actual and predictable failings;
  - Make appropriate course adjustments.

What are the 3 M's of ATM?

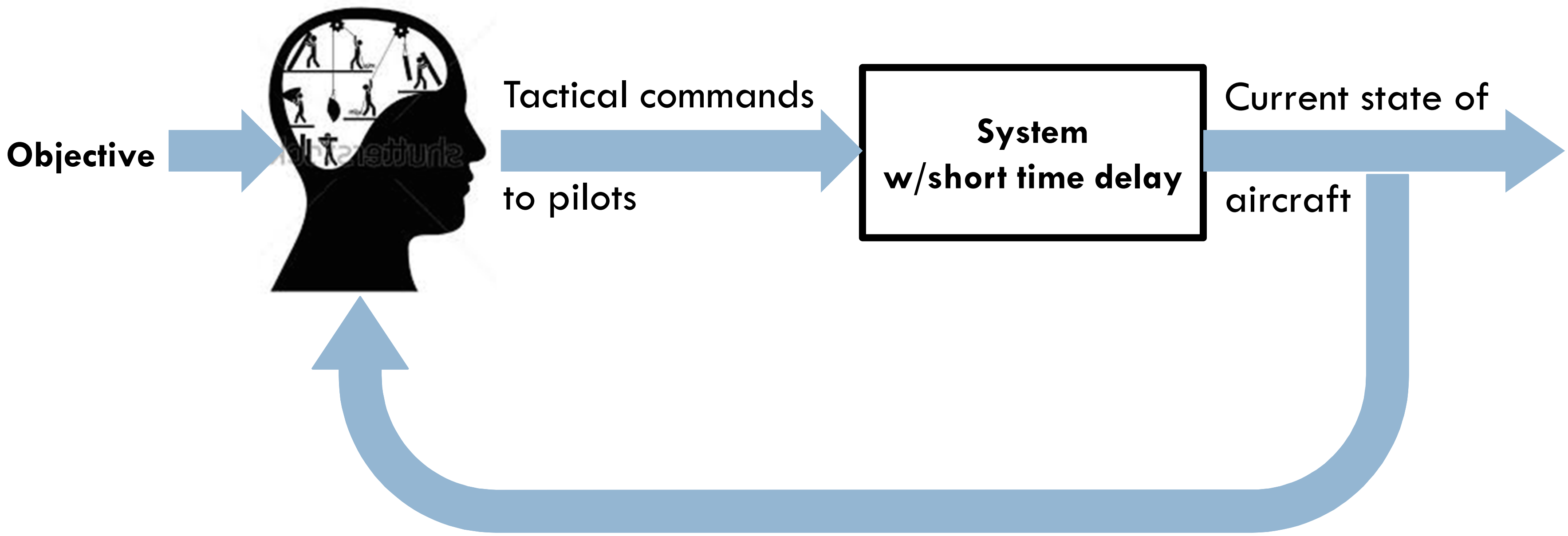
- Air Traffic Management (ATM) functionally divided into:
  - Air Traffic Control (ATC);
  - Traffic Flow Management (TFM).
- ATC achieved via Lagrangian specification…
  - Observer follows an individual fluid parcel as it moves through space and time.
- TFM achieved via Eulerian specification…
  - Observer focuses on specific locations in the space through which the fluid flows as time passes.

What are the 3 M's of ATM?

- The following three functions are performed (albeit in slightly different ways) in both ATC and TFM:
  - Monitoring
    - Observer or automated sensor monitors the flow of traffic (using either a Lagrangian or an Eulerian specificaiton) and communicates current state of the system.
  - Modeling and Decision-Making
    - Decision-maker or autonomous agent uses a model to predict the future state of the system and whether issues will arise, and subsequently determines a mitigation strategy.
  - Mitigation
    - Executor or automated actuator implements the mitigation strategy.

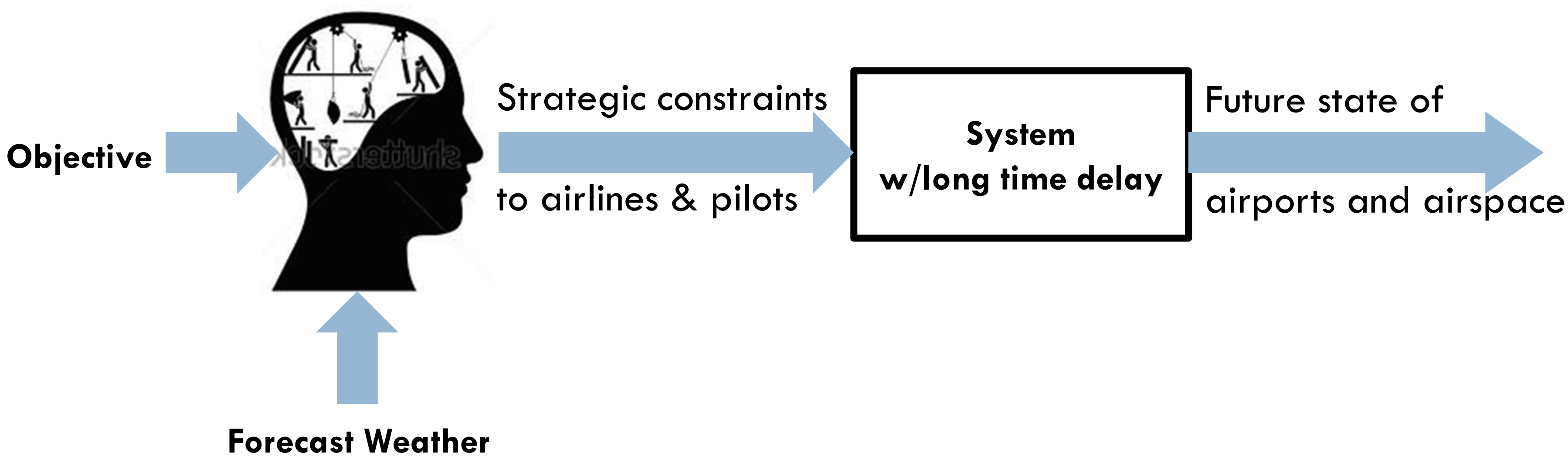
What are the 3 M's of ATM?

- In traditional ATC…
  - Human is monitor, (short term) modeler, (tactical) decision-maker, and (partial) mitigator



What are the 3 M's of ATM?

- In traditional TFM…
  - Human is monitor (of future), (long term) modeler, (strategic) decision-maker, and (partial) mitigator

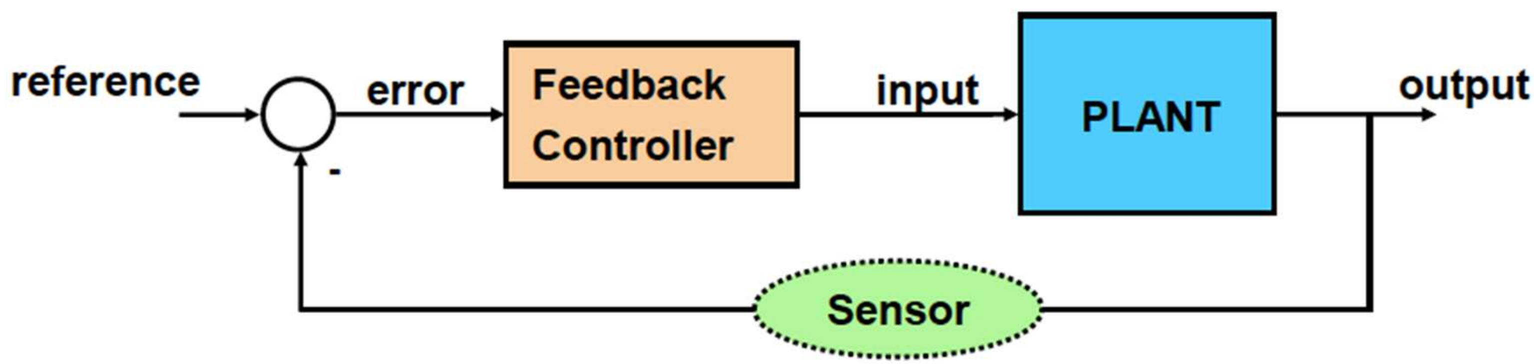


How can we use the 3 M's?

- This control theory analogy is useful as we think about and begin to introduce increased automation and autonomy…

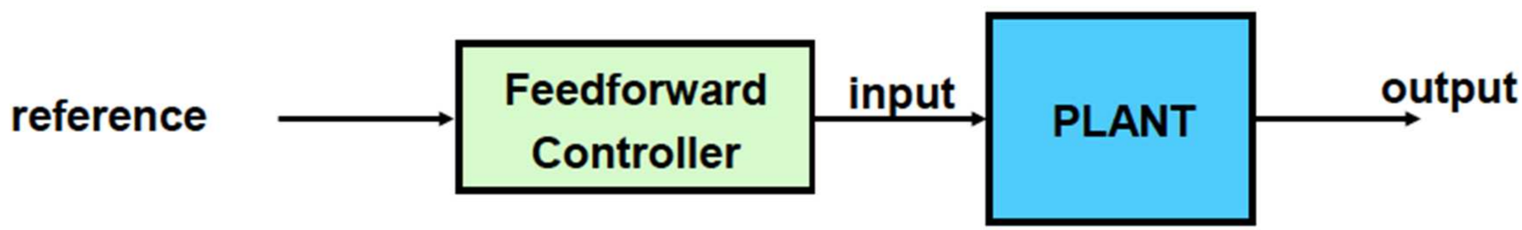
How can we use the 3 M's?

- Feedback control is reactive…
  - Compensates for disturbances;
  - Follows change in desired state (reference/set point).



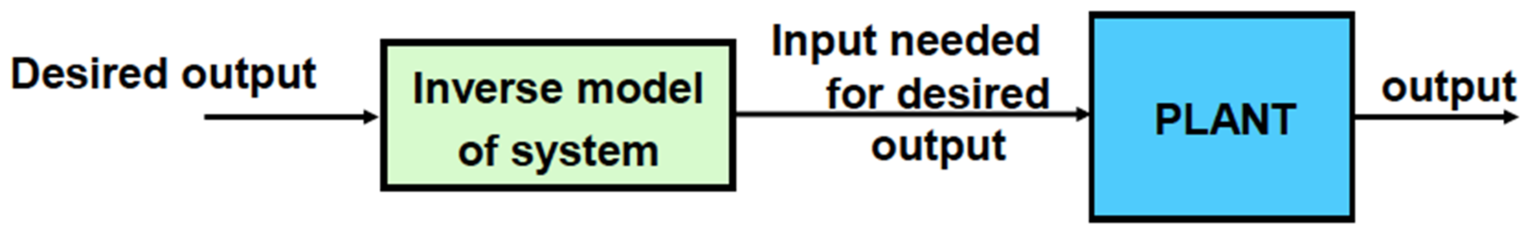
How can we use the 3 M's?

- Feedforward control is pro-active…
  - ✧ Responds to change in reference or forecast disturbance;
  - ✧ Based on prediction of plant (system) behavior;
  - ✧ Can react before error actually occurs;
  - ✧ Overcome sluggish dynamics and delays.



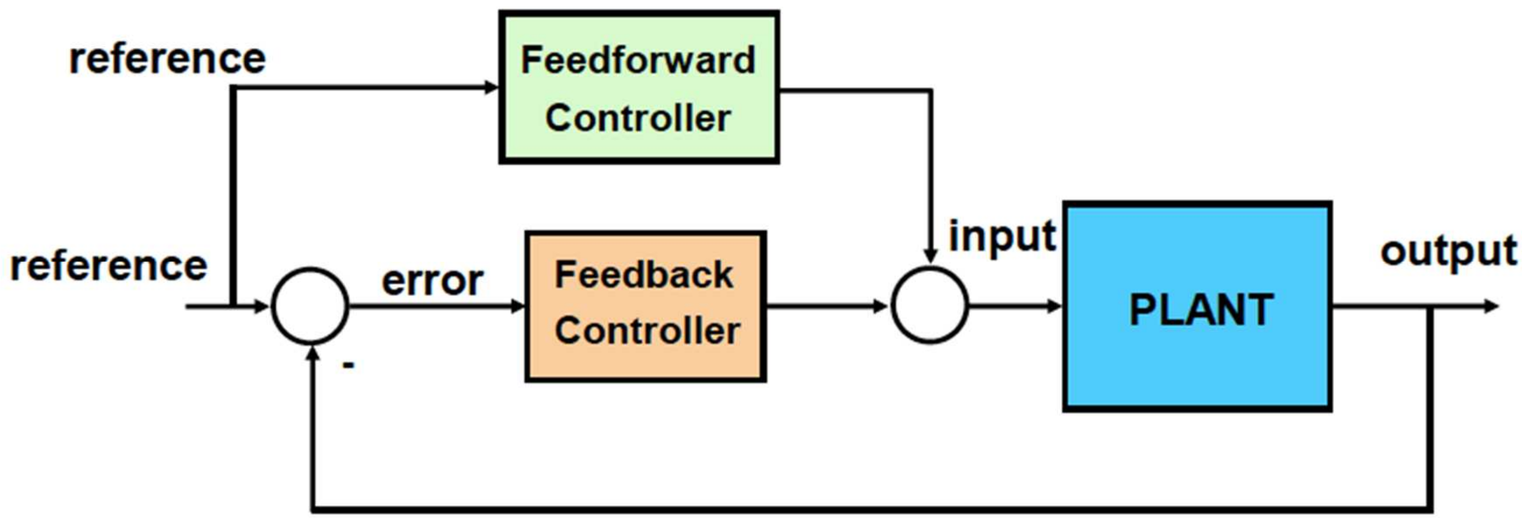
How can we use the 3 M's?

- Feedforward control often implemented as model-based predictive control
  - Utilizes inverse model of the plant;
  - Can compensate for known plant dynamics, delays;
  - System response must be predictable.



How can we use the 3 M's?

- Feedforward and feedback control are often used together…
  - Feedforward control provides pre-emptive response;
  - Feedback control fills in the rest of the response accurately, compensating for errors in the model.



How can we use the 3 M's?

- Feedback control limited by speed and accuracy of…
  - Monitoring – detection of trajectory deviations;
  - Modeling and Decision-Making – formulation of response;
  - Mitigation – execution of response.
- Feedforward control limited by accuracy of…
  - Monitoring – detection of trajectory and forecast deviations;
  - Modeling and Decision-Making – formulation of response;
  - Mitigation – execution of response.

How can we use the 3 M's?

	Monitoring	Modeling and Decision-Making	Mitigation
Reactive – Feedback	Sensors that quickly and accurately detect trajectory deviations.	Models to predict immediate effects of trajectory deviations; Deterministic decision support and optimization tools	Business processes, communication tools and actuators that enable quick and accurate actions.
Proactive – Feedforward	Sensors that accurately detect trajectory deviations; and weather forecast deviations and variability.	Models to predict combined future effects of trajectory deviations and weather; Stochastic decision support and optimization tools.	Business processes, communication tools and actuators that enable quick and accurate actions.

How can we use the 3 M's?

- 3M-Matrix may be used to determine how individual and collective NextGen technologies stack up against the need for greater speed and accuracy in monitoring, modeling, decision-making, and mitigation.
- 3M-Matrix may also be used alongside a R&D Project Portfolio Optimization-Framework to manage the NextGen research and development process.

R&D Project Portfolio Optimization

- Decisions:
  - Select (start/terminate) R&D projects in which to invest;
  - Allocate available resources to the selected projects.
- Several deterministic/stochastic project attributes:
  - Required investment levels;
  - Performances/returns;
  - Time to implement;
  - Fixed activity costs;
  - Dependencies.

R&D Project Portfolio Optimization

- Goal:
  - Maximize expected total discounted return.
- Differences from Financial Portfolio Optimization
  - The realization time for the return of a project is dependent on the investment made on that project;
  - Correlation among the variances of returns of technologies is dependent on investment levels;
  - Technologies have dependencies which can have a positive or negative effect in the realization of joint returns.

R&D Project Portfolio Optimization

	Stochastic	Inter-dependencies	Organizational constraints	Resource Allocation	Complete Dynamic Rebalancing of Portfolio
April et al. (2003)	✓			✓	
Bardhan et al. (2006)	✓	✓	✓		
Campbell (2001)	✓	✓			
Chan et al. (2007)	✓		✓		✓
Dickinson et al. (2001)		✓	✓		
Elfes et al. (2005)			✓	✓	
Ghasemzadeh et al. (1999)		✓	✓		
Gustaffson&Salo (2005)	✓	✓			✓
Lee et al. (2001)	✓	✓			
Luenberger (1998)		✓	✓		
Norkin et al. (1998)	✓		✓	✓	
Sallie (2002)		✓	✓		
Utturwar et al. (2002)		✓	✓		
PROPOSED APPROACH	✓	✓	✓	✓	✓

R&D Project Portfolio Optimization

- Methodology involves a multistage stochastic programming model with endogenous uncertainty, where:
  - Risk-neutral objective measured by the overall discounted return over an infinite time horizon;
  - Required investments and returns defined by probability distributions;
  - Uncertainty in returns resolved gradually based on investments;
  - Option always exists to terminate projects.

R&D Project Portfolio Optimization

- The outputs of the model are:
  - Optimal investment allocations for the current period;
  - Starting, continuation or termination decisions for projects;
  - Investment decisions and allocations with recourse options for future periods.

Key Research Questions

- Given aforementioned Frameworks… for a given ATM problem:
  - Centralized vs. distributed monitoring?
  - Lagrangian vs. Eulerian Specification?
  - Centralized vs. distributed decision-making?
  - Deterministic vs. stochastic decision-making?
  - Centralized vs. distributed mitigation?
  - Experimentation and project portfolio optimization?
  - Technology and concept of operations performance?