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Abstract

Airline companies around the world develop next generation optimal network planning solutions to maximize revenues and minimize operational expenditures. Such solution entails a powerful user interface, simulation capabilities, customizable rules/workflows, and integration with a variety of existing internal & external systems. Primary objectives are to enhance business intelligence, minimize unprofitable flights, improve schedule quality, and reduce time involved with schedule plan creation.

The purpose of this document is to illustrate HCL’s relevant domain knowledge, problem statement understandings, and industry-wide expertise. The intended audience includes Airline Executives, Architects, and Project Owners.
### Abbreviations

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Acronyms (Page No.)</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ATM/CATM (20)</td>
<td>Air Traffic Management/ Collaborative Air Traffic Management</td>
</tr>
<tr>
<td>2</td>
<td>CDM/ACDM (20, 22)</td>
<td>Collaborative Decision Making/Airport Collaborative Decision Making</td>
</tr>
<tr>
<td>3</td>
<td>SWIM (18, 21)</td>
<td>System Wide Information Management</td>
</tr>
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<td>4</td>
<td>SES(6)</td>
<td>Single European Sky</td>
</tr>
<tr>
<td>5</td>
<td>NGATS (5, 18, 21, 22, 24)</td>
<td>FAA “Next Gen” project or Next Generation Air Transportation System</td>
</tr>
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<td>6</td>
<td>SESAR (5, 18)</td>
<td>Single European Sky ATM Research Programme</td>
</tr>
<tr>
<td>7</td>
<td>CEP (9)</td>
<td>Complex Event Processing</td>
</tr>
<tr>
<td>8</td>
<td>BPM (10, 19, 20)</td>
<td>Business Process Management</td>
</tr>
<tr>
<td>9</td>
<td>MRO (12)</td>
<td>Maintenance, repair, and operations</td>
</tr>
<tr>
<td>10</td>
<td>BPEL (9, 19, 22)</td>
<td>Business Process Execution Language</td>
</tr>
<tr>
<td>11</td>
<td>ESB (9)</td>
<td>Enterprise Service Bus</td>
</tr>
<tr>
<td>12</td>
<td>CPLEX (10, 11, 15)</td>
<td>Short name of IBM product: “IBM CPLEX Enterprise Server”</td>
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<tr>
<td>13</td>
<td>RDBMS (12)</td>
<td>Relational database management system</td>
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<td>14</td>
<td>NoSQL (12)</td>
<td>Next Generation Database</td>
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<tr>
<td>15</td>
<td>RAM (12)</td>
<td>Random-access memory</td>
</tr>
<tr>
<td>16</td>
<td>SMP (12)</td>
<td>Symmetric multiprocessing</td>
</tr>
<tr>
<td>17</td>
<td>CUDA (13)</td>
<td>NVIDIA's parallel computing architecture</td>
</tr>
<tr>
<td>18</td>
<td>FAA (17, 20)</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>19</td>
<td>OGC (17, 21, 22)</td>
<td>Open Geospatial Consortium</td>
</tr>
<tr>
<td>20</td>
<td>SOA (17, 18, 19, 21)</td>
<td>Service-oriented architecture</td>
</tr>
<tr>
<td>21</td>
<td>COTS/FOSS (14, 17)</td>
<td>Commercial Off-The-Shelf/Free and Open Source Software</td>
</tr>
<tr>
<td>22</td>
<td>BPMN (18, 21)</td>
<td>Business Process Model and Notation</td>
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</tbody>
</table>

Additional description.

4. Single European Sky (1). It was launched by the European Commission in 1999. Its primary aim is to meet future capacity and safety needs through legislation. On the technology side, SES is supported by the Single European Sky ATM Research (SESAR) Programme.

5. FAA “Next Gen” project or Next Generation Air Transportation System (NGATS) (2). NextGen will be compatible with Europe’s Single Sky initiative through technologies developed under the aegis of the Single Sky European ATM Research (SESAR) program.

6. Single European Sky ATM Research (SESAR) project (3). SESAR is the European initiative equivalent to the FAA “Next Gen” (NGATS).
Use Cases

Airline network planning is a process of designing, creating, and publishing the Network Plan. There are multiple short-term and long-term network planning use cases.

1. Short-term use cases
   a. Plane switching use case, where planes need to be substituted to similar or larger/smaller plane due to mechanical problems, delayed flights, oversold/undersold situations
   b. Crew recovery use case, where the flight crew for the plane is incomplete due to illness, missing connecting flights, flight delays, etc.

2. Long-term use cases
   a. Opening new flight routes
   b. Decreasing/increasing of flight frequency on an existing route due to seasonal/long-term change in demand/profitability
   c. Closing existing routes due to change in demand/profitability

Fleet rebalancing to address (predicted) changes in passenger volume and business class/coach demand ratio on each route.
Requirements and Assumptions

Solution Architecture:

1. Proper technology selection process requires a deep dive into existing systems architecture and currently employed technologies
2. “Best of Breed” Open Source alternatives are viable in an airline company environment
3. The solution should offer versatility, follow available standards, and fit closely with typical airline company’s long-term broader goals
4. Strong focus on user experience and overall performance is very much required

Data Sources (available data points from existing services/databases):

1. Flight leg cost (duration, fuel use for each type of aircraft) database or service
2. Maintenance schedules, cost, facilities
3. Ground crews availability, cost
4. Flight crews availability, schedules, overnight restrictions
5. Aircraft fleet structure, availability, aircraft carrying capacity, seats configuration
6. Airport/terminal costs/constraints
7. Current and predicted ask/demand/fares dynamics on major routes
Solution Foundation Components

The envisioned solution consists of the following fundamental Software Oriented Architecture conformant components:

1. **Business Process Server** allows developers to orchestrate, create, and manage business processes. Processes are generally long-running stateful processes or short-running processes (stateless/stateful) triggered during workflow execution. Such workflows may have dependencies on chained completion of previous steps. This centralized system provides a secure web UI and powerful developer IDE integration for process creation and management following BPEL standards. Programmatic control via code or Web Services offers interoperability with legacy systems and new solutions alike.

2. **Business Rules Server** facilitates graphical rule creation and management, making it easier for general business users and data analysts to define sophisticated rules. The underlying Business Rules Server repository is leveraged by Complex Event Processors while handling streams of events. External applications may also integrate with the Business Rules Server to manage and control rule sets via Web Service calls.

3. **Complex Event Processing Servers** are the workhorses which ingest streams of events and execute Business Rules in memory (essentially transactional conditions and actions) to identify or react to individual events of interest. CEP rules establish relationships, hierarchies, and identify patterns between individual events. Common applications for CEP include low-level transaction response, fraud detection, and dynamic pricing adjustments. The most extensively used features are support for temporal reasoning, detecting absence of events, and processing event streams while considering previous events inside of sliding/moving windows, i.e. a time period.

4. **Enterprise Service Bus** serves as the transport mechanism between heterogeneous components in new and existing systems. ESB implementation is an industry best practice when connecting many disparate systems, and recommended for secure mediation of each transaction throughout the environment.
Core Functionality of the Solution

1. **Network optimization modeling** functionality:
   a. Mathematical models capable of finding optimized network structures. This is core functionality to address the network planning task. Such models will be plugged into various scenarios to meet airline network planning objectives.
   b. Mathematical models capable of allowing an analyst to interact and explore "what-if" scenarios while changing the network to respond to business demands. This functionality is to allow human input into the network planning task to orchestrate and direct mathematical model reasoning to be fine-tuned to achieve a business goal. Human interaction is vital because it might not be possible or practical to digitize all business factors and convert all business logic into equations and/or programming logic.

2. **Business Process Management** functionality:
   a. Business Process Management enables analysts to execute recurring long-running simulations against both historical and real-time data, to validate and to further hone production business rules and workflows. BPM provides staging, versioning, and change control of processes and artifacts throughout the solution, i.e. in isolated development/staging/production systems. This facilitates playing out various identified “what-if” scenarios in a controlled environment, manual validation of expected outcomes, process benchmarking, ongoing process optimization, and process governance as changes are accepted and promoted to production.
   b. Ability to dynamically handle situations in which automated actions or recommendations can be established using Complex Event Processing and combinations of relevant Business Rules.
   c. Ability to integrate external systems/services inside multi-step business process workflows. Enterprise Service Bus can leverage 3rd party product APIs or Web Services, providing extensible processing capabilities. For example, IBM CPLEX Enterprise Server provides Web Services for submitting jobs for processing. Business Processes may establish
interdependencies on prior step completion (such as a CPLEX linear programming model job) within a defined workflow.
Solution Capabilities

Database Layer

The database layer carries data persistence functionality for:

1. Data dictionaries
2. Business rules
3. Fleet data
4. Global airport data
5. Airline fleet data
6. Particular airline and other airlines passenger travel historical data
7. Various cost data (maintenance schedules, maintenance centers [MRO] characteristics, flight and ground crew availability/cost)

Some components of the database layer could be served not by a database, but by a service. Also, let’s explore if there are special scalability or special query requirements which will warrant special databases (such as NoSQL or graph database). Let’s consider an example of airport-to-airport flight duration, distance and cost for a particular model of airplane. Let’s assume there are no more than 1,000 airports the airline could be interested in flying into. There should be on order of 1,000,000 possible single-leg flights between these airports, while this number will be reduced to exclude direct legs between distant minor airports. Let’s assume there are ~10 different aircraft types in service. The database will store on order of 1,000,000 to 10,000,000 records to represent the matrix of possible flights, which is a reasonable scale for traditional RDBMS. A particular mathematical model might call for an in-memory array to store such cost matrix for faster lookup during computation. Actual airport-to-airport leg cost data could be originated from (external) service, where the database and/or in-memory array could be used to cache the dataset. The dataset might not be large enough to call for a graph database. Graph traversal operations could be completed in-memory over the cached dataset array.

Modeling Layer

The modeling layer connects data sources into mathematical models. Such models forecast travel supply and demand, help to find an optimal network plan within static supply/demand scenarios
and aid with the outcome prediction for network plan change
exploration.

Data availability/granularity/precision as well as the prediction
spread of each model could vary. In some cases, historical data
trending deployment lesser cost could be a deciding factor. More
complex models (also based on extended datasets) could be
deployed later and/or used for special use cases.

Let’s compare a historical trending approach to an extended
forecasting model for airport demand forecasting:

**Historical trending** will include complete sales data for airports
where the airline flies. Note that many airports will be out of reach of
this data set. Many destinations from airports where an airline flies
will be omitted if the airline doesn’t cover these destinations from
these airports. Historical trending could be enhanced with some
volume and sales data from other airlines, but this data won’t have
such a level of granularity and precision.

**An extended airport demand forecasting** model will enhance
these datasets with more data elements such as aircraft movement,
scheduled/charter passenger traffic, freight traffic patterns, fares,
area demographics (population, [disposable] income, employment)
and area economic indicators.

The data elements’ granularity/precision as well as the pattern
discoverability determine the types of mathematical models which
could be used (such as time-series analysis, regression models,
neural networks, etc).

Each airport demand forecast is tightly connected to other airport
local characteristics and non-air travel availability and cost
within/between locales.

Every model could have varying run times. There could be different
scalability challenges and mixes thereof:

1. Algorithm requires most of the data to be placed into RAM,
   but the dataset exceeds the practical limit of RAM for single
   server.

2. Algorithm requires a high number of passes which takes
   long time on a single CPU.

These challenges may be addressed by various measures:
- Sampling, using subsets instead of a full data set, is
  acceptable in many situations
- SMP as far as it is practical (~128 cores with AMD; lesser
  number of cores, but comparable performance with Intel)
- Intel Phi. Disadvantages: fairly new. Advantages: very cost- and space-efficient, HPC especially, for a restricted set of algorithms, where supported by Intel libraries C/C++ development is warranted
- CUDA. Advantages: well established, supported by MATLAB/GNU Octave. Disadvantages: only some vector/matrix computations are accelerated efficiently
- RevoScaleR for R applications
- SAS HPA for SAS applications

**Visualization Layer**

The visualization layer allows an ergonomic display of data coming from various layers. Data may be obtained directly from the database layer, or indirectly via the modeling layer.

Visualization is important to interpret data and data models to drive the exploration and decision making processes. Visualization of airline networks has some traditional and special visual dimensions to be visualized:

**Spatial visualization via custom maps**
- For country-wide/intercontinental scale
- For airport infrastructure/approaches scale

**Using:**
- Points data (point of interest, airline offices, etc.)
- Line data (flight path, service vehicle/crew/passenger routes)
- Area data (restricted flight zones, etc.)

**In:**
- 2D
- 3D space
- High-D space (2D space with 3\textsuperscript{rd} dimension as time, animation to visualize time-series)

**Visualization of mathematical models:**
- Graphs
- Surfaces
Visualization of data subsets:
- Dynamically generated reports
- Interactive subsets snapshots which allow further data grouping, exploration (Excel-like functionality)

There are some visualization techniques which are optimized for aeronautics use cases:
- Traffic density chart map
- Airports and their connections map
- Hybrid bar charts on the map with flight path animation

COTS and FOSS Capability Matrix

<table>
<thead>
<tr>
<th>Development Platform</th>
<th>Commercial Off-The-Shelf (COTS) software</th>
<th>Free and open-source software (FOSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oracle</td>
<td>WSO2</td>
</tr>
<tr>
<td>Complex Event</td>
<td>Event Processing</td>
<td>Complex Event Processor (JBoss Drools Fusion)</td>
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<tr>
<td>Processing</td>
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<tr>
<td>Enterprise Service</td>
<td>Service Bus</td>
<td>Enterprise Service Bus (Apache Synapse)</td>
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<tr>
<td>Bus</td>
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<tr>
<td>Linear programming,</td>
<td>IBM ILOG CPLEX Optimizer</td>
<td>GNU Octave</td>
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<tr>
<td>optimization</td>
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<td>MATLAB</td>
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<tr>
<td>Non-linear</td>
<td>MATLAB</td>
<td>GNU Octave</td>
</tr>
<tr>
<td>Function</td>
<td>Software</td>
<td>Notes</td>
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<td>-----------------------------------</td>
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<td>--------------------------------------------</td>
</tr>
<tr>
<td>Programming, optimization</td>
<td>Mathematica</td>
<td></td>
</tr>
<tr>
<td>Machine learning</td>
<td>MATLAB with extensions</td>
<td>Limited support in Weka, Octave, R</td>
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<tr>
<td>(neural networks, genetic</td>
<td></td>
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<tr>
<td>programming, Bayesian networks)</td>
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<td>Regression models,</td>
<td>SAS</td>
<td>R</td>
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<tr>
<td>other forecasting models</td>
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<tr>
<td>Database Layer</td>
<td>Oracle</td>
<td>MySQL</td>
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<td></td>
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<td>PostgreSQL</td>
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<tr>
<td>Geospatial Situational Awareness;</td>
<td>Snoflake</td>
<td></td>
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<tr>
<td>high performance visualization of</td>
<td>Luciad</td>
<td></td>
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<tr>
<td>situational awareness applications;</td>
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<tr>
<td>Geospatial Situational Awareness</td>
<td>ESRI</td>
<td></td>
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<tr>
<td>for browser-based environments;</td>
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<tr>
<td>Mobile Geospatial Situational</td>
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<tr>
<td>Awareness; Air Traffic Playback</td>
<td></td>
<td></td>
</tr>
<tr>
<td>and Analysis. FIXM and AIXM viewers</td>
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</tr>
<tr>
<td>Extended spatial analysis</td>
<td>EMC Greenplum.</td>
<td>Cloudera Impala (open source, but not free)</td>
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<td></td>
<td>Particular strength for extreme</td>
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<td></td>
<td>scale-out</td>
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<tr>
<td>MPP</td>
<td>IBM Netezza.</td>
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<td></td>
<td>Particular strength for near-real-time analytics</td>
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<tr>
<td>Oracle Exalytics (in-memory analytics)/Oracle Exadata(OLAP)</td>
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</table>
Extended Functionality of the Solution

Summary

FAA NGATS and EUROCONTROL SESAR could be used to create a data dictionary harmonized with US and European systems, and to create SOA architecture based on standards which will facilitate B2B data acquisition and dissemination. Introduction of OASIS, OGC compliant SOA architecture will make integration of 3rd party COTS/FOSS considerably easier and dramatically reduce the amount of in-house program code to be written and maintained. NGATS/SESAR data dictionaries, schemas, SOA interfaces do not need to be fully implemented from the start. Some simplification of data elements into the most important attributes for Network Optimization tasks could take place initially. An example could be using a leg route cost+duration database instead of a fully-blown NGATS-compliant implementation. More information-rich datasets could be introduced at later phases of the project and additional benefits for Network Optimization will be realized.

Data-rich aeronautic systems and SWIM best practices

Data integration from different sources importance increases for use cases when extended functionality/dataset coverage is required. A wealth of public, subscription, and B2B data could be brought in-house. The volume of data might call for a Big Data approach to data persistence and the modeling layer. Therefore, MPP and/or Hadoop solutions for data persistence and scale-out analytics platforms could be considered. The variety and volume of data includes more factors and data dimensions to consider for modeling and forecasting. Many concepts and trends explored in EUROCONTROL STATFOR forecasting reports might need to be taken into consideration:

- Airlines capacities, new aircraft orders
- Delay statistics and root case analysis data across airlines and airports
- Routes, airline alliances to be created/closed
- Airlines out of business, failed, lost license, etc.
- Financial data about airline performance
- Fuel prices, long-term peak oil forecasts
- Aircraft manufacturers dynamics
- Airport dynamics, restructuring, closures
- Regulatory changes
- Fare dynamics
- Alternative transportation availability and dynamics
- Passenger traffic patterns
- Demographic predictions
- Demand forecasts, demand excess over airport capacity predictions
- Travel distance and aircraft size trends/forecasting
- Economy trends/forecasts for regions/countries
- Forecast models of external sources

Non-SOA Plan Optimization Collaboration Use Cases and Solutions

Even though the SOA route of BPM orchestration is the most widely accepted, it could come with a significant rework of internal applications, depending on the current solutions in place. We had demonstrated that Open Standard Data Architecture allows enhancing BPM orchestration functionality with additional data exchange merits. Still, business drivers might not justify narrow or wide re-architecture of the system in some cases. Therefore, let's mention other technologies which could help with Network Plan Optimization use cases.

If data scientist collaboration is envisioned as important and significant, then it might be worth considering the Chorus product. Chorus is usually deployed as part of an EMC Greenplum stack. Chorus allows Agile collaboration and answers most data science challenges for airline network optimization tasks. Chorus could be considered as a Sharepoint alternative which is very data-driven and supports Agile collaboration. Chorus doesn't support BPM (BPMN, BPEL) integration at this point.

The Oracle BPM Suite might also be considered as an excellent alternative with perceived minimal changes to existing system. Oracle is widely used for persistent layer in aeronautical applications.
Conclusion

This document articulates a high-level solution approach to address typical airline network optimization needs. We reviewed primarily BPM orchestration within SOA architecture approach scenarios with various degree of complexity and various level of harmonization with Open Data Standards whenever relevant. Many factors could decide the architectural path, and we are looking for an in-depth examination of project specifics to fine-tune the proposed solution approach further.
Addendum

Forecasting Considerations

EUROCONTROL STATFOR forecast models structure is important to consider as a case study (please refer to diagram on page 30 of (4)).

Such concepts/views might need to be trended on a global scale or regional scale for a particular airline and competing airlines.

There are calls for “AIRPORT-COLLABORATIVE DECISION MAKING” (A-CDM) facilitation by the Airports Council International (ACI) (5). ACI plans to develop:

- a best practices guide for globally-harmonized A-CDM implementation
- specifications for globally-harmonized A-CDM
- specifications for interchange of A-CDM data at airports with other data exchange models for flight CDM such as AIXM, WXXM and FIXM

The maturity of such harmonization efforts and data availability forecasts needs to be aligned with business goals. Harmonized data elements, data dictionaries and schemas could be introduced to make an in-house solution more future-proof and ease the complexities of leveraging external sources.

Business factors might be deemed important to be compatible with data flows coming from FAA NGATS (Next Gen) sites. There are eight existing “Metroplex” areas in the US which cover the busiest aircraft traffic locales, while five more will be deployed in 2012/2013 (6). NGATS data are more relevant for short-term network traffic optimization use cases, however a Big Data approach could mine valuable information for long-term forecasting as well.

FAA NGATS deployment will introduce following systems:

- Automatic Dependent Surveillance Broadcast (ADS-B)
- Collaborative Air Traffic Management (CATM)
- System Wide Information Management (SWIM)
- Time-Based Flow Management (TBFM)
- En Route Automation Modernization (ERAM). (7)

The Federal NGATS/Next Gen development group envisions an engagement between different products and technologies as represented in the diagram on the page 12 of (8):
Federal NGATS/Next Gen development group states that Business Process Model Notation (BPMN) diagram might be useful tool for DoDAF operational views (9). Please note OV-* notation on the diagram which refers to DoDAF views. Business Process Management could be aided by modeling using BPMN and BPEL. BPEL4WS could work together with WSDL for web services.

Business Process Execution Language (BPEL) and Business Process Modeling Notation (BPMN) could be used in service orchestration while placed into Enterprise Server Bus context (note NGATS diagram depicted on page 3-6 of (10)).

**Open Standards Data Architecture**

Some concepts of NGATS designs could be considered for this implementation whenever the current/future business value will offset additional development complexity. NGATS development models (prepared by MITRE) include a wide range of considerations per NGATS Reference Model diagram depicted at page 18 of (11).

The NGATS Data Reference Model is of special interest since it can facilitate integration with external data sources.

A proposed solution could re-use the Open Standards data dictionary, data elements and schemas for entities in datasets used for Network Optimization analytics whenever practical. Let’s consider following Data Architecture:

- Employ Aeronautical Information Management (AIM) Data Models to enable data acquisition through information exchanges:
  - -- Aeronautical Information Exchange Model (AIXM)
  - -- Aeronautical Information Exchange Model (AIXM)
  - -- Airport Operations Information Exchange Model (ANXM)
  - -- Weather Exchange Model (WXXM)
  - -- Terrain Information Exchange Model (TIXM)
- Employ geo-spatial standards:
  - -- Geography Markup Language (GML) and OGC-compliance
  - -- ISO 19100
  - -- Geospatial Web Feature Services and Web Map Services
- Conform to World Wide Web Consortium (W3C) specifications in using various XML technologies
- Conform to OASIS in SOA and Web Services
Let’s consider gains in following these open standards:

- Easy integration with external sources feeds for analytics
- Some results of analytics could be fed back into exchanges for AIRPORT-COLLABORATIVE DECISION MAKING”(A-CDM) and other B2B channels
- Very simple integration with a plethora of spatial visualization/analytical tools via GML/OGC, with aeronautical visualization/analytical tools via *XM Exchange Models
- Re-use of data architecture, design time savings
References


**Author Info**

Andriy has over 20 years of experience in the areas of data management and software development. Andriy is a Sr. Solution Architect with HCL’s ERS-SEG-TFG.

Some of his work includes:

- Led the Big Data infrastructure work at CMS with Lockheed Martin. CMS is the world largest medical insurance provider.

- Served as a product owner of national “Transitions of Care” Reference Implementation project with Lockheed Martin. This project consolidated HIT community efforts to establish next generation of HL7 data exchange standards [http://wiki.siframework.org/Transitions+of+Care+%28ToC%29+Initiative](http://wiki.siframework.org/Transitions+of+Care+%28ToC%29+Initiative)

- In 1998-2000, Andriy designed NoSQL GIS architecture with some MapReduce paradigms of image processing which demonstrated very high scalability/cost characteristics
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HCL is a $6.2 billion leading global technology and IT enterprise comprising two companies listed in India - HCL Technologies and HCL Infosystems. Founded in 1976, HCL is one of India’s original IT garage start-ups. A pioneer of modern computing, HCL is a global transformational enterprise today. Its range of offerings includes product engineering, custom & package applications, BPO, IT infrastructure services, IT hardware, systems integration, and distribution of information and communications technology (ICT) products across a wide range of focused industry verticals. The HCL team consists of over 90,000 professionals of diverse nationalities, who operate from 31 countries including over 500 points of presence in India.

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