National Aerospace Planning Process Enhancements

Analysis and Innovation

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Abstract

New advanced decision support technology concepts have been developed to support Air Domain Awareness (ADA) and the National Aerospace Planning Process (NAPP). This report reviews and validates the NAPP requirements based on consultations with 1 Canadian Air Division, assesses relevant existing tools and technologies, tabulates promising research directions, and proposes a set of innovative improvements for implementation in a NAPP Enhancement Prototype "NEP".

Four ADA innovations, hosted in Google Earth, are proposed. These will enable NEP to better support visualization of sensor coverage, detect coverage gaps, visualize future weather, and analyse dynamic threats to vital points. New visual analytics tools for NEP are proposed that will reveal subtle long-term temporal, geospatial, and behavioural patterns for Resource Awareness and Total Air Resource Management (TARM).

NEP will include novel tools for air force resource visibility and resource management, including tools for vertical awareness (down to the Wings and squadrons), and horizontal awareness (forward and backward in time). Asset availability awareness is described based on "Dashboard" and "Magnet's Grid" visualizations. A "Hockey Card" metaphor encapsulates the key elements of each mission. To rapidly respond to un-forecast events, a resource management app scans existing Air Tasking Orders and proposes viable re-planning solutions based on: rapidity of response, ability to dwell if required, and the availability of an appropriate payload.

This is the first of two reports. The second report documents the subsequent design and implementation of the NEP, and its demonstration to the Air Force.

Executive Summary

This report is a deliverable in the Decision Support for National Aerospace Planning Process (NAPP) Enhancements research contract from Defence Research and Development Canada. The purpose of the contract was to examine operational challenges faced by the Combined Aerospace Operations Centre (CAOC) at 1 Canadian Air Division, assess what technologies could address those challenges, invent new solutions based on those technologies, and then build a "NAPP Enhancements Prototype" (NEP) to test and demonstrate the selected innovations.

Background

The CAOC is the Combined Force Air Component Command (CFACC) backbone for force employment. As such the CAOC uses the NAPP to provide rapid and effective operational planning and tasking for supported commanders. Production of Air Tasking Orders at the NAPP improved significantly during the past decade with the acquisition of NAPP Integration Capability (NAPPIC) software, but a number of inefficiencies and bottlenecks remain. The bottlenecks are most acutely obvious during exercises and disasters, when rapid turnaround is essential.

Based on insights gained from a previous assessment of the NAPP [5], this contract focused on developing concepts, models, algorithms, and tools to address:

- air domain awareness,
- resource visibility, and
- resource management.

Results

Chapter 2 reviews requirements and deficiencies identified in the CAE report [5] and extends and updates them based on the CAOC experience of one of the authors (Stroud) as well as on a site visit to the CAOC. A key insight from that visit was that NAPPIC software was engineered to address many of the known deficiencies, but is unable to do so because of poor upward and downward flow of necessary data. The review of current technologies in Chapter 3 revealed other aerospace planning and scheduling tools that push the state of the art, and also highlighted relevant ideas from outside the air force planning domain.

The research focus of this contract was accordingly shifted to focus on innovative solutions that are not already available in NAPPIC and other air force tools. Twenty one potential innovations for domain awareness, resource visibility, and resource management are described are described in some detail in Chapter 4 and prioritized in Table 5 based on a joint review by the Technical Authority and the project team.

The Air Domain Awareness innovations all appear as intuitive visualizations in Google Earth focused on the future. Analysts can use a time-slider to view spatio-temporal renderings of sensor coverage and thus detect coverage gaps (Sections 4.1.1 and 4.1.2). They can also view (Section 4.1.3) animated future-weather maps to achieve visual rather than textual weather awareness. Section 4.1.4 proposes a new approach to Risk Rings to

better protect vital points.

Section 4.2 proposes two Visual Analytic (VA) tools for achieving awareness of the long-term (e.g. annual) patterns of operations, in support of the Total Air Resource Management (TARM) process at the CAOC.

Resource visibility innovations are described in Section 4.3. Section 4.3.1 describes how logistics and readiness awareness can also be hosted within Google Earth, using colour-coded icons, a “halo” effect, and drill-down for further details. Section 4.3.2 proposes a “dashboard” approach to hierarchical asset and resource awareness for aircraft, personnel, and logistics. Section 4.3.3 proposes a “Magnets Grid” strategy for detailed visualization of air assets (i.e. aircraft).

Sections 4.3.4 through 4.3.4.1 propose “Mission Hockey Cards” to summarize all the missions that are planned and underway. Placing all elements of a mission, including assets, timetable, and desired effect, into a single container reflects the way the planners approach their work and thus may be more effective than current planning tools which focus more on lines of tasking for each aircraft.

Section 4.4 uses the above tools, plus some new algorithms, to provide support for what-if scenarios, planning, and re-planning of missions. A planner first employs an efficient “fuzzy request for effects” user interface to specify the required effect of the new mission. NEP uses this to search for necessary assets among untasked aircraft and current missions. The NEP creates three recommended solutions corresponding to:

- The most timely response
- The best-equipped response
- The response with the least ripple effect (i.e. fewest changes to existing missions).

These three options are presented to the users as three rows of Mission Hockey Cards, with one Card for each new mission and for each ripple effect. The success of each new mission and the severity of ripple effects are evaluated numerically using new algorithms.

Significance

This report provides a vision for what could be achieved if the divisional, wing, and squadron databases can be federated in a future CAOC. The vision expressed in this document provided a foundation for the NEP, as documented in [13], and subsequently demonstrated to 1CAD.

This research has also:

- Updated previous studies of the current state of the art at the AOC and CAOC
- Provided a summary of relevant technologies and visualizations

This project has therefore developed new advanced decision support technology concepts to support ADA for the NAPP and the CAOC.

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1 Introduction

This report describes research into decision support strategies for "Decision Support for NAPP" (National Aerospace Planning Process) Enhancements, conducted under contract W7701-125270/001/QCL for DRDC Valcartier.

1.1 Background

This project is a continuation of the work conducted by DRDC Valcartier with respect to the Joint Command Decision Support for the 21st Century (JCDS 21) initiative. Specifically, this project builds from an investigation [5] into the innovative use of technologies, tools and processes to support the RCAF's transformation of its Combined Air Operations Centre (CAOC) located at 1 Canadian Air Division Headquarters', Winnipeg, Manitoba.

Through the use of aerospace power, the RCAF's mandate is to [50]:

- Protect Canada and Defend our sovereignty
- Defend North America through NORAD
- Contribute to international peace and security, including support for United Nations, NATO, and coalition operations, peacekeeping and humanitarian aid

Doctrinally, aerospace power is defined as "the element of military power that is applied within or from the air and space environments to achieve effects above, on, and below the surface of the Earth" ([16] pg 18). Section 1.1.2, below, expands on this mandate to *achieve aerospace power effects*.

The RCAF's use of aerospace power is the responsibility of a two-star general who conducts his responsibilities of command, control and sustainment through the CAOC.

1.1.1 National Aerospace Planning Process

The primary objective of the NAPP is to provide a "network-enabled, effects based, and results-focused process for the delivery of aerospace power" [5].

The NAPP is a continuous, deliberate planning process executed via three distinct but inter-related planning cycles (yearly, monthly and weekly) that define the CAOC's "battle rhythm". The NAPP provides a construct for integrating and coordinating activities beginning with the collation of requests through options analysis to the assignment and monitoring of air tasks. Within the CAOC, the Air Operations Centre (AOC) is responsible for executing the RCAF mandate through the employment of air assets drawn from 13 wings across Canada. The process of planning, tasking, executing and assessing the various missions in support of the RCAF's mandate is termed "force employment".

The wings, at the tactical level, are responsible for providing air assets to conduct RCAF aerospace missions. In preparation for the spectrum of planned and un-planned missions, air assets are at held at various states of "readiness", measured in minutes, hours, days or weeks. The collective execution and sequencing of missions constitutes RCAF aerospace power. The process by which air assets are organized, trained and equipped is termed "force generation".

With limited financial and personnel resources, a recent Commander of 1 Cdn Air Div has expressed a desire to see the CAOC provide "global services" from Winnipeg with a minimal forward deployed footprint in theatre for deployed operations. This would provide the capability to "reach forward" from Winnipeg rather than "reach back" from theatre, which is the case today.

1.1.2 Effects-Based Operations and Readiness

In accordance with the above mandate to "achieve effects above, on, and below the surface of the Earth," the Air Force employs a continuous cycle of sensing, commanding, and acting as illustrated in Figure 1-1. This focus on achieving "effects" is frequently mentioned by RCAF leaders.

LGen André Deschamps, a previous Commander of the Royal Canadian Air Force (RCAF), for example, asserts the effects-based mandate of the RCAF and associates that mandate with the importance of "being ready," as follows:

> "Success in operations, my number one priority, rests on a foundational pillar of readiness – that is, our ability to act – to **deliver the right air effect, at the right time and the right place**. It demands that our capabilities exist in various states of readiness...
>
> The CAOC allows us to effectively allocate and rapidly re-group and re-task capabilities to force employers and thereby better support operational commanders.
>
> Now, it goes without saying that airplanes are fast – that is, faster than land- or sea-based capabilities.
>
> Therefore, the inherent nature of air power allows us to respond rapidly. Our agility and resilience are important organizational values that are foundations of our readiness." [15]

LGen Deschamps goes on to explain that readiness, for the Air Force, means the 24/7 ability to respond to a crisis with fighter aircraft in minutes, search and rescue aircraft in half an hour, and maritime surveillance aircraft in half a day.

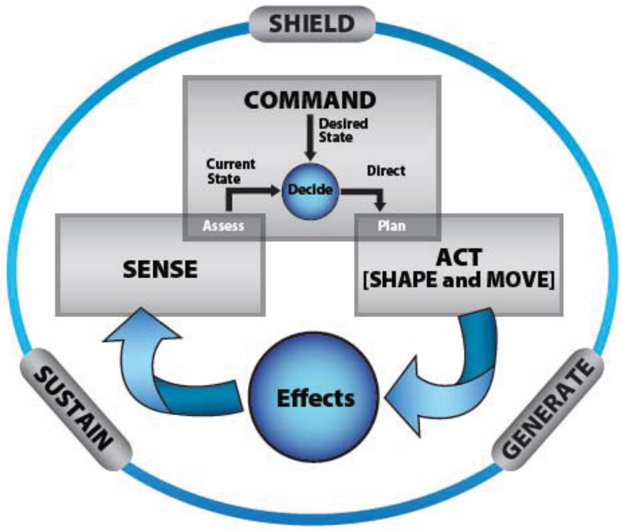


Figure 1-1 Air Force Functions

Air Force operations are a continuous cycle of activities, focused on achieving required effects. This contract seeks to support the "decide" bubble though improved situation awareness (knowledge of the current state), course of action analysis (assessment of various command directions), and productions of plans. (figure is from [16] page 35).

1.1.3 Air Domain Awareness (ADA)

Air Domain Awareness is not a mature and well documented concept within the RCAF. Based on RCAF doctrinal characterizations of the air domain and a blending of doctrinal definitions and characteristics of US Coast Guard Maritime Domain Awareness (MDA), Baker and Sciopone proposed the following definition of ADA as it pertains to Canadian interests:

> "Effective understanding of anything associated with the air domain that could affect security, safety, economy, or environment of Canada." ([5] pg 60)

In their discussion of what is meant by "anything associated with the air domain," Baker and Sciopone focus on "Non-Real Time" and "Real Time" factors associated with own-forces ([5] pg 61), as follows:

- **Non-Real Time:** Non-real time factors outside the operational context include the constraints affecting the employment of airframes (e.g., maintenance, modernization), the RCAF's operational capacity (e.g., number of aircraft in each fleet, aircraft readiness, aircraft sustainability, aircraft deploy-ability), and human resource factors such as the availability of personnel to operate the aircraft. Information about such factors is typically provided by the wings and the squadrons. An appreciation of these factors helps with the planning portion of employing aerospace resources in response to RFEs.

- **Real-Time:** Real-time factors listed in the report focus on the operational status of aerospace resources currently employed by the Air Force. This includes, for instance, the geographical positions, configuration, load, and crew composition of all airframes. They include both force generation and force employment missions as discussed in Section 1.1.4. Information about these factors supports operations personnel maintain the current situation awareness and respond to contingency events.

Recent developments in RCAF aerospace doctrine has afforded us an opportunity to expand the current definition of ADA to include awareness of red forces, neutral, environmental, and other factors as depicted in Figure 1 2 below.

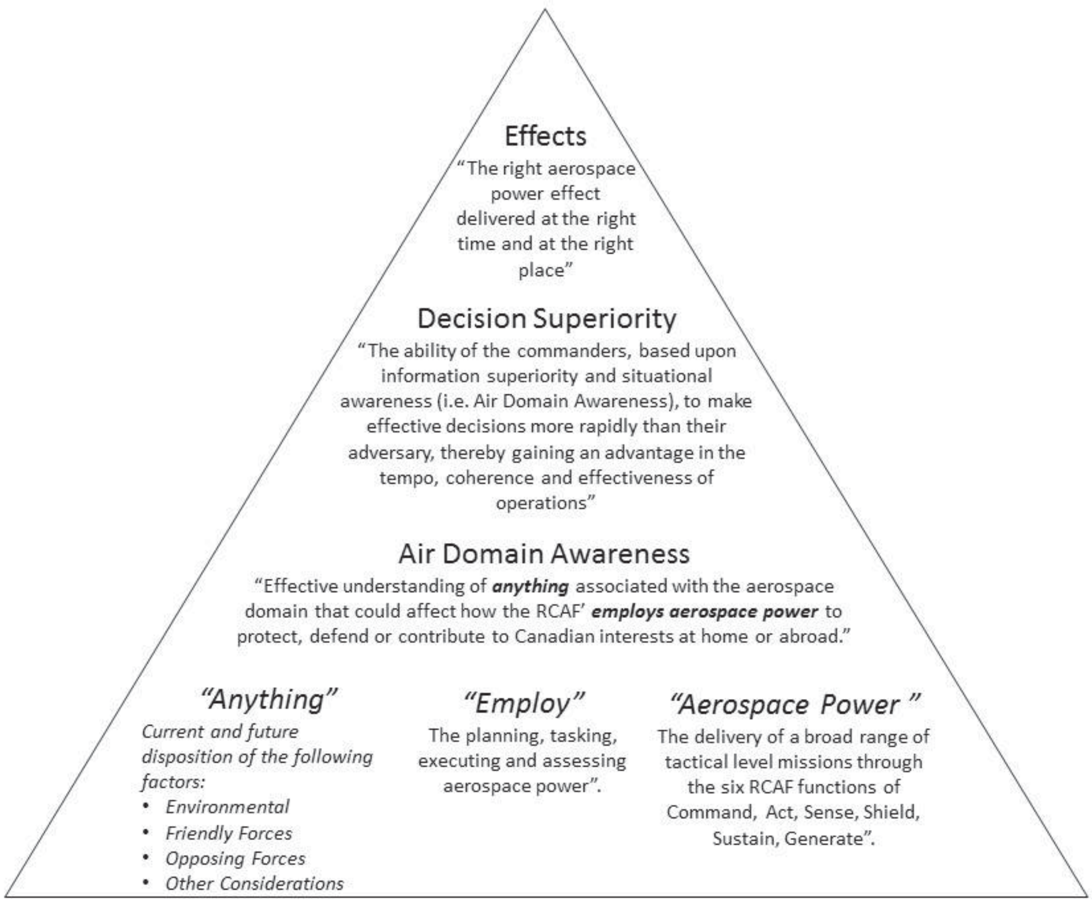


Figure 1-2 Air Domain Awareness in Support of Effects-Based Operations
Based on CF doctrine and discussions with CAOC personnel, we understand Air Domain Awareness (ADA) as illustrated here. The sketch highlights how better ADA leads to better decisions and thus supports effects-based operations.

Canadian Forces doctrine ([16] as referenced in [5] pg 63) groups Air Force capabilities under six functions: Command, Sense, Act, Shield, Sustain and Generate. The term "situational awareness" has emerged as a fundamental belief upon which "Sense" operational doctrine is built.

The Sense function is the capability that provides the commander with knowledge to achieve decision superiority, of which:

- Decision superiority provides the operational advantage over an adversary through superior situational awareness
  - Decision superiority is defined as "the ability of the commanders, based upon information superiority and situational awareness, to make effective decisions more rapidly than their adversary, thereby gaining an advantage in the tempo, coherence and effectiveness of operations"
  - One of the outcomes from decision superiority at the operational level is the delivery of "the right aerospace power effect at the right time and right place" at the tactical level
- Situational Awareness is defined as "the knowledge of the elements in the battle space necessary to make well informed decisions."
- Situational awareness provides a combined picture of the operational environment including knowledge of:
  - Adversaries
  - Weather and terrain
  - Own forces
  - Other friendly, allied, or coalition forces; and
  - Other entities (increasingly important under the comprehensive approach)

The recently formulated concepts around situational awareness are ideally suited to provide additional context to the term "anything" as used and defined in the CAE proposed definition of ADA. This, plus including key terms from the RCAF's mandate, will add additional context from which to develop a robust set of taxonomies to support potential decision support solutions for this project.

Building from the CAE definition and linking to recent developments in RCAF doctrine, we propose the following definition for Air Domain Awareness:

- "Effective understanding of **anything** associated with the aerospace domain that could affect how the RCAF **employs aerospace power** to protect, defend or contribute to Canadian interests at home or abroad."

To clarify this proposed definition, we explore below the terms "anything," "employ," and "aerospace power." Additionally, we propose to incorporate the above concepts of Non-real time and Real time factors into the term "current and future disposition."

"Anything"

Building from the CAE report, we propose to group the knowledge elements from the term "situational awareness" into four categories typically used during the planning of aerospace missions:

- **Environmental.** Current and future disposition of weather, terrain and any hazards to navigation
  - **Weather** is considered one of eleven characteristics of aerospace power that must be understood for optimal employment of air assets. For example, "bad" weather creates difficulties with take-offs and landings, navigation, target acquisition and weapons delivery. Given the potential impact of unfavourable weather on any type of aviation activity, hourly updates of current weather and frequent updates of forecasted weather are provided to the aviation community
  - **Terrain** is considered another characteristic of aerospace power that must be understood. Like "bad weather", vertical characteristics of the topography can create difficulties with take-offs and landings, navigation, target acquisition, weapons delivery and sensor coverage, whether surface-based on airborne
  - **Hazards to Navigation** normally encoded as a Notice to Airmen (NOTAM). A NOTAM is a notice filed with an aviation authority to alert aircraft pilots of potential hazards along a flight route or at a location that could affect the safety of the flight. For example, NOTAMs are provided when a runway at a specific location or a navigation aid is unavailable for a specified time period. Given the potential impact of these hazards to flight operations, NOTAMs are rapidly distributed to the aviation community.

- **Friendly Forces.** Current and future disposition of static and dynamic land, sea and air assets.
  - The RCAF plans and executes its mandate centred on the intent and capabilities of friendly and opposing (i.e. enemy) forces. Awareness of the disposition of static and dynamic land, sea and air assets from both orders of battle at all three levels of command, now and at some point in the future, defines capabilities and is the focus of the operational commander's decision making process.
  - The term "assets" implies any and all resources required to execute (and sustain) the mission. These assets could be characterized as "mission specific" (i.e. aircraft and aircrew), "mission support" (i.e. Personnel, Intel, Maintenance, Logistics, IM/IT) and "force protection" assets. Organizationally, 1 Cdn Air Div has been structured to group like air assets together to define domains of responsibility. RCAF missions are planned grouping like air assets as characterized above

- **Opposing Forces.** Current and future disposition of static and dynamic land, sea and air assets.
  - The RCAF plans and executes its mandate centred on the intent and capabilities of friendly and opposing (i.e. enemy) forces. Awareness of the disposition of static and dynamic land, sea and air assets from both orders of battle at all three levels of command, now and at some point in the future, defines capabilities and is the focus of the operational commander's decision making process.
- **Other Considerations.** Under the "comprehensive approach" to operations, it may be required to cooperate with many entities that are not within the military chain of command such as Canadian Other Government Departments during 2010 Vancouver Winter Olympics, but also other agencies in an operational area, such as humanitarian organizations during the 2010 Haiti earthquake and Non-Government Organizations

during aerospace operations over Afghanistan and Libya. The term "joint, integrated, multinational, and public" was coined to describe relationships within this broad spectrum of entities, and it constitutes a new and special type of liaison of increasing importance in the modern operating environment.

"Employ"

This term is linked to the doctrinal responsibilities of the Commander 1 Cdn Air Div, and by extension, the CAOC. "Force employment" is defined as the process of planning, tasking, executing and assessing aerospace power". The NAPP provides a construct for integrating and coordinating force employment activities over various timeframes

"Aerospace Power"

This term is linked to a set of capabilities, with each sub-set of capabilities supported by a mission, or a range of missions, conducted to achieve an aerospace power effect. Currently, there are 23 different mission types from which to "employ aerospace power to protect, defend and contribute to Canadian interests at home or abroad".

1.1.4 Air Domain Awareness of Blue Forces and Plans, Including FG

In the context of maintaining ADA, the Commander 1 Cdn Air Div typically asks the following:

- "Where are the airplanes?"
- "What is our plan?"
- "Does the plan need to change?"

The CAOC is responsible for Force Employment (FE) planning, but the Wings are responsible for Force Generation (FG) planning, as shown in Table 1.

Table 1 Different Treatment of Force Employment and Generation

	Force Employment	Force Generation
Fraction of all flights	30%	70%
CAOC Visibility	always	not always
Where planned	at CAOC	at Wings

The AOC must therefore take special care to be aware of, and to give commanders awareness of relevant RCAF resources on FG missions. The term "relevant" is situation-dependant, but might include, for example, FG missions that will intersect FE missions, or FG missions that use resources that may be required for FE missions. In one anecdote, the Commander of First Canadian Air Division was traveling in the US, saw Canadian aircraft at a US Base, and could not explain to his hosts what they were doing there.

1.2 Contract Objectives

The objective of this contract [57] is to develop new advanced decision support technology concepts in the following areas:

- Improved Air Domain Awareness (ADA) for the National Aerospace Planning Process (NAPP) and for the Combined Aerospace Operation Centre (CAOC)
- New technologies, tools and processes for the 1 Canadian Air Division (1 Cdn Air Div) to support CAOC Transformation and future Air Force Command and Control (AFC2) requirements.
- Vertical and horizontal coordination and collaboration of AFC2 information at different levels within the NAPP.

The contract statement of work also lists a number of technology concepts to be specifically addressed in this contract. Table 2 provides a list of these concepts, with cross-references to the sections of this report where those concepts are addressed.

Table 2 How the Specified Technology Concepts have been Addressed

page	Technology Concept	Addressed by	Where
12	• improve Air Domain Awareness	• Coverage awareness • Gap analysis • Weather awareness • Air traffic awareness • Vital points	4.1.1 4.1.2 4.1.3 4.2.1
12	• provide multi-level logistics information and analysis	• Logistics awareness • Logistics drill-down	4.3.1.2 □
12	• explore multi-level co-ordination mechanisms	• Halo visualization • Halo drill-down • Hierarchical Gantt	4.3.1.2 4.3.1.2 0
13	• close gap between information need and information gathering	• e.g. Surveillance gap analysis • e.g. Sensor coverage awareness	4.1.2 4.1.1
13	• review preliminary requirements and deficiencies previously known and complete requirements analysis	• Requirements analysis	1.1.3
13	• review current technologies and tools supporting or believed to further enhance ADA	• Technology review	2.1
13	• rank and validate key requirements and identify promising decision support technology research directions	• Prototype element ranking	2.1
13	• develop solutions supporting user queries and providing information visibility	• Visual Analytics: Google Earth, Gantt, Hockey Cards	4.1 4.2 4.3
13	• investigate how centralized and distributed information-gathering may enhance ADA	• (de-scoped as per Kick-Off Meeting)	4.1.2
13	• effectively allocate and rapidly re-group and re-task resource/asset and capabilities in support of operational commanders	• Resource Visibility • Gantt Visualizations	4.3.2 4.4
13	• generate and integrate a logistics picture component	• Halo visualization • Halo drill-down	4.3.1.2 4.3.1.2
13	• logistics picture to provide asset visibility hierarchical visualization	• Google Earth view • Halo drill-down • Dashboards	4.3.1 4.3.1.2 4.3.2
13	• assess resource readiness	• Icons for Bases • Stoplights • Dashboards • Hockey cards • Hockey card browser	4.3.1 4.3.2 4.3.3 4.3.4 4.3.4.1
13	• analyzing contingency situations (e.g. through simulation)	• Hierarchical Gantt • Fuzzy Request for Effect • Ripple Effects	4.4.1 4.4.2 4.4.3
14	• account for multi-level analysis of assets and asset readiness	• Long-term patterns for TARM • Hierarchical Gantt • Halo visualization • Hockey card browser	4.2 4.4.1 4.3.1.2 4.3.4.1
14	• account for multi-level analysis of customer demand	• Fuzzy customer request for effect	4.4.2

14	• asset and plan execution monitoring	• Hierarchical Gantt • Inserting NFE or NOTAM • Mission Play Diagrams • Dynamic Hockey Cards	4.4.1 4.4.2 4.3.4.1 4.3.4.1
14	• provide resource visibility for NAPP/unit level air domain awareness	• Hierarchical Gantt • Halo visualization	4.4.1 4.3.1.2
14	• propose, design, develop, and asses a NAPP Enhancement Prototype "NEP"	• NEP Architecture • NEP Scenarios	NEP Final Report
14	• NEP supports exploration of resource allocation solutions	• Adaptive resource allocation	4.4.4 4.4.5
14	• NEP recognizes mission priorities	• Mission Hockey Cards highlight mission priority • Fuzzy effects • Algorithms use mission priority	4.3.4 4.4.2 4.4.5
14	• NEP supports resource allocation in response to dynamic events (NFE and exogenous)	• Fuzzy Request for Effect GUI • Re-planning GUI	4.4.2 4.4.4
14	• NEP helps maintain consensual planning between CAOC and CAOC's clients	• Hockey-Card what-if • Fuzzy effects • Dashboard collaboration	4.4.4 4.4.2 4.3.2
14	• develop resource allocation models and algorithms	• Ripple Effect model • Fuzzy Logic for 3 options	4.4.3 4.4.4
14	• explore mechanisms for multi-level planning coordination	• Hierarchical Gantt • Dashboard Collaboration • Fuzzy Logic for 3 options	4.4.1 4.3.2 4.4.4
14	• demonstrate a preliminary vision for vertical and horizontal NAPP coordination and collaboration	• Long-term patterns for TARM • NEP Architecture • NEP Scenarios	4.2 Ref [13]
14	• support asset readiness assessment	• Hockey card browser	4.3.4.1
14	• support plan validation and verification	• Re-planning GUI with re-calculated metrics	4.4.4
14	• assess change-sensitivity (i.e. ripple effect)	• Ripple Effect model • Fuzzy Logic for 3 options	4.4.3 4.4.4

1.3 Contract Scope

The scope of the NAPP Enhancements contract is the combined scope of this Analysis and Innovation report, the NEP Final Report, the NAPP Enhancement Prototype software, and the final demonstration. The scope of each of those elements is described in Sections 1.3.1through 1.3.4.

1.3.1 Scope of Deliverable 1: This Analysis and Innovation Report

The first deliverable of this contract is this report, which was produced during the early months of the project. This report has the following scope:

- Task 1.1: Review current CAOC methodologies and technologies to identify requirements, deficiencies, and opportunities for improvements (see Section 2)
- Task 1.2: Review the current state of the art in technologies and tools that are relevant to Air Domain Awareness (see Section 3)
- Task 1.3: Identify research priorities (see Section 2.1)
- Tasks 1.4 and 1.5: Develop ADA solutions supporting user queries and providing information visibility. This includes an analysis and prioritization of possible innovative solutions (see Sections 4.1 and 4.2).
- Task 2.1: Develop resource visibility solutions supporting a vertical and horizontal recognized logistics picture. This also includes an analysis and prioritization of possible innovative solutions (see Section 4.3).
- Task 2.2: Develop resource management solutions supporting multi-level planning coordination, rapid re-planning, course of action assessment, and plan validation. This includes an analysis and prioritization of possible innovative solutions (see Section 4.4).
- Tasks 1.4, 2.1, and 2.2: Prioritization of the innovative technology (Table 5).

1.3.2 Scope of Deliverable 2: The NAPP Enhancement Prototype Final Report

The second deliverable of this contract is the NEP Final Report [13], which describes the design process and research results. That report has the following scope:

- Tasks 1.4, 2.1, and 2.2: High-level design, architecture, and system engineering ([13] Sections 2 and 4)
- Tasks 1.4, 2.1, and 2.2: Development of demonstration scenarios ([13] Section 3)
- Tasks 1.4, 2.1, and 2.2: Database design for the demonstration scenarios ([13] Section 5)
- Task 2.1: Implement resource visibility prototype solutions supporting a vertical and horizontal recognized logistics picture ([13] Section 6).
- Task 2.2: Implement resource management prototype solutions supporting multi-level planning coordination, rapid re-planning, course of action assessment, and plan validation. ([13] Section 7, 8, and 9).

1.3.3 Scope of Deliverable 3: NAPP Enhancement Prototype (NEP)

The second deliverable is the NAPP Enhancement Prototype (NEP), which is a suite of software elements that engage the key design challenges of the proposed innovations, and support a final technology demonstration. The NEP illustrates new strategies for resource visibility, resources management, decision support, and improved Air Domain Awareness. The prototype design addresses such topics as:

- Logistics awareness
- Resource readiness awareness
- Asset visibility and readiness awareness
- Monitoring of operations vs. plans
- "What if" and contingency analysis
- Re-planning, for example in response to requests for Non-Forecast Effects
- Maintenance of vertical (from squadron to NDHQ) consistency in planning and execution
- Plan validation
- Assessment of plan robustness

The "prototype" nature of the NEP influences its scope as follows:

- The NEP is not designed to be operational. For example it does not have connections to the full suite of databases that an operational solution would require.
- The NEP is more than a mock-up. Thus for example it uses real algorithms to generate the "what-if" scenario visualizations so that users can accurately assess the viability of the underlying innovations. It is not just Photoshop artwork.
- The NEP focuses on "high-leverage" technology innovation. To do this, it avoids extended development of high-cost industry-standard features such as multi-level security, multi-format data support, or support for multiple browsers (unless such items are identified as high-risk and requiring innovation).

The SOW requires that the NEP support "vertical" as well as "horizontal" resource visibility. "Vertical" means the ability to drill-down from the CAOC to the Wings and the Squadrons. "Horizontal" means the ability to view impacts ("ripple effects") on varying time-scales. Thus the NEP strives to provide:

- Drill-down to an individual aircraft
- Visualizations and briefings that help communicate to the commander of 1Cdn Air Div
- Very rapid options analysis, focused on "what is possible, on very short notice?"
- Ripple effects out to two weeks. Under normal operational tempo, we expect most ripple effects to have died out within the 2-week period (see B.1)..

The horizontal and vertical scope of the NEP is indicated by the dashed blue line sketched in Figure 1-3.

1.3.4 Scope of Deliverable 4: Demonstration and Video

The third deliverable is a demonstration of the NEP using the scenarios defined in the NEP Final Report [13]. This demonstration is intended for "live" presentation but has also been recorded on a video for easier distribution.

The Final Report describes how to install the NEP and gives an overview of the standard demonstration scenario. A separate document "NAPP Enhancement Prototype: Demonstration Instructions" [68] provides step-by-step demonstration instructions.

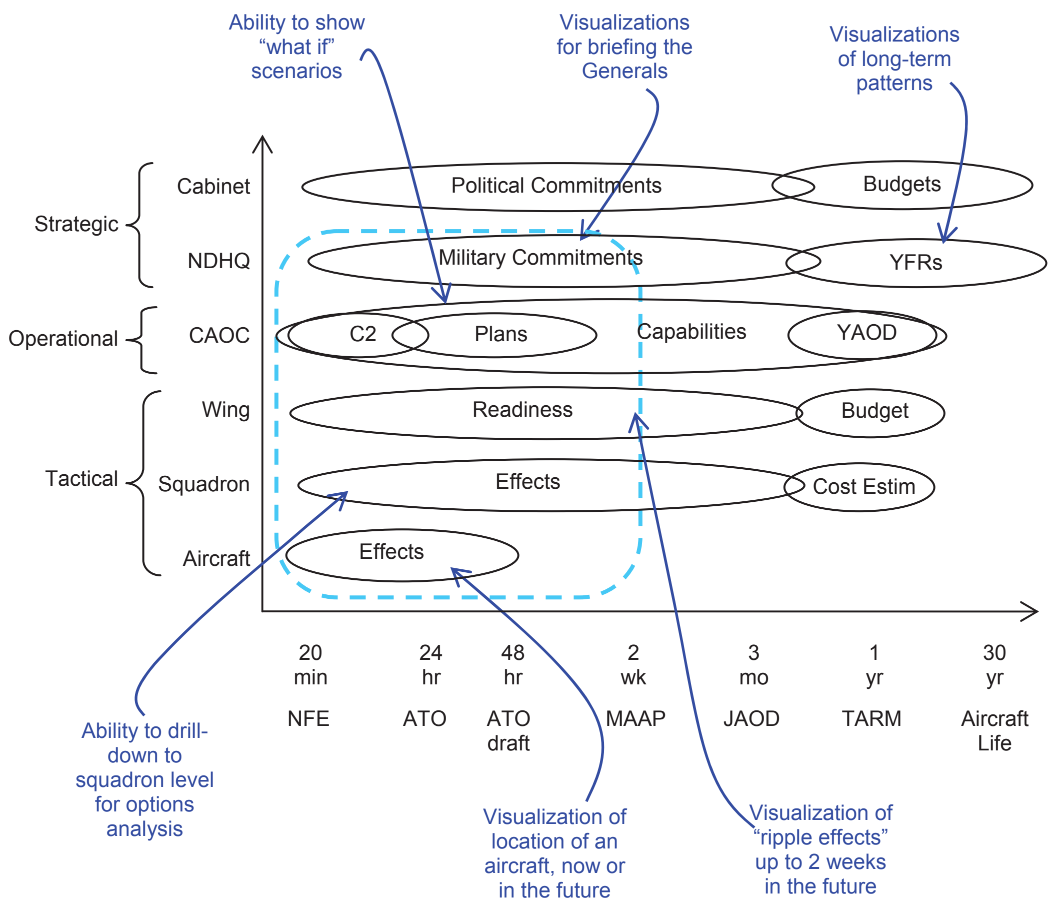


Figure 1-3 Vertical and Horizontal NAPP Coordination

The RFP describes the "vertical" dimension as providing "visibility into the Operational Level, Wing Level, and Squadron Level." It describes the "horizontal" dimension as "integrating the different NAPP phases." This sketch illustrates key products at each vertical level, and for each time scale. The NAPP Enhancement Prototype (NEP) will focus on a subset of these elements, as illustrated by the blue box.

2 Opportunities to Support the CAOC

This section addresses Task 1.1of the SOW [57] by updating the requirements analysis of previous DRDC studies of the NAPP. The starting point for this analysis is the Baker and Scipione report (Section 5.4 of [5]), with updates based on one author's (LCol (ret'd) Doug Stroud's) air force experience as well as on a fact-finding visit and tour of the CAOC in Winnipeg, as documented in Appendix B.

Section 2.1 ranks the operational value of each improvement, assesses its achievability within this contract, and indicates how well it aligns with the scope of this project.

Sections 2.2 through 2.4 then focus on how the specific CAOC requirements map into this contract's focus on Air Domain Awareness, resource visibility, and resource management.

2.1 Prioritization of Relevant User Requirements

Table 3 lists the requirements and opportunities for improvements based on Sections 5.4, 7.4, and 7.5 of [5] and on insights gained from the site visit to the CAOC Appendix B.

Note that Table 3 is not an agenda for this contract. As noted in the table, many of the identified requirements are outside the scope of this project. Furthermore some of this project's innovations, as listed in Section 4, do not stem directly from this list of requirements.

Table 3 Prioritization of Relevant User Requirements

Ref. Num.	User Requirement & Discussion	Opera-tional Value	Achiev-able on this project	Align-ment to this Project
1	**Import Force Generation missions into the CAOC** • The CAOC only handles ATOs for Force Employment missions, reducing their awareness of Force Generation (FG) missions (Section 5.4.1 of [5]). • If FG mission plans were continually accessible at the CAOC, they would be better prepared to respond to requests for Non Forecast Events (NFE). • Validated at the CAOC visit • Core problem is to create a data pipe from FlightPro (Unclassified domain) to NAPPIC (Classified domain).	high	very low	med
2	**Auto-feed information from Wings up to the CAOC.** • CAOC staff highlighted the inefficiency of time spent repetitively entering and re-entering the same data manually into multiple planning and operational systems (Section 5.4.4 of [5]) . • For example arrival and departure data are currently sent by email and hand-typed in (Section 5.4.2 of [5]) but are not consistently received. • This compromises the reliability of the "current ATO" and thus of blue forces in the Recognized Air Picture (RAP) • This compromises the ability of the CAOC to perform post-mission analysis (planned vs actual)	high	very low	med
3	**Feed mission execution information down to the Wings** • Oversight of ATO execution and management would be enhanced by providing real-time information to the Wings (Section 5.4.1 of [5]). • The Wings should be able to track on-going in-theatre operations in detail (B.1) • This could have a positive impact on sustainability (e.g. flight crew training, aircraft hour's burn rate per tail number) (Section 5.4.3 of [5]). • Caution: the lines of communication from deployed operations still need to come through CAOC and not directly to the Wings	high	very low	med
4	**Develop customizable displays for the Wings and Squadron Ops** • Exploitation of real-time information and collaboration would require new customizable displays for the Wings (Section 5.4.2 of [5]).	med	low	low
5	**Provide a single Common Operating Picture (COP)** • Current COP uses three separate systems (C2PC, US FAA Traffic, and RWS (Section 5.4.2 of [5]). • AOC staff want a single display that presents track information in real time (Section 7.5.7 of [5]). • This should include the ability to focus on specific aircraft • This should include the ability to drill-down for e.g. payload, prudent limit of endurance, personnel, flight plan.	high	med	high (sections 4.1, 4.3)

6	**Provide satellite-linked real-time location information** • Some RCAF flights are tracked using radar IFF, and do not use satellite reporting links (Section 5.4.3 of [5]). This means CAOC is blind to their location when they are out of radar range. • Real-time location updates could be achieved using secure satellite reporting (similar to that used by commercial aircraft)	high	very low	low
7	**Provide supported commanders (SCs) with detailed information** • Provide remote workstations so SCs can track detailed assets or personnel on flights, thus providing better situation awareness (Section 5.4.3 of [5]). • Caution: this might lead to SCs asking for specific RCAF assets rather than effects, thus undermining the chain of command. SCs must still communicate through the CAOC	med	low	low
8	**Display near-real-time dynamic Air Tasking Order (ATO)** • Provide the AOC and CAOC with an information package that contains all the information in an ATO, but continually updated to reflect the current mission status (Section 5.4.3 of [5]). • This must include the ability to visualize the baseline plan	high	high	high (section 4.3.4.1)
9	**Support dynamic re-tasking** • Provide the AOC and CAOC with all information to support dynamic re-tasking (Section 7.4.1 of [5]). • During exercises, the tempo of operations is so high that the normal re-planning process does not work	med	med	high (section 4.4)
10	**Joint COP** • The COP should include joint operations: air force, army, special ops, and navy assets (B.1)	med	med	med
11	**Integrate enhanced decision support tools** • Planners at the Wing and Squadron level might gain value from tools that help with scheduling (Section 5.4.5 of [5]).. • For example, air mobility planners need to know that ground support equipment for loading and unloading an aircraft must be sent as the first-priority load when deploying a squadron	med	med	low
12	**Provide options analysis tools** • Provide decision-support tools to facilitate options analysis and thus select the best course of action while understanding the resulting consequences. • Achieve Level 3 Situation Awareness (ability to project into the future [21]) in order to predict the outcomes (including ripple effects) from making modifications to the previously established plans (Sections 7.5.3 of [5]). • Simulate or “war-game” different scenarios to see ripple effects (Section 7.5.3 of [5]). • Currently options analysis and re-planning require “re-rolling all the missions” through NAPPIC	high	med	high (section 4.4)
13	**Implement an air surveillance network** • Implement a network of surveillance systems to persistently and effectively monitor all entities within the air domain, particularly in Canada’s northern region (Section 7.5.1 of [5]) • Network could be comprised of both unmanned and manned aerial vehicles as well as mobile and fixed ground sensors	med	low	very low

14	**Improve surveillance technologies** • Identify, develop, and deploy new detection and surveillance technologies (Section 7.5.1 of [5]) • Find strategies to optimize and allocate mobile and fixed sensors to optimize coverage and improve information gathering. • Bring in data from other government departments	med	low	low
15	**Improve surveillance data fusion** • Fuse surveillance data from multiple simultaneous sensor feeds (Section 7.5.2 of [5]) • Integrating surveillance data with intelligence and information including aircraft and passenger databases, crew databases, watch lists, cargo databases, terrorist databases, flight profiles, and aircraft characteristics. • The AOC should have awareness of the coverage provided by surveillance assets	med	med	high (section 4.1)
16	**Detect anomalies** • Develop algorithms to detect and identify data related to platforms deviating from normal patterns of behaviour (Section 7.5.4 of [5]). • An example anomaly: an aircraft not following its flight plan. • Develop user interfaces to visualize anomalies or alert operators.	med	med	low
17	**Identify contacts** • Fuse identity information received from multiple sensors in order to facilitate the identification of tracks (Section 7.5.5 of [5]). • Validate identity and alert operators to ambiguities or conflicts	med	med	low
18	**Assess threats** • Develop tools and algorithms to augment operator's assessment of threat level for a contact (Section 7.5.6 of [5]). • Use kinematic data, and past behaviour, to project the possible future behaviour of a contact. • Infer the capability, opportunity, and intent of a contact.	med	med	low
19	**Disseminate information** • Develop an open architecture for data sharing with web-based information storage and access (Section 7.5.8 of [5]).	med	low	med
20	**Generate a briefing video** • Provide a tool that efficiently (i.e. semi-automatically) produces an animated YouTube-like video that summarizes the next 24 hours of operation • The video would be forward-focused (i.e. mainly concerned with "what will be happening") • This could be used during "morning prayers" briefing, and then left on the secure networks for commanders to review as required. • It might include map-based animations of the most-important planned missions, weather, readiness status of bases. • It might include graphical products such as operational tempo, force-generation activities, personnel status. • It might include video elements such as snippets of current events, or RCAF in the news.	med	med	med

21	**Visualize weather patterns** • Overlay expected weather patterns as graphical overlays (Table 7-1 of [5]). • Link the weather display to the time-slider so that changing weather patterns are visually linked to planned operations • This would only be valuable if better than the current text-only display (B.2)	med	high	high (section 4.1)
22	**Use automation to compensate for inadequate staffing** • Typical NATO CAOCs are staffed by 600 people, surging to thousands of people • Canada's CAOC is much smaller, and thus will benefit from technologies that reduce the workload on existing staff (B.1)	med	med	high (all sections)
23	**Use a digital model of cause-and-effect** • NAPPIC has an internal model of cause-and-effect in the air force domain • The only way to predict ripple effects is with such a cause-and-effect model (B.1)	high	med	high (section 4.4)
24	**Visualize Threat and Risk** • The AOC and CAOC sometimes need to visualize Threat and Risk from known disposition of enemy assets. • This may refer to a "high value asset" which may be fixed or moving. • This is currently sometimes done with Threat Rings (B.1)	med	med	med (section 4.1.4)
25	**Communications awareness** • Domain awareness at the AOC should include awareness of communications between aircraft and squadrons (B.1)	med	med	med (section 4.3.1.2)

2.2 Requirements for Air Domain Awareness

The following Air Domain Awareness (ADA) deficiencies will be addressed in the NEP:

- **Provide a single Common Operating Picture** (see Table 3-5): the NEP will demonstrate new visualization strategies for assembling a variety of information into a single COP, as described in Section 4.1.
- **Display a near-real-time visual Air Tasking Order** (see Table 3-8): the NEP will be able to display the current location and status of all assets, with drill-down capability.
- **Surveillance Data Fusion** (see Table 3-15): the NEP will provide drill-down information on air bases, and on deployed air assets. It will also show radar coverage visualization.
- **Visualize weather patterns** (see Table 3-21): the NEP will provide weather map overlays that slide into the future.
- **Use Automation** (see Table 3-22): none of the new ADA components in the NEP will require (in a future operational deployment) laborious data insertion or preparation.
- **Visualize Threat and Risk** (see Table 3-24): the NEP will explore potentially improved "threat rings" to demarcate emerging threats around high value assets.

- **Communications Awareness** (see Table 3-25): drill-down for deployed assets will include access to a record of recent communications.

2.3 Requirements for Resource and Assets Visibility

The following resource and assets visibility deficiencies will be addressed in the NEP:

- **Provide a single Common Operating Picture** (see Table 3-5): the COP, as described in Section 4.1, will include visual indicators or readiness, and a drill-down recognized logistics picture.
- **Support Dynamic Re-Tasking** (see Table 3-9): the NEP will provide a user interface for browsing available assets and drilling down for more information about logistics and asset readiness.
- **Use Automation** (see Table 3-22): none of the new resource visibility components in the NEP will require (in a future operational deployment) laborious data insertion or preparation.

2.4 Requirements for Resource Management

The following resource management deficiencies will be addressed in the NEP:

- **Support Dynamic Re-Tasking** (see Table 3-9): the NEP will provide algorithms for assessing the “cost” of re-tasking assets. It will also provide a user interface for browsing available assets taking into account this cost.
- **Provide Options-Analysis Tools** (see Table 3-12): the NEP will provide decision-support tools to facilitate options analysis and select the best course of action. This will include algorithms to assess the “cost” of the ripple effect of a change of plan.
- **Use Automation** (see Table 3-22): none of the new ADA components in the NEP will require (in a future operational deployment) laborious data insertion or preparation.
- **Model Causes and Effects** (see Table 3-23): automated tools for options analysis and re-tasking will incorporate domain models of cause and effect, where necessary.

3 Current Technologies and Tools Relevant to the CAOC

This section reviews current technologies and tools that may be useful in the research and development of technology concepts for air domain awareness, air resource visibility, air resource management, or air force planning. This includes tools that provide core infrastructure for the NEP, systems that have addressed similar problems in other domains, and research into solutions of exactly these domains.

3.1 IT Standards and Infrastructure

This section reviews tools that were assessed as possibly relevant within the core infrastructure of the NEP.

3.1.1 Service Oriented Architecture and REST

System developers within DRDC (see Section 3.1.2), DND[43] and the US DoD [61] have adopted Service Oriented Architecture (SOA) as the preferred architecture for new developments. SOA as a design paradigm promotes principles such as loose coupling, service contract, autonomy, abstraction, reusability, statelessness, discoverability and composability.

Representational State Transfer (REST) is an architecture for building distributed web programs [1] for deployment within an SOA. The functionality of a distributed web program is split up into multiple web 'services,' each of which is a program that may be running on a foreign server on the web. Services typically provide data or run an algorithm.

Splitting a single program into multiple services is useful because it promotes code reusability. A piece of code that performs a specific function can be used by multiple applications when it is freed from a large program and implemented as a small and autonomous service. Packaging these pieces of code as web services enhances the reusability by enforcing a common calling syntax (e.g. REST or SOAP) mediated by the servers.

REST creates "RESTful" web services using the following basic web technologies:

- The HTTP methods (GET, PUT, POST, DELETE, HEAD, OPTIONS)
- The Uniform Resource Identifier (URI) naming standard
- Standardized data exchange formats (typically XML or JSON) [58]

REST-style architectures consist of clients and servers. Clients initiate requests to servers using the simple HTTP commands listed above. The servers then activate the REST service, pass it the required parameters, and return a result to the client.

The REST-style architecture is a simple and elegant way of providing web services. Other kinds of web services programming such as SOAP and CORBA use “heavyweight” architectures and the resulting services are “far too complex, impossible to debug and won’t work unless your clients have the exact same setup as you do”[58]. These kinds of web services reinvent the wheel - they “unnecessarily build protocols and standards on top of the HTTP protocol” [58] when really all that is needed to provide web services is the six basic HTTP commands defined in the HTTP protocol: GET, PUT, HEAD, DELETE, POST, OPTIONS. These six commands manipulate data and provide all the functionality a web program requires.

In a RESTful service, every object (an object is simply a named piece of data or service) has a unique URI. A client program sends a GET request to that object’s URI to retrieve that object. To retrieve only the metadata for an object, a HEAD request is sent to that same URI. To create an object, a client sends a PUT request to a URI. The URI would contain the desired name of the object and the REST service would then create an object with that name. To delete an object, a client sends a DELETE request to that object’s URI [58].

There is general consensus that RESTful services offer the following advantages:

- **Fast:** REST applications are fast because they are stateless. This means that “every HTTP request happens in complete isolation. When the client makes an HTTP request, it includes all information necessary for the server to fulfill that request. The server never relies on information from previous requests” [58]. It is therefore easy to distribute a stateless application across load-balanced servers. Since no two requests depend on each other, they can be handled by two different servers and this makes program execution faster.
- **Scalable:** Because they are stateless, REST programs are also scalable: “Scaling up is as simple as plugging in more servers into the load balancer” [58].
- **Reliable:** REST programs are reliable because the HTTP commands GET, PUT and DELETE are idempotent. An operation is considered idempotent if it has the same effect whether it is applied once or multiple times. For example “if you DELETE a resource, it’s gone. If you DELETE it again, it’s still gone”. Thus REST allows a client to “make reliable HTTP requests over an unreliable network. If you make a GET request and never get a response, just make another one” [58]. Even if the earlier request managed to be processed, the second request will not cause any problems.

3.1.2 ISTIP and VOiiLA

The Command, Control, and Intelligence (C2I) section at DRDC Valcartier is developing the following architecture building blocks for its software infrastructure [9]:

- **Intelligence Science and Technology Integration Platform (ISTIP):** an SOA platform for innovative services in support of intelligence and command and control.
- **VOiiLA:** human-computer interaction front end for the exploitation of the ISTIP services.
- **Multi-Intelligence Tools Suite (MITS):** intelligence related tools that exploit the ISTIP services and the VOiiLA components

- **Multi-Intelligence Capability Test Bed (MICTB):** hardware, instrumentation, simulators, software tools, datasets and other support elements needed to conduct testing and evaluation of multi-intelligence capabilities.

ISTIP and VOiiLA services that add value to the NEP will be used. Additionally new services that are built for the NEP will be made to conform to the ISTIP and VOiiLA architecture where possible.

3.1.3 Google Earth Plugin and Keyhole Markup Language (KML)

Google Earth provides a highly functional geographic visualization user interface, with good support for displaying tracks and overlays as a function of time under the control of a time-slider. The CAOC already uses Google Earth, and NAPPIC can export to it. Keyhole Markup Language (KML)[72] is the data exchange language used by Google Earth.

The Google Earth Plugin [29]embeds the functionality of the Google Earth application into a web page and supports an application programmer's interface (API) not available with the on-line version of Google Earth [28]. Javascript developers can use the API to create powerful Google Earth applications. The plugin API is divided into two main classes:

- A KML class containing the KML elements that run in the on-line Google Earth application. Thus all of the functionality available in the regular Google Earth application is available in the plugin: KML elements and objects such as placemarks, lines, paths, overlays, 3D models, tours and animation sequences are supported in the plugin environment. In fact a KML file which runs in the regular Google Earth application can be loaded and displayed in the plugin without alteration.
- A plugin-specific class that allows programmers to, for example, set the rate at which the clock in an animation ticks, programmatically change the position of the Google Earth camera or even modify a KML file that has already been loaded into the browser.

Extension libraries which expand the functionality of the API have also been built for developers [30]. These libraries provide additional functions which, for example, enable users to edit lines and polygons that have been drawn on the screen. Other functions perform useful mathematical operations such as calculating the distance between two points, computing a bearing from point A to point B, determining the area of a polygon drawn on the screen or determining if a point is within a polygon.

3.2 System Modeling and Automated Reasoning

To assess asset readiness, recommend new plans, estimate the severity of ripple effects, and validate re-planning options, some form of automated reasoning will be required. All automated reasoners require a knowledge base describing the real-world domain, and the rule or constraints that can be used for reasoning.

This section reviews formal structures that can be used for modeling the domain (Sections 3.2.1 through 3.2.3) and automated reasoners that can be used with those models (Sections 3.2.5 through 3.2.9).

3.2.1 Air Force Operations Knowledge Base

Air force operations are governed by a very large collection of rules and constraints. We did not find a "standard" taxonomy or ontology for these rules, but such a taxonomy should include:

- **Asset Operational Windows:** types of assets, performance constraints determined by the laws of physics and aircraft design specifications. This might include for example rules determining how much weight an aircraft can carry, or how quickly fuel is burned as a function of speed, load, and altitude, what sort of landing strip is required, or what kinds of weather are required.
- **Payload Operational Windows:** performance specifications for instruments and payloads, such as how far an aircraft can "see" with its FLIR or radar sensors, or what kinds of weapons can be carried. This includes how long it takes to remove or install a payload.
- **Asset Maintenance:** description of maintenance regimes, including how often each maintenance procedure is required, how long it takes, and who can do it.
- **Recovery from Common Failures:** list of common failures (e.g. flat tire, dead battery, landing gear not serviceable), typical time to get spare parts, time required to repair, personnel required.
- **Logistics Database:** where are spare parts, how quickly can they be transported.
- **Personnel:** descriptions of:
  - Thirteen trades, with various sub-certifications within those trades, and maintenance requirements for certifications
  - Operational windows for various tasks: how long can personnel work, how long is required for them to rest before resuming activities.
  - Locations of people, status, and how quickly can they be called up.
- **Standard Operating Procedures:** preplanned patterns of operation for aircraft, mission priority system, standard positioning of aircraft and crews for rapid deployment, standard repositioning of assets for expected call-ups.

The creation of a comprehensive air force operations knowledge base is a huge task. CAOC leaders reported that ISS spent "hundreds of millions of dollars" (see B.1) creating the knowledge base used by NAPPIC.

3.2.2 Ontologies, OWL, and Protégé

Ontologies are used to capture knowledge about some domain of interest ([36] pg 11) in terms of domain objects, their properties, and their links to other objects. The Web Ontology Language (OWL) is a standard ontology language defined by the World Wide Web Consortium (W3C) [70] that is built up from the following components:

- Classes
- Properties
- Individuals
- Restrictions

- Rules

OWL-DL is a specific sub-type of OWL that allows only those properties, restrictions, and rules that can be understood by Description Logic (DL).

Protégé [64] is a public-domain ontology editor and knowledge acquisition software tool. It includes the following standard or plug-in features:

- List-based insertion and editing of all components.
- Form-based insertion and editing of individuals.
- User-configurable visualization.
- Consistency checking using the Pellet reasoner
- DL reasoning to infer class membership of individuals
- Rule-based reasoning using Semantic Web Rule Language (SWRL) to infer properties of individuals.

There are a number of published papers describing relevant attempts to build an ontology describing the operational elements in Section 3.2.1. Frantz and Franco [24] describe using Protégé to develop an OWL ontology for Air Tasking Orders, part of which is shown in Figure 3-1. They eventually separated the ontology into four smaller ontologies (aircraft, target, mission and configurations) to make it manageable. Farrell et al [22] describe the "Cornerstone" upper ontology that describes joint missions, plans, and requests for effects. A high-level ontology suitable for describing the operational elements discussed in Section 3.2.1 was not found.

3.2.3 C2Core and UCore

Command and Control (C2) Core is a Department of Defense (DoD) information sharing initiative [8] based on the "Universal Core" (UCore) common upper ontology which is shown in Figure 3-2. The overarching goal of C2Core is to support national and coalition warfighters by improving joint interoperability at the data and information layer. It does this by publishing and evolving agreed-upon standards that exchange partners (services, combatant commands, and agencies) can use to share data more broadly, efficiently and effectively. It supports the US Department of Defense (DoD) Net Centric Data Strategy (NCDS) by enabling data to be visible, accessible, understandable, trustworthy and interoperable.

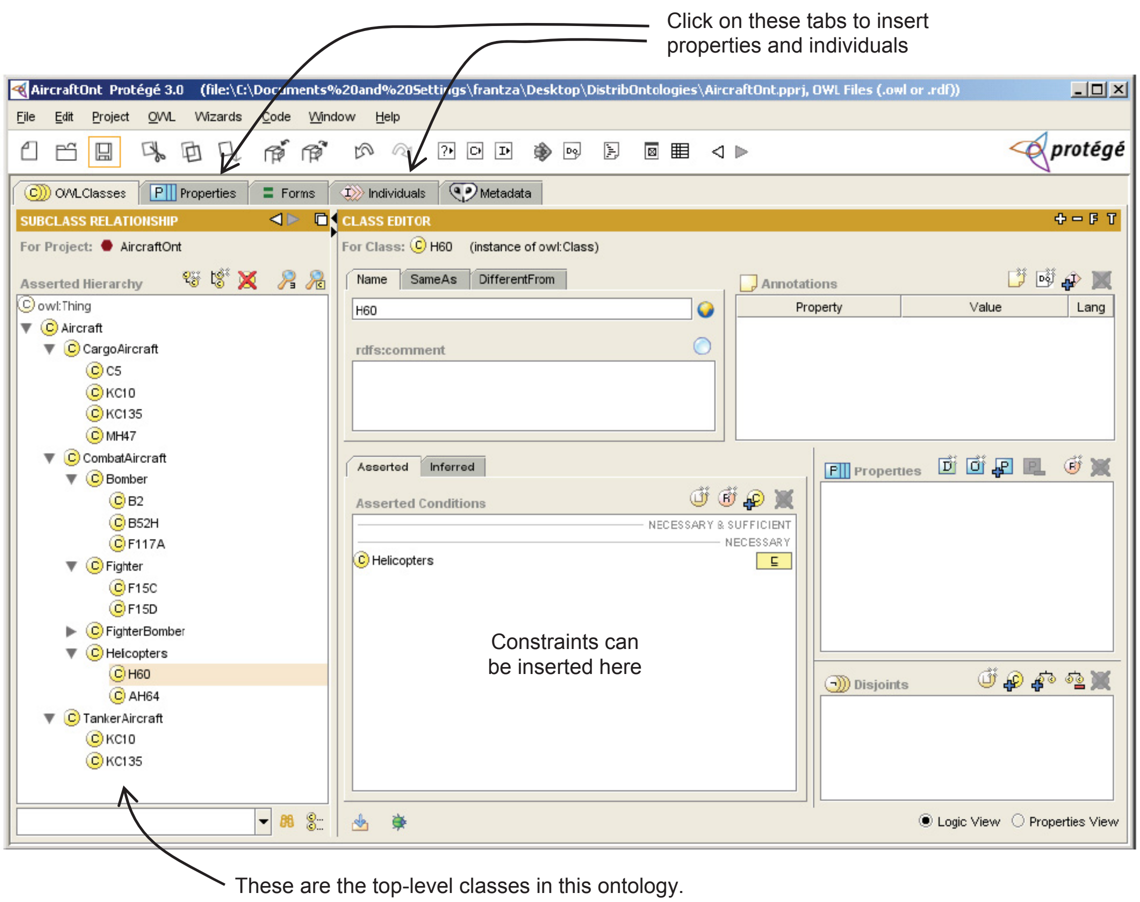


Figure 3-1 Using an Ontology to Represent Domain Knowledge

This figure shows part of a high-level ontology created by Frantz [24] to represent the air force logistics and operational assets domain. Rules can be added to represent cause-and-effect models. The ontology is displayed here in Protégé as a table, but it can also be displayed using network.

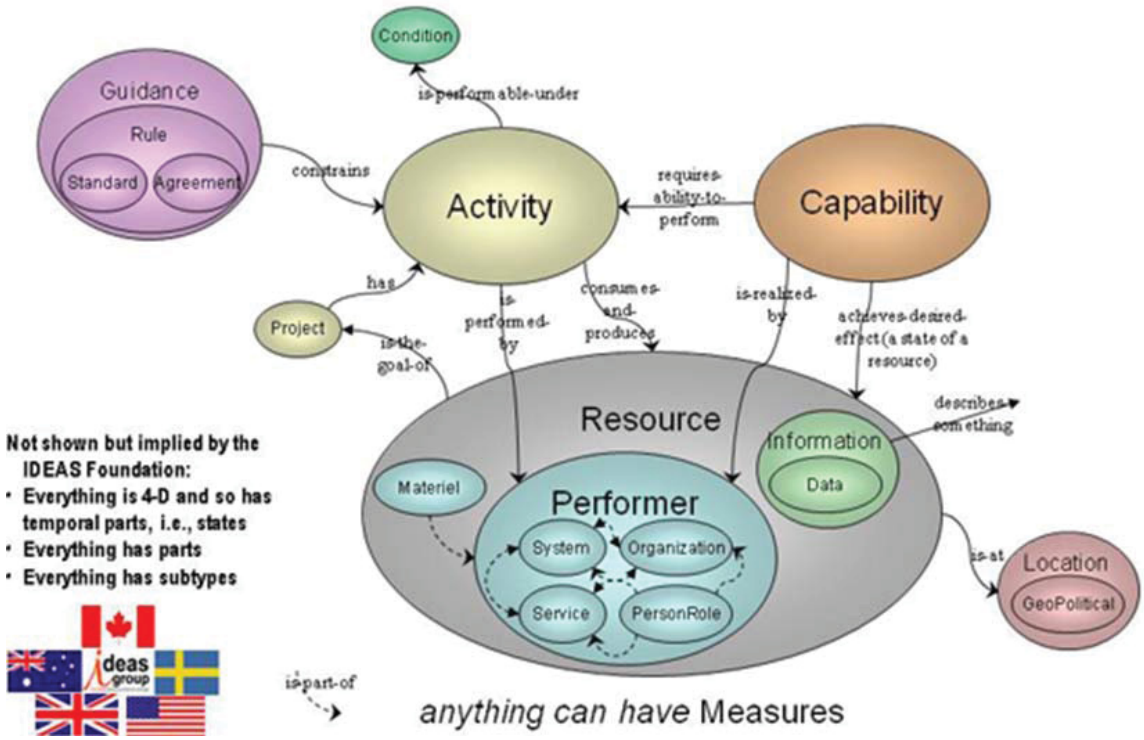


Figure 3-2 UCore Domain Model

Canada and its closest allies have collaborated to establish the UCore Conceptual Domain Model shown here (from [17]) for describing defence activities at a very high level.

C2Core consists of an ontology and an XML representation of information in that ontology. Data from C2Core is formatted and encoded into standardized messages so that distributed systems within the C2 domain can communicate with each other using a common vocabulary.

The C2Core ontology is designed to be general enough to accommodate joint, land, maritime, air, space, and cyber-space environment concerns. C2Core developers determine the most commonly shared vocabulary within these various C2 domains – general terms that "pertain to a commander's ability to organize forces, understand the situation, plan for joint operations, decide on courses of action, direct subordinate commanders, and monitor progress" [63].

Figure 3-3 illustrates how C2Core belongs to a hierarchy of ontologies descended from UCore. UCore, sometimes referred to as the "Common Upper Ontology", describes very general concepts that are the same across all supported knowledge domains.

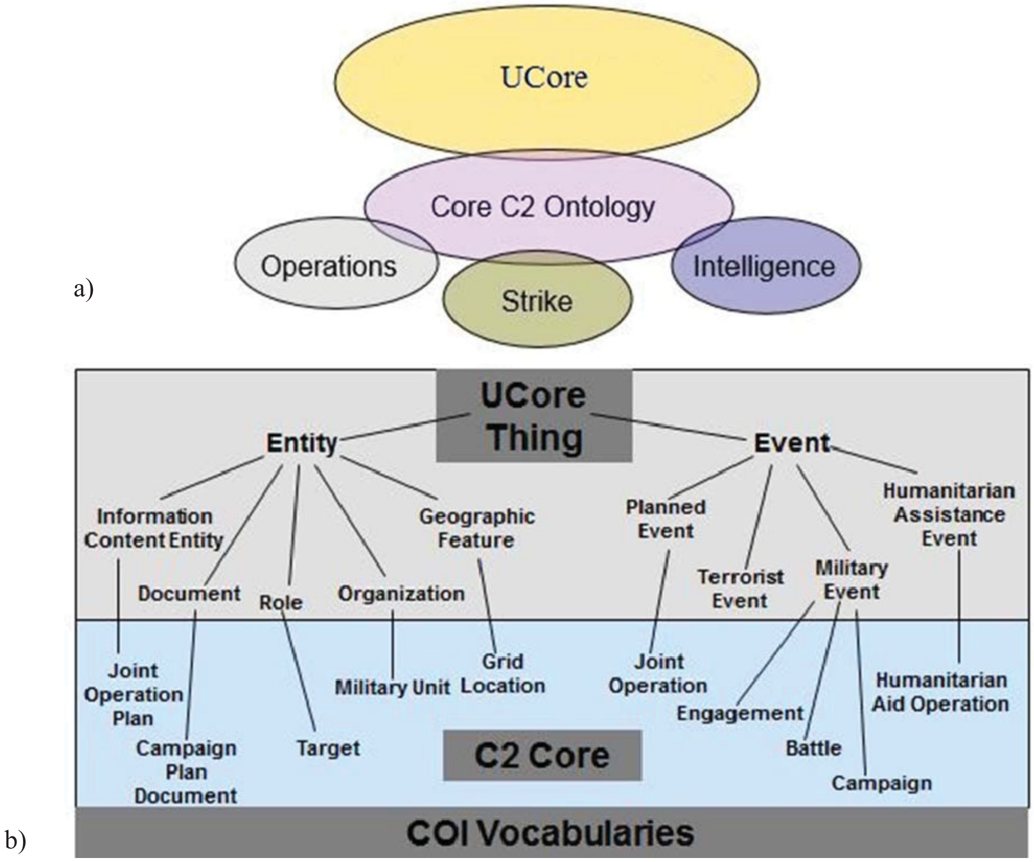


Figure 3-3 UCore and C2Core within a Hierarchy of Ontologies

C2Core is an extension of the UCore ontology, and supports vocabularies (a) such as Operations, Strike and Intelligence for C2-related Community Of Interest. C2Core classes are therefore sub-classes of UCore classes, specialized to military command and control (b).

3.2.4 Ontology Reasoners

Ontology reasoners are useful for deriving inferences from an ontology. A number of reasoners are available, including the following that were assessed by Davenport [11] for maritime domain awareness:

- Pellet 2: Tableau-based DL and Semantic Web Rule Language (SWRL) reasoning
- Jess: rule-based reasoning for SWRL
- FaCT++: LISP-based DL reasoning
- HermiT 1.2.3: Tableau-based DL reasoner
- BaseVisor: forward-chaining reasoner for OWL2-RL

Davenport concluded that only BaseVisor [69] was fast enough to have practical value as a domain awareness tool.

3.2.5 Description Logic Reasoners

Any class within a Description Logic ontology can be given necessary restrictions or existential restrictions, as described in Table 4. Whenever an individual of that class is inserted into the ontology, that individual must conform to those restrictions. DL reasoners can change the class of individuals but not their properties.

Table 4 How DL Reasoners Use Restrictions

Type of Restriction	Example Restriction	How DL Reasoners Can Use Them
Necessary	Every person with class "twin" must have at least one sibling	Used to validate the integrity of a knowledge base
Existential	Any person who shares a birthdate with exactly one sibling must have class "twin"	Used to create new facts about class membership of individuals

3.2.6 Description Logic Rule-Based Reasoners

OWL-DL supports rules that are expressed in Semantic web Rule Language (SWRL). Unlike necessary and existential restrictions, SWRL rules are able to change the properties of individuals. Here is an example of a SWRL rule:

```
airAsset(?a) ∧ airport_item(?h) ∧ payload(?c) ∧ _assetHasOnBoard(?a, ?c) ∧
 _assetHasDeclaredDestination(?a, ?h) ∧ airportCannotHandle(?h, ?c) →        (3-1)
                              _cargoProblem(?a, ?h)
```

This rule means "given any aircraft *a* with any payload *c* heading for any airport *h*, if the airport cannot handle payload *c*, then the aircraft will have a cargo problem when it lands at *h*.

Certain types of rules are forbidden within SWRL in order to maintain OWL-DL's "guarantee" of correctness. Most significantly, OWL-DL has an "open world" assumption that forbids the reasoners from recognizing default values. An earlier report ([11] Section 3.7) has discussed this problem in detail and recommended an innovative solution.

3.2.7 Non-DL Rule-Based Reasoners

Rule-based reasoners are of the form "wherever *x is true* then *do y(x)*". Most rule-based reasoners such as DROOLS [44] place few restrictions on the actions "*y(x)*" that can be triggered.

3.2.8 Case-Based Reasoners

Case-based reasoning (CBR) is a problem-solving paradigm developed in artificial intelligence (this description is based on [37] Section 3). In contrast to traditional knowledge based systems, a case-based reasoning system functions by similarity-based retrieval from a library of "cases". Each case is a self-contained example of how to solve (or not solve) a particular class of problems. A CBR system solves a problem by recalling past experiences (problems) that are similar to a current situation (problem). Each case in a case-base encodes a body of knowledge on a problem's features and on the success of the solution. The retrieved cases' solutions may be adapted to construct a solution for the current situation (problem).

Some of the advantages of CBR systems are:

- A CBR system does not rely on an explicit domain model, making knowledge authoring much easier to handle;
- Implementation of a CBR system is reduced to identifying the main features of a problem domain, a task much better defined and manageable than encoding the entire domain model;
- By applying database techniques, a CBR system is easy to scale up;
- CBR systems are incremental as they can acquire new knowledge through their life cycle (they learn from past experiences);
- People who are non-computer experts find it easy to author the cases.

The main challenges when implementing a CBR system are:

- There must be a database of representative problems that occurred in typical situations.
- Items in the database may need to be "marked up" to indicate the level of success in solving the problem.
- There must be a formal set of attributes that characterize a new problem in a way than can be compared to matching attributes in the database.

The typical CBR cycle consists of four processes:

- Retrieve the most similar case or cases to the current situation;
- Reuse the information and knowledge in past similar cases (situations) to solve the current problem;
- Revise the proposed solution or solutions from past cases;
- Retain the new parts of this experience likely to be useful for future problem solving.

Previous Case-Based research at DRDC [37] has used the jCOLIBRI framework for Case-Based reasoning [33].

3.2.9 Reasoning by Simulation

Simulation and Modeling has emerged as an important component of military decision aids, over the past decade [14, 27, 35]. For this discussion, a "simulation" solution is not concerned with recreating a virtual world, but rather with digitally reproducing realistic and variable behaviour of assets and resources.

Thus a typical simulation analysis would proceed as follows:

- Begin to loop over simulation cases
  - Choose a course of action (COA)
  - Insert realistic performance (e.g. time to re-fit, time to get approval, time to re-

deploy, realistic speed)

- Insert random events (e.g. aircraft is late departing, mechanical failure, weather) with statistical distributions that are realistic
- Model how resources might respond to unexpected events
- Calculate measures of effectiveness (MOEs) to quantify how well the desired effect was achieved for this simulation case. These MOEs could be designed to accept a "Fuzzy RFE" (see Section 4.4.2).

- Repeat the loop over many cases
- Look for correlations between the COAs and the MOEs, and recommend the COA with the best MOEs

This form of analysis has the advantage of providing insights into the robustness of a COA in the face of unexpected problems.

3.3 Visual Analytics and Sense-Making

The accepted definition of Visual Analytics is:

> Visual analytics is the science of analytical reasoning facilitated by interactive visual interfaces. ([65] pg 4).

At its core, therefore, Visual Analytics is analytical reasoning or "sense-making" (making sense of the evidence) and is thus very relevant to situation awareness, options analysis, and planning. Figure 3-4 shows how sense-making is inherently iterative: the analyst collects information, forms theories about what that information means, then seeks more information to validate or invalidate those theories, etc. The analyst has "made sense" of the data when the "meaning" of the information is successfully translated into a "story" ([18]) that can be briefed to the commanders.

The coordinated display of multiple views of information [38] is an important visual analytics strategy. Such coordinated displays provide very tight and efficient foraging loops, and also reveal patterns that are useful in sense-making.

Sense-making typically looks different for Air Domain Awareness than for planning and re-planning. In Air Domain Awareness, typical sense-making activities are:

- **ADA Foraging:** looking for anomalies in sensor data, reviewing intelligence files, tracking indications and warnings, comparing to what is normal, assembling contacts into tracks, and projecting into the future.
- **ADA Sense-Making:** predicting destinations, assessing possible motivations, rejecting unlikely explanations, creating plausible explanations, assessing whether the data is consistent with the hypothesis, creating one or more "stories" that explain the observations.

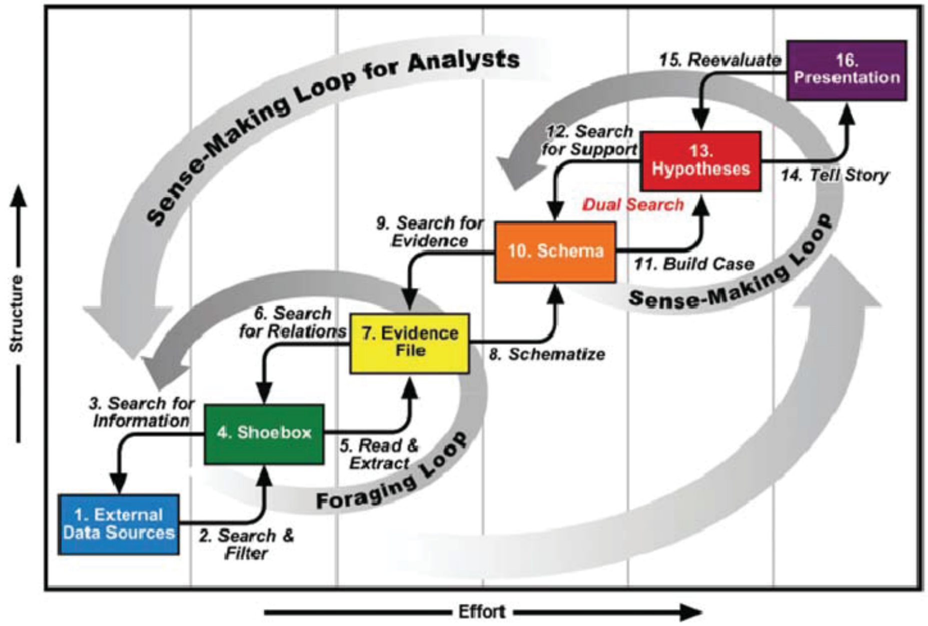


Figure 3-4 The Sense-Making Process

Situation Awareness, and thus Air Domain Awareness, may include a "foraging loop" and a "sense-making loop" in which analysts try to make sense of multiple pieces of evidence (from [65] pg 44 based on [55]), .

In planning and re-planning (NAPP), typical sense-making activities are:

- **NAPP Foraging:** creating a set of re-planning options, characterizing the ripple effects, validating the new plans, resolving conflicts.
- **NAPP Sense-Making:** assessing the "cost" of the various re-planning options, conducting a trade-off analysis, communicating the options and recommending the best course of action.

3.3.1 Interactive Gantt Charts

A Gantt Chart [25, 48] plots "tasks" along horizontal lines with time in the x-axis. In its simplest form, each mission can thus be plotted as a coloured line segment that starts and ends at the mission's start and end times. More complex Gantt charts would show the inter-dependency of missions using vertical connecting lines as illustrated in Figure 3-5.

CAOC and Wing planners routinely use Gantt Charts for mission planning. Air transport planners, for example, use one "line of planning" (i.e. one Gantt line) for each aircraft rather than for each mission, thus reducing the total number of required lines. Many RCAF Wings use FlightPro software, shown in Figure 3-6, for planning their operations. Similar Gantt charts are used in NAPPIC, but no screen-grabs are available.

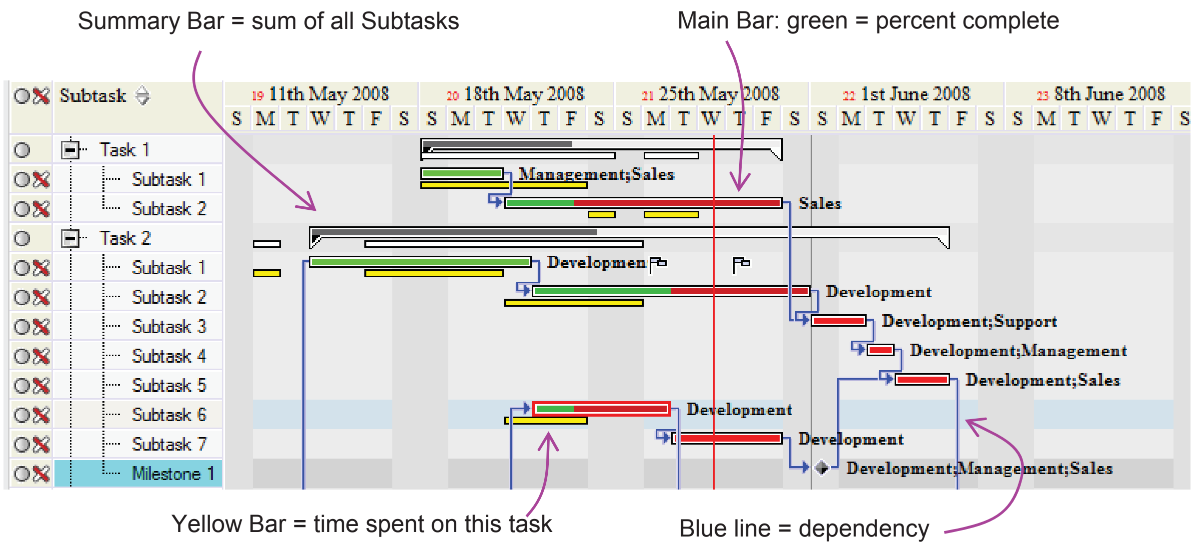


Figure 3-5 Example Gantt Chart Showing Dependencies

Gantt charts associate tasks with time periods. In this example (from [19]) the main bars represent the total work to be done in a sub-task and the yellow bars show hours spent. Blue lines show dependencies – for example Subtask 2.3 cannot start until 2.2 and 1.2 are complete. The grey bars show progress in each Task, as a sum of all the Subtasks.

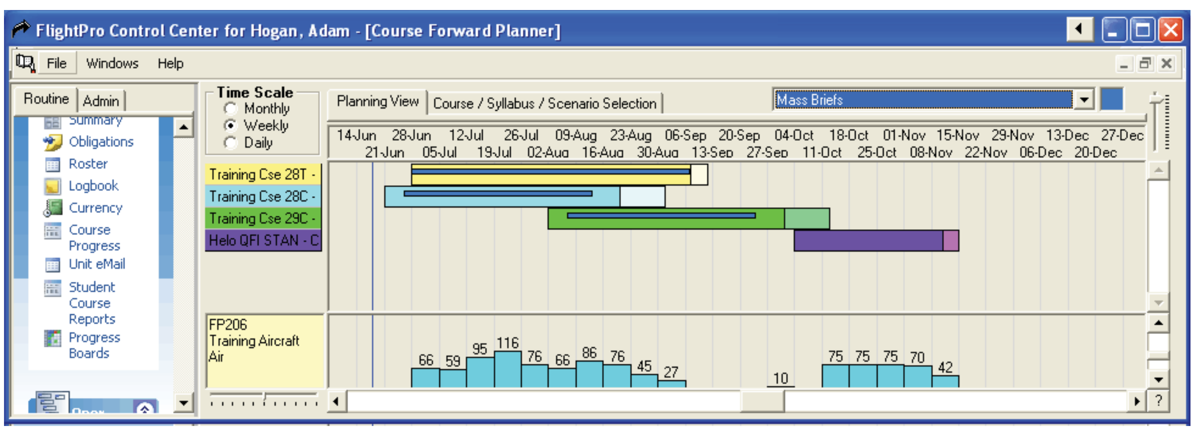


Figure 3-6 FlightPro Gantt Chart for Planning Flights

FlightPro software uses Gantt charts as shown in this screen grab (from [52]). Note the time slider along the bottom.

The following subsections propose ways to extend the Gantt diagrams to:

- Identify multiple Courses of Action (COAs),
- Assess the advantages and negative impacts of all the choices, and
- Communicate the reasoning to CAOC decision makers.

3.3.2 Visual Analytics for Evacuation Scheduling

There are few published papers that apply visual analytics to scheduling, decision-making, and transportation. A relevant paper by Andrienko *et al* [2] focuses on using visual analytics to help in rapid planning of ground-evacuation from an urban natural disaster. They describe the concept of operation of their system as follows:

> "The idea is that the automated tool produces a "draft" schedule. The planner evaluates this schedule, identifies parts needing improvement, and directs the further work of the automatic tool for revising the schedule.
>
> "Our goal has been to design and implement a tool or a combination of tools that would allow a planner to efficiently assess the acceptability of a schedule, detect possible problems, understand their reasons, and find appropriate ways to solve or alleviate them. The complex structure of the information to be analyzed necessitates the use of several coordinated displays. " ([2] page 43)

Unfortunately the visualizations focus on characterizing the efficiency of many repeated trips from the evacuation site – a task that does not overlap well with RCAF re-planning and re-tasking.

3.3.3 Google Maps Visual Analytics for Route Planning

Google Maps provides two state-of-the-art route-planning tools: one for drivers and one for transit riders. Both use the strategy of multiple coordinated views.

The "Driving Directions" tool, shown in Figure 3-7, assesses routes based on travel time, but also shows route length. It suggests the three best routes, but avoids routes that are trivially different from each other, thus giving users insight into whether the recommended route is the "obvious favourite" or one of many comparable options. Users can ask "what if I go via xyz Street?" by dragging the route as shown in Figure 3-7.

The "Google Transit" tool, shown in Figure 3-8, recommends a series of trip segments by foot, bus, train, and ferry. Routes are encoded as a set of transfers. Like Driving Directions, it offers multiple routes and indicates how good each one is, in this case by showing travel time and the number of connections. Users can no longer drag and drop to find new routes

Google Transit uses a "Transfer Patterns" algorithm that pre-calculates a table showing which routing choices (i.e. patterns of transferring between buses) are never useful when going from each zone to each other zone [6]. This makes the search space small, so that Google Transit can provide users with truly optimal routes in real time.

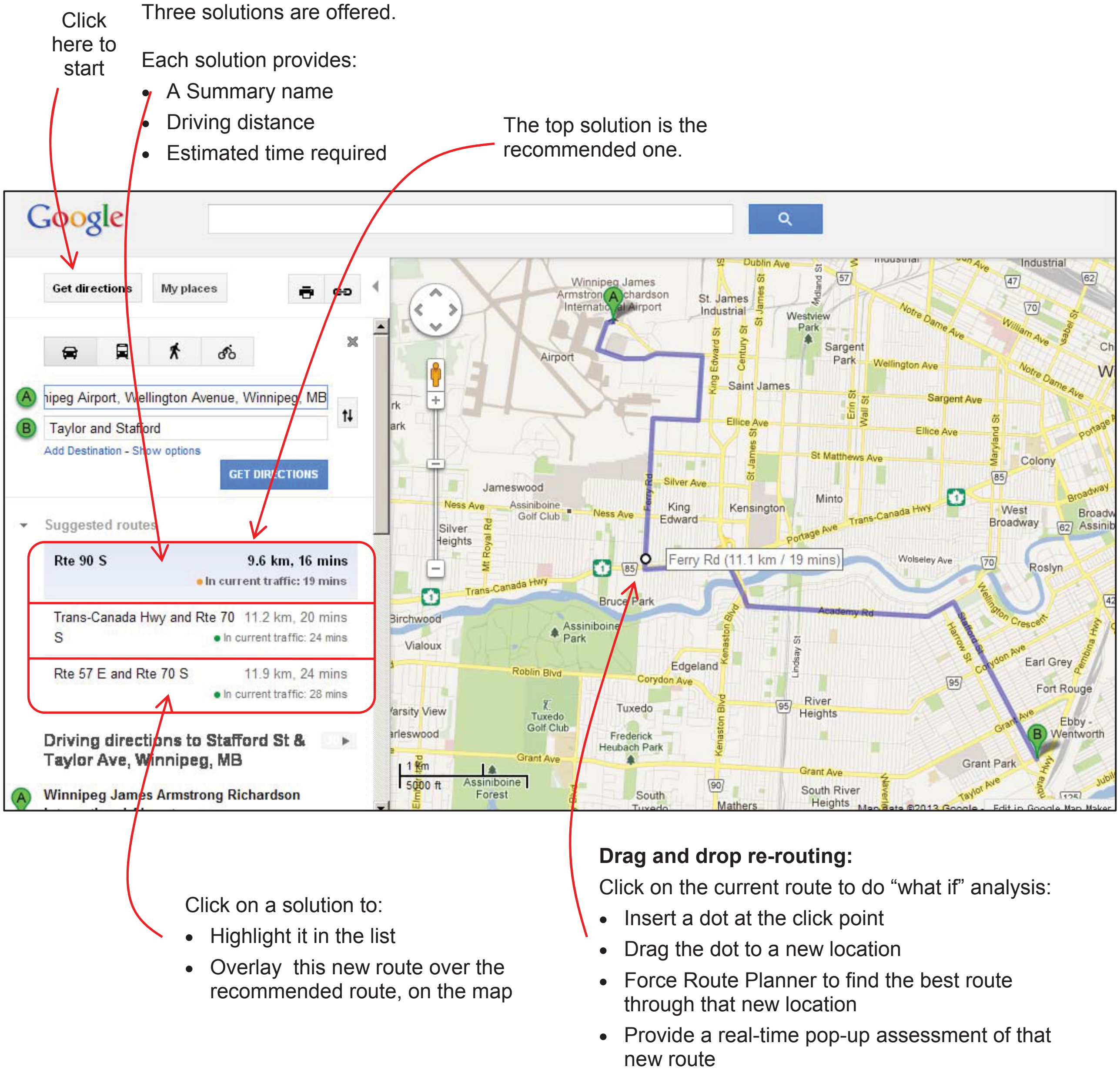


Figure 3-7 Google Driving Directions Route Planner

Clicking on "Get directions" in Google Maps [31] brings up a route-planning page with real-time "what-if" capability. The tool assesses each route based on "distance" and "time" metrics. It then lists the best three options, avoiding options that are too similar to each other. Users can explore options by dragging the route and viewing the metrics in real-time. Note the coordinated multiple views: a list of options on the left, actively linked to the map on the right.

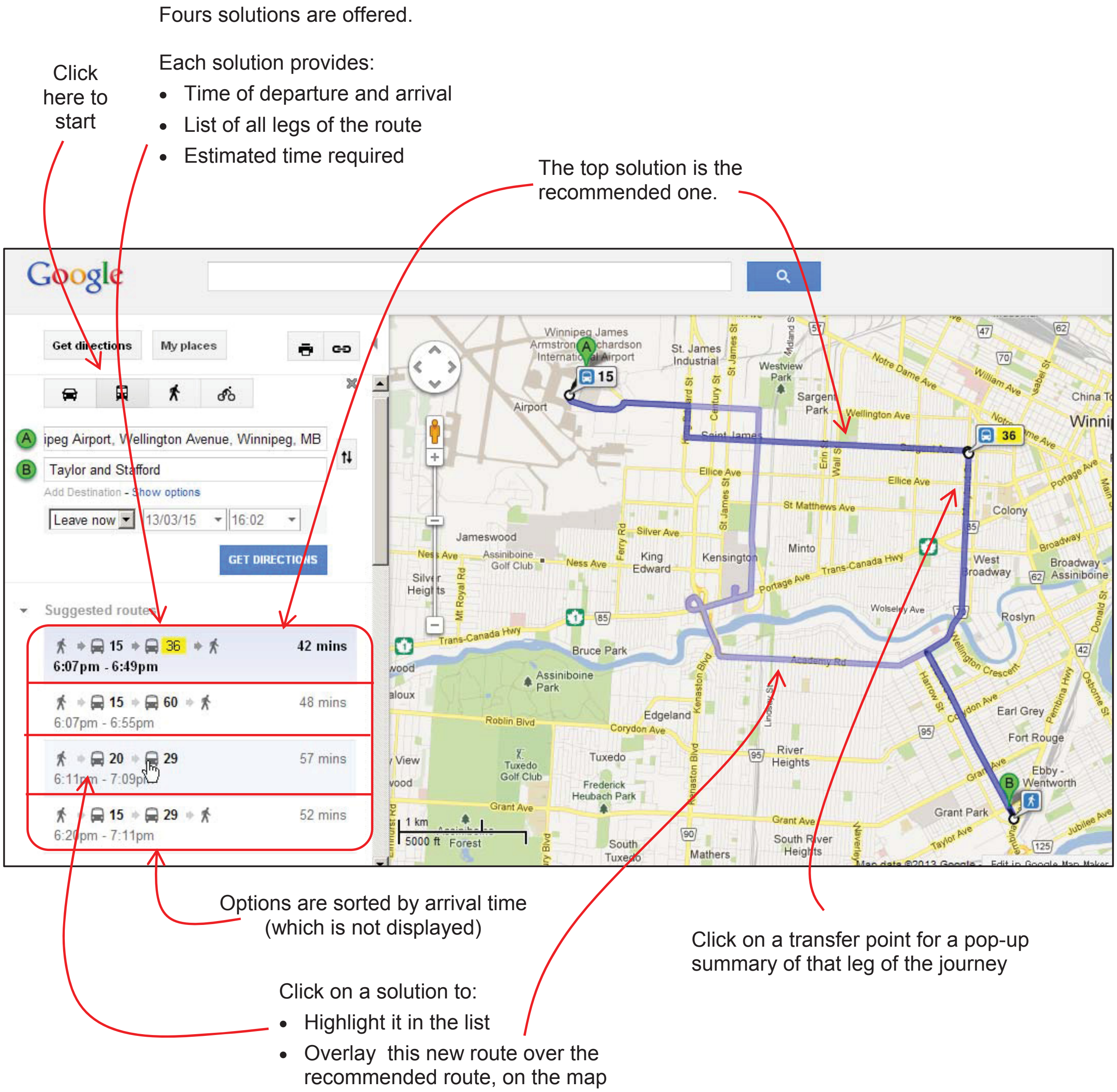


Figure 3-8 Google Transit Route Planner

Google Transit [32] is similar to Driving Directions (Figure 3-7) but does not support drag-and-drop rerouting because buses cannot be re-routed by the riders. The tool assesses each route based on travel time and the number of connections. Departure time influences the efficiency of connections, and thus becomes a significant planning parameter.

3.4 Existing Air Planning and ADA Tools

This section reviews relevant existing software tools for Air Planning and Air Domain awareness.

3.4.1 NAPPIC

The National Aerospace Planning Process Integration Capability (NAPPIC [41]) is a software suite for mission planning and visualization, created for the RCAF by Intelligence Software Solutions [40]. NAPPIC is the primary tool that currently supports the CAOC through the plan, task, execute and assess phases of the force employment processes (see Figure 3-9). NAPPIC is also used by tactical level units across Canada including Air Component Coordination Elements (ACCE), wings and squadrons.

NAPPIC resides on a classified network and interfaces with the Request for Effects (RFE) system and Airlift Dynamic Scheduling System (DSS) (unclassified network) to provide data flow through the National Aerospace Planning Process. NAPPIC does not interface with the Airshow RFE system, which is public facing and resides on the internet.

NAPPIC is built on the C2Core platform (see Section 3.2.3).

Key features of NAPPIC are[41]:

- Mission Planning:
  - Hierarchical strategic planning support with mission linkages and including AOD creation/management
  - Pairing of C2 missions to tasked missions
  - Full task management tools including mission templates, packages, copy from ABP and MAAP Briefing auto-generation

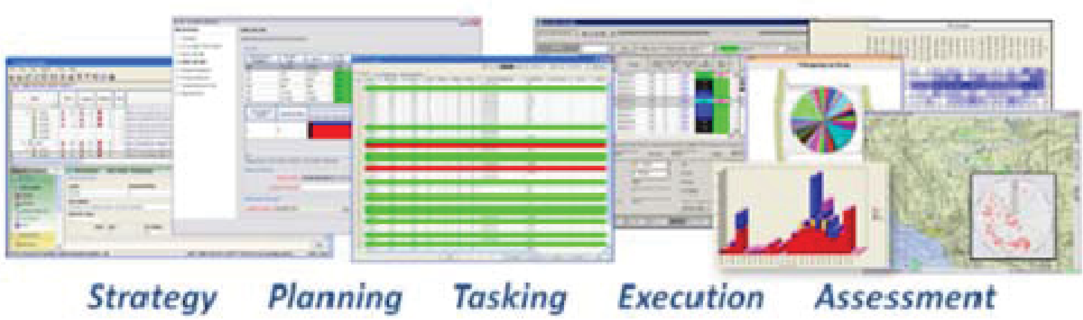


Figure 3-9 NAPPIC
The National Aerospace Planning Process Integration Capability (NAPPIC) provides advanced tools to support all phases of CAOC operations.

  - Flexible mission planning support with air location, ground alert, wide area geographic, reconnaissance, command and control and direct attack mission types.
  - Tanker planning and management tools supporting tanker pairing and refueling contracts

- Mission Visualization:
  - Execution management capability including mission state/status monitoring, mission re-planning, spins publishing etc.
  - Live display of approved mission requests from the RFE database and many-to-many pairing of mission requests to missions
  - Airspace creation, deconfliction, management and ACO generation tools
  - ATO production and publishing through a dedicated management interface

- Dynamic Information Sharing
  - Friendly Order of Battle and Enemy Order of Battle database query, visualization and management including ABP, configurations, components, resources, profiles, C2 agencies, TAC Info, operating locations and taskable units
  - Dynamic web client providing execution functionality for wings and units including management of unit and operating location status, targeting views, documents and reports
  - Import of airlift missions from DSS including new, update and delete actions
  - TBMCS interoperability including full USMTF 2000/2004 compliance
  - Intelligence/target management with MIDB 2.1 interface

3.4.2 Strategic Worldwide Integration Capability

ISS, the same company that sells NAPPIC, also sells Strategic Worldwide Integration Capability (SWIC) [42] software for Air Operations Centers. SWIC fully supports the following elements of the air tasking cycle:

- Strategy
- Targeting
- Data Management
- Airspace Management
- Mission Planning
- Tasking Order/Airspace Control Order Generation
- Execution Management
- Assessment

SWIC supports 3000 lines of task (i.e. 3000 operational air frames)

3.4.3 Acumen

The Advanced Capability for Understanding and Managing Effects Networks (ACUMEN) application assesses status, detects problem areas, and develops recommendations at all levels within a Strategic Plan from objectives to mission execution [39]. ACUMEN, like

NAPPIC, is built on the C2Core platform. ACUMEN is under consideration by the RCAF as part of the “next state” of CAOC technologies.

ACUMEN automates key operational assessment workflows including:

- Near real-time monitoring of plan status;
- Causal linkage analysis;
- Prediction of plan element achievement;
- Re-allocation analysis; and
- Report and briefing generation;

It also supports the compilation of lessons learned from past performance information to help determine the likelihood of future success.

ACUMEN was developed to answer the following questions typically posed by operational commanders and their staff:

- How am I doing on my plan?
- How well is my plan doing?
- How can the plan be improved?
- What lessons learned from executing previous plans can improve our performance on current/future conflicts?

ACUMEN integrates with a number of existing systems including:

- Integrated Warfare Planning Capability (the USAF system of record for strategy task planning),
- Joint Targeting Toolkit, and
- Theater Battle Management Core Systems.

Structured messages such as Battle Damage Assessment Reports, Mission Reports, Daily Intelligence Summaries, and Intelligence Summaries are supported. These tools and sources are supported if they are available, but not required.

Assessment products are provided via services. ACUMEN is designed to allow integration of new data sources, and is adaptable to different deployment environments. Data available via web services, databases, or structured messages may be used for automated monitoring of status. Unstructured data (PowerPoint, Excel, e-mail, imagery, video, etc.) may be associated to plan elements and used to support assessment status.

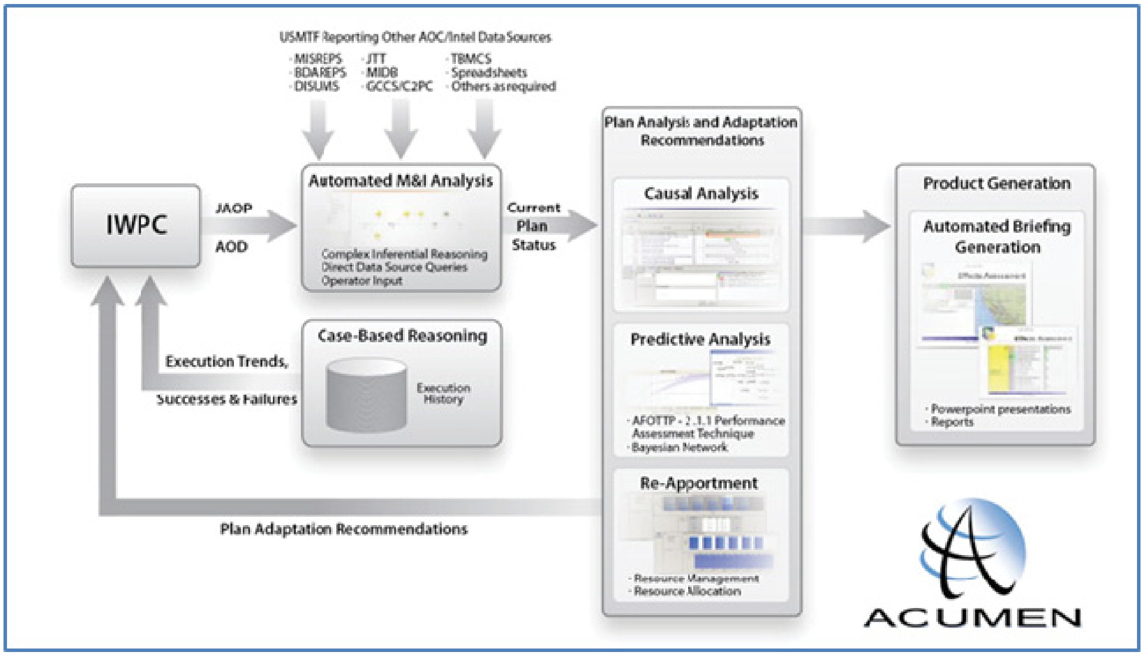


Figure 3-10 Summary of the ACUMEN Architecture

ACUMEN is a suite of tools for monitoring the success of missions, predicting potential problems, and generating mission reports.

3.4.4 Flight Pro

Flight Pro is a unit-level tool that is billed as an "Operations and Flying Training Management System" to support end-to-end planning and scheduling of a military flying squadron. It has been implemented on a classified network at a number of tactical and training RCAF squadrons, and is planned to be implemented at all RCAF squadrons in the future, as more units become support by a classified network.

Key features of FlightPro for Operations include:

- Provides real-time graphic tools and interfaces for full visibility of all activity, assets and personnel during planning, tasking, execution and reporting
- The suite facilitates flying scheduling covering conflict resolution, aircrew currency and qualification information, document management, and executive reporting facilities
- Allows for rapid re-planning

Flight Pro uses data from Theater Battle Management Core Systems (TBMCS) instead of from NAPPIC, which has caused a temporary problem in sharing Flight Pro data up from the Wings to the CAOC.

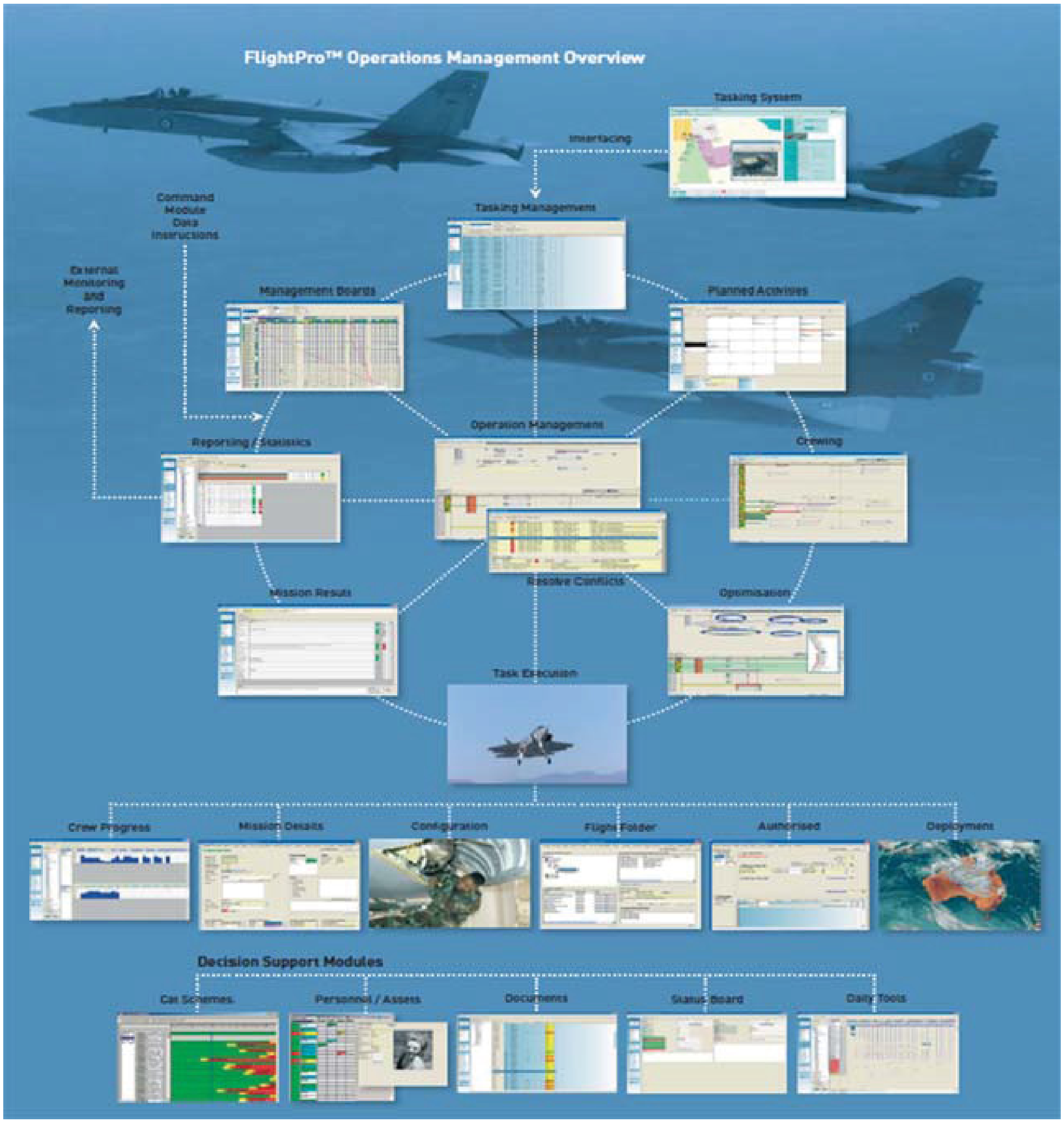


Figure 3-11 Flight Pro Operations Management Overview

Flight Pro provides comprehensive support to Wings and Squadron for scheduling missions, crew scheduling, maintenance tracking, and aircraft availability predictions.

3.4.5 Rapid Course-of-Action (COA) Analysis Tool

The Rapid Course-of-Action (COA) Analysis Tool [14, 59, 71] is a visual planning tool developed by the US Air Force Research Laboratory to allow US military transportation planners to perform COA analyses in minutes, instead of hours or days.

Leveraging existing simulation models of strategic air and sea movements (originally developed for long term planning), RCAT automatically performs calculations in the background while transportation planners sketch out alternative COAs. The model is invoked through simple user gestures as COAs are defined (e.g. drawing routes) and responses are provided within the user's decision action cycle (seconds). RCAT provides visibility into the model's assumptions and planning factors so the user can better understand and work with the model. Finally, COA summary tables are automatically built for dynamic presentations to leadership where trade-offs on alternatives can be made in real time, replacing static PowerPoint presentations.

RCAT provides more precision in early planning resulting in less re-planning through execution and more efficient use of mobility resources (planes, ships, fuel, crews, etc.).

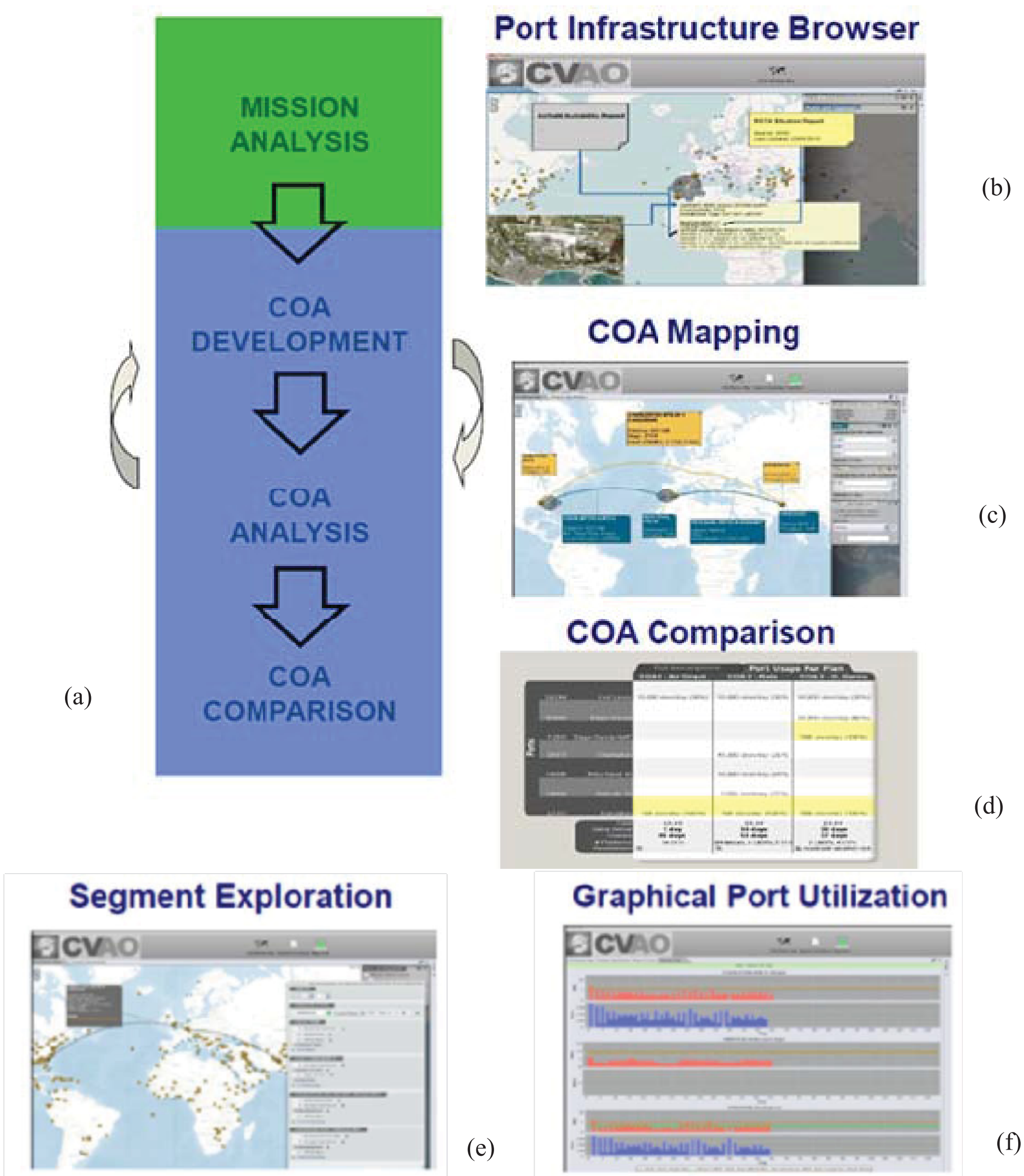


Figure 3-12 RCAT Core Elements
RCAT provides an integrated digital workspace for Airlift course-of-action analysis and what-if planning.

3.4.6 Command and Control Personal Computer (C2PC)

One of the primary ADA tools used in the AOC to provide real-time visual situational awareness of airborne aircraft movements is the Command and Control Personal Computer (C2PC) software application developed by Northrop Grumman. The AOC dedicates one of its four large situational awareness screens to C2PC at all times.

C2PC displays a Common Operating Picture (COP) from a Global Command and Control System (GCCS) based server or tactical data from other C2PC workstations on a classified network. Users can view and edit the COP, apply overlays, display imagery, or send and receive tactical messages to gain overall situational awareness.

Initially developed for the U.S. Marine Corps, the C2PC is now fielded by Defense Information Systems Agency, U.S. Navy, U.S. Coast, Guard, U.S. Air Force, U.S. Army and the RCAF.

Key features of C2PC are:

- Full COP track database add, edit, delete capabilities, plus manual and auto de-clutter
- Integrated messaging support for USMTF
- Simultaneous display of multiple independent map windows
- Multiple mapping projections
- Full mapping data support
- Full overlay editor with active alerts
- Track and overlay web services support
- Support for FAA and NAVCAN supplied air tracks

Figure 3-13 C2PC
An important feature of C2PC is its ability to run on a laptop as shown here. Overlay options are provided down the left side of the screen. The sample "situational awareness" display shows an aerospace mission route and airspace restrictions layered onto an air navigation map.

3.4.7 Traffic Situation Display and Remote Work Station

The AOC also uses radar data from the FAA's Traffic Situation Display (TSD) web service [10] and Automatic Dependent Surveillance – Broadcast (ADS-B) data from civilian websites [23] to display the locations of commercial air traffic. The military Remote Work Station (RWS) software can be used to view and analyse isolated tracks.

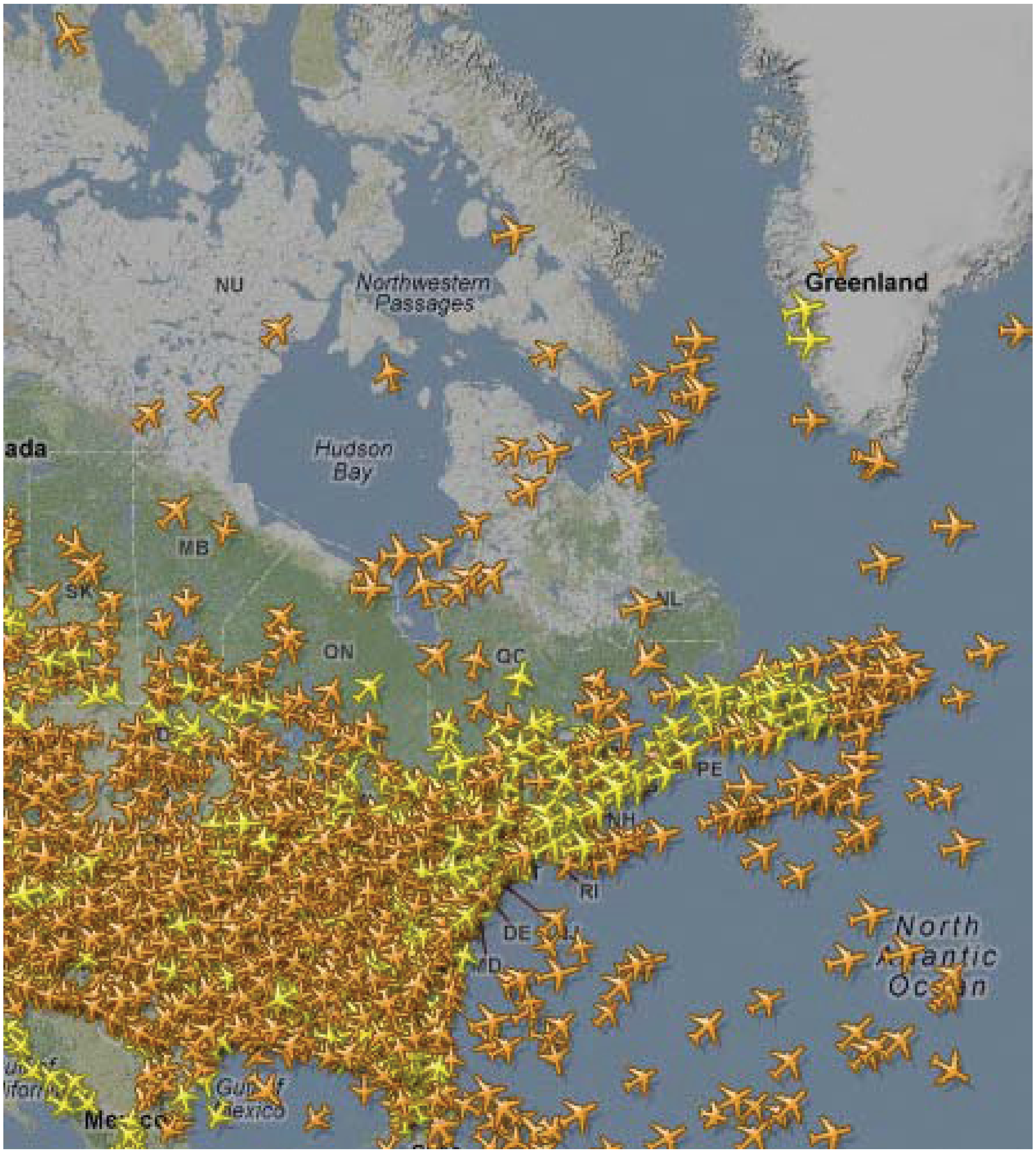


Figure 3-14 Tracking Commercial Flights with TSD and ADS-B
Flight Radar 24 [23] collects data on commercial flights from ADS-B (plotted in orange) and from the FAA's TSD web service (plotted in yellow) and plots them on Google Earth.

3.4.8 Command and Control Rapid Prototyping Continuum (C2RPC)

Command and Control Rapid Prototype Continuum (C2RPC) is a program that has been developed by the U.S. Navy to improve its situational awareness - “to make the fleet more adaptive and agile to changing mission needs, adversary tactics and threats” [53]. An important motivation was to “maintain operations during disconnected, interrupted and limited communications conditions while supporting centralized direction and de-centralized execution” [53].

C2RPC is a prototype that has been deployed to the Commander of the U.S. Pacific Fleet for evaluation and it “explores whether a distributed enterprise based on service-oriented architecture, shared plans/tasks data model and distributed data services can be implemented to provide effective support to C2 operations” [53].

C2RPC displays a geographic view of the Navy’s assets and automatically collects and displays operational and live information from the fleet. It provides drill-down capability using a “Halo Common Operating Picture” or “Halo COP” as illustrated in Figure 3-15. The Halo COP has the following standard icons:

- **Platform icon:** the ship’s identity, with drill down to get details about the platform
- **Task icon:** recent, current and future missions and tasks of the ship
- **Network operating icon:** the status of the ship’s networks and communications
- **Mission readiness icon:** the ship’s readiness to support specific mission requirements based on expert rules and other info
- **Unit readiness:** the ship’s current combat rating and its readiness for specific types of operation such as anti-aircraft or anti-submarine
- **Ship equipment reports:** status about ship equipment such as communications hardware, sensors, weapons.

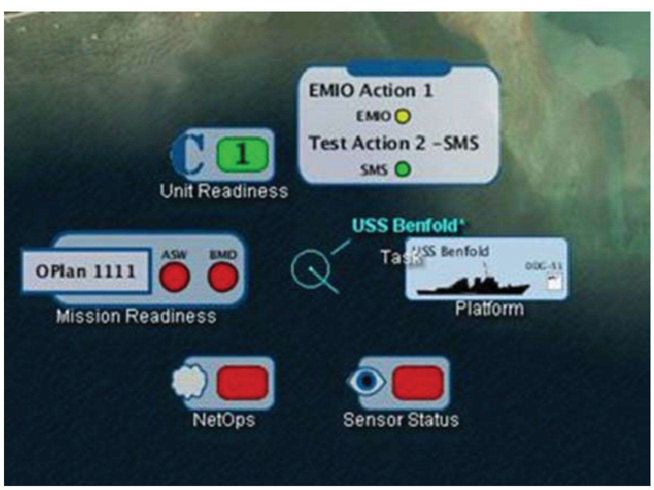


Figure 3-15 C2RPC Halo COP

When a user hovers the mouse over a platform, a halo of buttons or icons, which the developers refer to as a halo COP (common operational picture), appears.

C2RPC enables a user to find vessels in the vicinity of an event, for example, and determine which of these vessels are equipped to handle the problem. Using C2RPC's planning tools, new missions can be created, platforms can be assigned to missions and given particular tasks, and information about missions can be updated. A good introduction to C2RPC is available from on-line videos [45, 67].

C2RPC is a web application that uses Service Oriented Architecture (SOA). All that is required to run C2RPC is a standard web browser. The actual application – a set of web services – is hosted on web servers at the Space and Naval Warfare Systems Command Systems Center Pacific in San Diego [62]. The software provides a software development kit that allows third party development [62].

C2RPC uses a number of familiar technologies. Supported mapping services include Google Earth (it is not clear whether the stand-alone program or the Google earth plugin is used) and NASA World Wind [49]. Ozone Widget Framework (OWF) was also used to build C2RPC [54]. OWF is an open-source tool for organizing and displaying widgets (i.e. distributed web applications running inside an iframe) within a user's browser. Some of the C2RPC diagrams show SOAP interfaces.

3.4.9 Work-Centered Interface Distributed Environment (WIDE)

The Work-Centered Interface Distributed Environment (WIDE) is a technology demonstration program sponsored by the Air Force Research Laboratory (AFRL), focused on rapid rescheduling for Air Mobility Command and Control [59-60]. The program was undertaken with the following design goals:

- Provide an automated planner to assist users in solving complicated multiple-mission rescheduling problems taking into account critical planning factors such as airfield capacity (maximum on-ground constraints), crew-duty-day, airfield operating hours, diplomatic clearances, and minimum ground times.
- Display the solutions offered by WIDE clearly so that it is readily apparent readily apparent what missions have been rescheduled in what ways, what constraint violations have been corrected as a result of the rescheduling, and what constraint violations still remain.
- Allow users to tweak the planning constraints, for example by designating some constraints as unimportant and others as inflexible.
- Automatically calculate and offer to the users multiple possible solutions to increase the chances of finding a truly desirable solution.

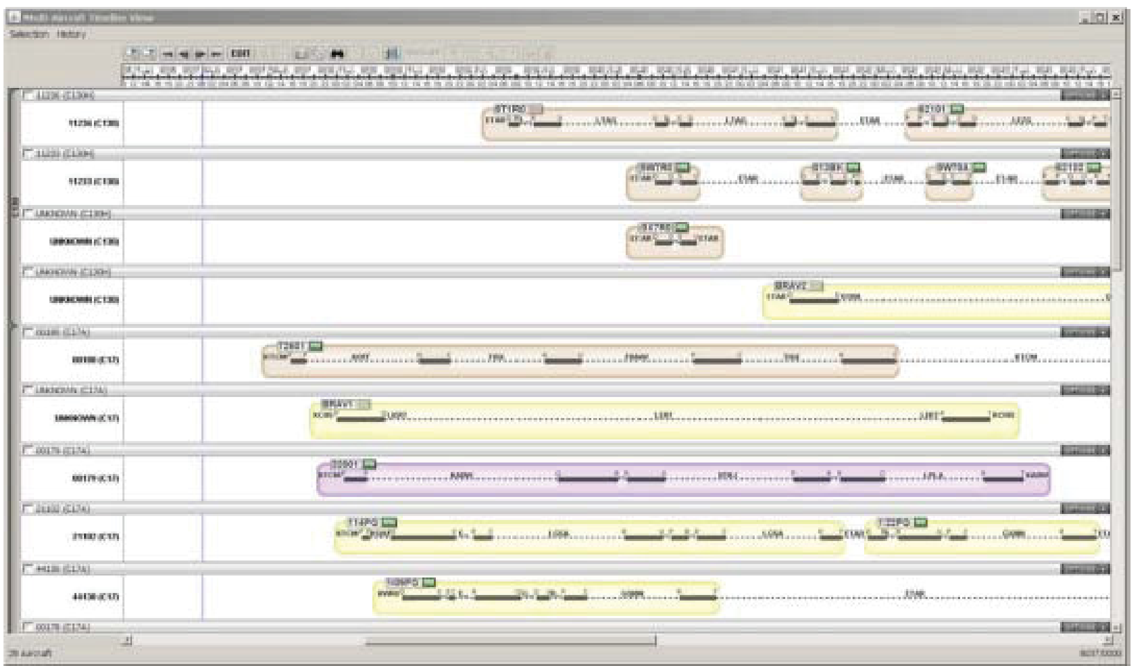


Figure 3-16 WIDE's Multi-Aircraft Timeline View

WIDE relies heavily on Gantt chart views. In this example, each Gantt chart shows one aircraft ("tail number") with annotations indicating the type of mission, planned time for each sortie, airport identifier, and necessary ground activity. Image is from [60].

WIDE's primary visualization tool is a set of linked Gantt chart such as the one shown in Figure 3-16. Available charts include multi-aircraft timeline, multi-airfield view, and a "compact timeline" which focuses on missions.

Of particular interest is WIDE's support for dynamic re-scheduling in response to NFEs and exogenous events using a hands-on Gantt chart. Planners can modify a mission segment and then ask rule-checking software to inform them if this new arrangement conforms to planning constraints.

During trials of WIDE, AFRL observed that even with the new interfaces, the search for a good new plan is arduous, and there is no way of knowing how close to optimal the new plan is because this is a very complex planning domain. They therefore developed optimization software called "Distributed World-Wide Aeronautical Planner" or "DWARP." They characterized the DWARP problem space as follows:

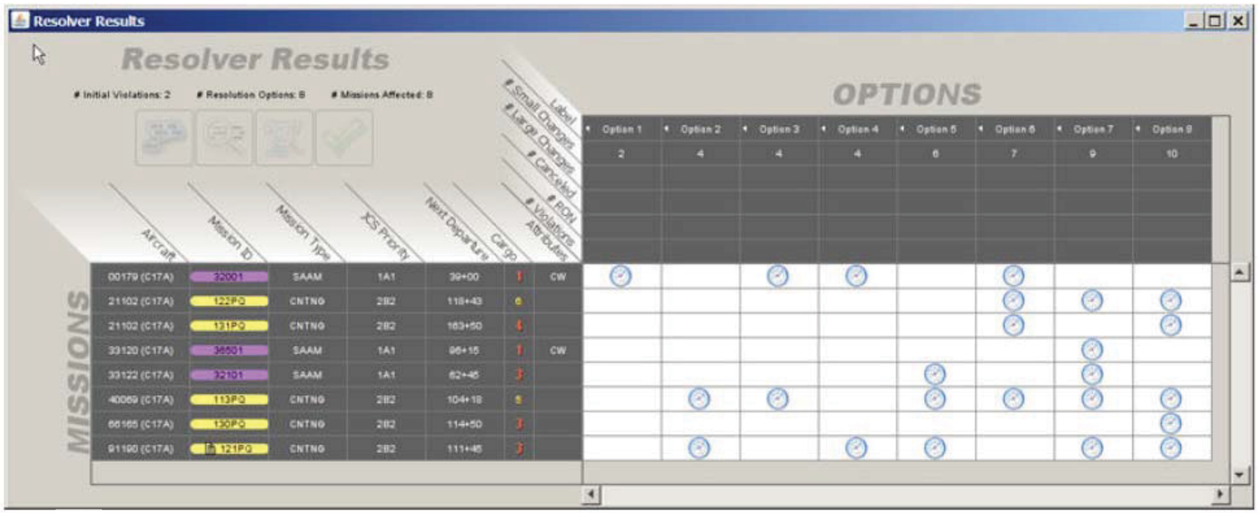
- "We are searching for solutions in a high-dimensional space.

  "We operate in an environment with missing critical information. The information about relative priorities of air missions and their cargo or passengers is generally not available in GDSS, although the user may have other sources for this information.
- "The user is the authority, knowing more about each individual problem element than the system. While users may not be able to optimally solve the problem, they can evaluate potential solutions, and can identify problems with them.
- "Schedules will not be executed precisely according to plan. Environmental factors and maintenance issues, among other factors, will perturb the plans. So just because a plan (a set of mission schedules) is legal doesn't mean it is a good plan–robustness in the face of further perturbations is a factor.
- "As a rule, re-planning decisions are not time-critical, at least not in the sense that solutions need to be found in seconds or small numbers of minutes. Taking an hour or even two to find and implement a re-planning solution is generally acceptable. This, of course, depends on the problem–there are cases when decisions need to be made quickly.
- "Thrashing (constantly changing solutions) is very bad. Re-planning missions takes coordination between multiple parties–air crews, ground crews, flight managers, and DIPS planners are just some of the people that may have to act on changes to mission plans.
- "Our rescheduling problems generally allow for multiple solutions. There are multiple measures of goodness for a plan. The user community has no consensus on a single scoring function that accurately reflects their preference for one solution." [59-60]

DWARP is designed to generate multiple possible solutions to each re-planning problem as shown in Figure 3-17. There are two characteristics of the problem space that make this necessary:

- There is no globally agreed upon scoring function, so there may be multiple solutions worthy of the user's time.
- There are often unrepresented critical information items such as high priority cargo, or an impending airfield closure, that only the user may understand and appreciate.
- This additional information can be used by the operator to further distinguish between

possible solutions.



(a)

(b)

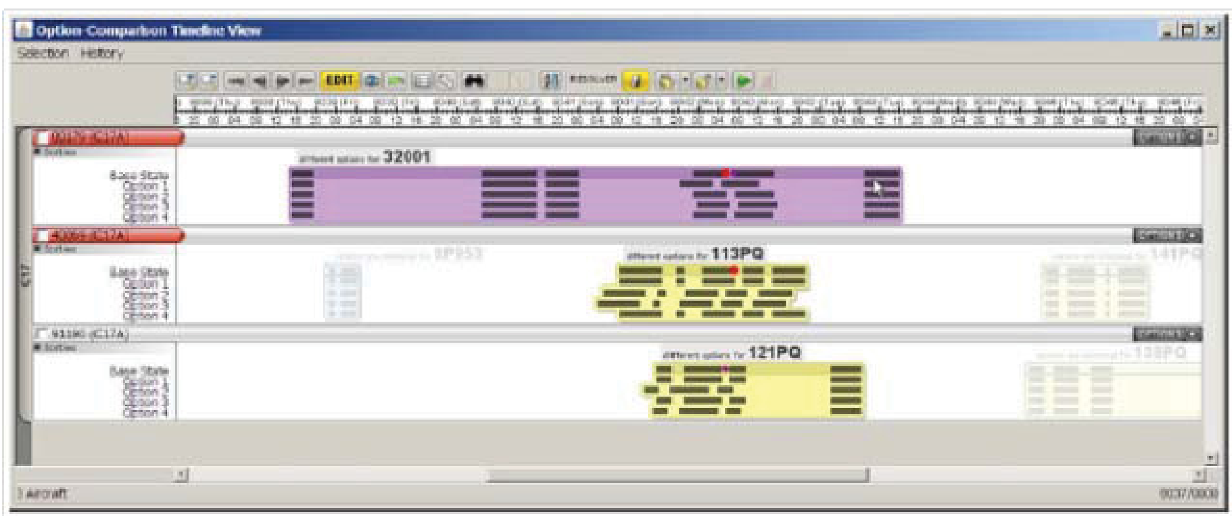


Figure 3-17 WIDE's Support for Options Analysis

This WIDE user interface does a trade-off between options under consideration. In the Resolver (a), each option occupies one column (there are 8 in this example) and the affected missions each occupy one row. As this is an airlift application, the missions are characterized by their cargo, the mission type, and the mission priority. Special mission attributes (e.g. distinguished visitor on-board) can be marked in code in the "attributes" column. The clock items indicate that at least one sortie in the mission was changed by less than 24 hours, and users can mouse-over the clocks to get more details. The Option Comparison Timeline View (b) the options are re-displayed as a series of timelines. Image is from [60].

4 Potential Innovations

This section develops technology solutions in response to the deficiencies summarized in Section 2, focusing on innovative command and control solutions for air domain awareness, options analysis, and information visualization. In accordance with the SOW [57], the discussion is broken down into two topics:

- **Solutions for Air Domain Awareness (Task 1):** Section 4.1 presents potential innovations to help the AOC achieve better operational air domain awareness and situation awareness as discussed in Section 1.1.3. Section 4.2 presents potential innovations for better Total Air Resource Management through better awareness of long-term patterns of activity.
- **Solutions for Resource Visibility and Decision Support (Task 2):** Sections 4.3 and 4.4 present potential innovations to support resource visibility, resource management, and rapid re-planning (i.e. re-group and re-task) within the CAOC.

Not surprisingly, these topics are somewhat intertwined, particularly when addressing future operations. For example Air Domain Awareness of future situations is an essential ingredient for course of action analysis. Similarly resource visibility created during the planning process may be helpful to ADA in understanding the meaning of an emerging situation. It is therefore appropriate and convenient that the proposed innovations share similar visualization strategies.

Table 5 acts as an index to the potential innovations discussed in Sections 4.1 through 4.4. For each innovation, it marks the expected relevance for ADA and NAPP, and indicates how high a priority this will be for the NEP based on direction given by the Scientific Authority. Not all of the listed innovations will be implemented in the NEP prototype.

Table 5 Priority of Potential Innovations

Ref. Num.	Brief Description	ADA Value	NAPP Value	Priority
4.1.1	Sensor coverage, as a function of time, superimposed on the Map View	●	●	1
4.1.2	Surveillance gap analysis	◖		3
4.1.3	Weather forecast animation superimposed on the map view	●	◖	1
4.1.4	Awareness around vital points	●	●	1
4.1.5	Automated You-Tube Briefing	●		not prioritized
4.2.1	Heat map visualization of annual RCAF patterns	◖	●	1
4.2.2	Topical visualization of annual RCAF patterns	◖	●	1
4.3.1	Use of Icons, "Halo COP," and Stoplights at CF Bases to represent readiness	●	●	1
4.3.2	Dashboard display of asset, personnel, and logistics readiness	●	●	not prioritized
4.3.3	Air Asset Awareness (Magnets Grid)	◖	●	1
4.3.4	Mission hockey cards, including dynamic cards, and "Play Diagrams" to iconify missions	●	●	2
4.3.5	Mission hockey card browser	●	◖	1
4.4.1	Visualization of hierarchical Gantt chart including inserting of an NFE or unexpected event.	◖	●	1
4.4.2 4.4.3 4.4.4	Assessing the Quality of Plans, including defining a fuzzy RFE, quantifying the costs of new plans, comparing plans		●	1
4.4.5	Re-Planner tool		●	1

4.1 Air Domain and Situation Awareness Innovations

This section proposes, for discussion, a number of innovative advanced decision support technology concepts for Air Domain Awareness. Sections 4.1.1 through 4.2.1 describe innovations that provide awareness of elements that are external to the RCAF, such as surveillance radars, weather, and commercial air traffic.

4.1.1 Sensor Coverage Awareness

Without sensor coverage awareness, an analyst has poor knowledge of the limits of Air Domain Awareness – he or she does not know whether the map is blank because there are no aircraft, or because there was no coverage.

Figure 4-1shows an innovative visualization of sensor coverage based on Kraak ([46]) and akin to Oculus's "GeoTime" visual analytics [56]. In this visualization, the spatial position of an aircraft of interest is represented by a "world line" [20] in which the [x, y] position represents the longitude and latitude of the aircraft, and the [z] position represents the time. In this visual space, a brief radar illumination of a zone appears as a flat surface; ongoing illumination appears as a volume; and radar from a moving platform appears as a wide ribbon in space and time. If the track of an aircraft pierces the plane, volume, or ribbon, then that aircraft should be detected. Rendering might get complicated at the edges of coverage, where large targets would still be detected, but small targets would normally be missed.

Because the vertical dimension represents time, moving the Google time-slider will cause the displayed volumes and aircraft tracks to slide up or down. An analyst could slide the "now" plane up to the top of the display to see only past events, or slide it down to ground level to see only future events.

A visual analytics solution could also provide "what if" analysis of the coverage gaps, such as:

- Determine where an undetected intruder might be, assuming he has a given radar cross section, has flown in a straight line at known speed, and has not been detected, The answer would generally be rendered as a ribbon with variable thickness and width. Part of the visual analytics solution would be to provide tools for interpreting that ribbon.
- Visualize the planned future actions of taskable sensors, based in a visual depiction of the coverage, and coverage gaps, as a function of time.

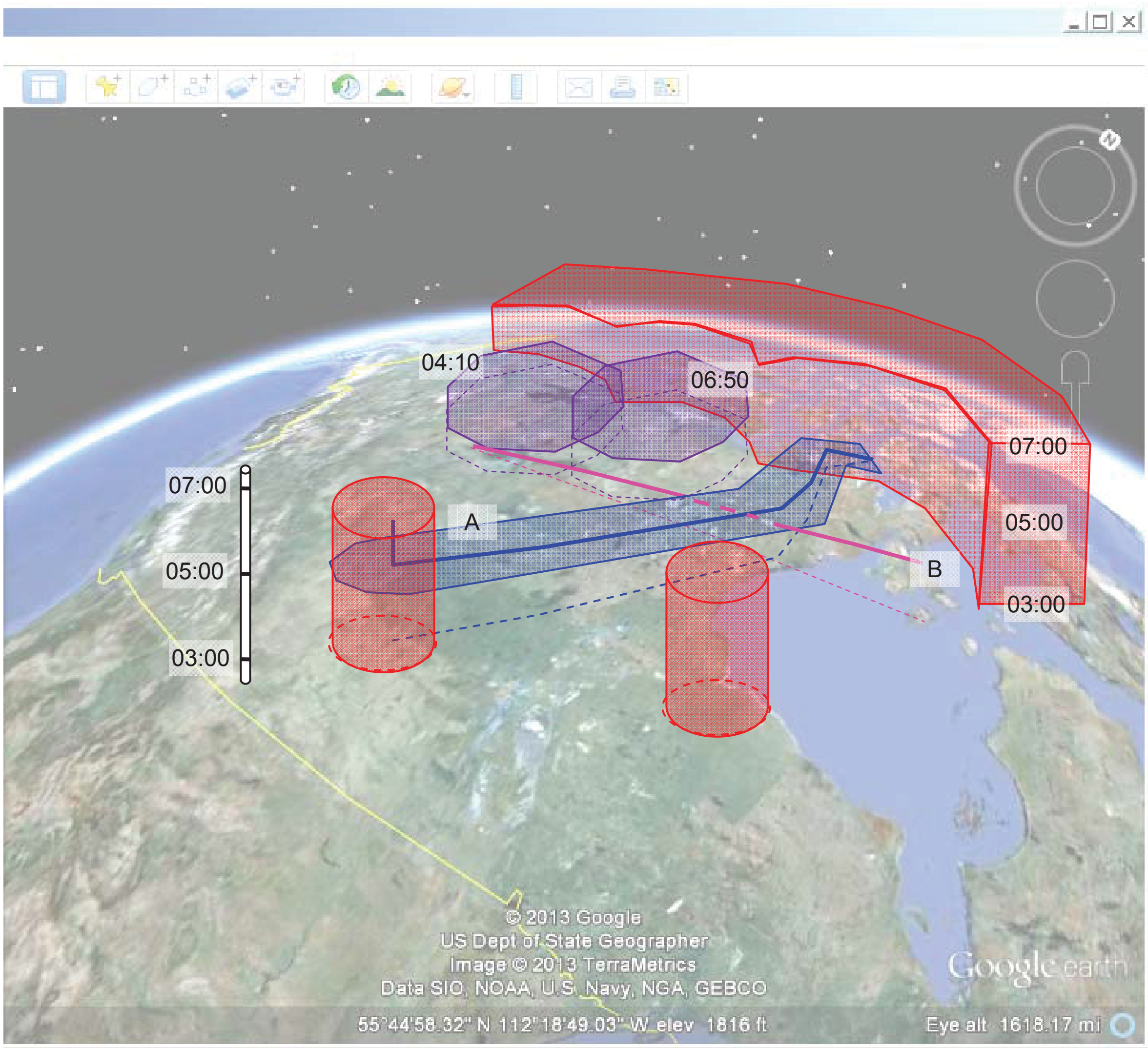


Figure 4-1 Visualization of Sensor Coverage

Sensor coverage over Canadian airspace is time-dependent, and hence may be best-visualized using both time and space. One rigorous solution is to use the vertical dimension to represent time (not altitude) as sketched here, and provide a rich three-dimensional rendering of the aircraft tracks and sensor swaths. Fast-flying aircraft have 3D world-lines with gradual slopes, and hence can more easily avoid intermittent sensor illumination. Fixed radars such as the North Warning line, Churchill, and Cold Lake cover semi-transparent volumes in space-time. In this sketch, an RCAF UAV, shown as blue line “A”, flies from the Arctic to Cold Lake with its surveillance radar on, and then lands. An unfriendly aircraft “B” departs from the Yukon and heads east without being seen by the periodic sensors shown in purple. The 3D view reveals, however, that aircraft B came within range of the radar for aircraft A.

4.1.2 Surveillance Gap Analysis

In some cases, sensor coverage may be intermittent or rare, as illustrated for example by the radar circles that occur at times "4:10" and "6:50" in Figure 4-1. When coverage is intermittent, a simple coverage map may show good geographic coverage and good temporal coverage, while hiding important gaps.

Apparently there is no effective tool for identifying such surveillance gaps, but the space-time view in Figure 4-1 might be a good starting point for an innovative new solution. Possible solutions include:

- Train an analyst to rotate and zoom the space-time view and thus detect coverage gaps. Provide the analyst with a 3D gap-marking device that can be exported from the space-time visualization into a textual description of the gap.
- Develop an algorithm to search for geodesic coverage gaps and automatically mark them. Geodesic gaps are of interest because a target aircraft with no knowledge of the sensor fields will normally follow a track that is a geodesic.

4.1.3 Weather Visualization

Show time-slider controlled animations of the observed weather in the recent past, and the expected weather in the future. Overlay these "recognized weather picture" graphics over the Geographic View of the Recognized Air Picture (RAP). Include day-night visualization, which is already built into Google Earth.

Note that this will only be worth exploring if it promises to achieve a shift from text-based weather awareness to image-based awareness.

4.1.4 Risk Rings for Awareness around Vital Points

Air Domain Awareness includes awareness of designated vital points on the ground or at sea. It is the job of the AOC to be aware of any salient threats to those vital points so that the commander can scramble a response if required.

Currently, the AOC can display "threat rings" at a pre-determined distance from the vital points. When a Track of Interest (TOI) crosses a threat ring, it may indicate an increased level of danger.

Figure 4-2 introduces the concept of a "Risk Ring," so-named because it discounts a threat if there is a mitigation in place for that threat. Thus for example a hijacked airliner represents less of a risk if it has a pair of CF-18s on its tail.

The Risk Ring answers the question "if we responded immediately, how soon could our assets engage this TOI?" or equivalently, "where that the TOI go with impunity?" The shape of a Risk Ring thus takes into account the speed and location of the TOI, the current locations, readiness, and capability of RCAF interceptors, and the coverage of any ground defensive installations. A countdown clock next to each Vital Point can also indicate how quickly a decision to launch must be made, as shown in the Figure.

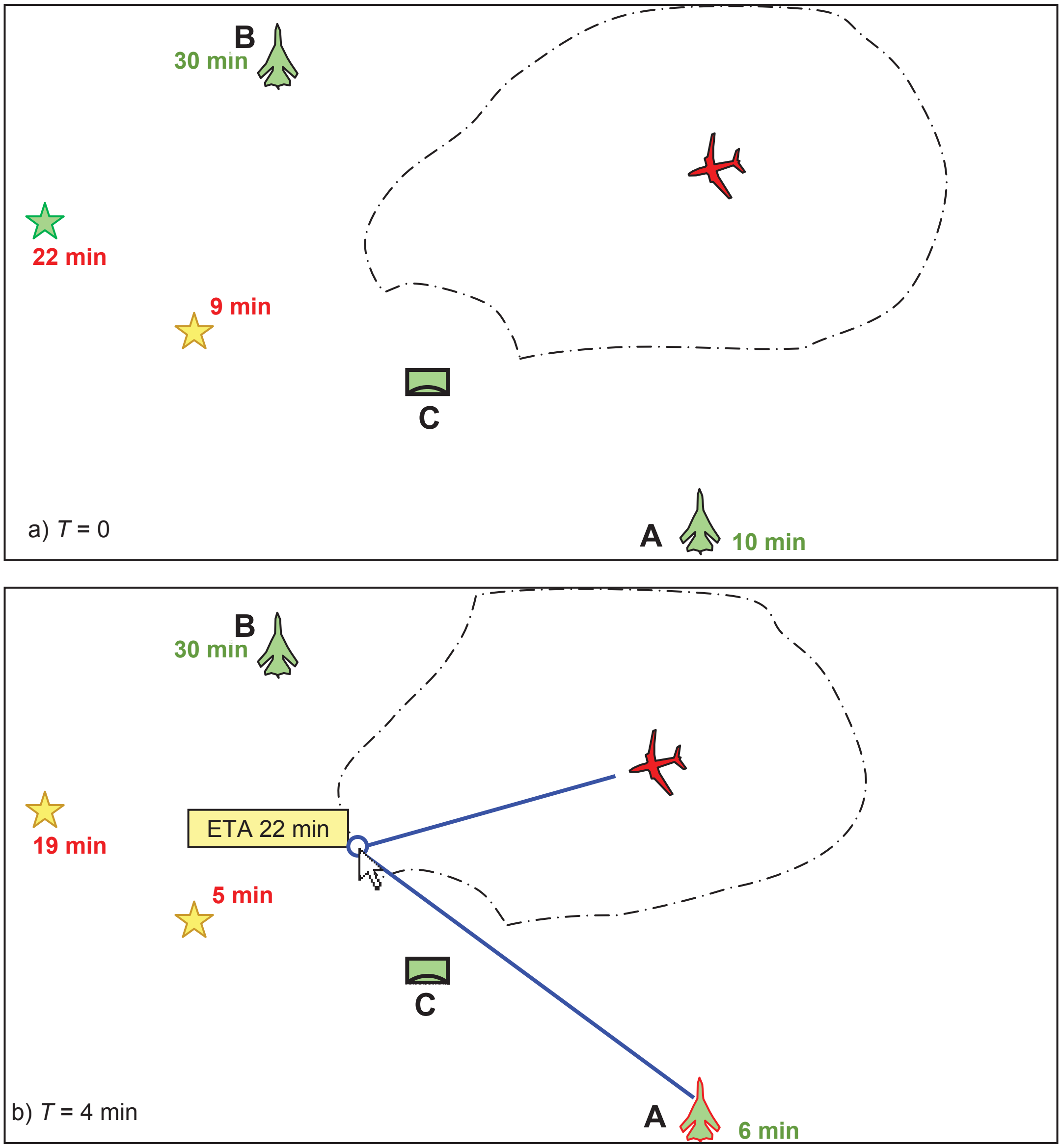


Figure 4-2 Dynamic Risk Ring Around a Contact of Interest

This novel visualization provides a visual summary of the risk associated with a Track of Interest (TOI) shown in red. In this example fighters are available at Base A on 10 minute notice and at Base B on 30 minute notice. Vital Points are marked with stars whose colour indicates increased threat or risk, and with red text that counts down to indicate how much time remains before an RCAF aircraft must be tasked. A "Risk Ring" is drawn around the TOI to mark where the aircraft can go with impunity, taking into account the status of all possible interceptors. In (a) the TOI has just been designated, so no fighters have been scrambled, but the Risk Ring still reflects how far the TOI could travel before a fighter, immediately tasked from either base, could intercept it. A ground-to-air weapon at C prevents unchallenged intrusion into its immediate vicinity. Four minutes later (b) fighters at A have been scrambled but are not yet in the air, and the TOI has moved forward, so the Risk Ring has changed as shown. Users can mouse-over the Risk Ring to read ETA to intercept at that location as shown. These displays would normally be overlaid onto Google Earth.

4.2 TARM Innovations

This section proposes two innovative technologies for visualizing long-term usage patterns within the RCAF. These tools reveal information that is not currently available to the Total Air Resource Management (TARM) planners, and thus may not be helpful to them, but until the technology is explored that question cannot be addressed.

4.2.1 Statistical Map of Annual Mission Patterns

Knowledge of long-term average RCAF traffic routes may be of value for TARM, revealing patterns of deployment that could help make a more efficient TARM for the following year. Willems [73-74] has published an algorithm for visualizing normal traffic patterns, as shown in Figure 4-3. This 2D coloured-wash visualization would be shown in Google Earth as a semi-transparent overlay onto map or satellite views.

This visualization tool, if implemented could be configured to display a variety of long-term statistics such as:

- Spatial distribution, including heavily-travelled routes, for various aircraft types;
- Seasonal patterns of deployment;
- Force generation vs. force employment statistics.

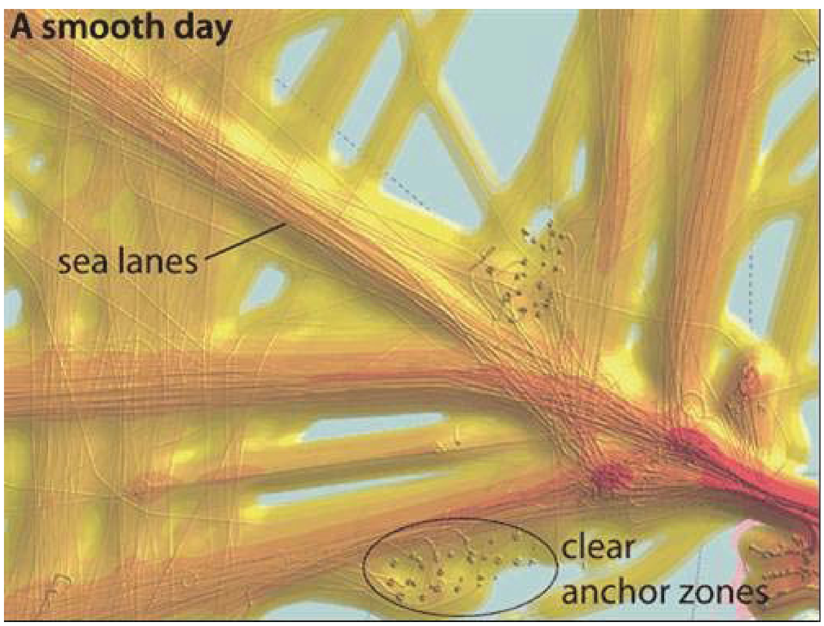


Figure 4-3 Visualization of Heavily-Travelled Routes
This visualization was generated from tracks of ships approaching Rotterdam harbour, in order to show where the highly-travelled routes are. A similar visualization could be used for Air Domain Awareness of routes highly travelled by commercial aircraft. Colours indicate historical traffic density, ranging from blue (zero) to red (maximum). [73-74]. An air traffic visualization could be modified to reflect the strong daily rhythms of commercial air travel.

4.2.2 Topical Visualization of Long-Term RCAF Mission Patterns

If the Statistical Map in Section 4.2.1 is useful, then more abstract views of the same data may also be useful. A state-of-the-art visual analytic tool for visualizing statistics of this type is the "Magnets Grid" tool available within ISTIP [34], as shown in Figure 4-4.

There was general consensus at the CAOC that it would be impossible to collect the statistics to populate the Statistical Map (Figure 4-3) and the Magnets Grid. The needed statistics are spread across Wings, Squadrons, and departments of 1 Canadian Air Division, behind firewalls, and at various levels of secrecy.

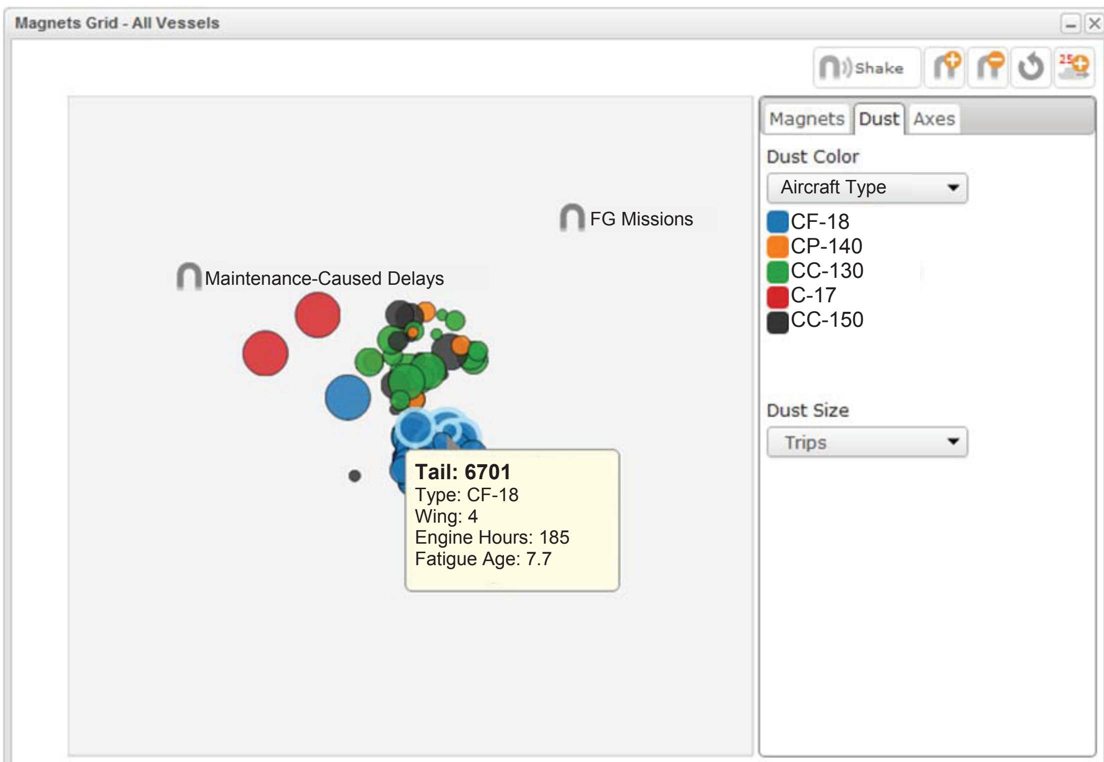


Figure 4-4 Magnets Grid

Magnets Grid portrays statistics in four dimensions (*x*, *y*, icon colour, and icon size) but analysts can extend this to many more dimensions by using "magnets" to represent new statistical dimensions. In this example, each icon represents one tail number in the RCAF fleet. A magnet attracts an icon mores strongly depending on whether that tail number has a high score in the magnet's dimension. Thus for example clicking on the "FG Missions" magnet causes tail numbers with many Force Generation excursions to move more quickly toward the magnet. (modified from: [34] Figure 20)

4.3 Resource Visibility Innovations

Sections 4.3.1 through 4.3.5 suggest innovations for rapid horizontal and vertical awareness of the RCAF resources, including assets and logistics.

4.3.1 Map-Based Resource Visibility

CAOC and OAC members commonly visualize their domain of responsibility geographically, so it is natural to offer geographically-mapped visualizations of resources, assets, and logistics. Section 4.3.1.1 proposes a set of colour-coded icons indicating, at the highest level, the readiness of the bases. The first level of drill-down will be a “Halo COP” that displays more details about readiness, as described in Section 4.3.1.2, with click-through access to more details. Logistics details are accessed through the Halo COP as described in Section 4.3.1.3.

4.3.1.1 Readiness Icons for RCAF Bases

Human factors research has shown that users can get an overview of information more quickly if it is represented using visual icons rather than words:

> “... a pictogram is better than a label, and recognizing an image is easier than reading text”[51, 66]

In this section we therefore examine possible advantages to assigning a unique icon to represent each RCAF Wing. These icons would be used in map views to mark the locations of the bases, and they would also be used in non-map views (see e.g. Section 4.4) to reference the Wing or the base.

The shapes of the icons should match existing base shields or iconic local features, as sketched in Figure 4-5. For example CFS Alert could use a Musk Ox icon and CFS Inuvik could use a stylized Inuit hunter, based on their crests.

a) A wolf for Cold Lake? b) A hunter for Inuvik? c) A tree for Greenwood?

Figure 4-5 Using Icons to Represent Bases and Base Status
A unique icon will represent each base so the users can very quickly recognize where a problems exists. For example an amber goose means a problem in CFB Goose Bay, and green Dogwood means that CFB Comox has no problems. These icons will be used in the Geographic and abstract views.

In the Map views, the icons act as both a base-identifier, and as the highest-level indicator of current readiness. The colour of each icon would represent the near-term readiness, as explained in Section 4.3.1.2.

4.3.1.2 Halo Common Operating Picture

The first level of drill-down in the map-based display will be a "Halo COP" operating picture similar to that used by Command and Control Rapid Prototype Continuum (C2RPC) [26] (see Section 3.4.8). Using the naval Halo as a guide, the Air Force Halo might include the following, as sketched in Figure 4-6:

- **Platform Icon:** top-level identifies the base. Click-through to get detailed information on base facilities and on the Wing and Squadrons located at that base.
- **Force Protection Condition (FPCON):** Normal, Alpha, Bravo, Charlie, or Delta
- **Message Board:** place for the base or the AOC to post C2 information.
- **Current Tempo:** top-level icon shows the number of missions currently underway at this Wing. This might be divided into two icons: operational missions and force generation missions. Operational missions with readiness problems are in red. Click to get a table with links to all the missions.
- **Readiness Stoplights:** an array of three stoplights represents base readiness on three time-scales, as described in Section 4.3.1.3.
- **Aircraft Tally:** top-level icon is a set if aircraft icons representing how many of each aircraft is present. Click on this to get a table of aircraft currently on the ground at this base, with ready-duty aircraft singled out
- **Allied Presence:** top-level icon is a set of flag icons. Click on this to get a summary of what all the visitors are doing.
- **Communication Status:** top-level icon shows the status of data links between that base and the CAOC. Click on this to identify which data links are working.

4.3.1.3 Map-Based Logistics Awareness

Although it is the responsibility of the Wings and Squadrons to achieve and maintain readiness to employ force, the AOC and CAOC have a responsibility to know the current and near-future readiness states. We propose that this could be done using the "green, amber, red" readiness stoplights already familiar to the CAOC. According to this scheme:

- Green means: able to deliver air power as planned
- Amber means: there is an issue impacting ability to deliver air power as planned
- Red means: air power cannot be delivered from this location

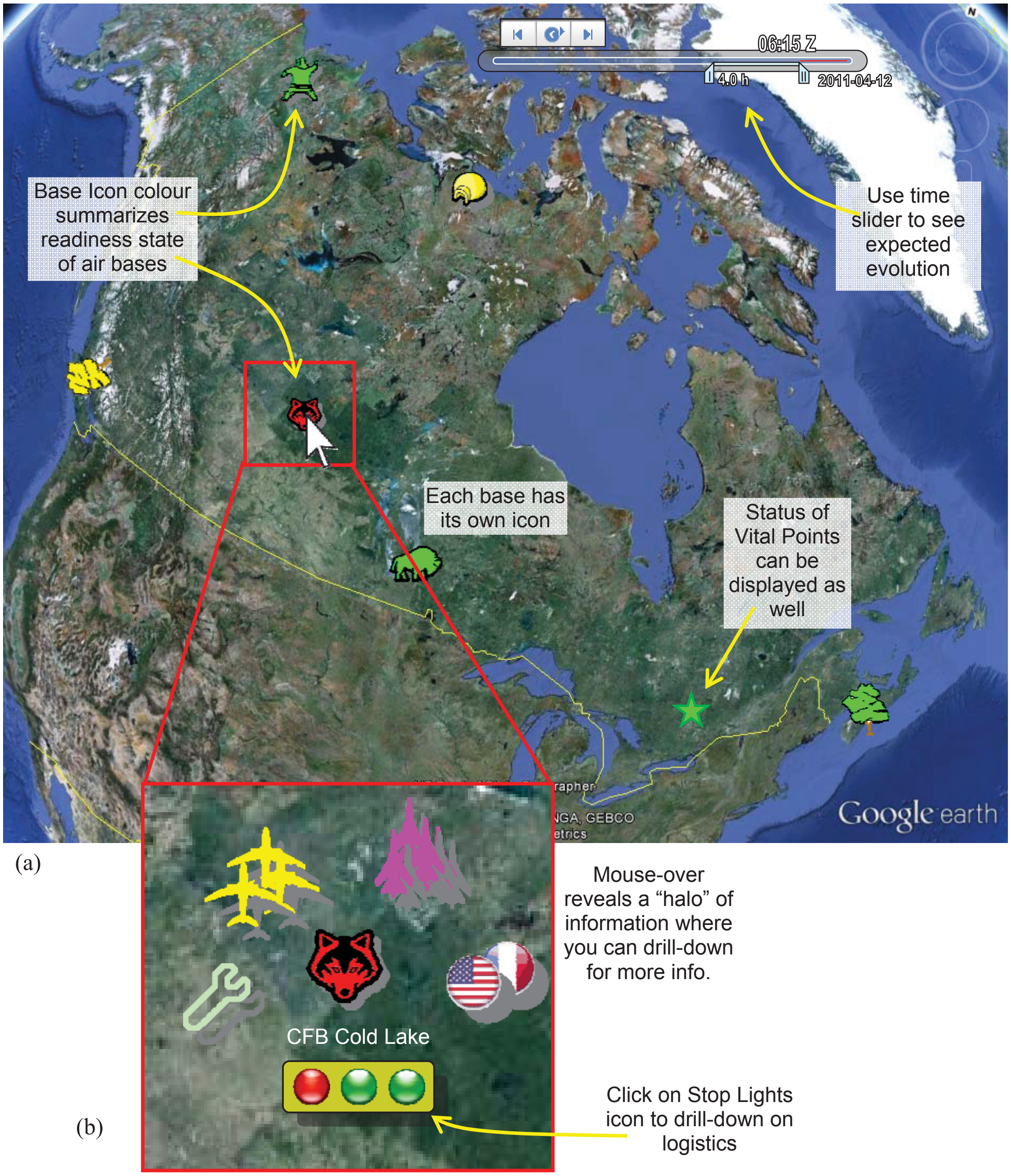


Figure 4-6 Stop-Lights and Halo for Readiness Awareness and Drill-Down

In this view a high-level summary of readiness is superimposed on Google Earth using a row of "Stoplights" where the left-most light represents readiness in the near future and the right-most light represents longer-term readiness. Users can drill-down for an explanation of each Stoplight status. When a user mouses-over a base, a "halo" of new information appears (b) and offers links to drill down for more details.

On the Map view, the icons marking every RCAF base will be coloured using this scheme to show readiness over the next 24 h as shown in Figure 4-6.

The goal for Logistics Awareness is to provide multi-level visibility into mission readiness, on a variety of time scales, and for various users. The levels can be summarized as follows:

1) **Base Icon Colour:** each base has an icon on the map. If that icon is red there is a readiness issue, as sketched in Figure 4-7a.
2) **Stop Lights:** mouse-over a base icon to get a Halo COP, which includes a set of three Stoplights that reveal temporal (i.e. "horizontal") information about logistics. In accordance with the RCAF rolling-wave planning process, the three Stoplights show logistics readiness at 0 - 24h, 24h - 72h, and 72h – 1 week.
3) **Logistics Network:** click on the Stoplights in the base icon, to open a list of all the logistics elements that influence the Stoplight status, in the form of "Notices to Airmen" or "NOTAMs" as sketched in Figure 4-7.

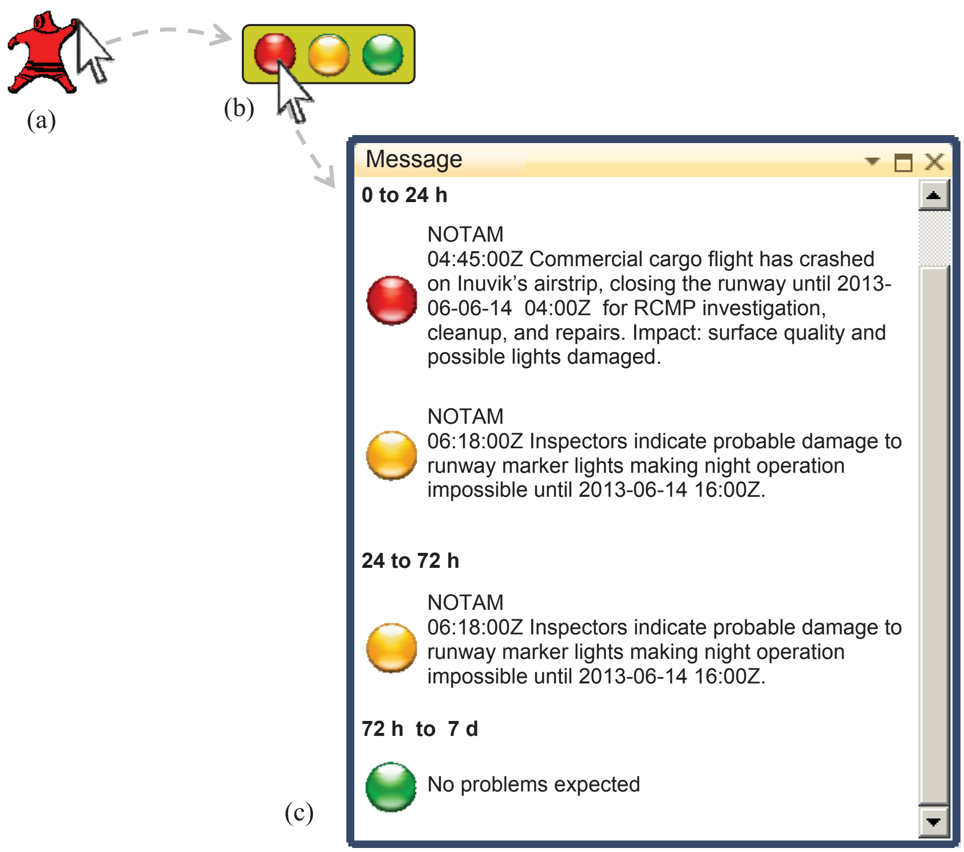


Figure 4-7: Drill-Down for Logistics Awareness
If a base has a problem, its icon will turn red (a). Mousing over that icon causes the Halo COP to pop up, which includes a stop-light (b) representing the readiness status in short, mid, and longer-term. Clicking on the stoplight brings up a more-detailed view of the current logistics (c). This reveals a Notice to Airmen (NOTAM) explaining that the runway is unavailable for 14 hours, and runway lighting may be unavailable for a further 24 hours.

4.3.2 "Dashboard" Asset, Resource, and Logistics Pictures

It is not always helpful to portray assets, resources, and logistics geographically – some users need to see statistics from the whole air force. Figure 4-8 introduces an "Asset Indicator Dashboard" that provides a single RCAF-wide summary of asset employment. Here the term "dashboard" means "An easy to read, often single page, real-time user interface, showing a graphical presentation of the current status (snapshot) and historical trends of an organization's key performance indicators to enable instantaneous and informed decisions to be made at a glance."[22] This use of a stacked bar-chart is based on a graphic previously used by MGen J.J.C. Bouchard [7] to summarize asset employment in the air force. See (Section ?? of [13] for the prototype implementation of the dashboard).

Hierarchical visualization of assets, resources, and logistics is provided by interactive graphics that are a natural extension of Bouchard's diagram, as sketched in Figure 4-7. Users can see the statistics broken down as follows:

Air Assets

- **Primary Visualization:** aircraft are categorized by their current activity: Maint3 (modifications), Maint2, Essential FG, Detached OPCON, FE Tasked Missions, and Untasked.
- **Breakout by Fleet:** aircraft are categorized as Fighter, Helicopter, ISR, Trainer, Transport, or UAV (Unmanned Aerial Vehicle);
- **Breakout by Wing**; aircraft are categorized by which Wing they belong to;
- **Breakout by time:** aircraft readiness is plotted as a function of time, with a logarithmic time scale, as sketched in Figure 4-7;
- **Show planned tracks:** show tracks for the next 24 hours, on a map.
- **Breakout Using Magnets:** aircraft are displayed as dots using the bar chart colour scheme. Users can select a "magnet" to pull dots in a specific direction depending on their attributes (e.g. prudent limit of endurance) as described in Section 4.3.3.

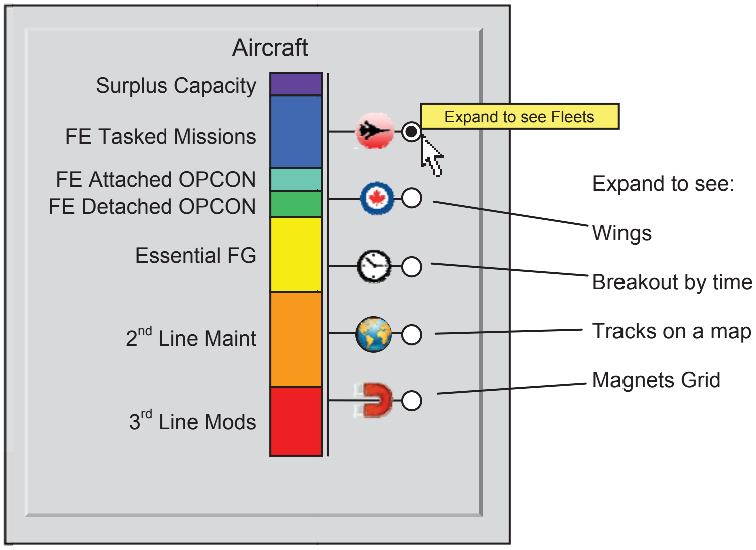
Users can combine queries (for example "what is the readiness of all fighters in Bagotville") by clicking on one of the detailed bar charts as shown in Figure 4-7(a) and then pulling out a new set of bar charts.

Operations Personnel:

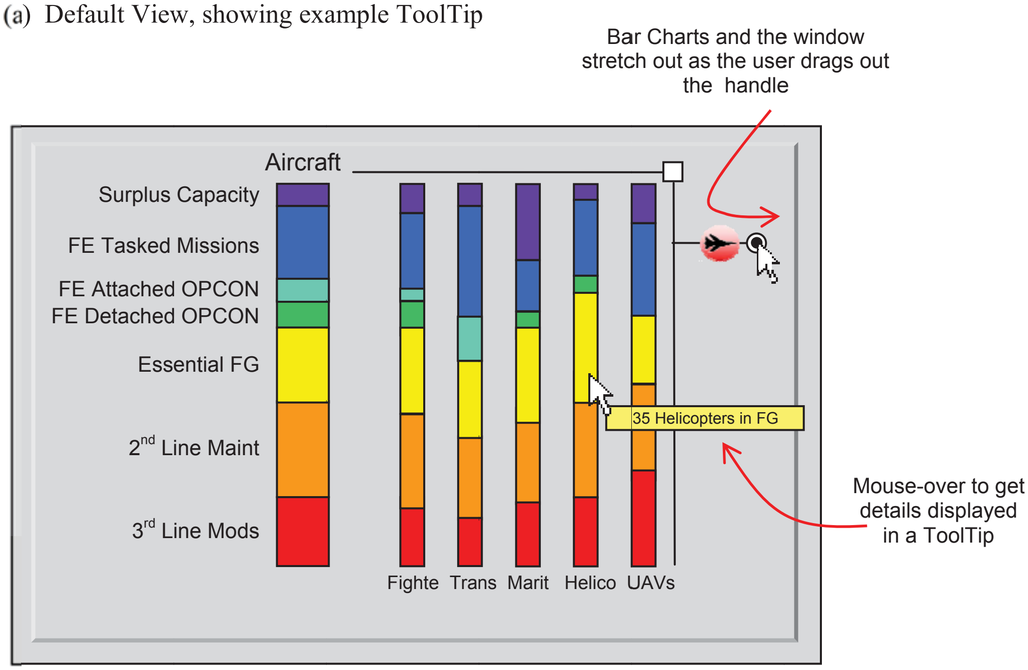
- **Primary Visualization:** personnel are categorized by their current activity: FE Tasked Mission, FE Detached OPCON, Essential FG, Leave, Professional Development, Reserve.
- **Breakout by Fleet:** personnel are categorized by their qualified aircraft: Fighter, Helicopter, ISR, Trainer, Transport, UAV, or all aircraft;
- **Breakout by Wing**; personnel are categorized by the wing they are members of;
- **Breakout by Rank:** personnel are categorized as: Civilian, Enlisted, NCO, Officer;
- **Breakout by Role:** personnel are categorized as: Logistics, Facilities, Ground Crew, Air Crew, Command and Control;
- **Breakout by time:** personnel availability is plotted as a function of time, with a

logarithmic time scale, as sketched in Figure 4-7;

-  **Breakout Using Magnets:** personnel are displayed as dots using the bar chart colour scheme. Users can select a "magnet" to pull dots in a specific direction depending on their attributes as shown in Figure 4-10 and Section 4.3.3.



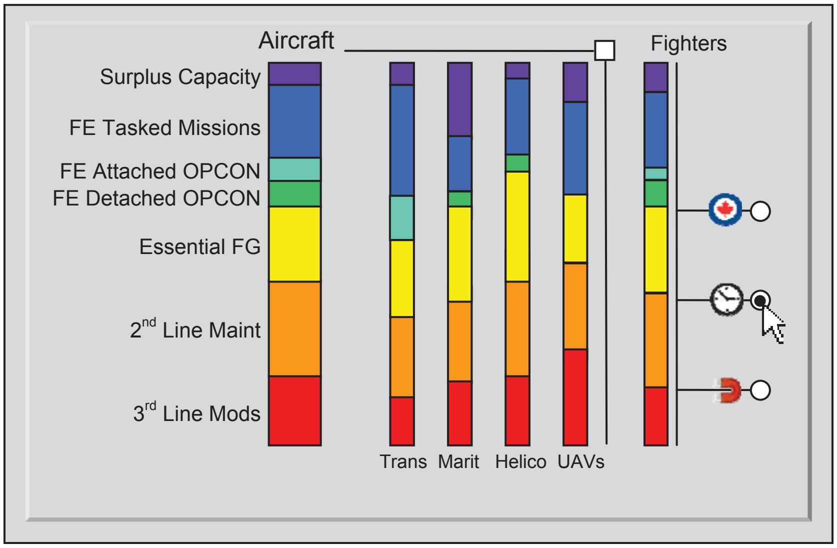
(a) Default View, showing example ToolTip



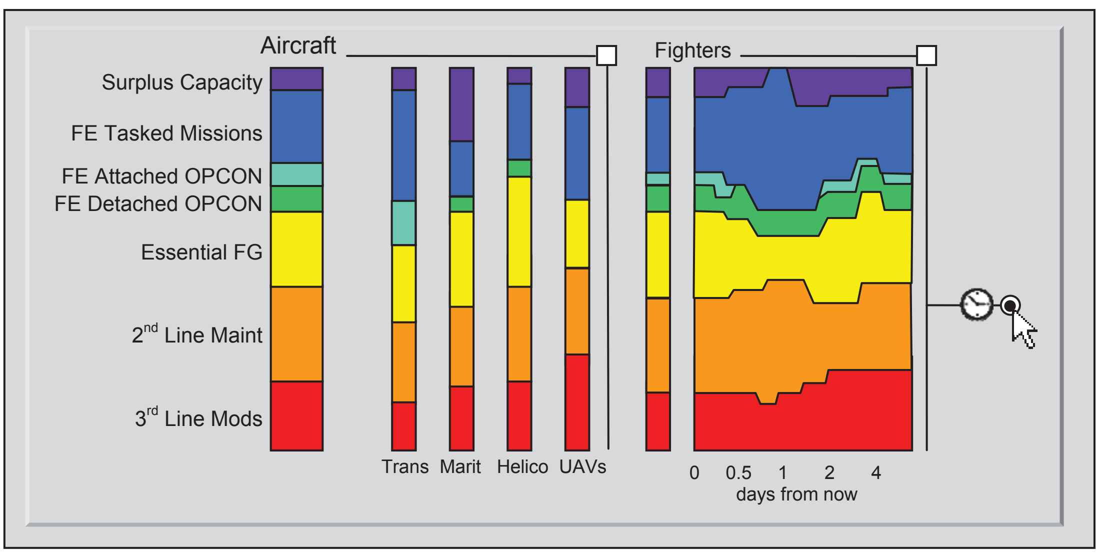
(b) Expanded to see the Fleets

Figure 4-8 Asset Indicator Dashboard

The asset indicator dashboard is designed to give a continual high-level view of assets (a), plus intuitive tools for drilling down to visualize more details. The stacked bar chart provides a high-level view of how all aircraft are currently employed. If a user pulls out the "fleet" pull-tab, new histograms expand into view (b) showing the employment statistics for each class of aircraft. Double-clicking on the small white box returns the display to its simplest form (a).



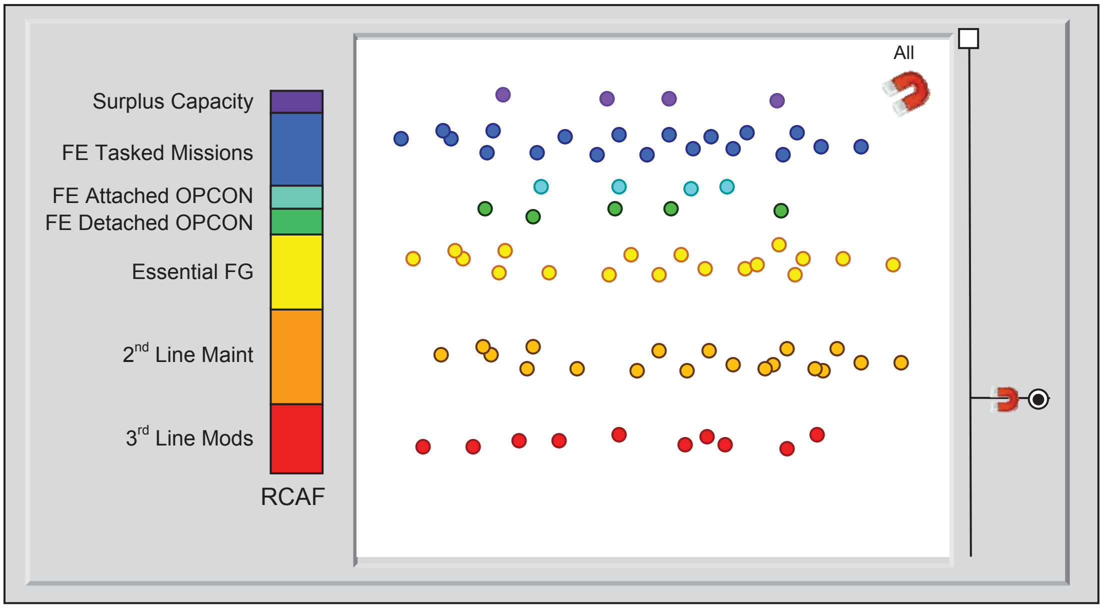
(a) A detailed bar chart can be selected for further expansion.



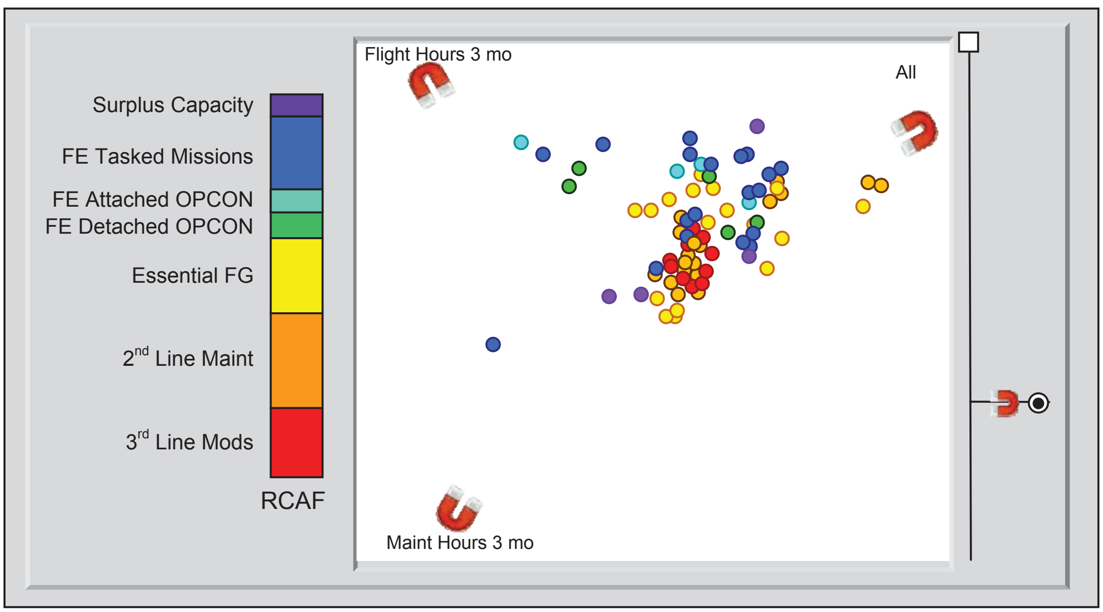
(b) In this case, time-evolution of fighter readiness is plotted.

Figure 4-9 Drilling Down on the Asset Indicator Dashboard

In this example, the commander wants to see how fighter availability will vary in the coming days. Clicking on the Fighter bar chart in Figure 4-8(b) pops it to the right as shown in (a) and adds pull-tabs for Wing, Time, and Magnets Grid. Pulling on the Time tab drags open a time-plot as shown in (b).



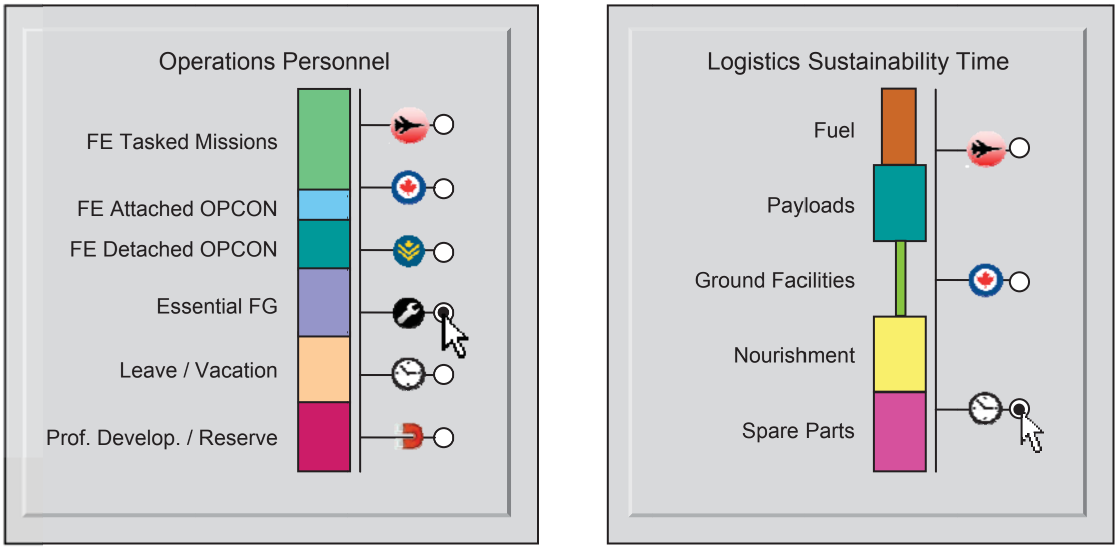
(a) Icon locations and colour when Magnets Grid is first pulled out.



(b) Use the magnets to pull icons according to their attributes.

Figure 4-10 Using Magnets Grid for Asset Awareness

Magnets Grid provides free-form exploration into the database. When it is first pulled into view (a) the assets are coloured and scattered to emphasize their relationship to the histogram. Add example magnets (b) and shake them to identify assets that have high flight hours and low maintenance hours. Interesting subsets can be circled and tagged in the database.



(a) Human Resource dashboard (b) Logistics dashboard

Figure 4-11 Human Resource and Logistics Dashboards

The top-level Human Resources Dashboard (a) shows what fraction of RCAF operational staff are currently working, and what they are doing. This can be explored using six different pull-out tabs, as discussed in the text. The Logistics Dashboard (b) summarizes the current logistics situation in terms of five topics, with three pull-out subtopics. The width of each coloured rectangle represents the number of hours before missions could be affected by a logistics failure. In this example sketch, Ground Facilities are stretched thin, with only half a day of sustainability.

Logistics:

- **Primary Visualization:** logistics status is categorized by the normalized worst-case sustainability time (in days) of the following elements: flight fuel, payloads (e.g. weapons, sensors, fuel bladders), ground facilities (e.g. electrical generator fuel), nourishment, spare parts.
- **Breakout by Fleet:** logistics is categorized by the aircraft that rely on it: fighters, transports, surveillance, helicopters, and UAVs, all aircraft;
- **Breakout by Wing**; logistics is categorized by the wing tasked with providing it;
- **Breakout by time:** expected logistics sustainability time (in days) is plotted as a function of time, with a logarithmic time scale, as sketched in Figure 4-9.

4.3.3 Magnets Grid Asset Browser

The Magnets Grid Asset Browser can be used to rapidly search RCAF databases to find air assets (i.e. aircraft) or personnel according to situation-specific criteria. Examples of aircraft search criteria are:

- Aircraft type
- Sustainability (current prudent limit of endurance)
- Installed equipment (e.g: weapons, fuel bladders, sensors)
- Travel time to a specific destination (including ground preparation time)

The best visual analytic tool for such an open-ended search is Magnets Grid [34], already introduced in Section 4.2.2. Figure 4-12 is a mock-up showing how Magnets Grid could be used for asset browsing, with each dot representing one aircraft in that example. When browsing people, each dot could represent one person.

When the Magnets Grid Asset Browser is embedded in a dashboard (see Section 4.3.2) the colour of each dot will be determined by the dashboard, and magnets that represent attributes already selected by the dashboard will be greyed-out.

This would be a significant improvement over the current support at the CAOC, where an analyst would have to scan the NAPPIC lines-of-tasking Gantt chart to see assets currently being used for Force Employment, and would have to call the Wings for a list of assets currently being used for Force Generation. When there are hundreds of missions it is difficult for current users to rapidly find the best asset.

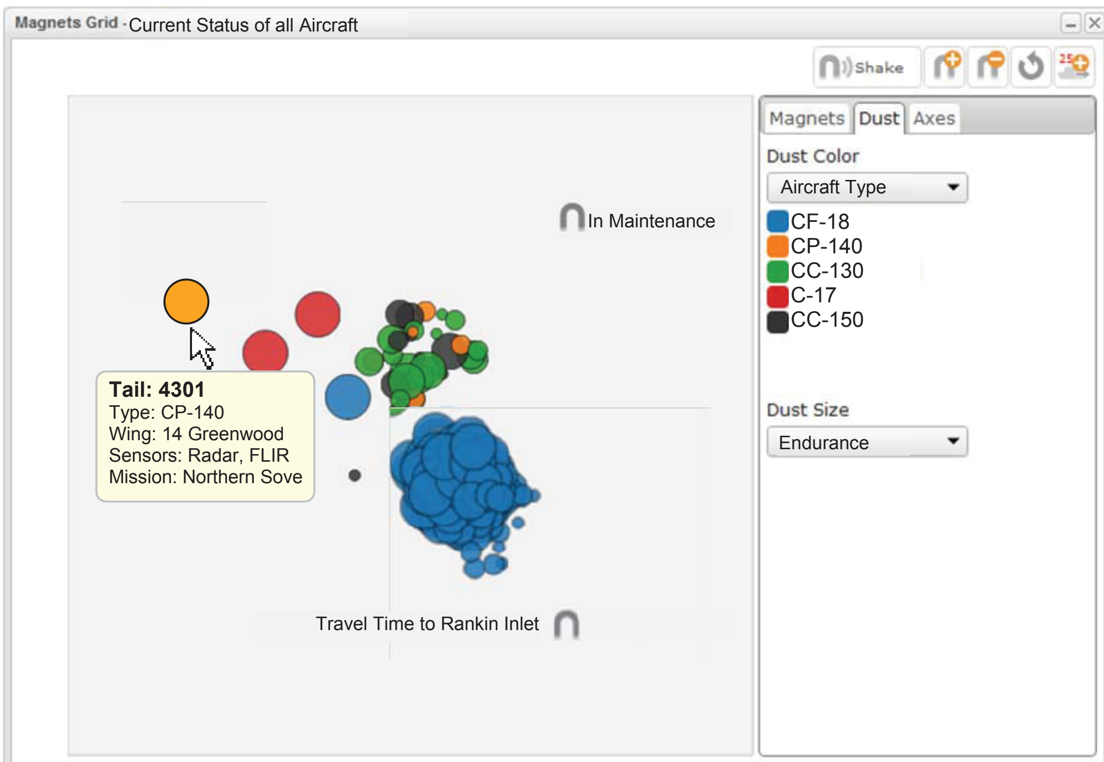


Figure 4-12 Air Asset Awareness Using Magnets Grid

When CAOC planners need to rapidly re-plan, an important question is “what air assets (i.e. aircraft) are available?” This mock-up shows how the Magnets Grid tool could be used for this purpose. In this example the analyst is looking for an aircraft that can get to Rankin Inlet quickly, and remain on station for a long time. He searches all fixed wing RCAF aircraft, using icon colour to indicate aircraft type, and icon size to indicate sustainability. He then assigns one magnet to show travel time to Rankin Inlet and discovers one aircraft (a CP-140 on Northern Sovereignty Patrol) with a very low travel time and high sustainability. Other magnets could be used to further refine the search, for example to find aircraft that can land on short runways. Clicking on the orange circle exports that aircraft to the options analysis tools (see Section 4.4).

4.3.4 Mission Hockey Cards

The visit to the CAOC revealed that planners think in terms of effects, missions, and packages. A "package" is a group of missions all working toward the same effect. Currently CAOC planners can browse Force Employment missions by scanning down the lines-of-tasking Gantt chart, but they cannot see Force Generation missions – they have to call the Wings for information about those. When there are hundreds of missions it is difficult for planners to rapidly review the missions that they need to be aware of.

We are proposing that missions be displayed and browsed graphically using a "Hockey Card" theme. Research [66] has shown that people recognize an image more easily and more quickly than they recognize text – the "image processing" components of the brain are faster than the "text processing" components. Similar Hockey Cards were suggested to the MSOCs for ship tracking ([12]) and were well received.

Figure 4-14 shows an example Hockey Card. The border of the card reflects the status of the mission (green, amber, or red), and symbols at the top indicate whether it is a NORAD or 1CAD mission, and its priority. Below that, icons and lines form a "play diagram" representing the mission in a conceptual space as discussed in Section 4.3.4.1. A simple timeline is also shown, together with links to other missions that share a contract with this mission. If a mission has more than three contracts, that table can be continued on the flip side, or as a pop-up. See Section ?? of [13] for a description of the prototype Hockey Card implementation.

Clicking the Google Earth icon causes the Map View (see e.g. Figure 4-6) to jump to the start time of the Mission, and to display the planned movements of all mission Assets.

The flip side contains more detailed, textual information similar to what would be seen in NAPPIC, with links to the ATO in NAPPIC. CAOC specialists should decide exactly what information should be shown on the flip side.

4.3.4.1 Mission and Package "Play Diagrams"

A key element of the Mission Cards is the "Play Diagram," as sketched in Figure 4-14a. These diagrams serve as a "visual signature" for each mission, in the same way that a hockey or football "play diagram" (see Figure 4-13) serves as a visual signature for the play. Thus they must meet the following criteria:

a) They must be automatically generated, from mission facts in the ATO and mission plan;

b) They should convey enough, but not too much, information. Thus for example they should hide geographic details, focusing on start and end points and perhaps key events in between, in the same way that a subway map hides geographic details. Play diagrams will thus distort the geography;

c) They should avoid using text, because our goal is to engage the visual brain rather than the textual brain of the user;

d) They should conform to pre-existing RCAF symbology as long as that does not conflict with (b).

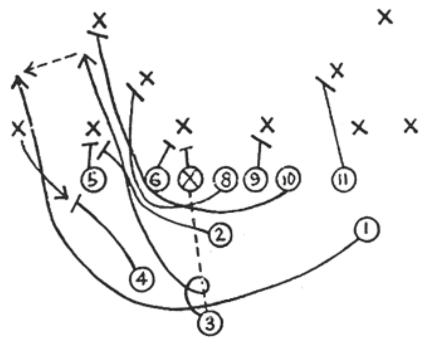


Figure 4-13 Play Diagram
Just as a football "play diagram," such as the one shown here, uses simplified movement patterns to illustrate a plan, the Mission Play Diagrams (see Figure 4-14 for example) present a simplified pattern to summarize a mission and its desired effect.

The design process for these diagrams should therefore include:

- Assembly of a "lexicon" of standard mission patterns, together with hand-drawn visual "signature shape" for each pattern. This lexicon should be reviewed by end-users.
- Assessment of where the required information will come from: what databases or software objects contain the required information?
- Creation and review of specialized code to generate the diagrams.
- Validation and review.

A similar Play Diagram should be developed to display "Packages" of missions.

4.3.4.2 Dynamic Hockey Cards

Once a mission is underway, the Hockey Cards may also be useful for tracking progress. Figure 4-15 sketches a possible "dynamic Hockey Card" that changes in the following ways as the mission or package proceeds:

- The border takes on a "blue candy stripe" shape, with the amount of blue proportional to the mission's fractional completion. Thus the border starts out all green and ends up all blue.
- Segments of the play diagram change to blue as they are completed
- Textual elements such as the schedule turn to blue as completed
- The Google Earth icon can be used to view the current location of the aircraft on the globe.

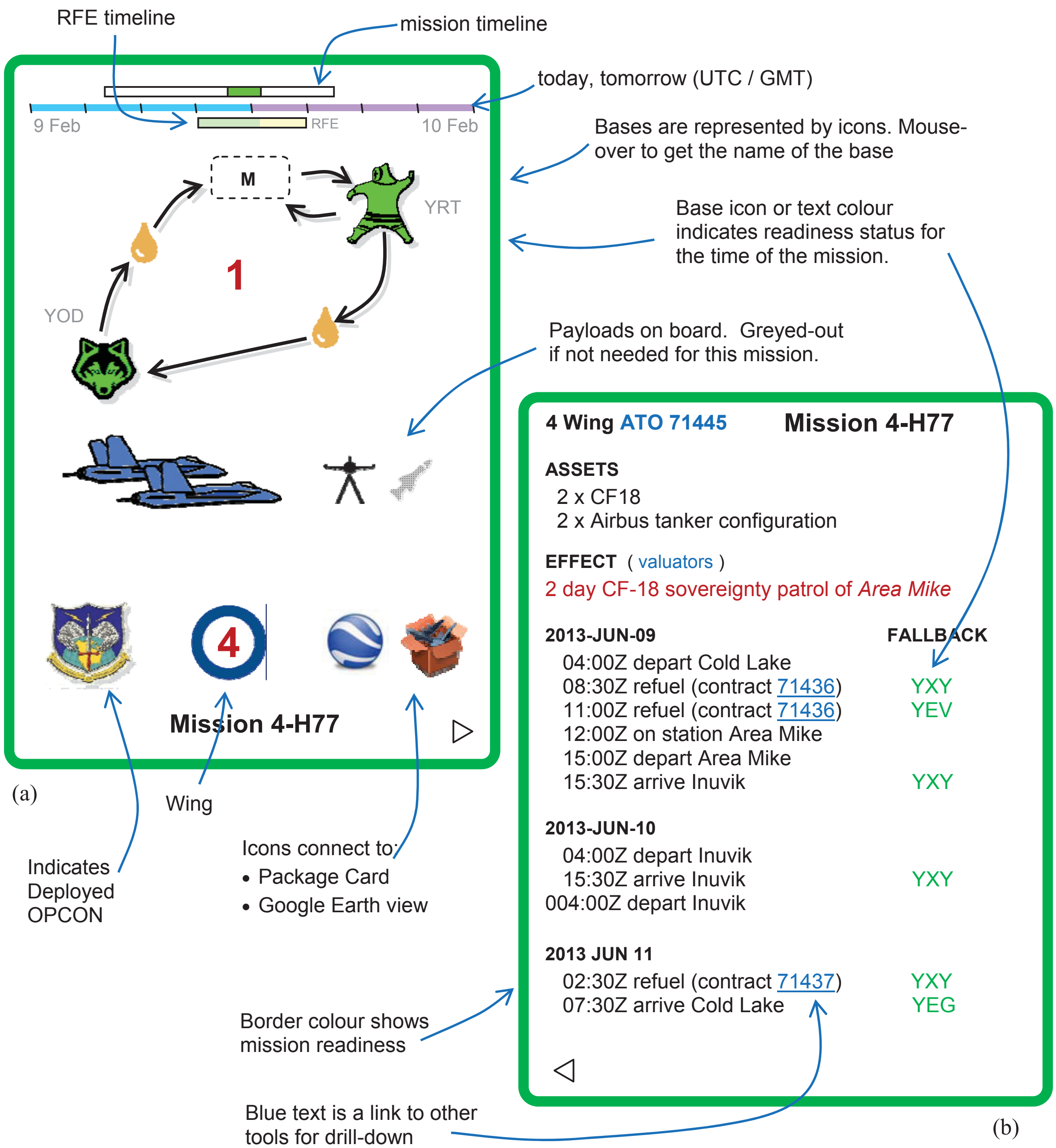


Figure 4-14 Mission or Package Hockey Cards

The front side of a Mission Hockey Card (a) provides a conceptual "Play Diagram" for the mission, drawn in conceptual space rather than map space. Icons for the mission aircraft are shown below the Play Diagram, together with a simple timeline. A table at the bottom left provides links to any Contracts associated with this mission. Clicking on the Globe icon causes the planned flight paths to be displayed on the Map View. Clicking on the Box icon brings up a "Package Hockey Card" that is very similar but includes contracts. Flip over the card to see more details (b).

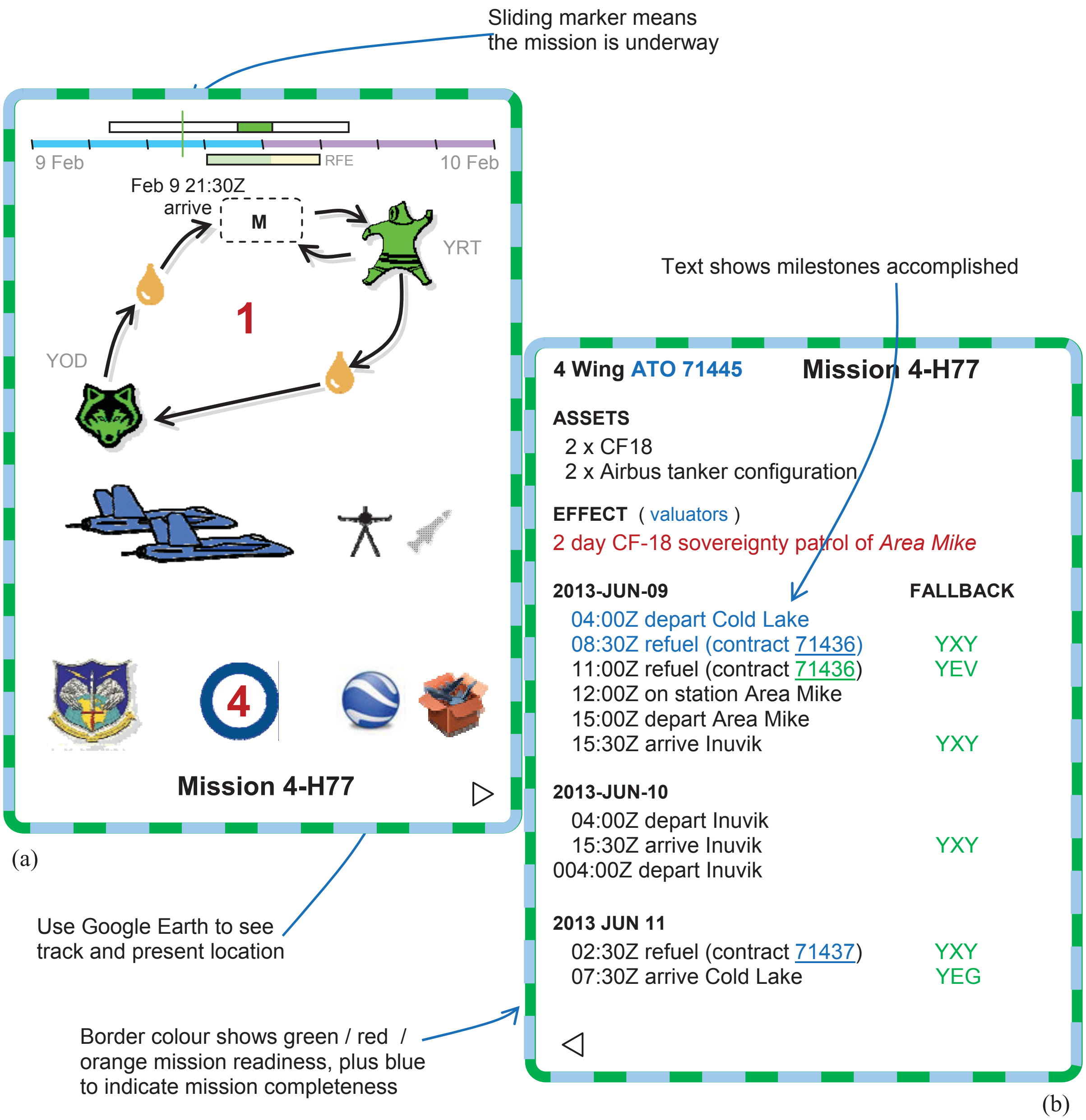


Figure 4-15 Dynamic Visual Air Tasking Order

Once a mission begins, the Mission Hockey Card (a) provides real-time updates on the progress of the mission.

4.3.5 Mission Hockey Card Browser

The value of Mission Hockey Cards is that they allow users to get a rapid overview of a large collection of upcoming missions, and to identify emerging problems. For this to work, a "Mission Hockey Card Browser" (MHCB) must be available. The MHCB must provide the standard browser functionality of rapid navigation, searching, and subsetting. Five candidate browsers are sketched below:

- Figure 4-16a shows a browser based on the "Cover Flow" GUI from *iTunes 7* (now abandoned in *iTunes 12*) and Apple *Safari 4*.
- Figure 4-16b shows a custom Hockey Card browser implemented by Oculus for DRDC's MAP project [34].
- Figure 4-16c is the iPhone Safari browser for recently-visited websites
- Figure 4-17a shows Google's *Images Tab* "knowledge wall" style browser, and
- Figure 4-17b shows the Top Sites knowledge wall in *Safari 12*.

The following requirements should be met by the selected MHCB:

- It should present the Mission Hockey Cards in a meaningful sequence. That sequence needs to be defined in conversation with the end-users, but the most likely approach will be to arrange the missions according to the time that they start.
- It should provide visually-effective browsing, for example by giving some sort of look-ahead so that users have a sense of location within the stack of all cards. *Cover Flow* does this by showing a reduced-quality version of the immediately neighbouring cards, and an edge-on view of a larger neighbourhood. Record Browser provides very little context – a few vertical lines to the left of the current card, and a slider/selector below the current card. The knowledge walls provide a detailed view of the current context.
- It should support searching and subsetting using various criteria, such as: time, aircraft, CF base name, requesting agency, or priority. For example a user should be able to view only those missions with Priority 1.
- When a card is selected, it should spawn a card viewer that provides a full-resolution view of all information on the front and back of the card, with live links, as described in Section Figure 4-14.

An off-the-shelf browser for the MHCB would be an excellent solution, if it can meet the above criteria. Safari's *Cover Flow* and Google's *Images Tab* browsers appear to be leading candidates. Safari's *Top Sites* would be even better if it can be modified to support a larger number of Mission Hockey Cards.

See Section ?? of [13] for a description of the NEP Card Browser implementation, which is most similar to Figure 4-16c.

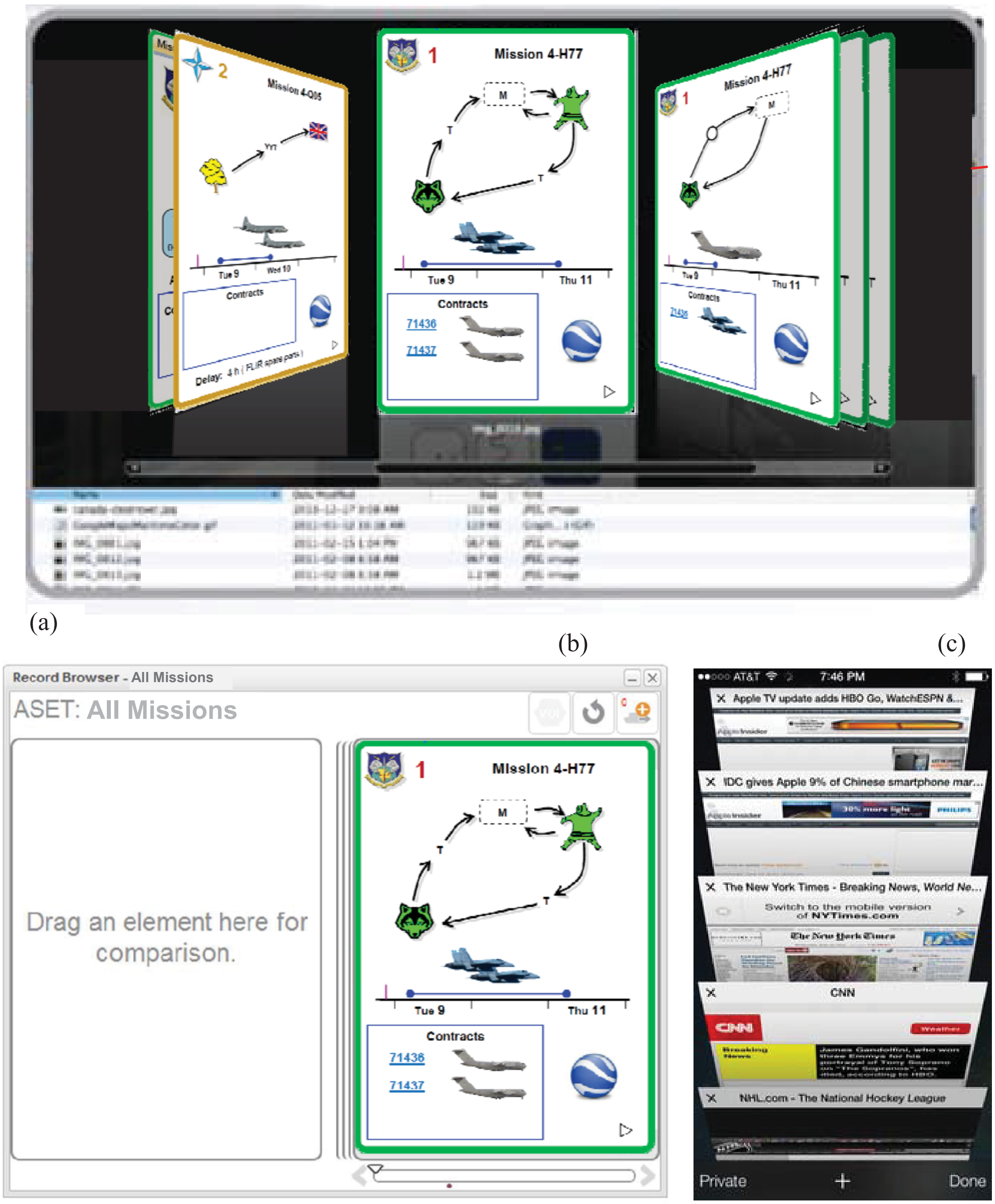
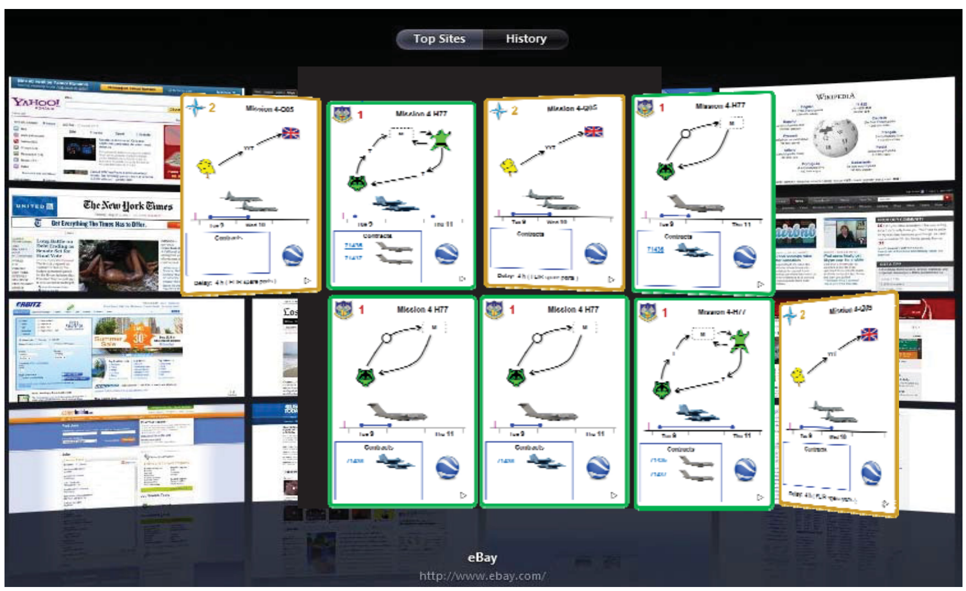


Figure 4-16 Mission Hockey Card Browser

The Hockey Card Browser could resemble an *iTunes* or *Safari* "Cover Flow" as sketched in (a) (based on Apple's *iTunes* 7 or *Safari* 4 [3-4, 12]) or the Record Browser (b) in DRDC's Maritime Analytics Prototype ([34]) or iPhone's safari history browser (c). The objective is to support rapid visual search for a specific mission, or a rapid overview of current operations.

(a)



(b)

Figure 4-17 "Knowledge Wall" Browsers for the Mission Hockey Cards
Image browsers have evolved since *Cover Flow* (Figure 4-16a) was introduced, so that users are now familiar with "knowledge wall" browsers such as Google's *Images Tab* (a) and Apple Safari's *Top Sites* (b). *Images Tab* assembles an unlimited number of thumbnail images into a very tall virtual collage, and provides a scroll bar for navigating down. *Top Sites* presents a maximum of 24 images on a 3D curved wall, with a slightly reflective floor. The curved wall brings lateral images closer and thus seems to compensate for our central-focus vision system. Mission Hockey Cards could be arranged using the *Top Sites* model, as sketched here, but we would need a mechanism similar to that used in *Images Tab* to scroll down.

4.4 Resource Management and Re-Planning Innovations

This section explores innovative planning tools for responding to non-forecast effects and exogenous events. Our solution uses multiple coordinated views of a generalized “Gantt Chart” (see Section 3.3.1) and an options-analysis array of Mission Hockey Cards (Mission Hockey Cards were introduced in Section 4.3.4).

We are interested in three types of unexpected events:

- **Exogenous Events:** This is typically a facility shut-down or a poor-weather forecast, and is accompanied by a Notice to Airmen (NOTAM). These will be inserted into the NEP using a demonstration script.
- **Resource Unavailability:** A key resource, such as an aircraft or crew, has become unavailable, for example due to malfunction or illness. These will be inserted into the NEP using a demonstration script.
- **Resource Reassignment:** A key resource, such as an aircraft or crew, has been reassigned to a higher-priority mission. Events of this type occur due to a ripple effect from other planning activities in the NEP.

4.4.1 Hierarchical Gantt Visualization of Missions

We investigated using Gantt charts as the primary visualization for elaborating resource allocation solutions, and for course-of-action assessment (COA). These charts would be used to communicate the following:

- The current baseline plan
- The reason that the baseline plan is red-lined
- At least three alternative plans
- Ripple effects from the plan changes that are being contemplated
- Multiple levels of detail on all the above.

This is an ambitious use of Gantt charts, so we explored new rendering strategies. To avoid the charts becoming so cluttered that they are difficult to interpret, we proposed the following strategies:

- Define a suitable hierarchy, as sketched in Figure 4-18.
- Make the Gantt lines easily collapsible throughout the hierarchy.
- Use pop-ups and mouse-over tool-tips to reveal annotations only when needed.

Note in Figure 4-18(a) that at the highest levels of the hierarchy, a separate Gantt line is assigned to each “package” and Mission. This is in contrast to the practise of some RCAF Wings which use “lines of tasking” in which the number of Gantt lines matches the number of aircraft available at any one time, and missions are placed side by side along the Gantt lines.

A decision was made early in the project to not develop new Gantt Charting tools because Gantt Charts are already broadly used in FlightPro and NAPPIC.

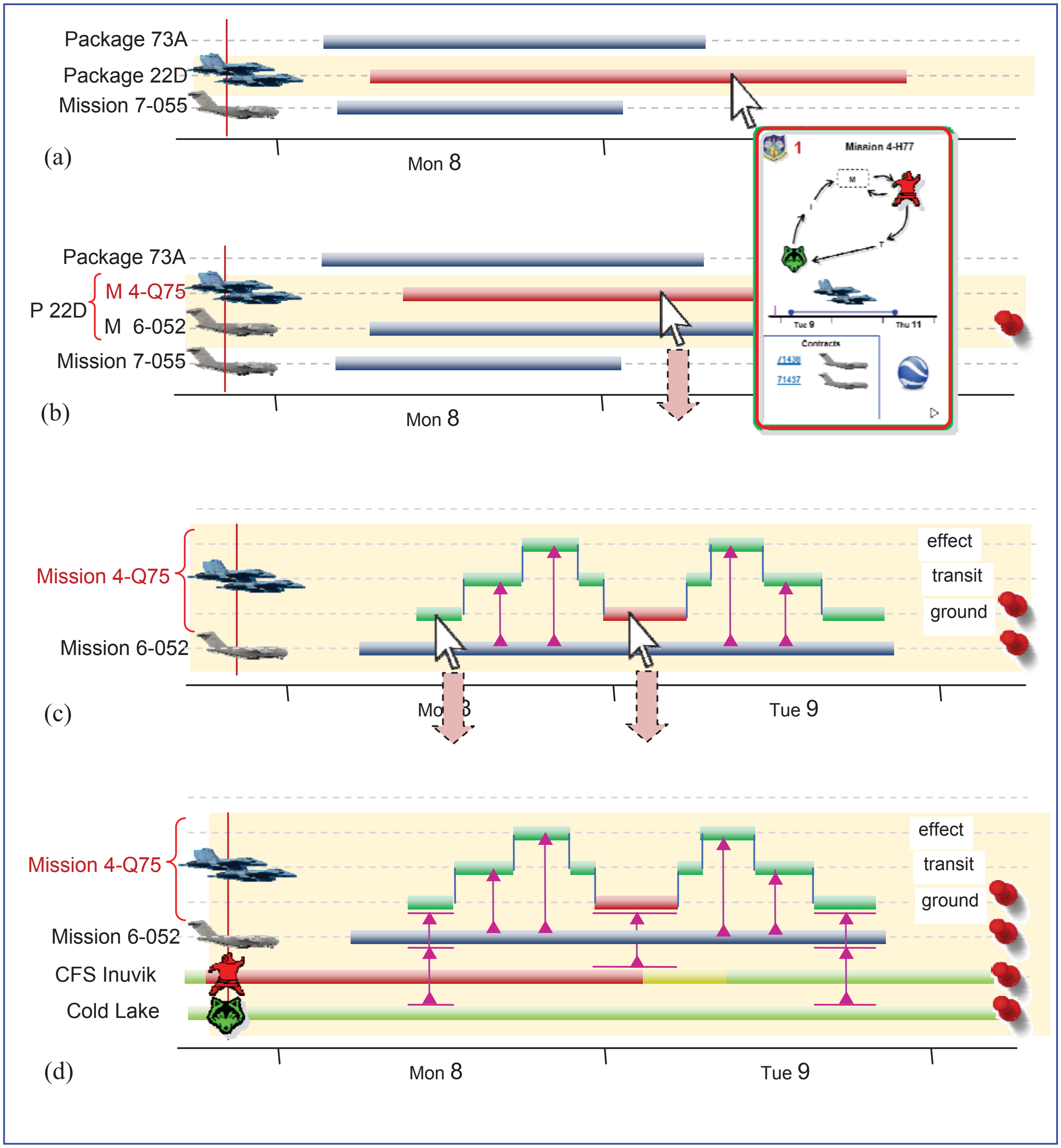


Figure 4-18 Hierarchical Gantt Visualization of a Mission

This diagram summarizes some Gantt Chart innovations that were explored. Reviewing the missions and packages in the Gantt chart, Package 22D shows red (a). Hover over any mission line to bring up its Hockey Card (4-Q75 shown in miniature in this sketch). Click once to show the missions (b) in the package. Drag the line down to expand it one level (c), revealing the timing and health of ground, transit, and "effect" phases of the package. Drag down again on the red bar and blue bar to show the resources that are supporting that part of the mission). Purple lines show support (for example CFS Inuvik was intended to provide a landing strip in this example. Click on the pins to release each expansion. Resources playing a fallback role are not shown in this sketch, but could be included in the NEP. These concepts were not implemented because Gantt Charts are already widely used in NAPPIC and FlightPro.

4.4.2 Fuzzy Request for Effects

Good re-planning requires good judgement about the operational goals. NEP must thus be able to judge the operational values of all new mission plan candidates, and trade them off against the lost operational values due to “ripple effects” (changes made in other plans to accommodate the new mission). Air Force doctrine attributes value to a mission according to how well it delivers “the right air power effect, at the right place, and the right time.”

We explored a solution based on fuzzy logic [47]. The fuzzy value model can be summarized as follows:

- Overall weight reflecting the priority of the mission. A mission with Prority 1 has highest “Priority Value”
- Full “Arrival Value” is given to an aircraft that can arrive before a given time goal. Arrival Value falls off for aircraft that can only arrive after the time goal, as sketched in Figure 4-19.
- If a dwell capability is required, zero “Dwell Value” is given for aircraft that cannot dwell. The Dwell Value increases with the dwell capability of the aircraft.
- A list of “ok aircraft” is established, and solutions that use unlisted aircraft have zero value. Planners can influence the relative values of Aircraft in the list.
- A list of required payloads, payload quantity, and payload value is used to specify the fuzzy value of various payload configurations.

A serious concern with such a solution is that it requires quite a lot of input from the operators to specify the fuzzy RFE (FRFE) for every mission. Insertion of FRFEs must be routine, so that when a crisis occurs the NEP can scan through FRFEs of existing missions in search of a good re-planning solution. If the FRFE process demands too much time from air force planners, this solution will fail. We addressed this using the following strategies:

- The fuzzy model was kept simple.
- An intuitive form-based user interface was used.
- Options are selected from pull-down lists based on textual descriptions.
- Users can load default values by selecting a “Mission Type.”
- Users can extend the list of Mission Types by inserting “Pre-Planned Mission” configurations.

See Section ?? of [13] for a description of the prototype Re-Planner.

4.4.3 Evaluating Ripple Effects Due to Re-Planning

Every decision to pull an asset from one mission and re-assign it to a new mission should try to minimize the resulting ripple effects. A numerical value “*R* ” is reported in the Re-Planner (see e.g. Figure 4-20) as a quantification of the magnitude of that ripple effect. *R* is typically calculated as the sum of the reduced RFRE values, for all the affected missions.

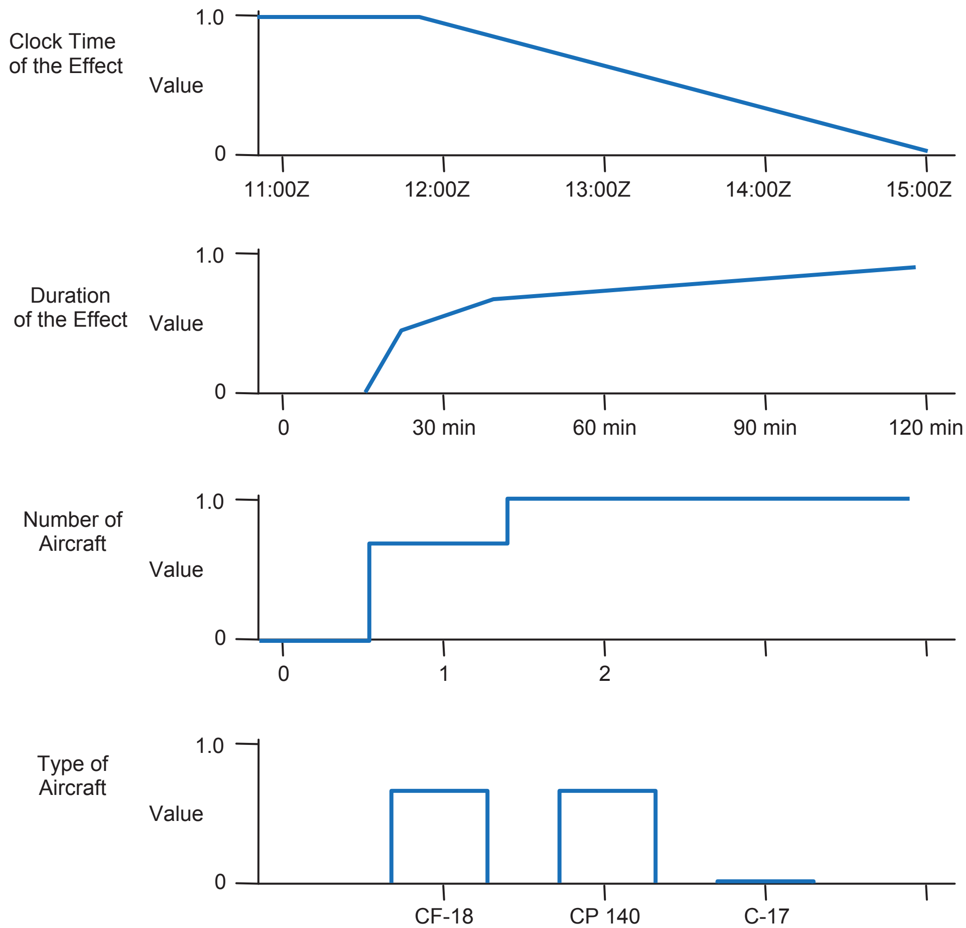


Figure 4-19 Example Fuzzy RFE

The "Fuzzy RFE" model describes flexibility in the Request For Effects (RFE) or Non Forecast Event (NFE). In this example, a mission's effect has full value if it starts as early as possible, but time spent after 12:00Z has diminishing value. It must have duration of at least 15 minutes to be valuable, but continues to increase in value as it endures longer. One aircraft is almost as good as two, and there is no need for more than two aircraft. The FRFE could be achieved by a CF-18 or a CP-140 but not by a C-17.

4.4.4 Comparison of Multiple Options

Once the FRFE model has been defined, the planner can press a button to open an Options Analysis form, as shown in Figure 4-20. This window shows three options, with one row of cards for each option, as in Google Transit [32]. The Re-Planner calculates the quality of each option in terms of values defined in Section 4.4.2, and displays them graphically.

Analysts can investigate variations on the recommended plans in two ways:

- **Modify the mission plan**: click on any card, flip it over, change various parameters such as payload or time of departure, and replace the card.
- **Replace the Aircraft:** select a different existing mission plan, drag it into the re-planning tool, and drop it over the card that is to be replaced.

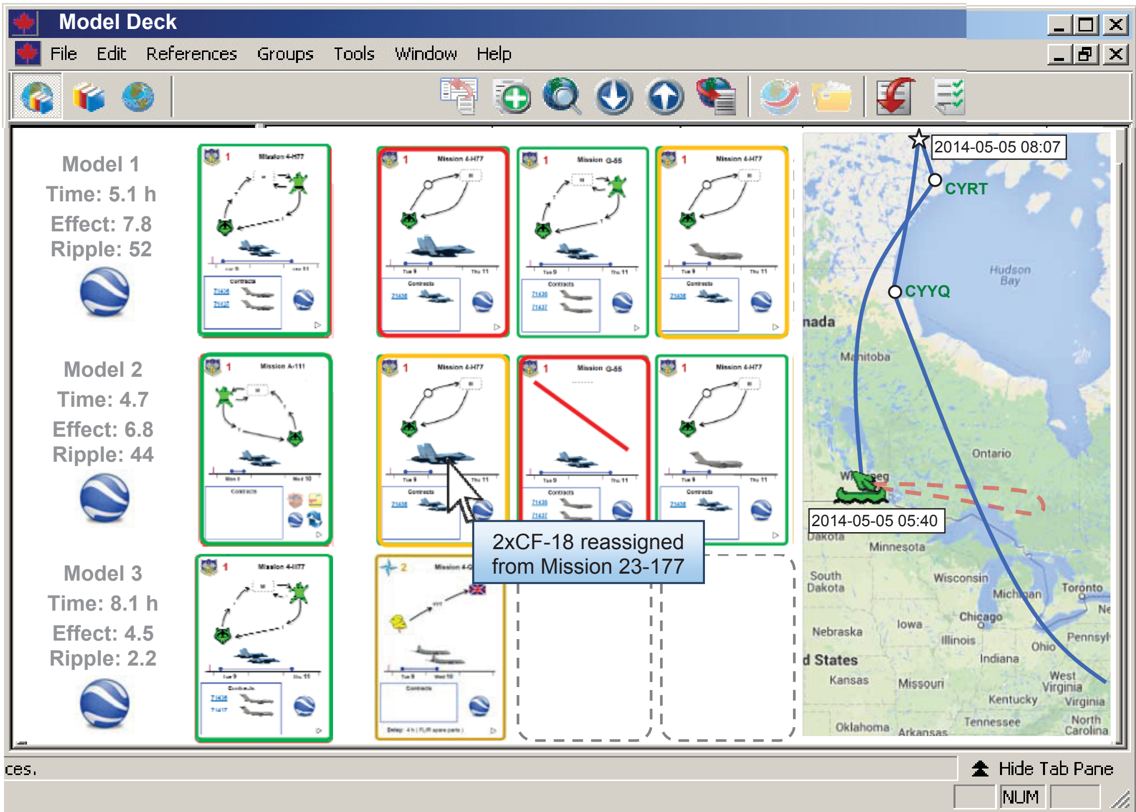


Figure 4-20 Emerging Solution in the Package Re-Planner Window

Each row of cards represents a different re-planning model and its ripple effect. Mouse-over a row of cards to see a sketch-map of that proposed solution, with proposed missions shown in blue, and broken missions (cancelled or delayed) shown with red dashes. Right-click on a card to pop up its Gantt chart, request recommended re-planning solutions, or view the full-size mission card. As the problems with the each re-planning model are resolved, the cards in that row go green. In the end, each row contains cards for every mission that was impacted by the re-planning. Users can mouse-over each of these cards to see how that mission was impacted. Click on the Google Earth icon to view the old a new plan geographically. If required, both displays can be exported to a PowerPoint slide for use as a briefing of the Options Analysis.

Whenever the plan is modified, NEP re-calculates the quality of the effect, and the ripple effect, and modifies the displays accordingly.

4.4.5 Choosing the Three Recommended Options

A key element of the Re-Planner design is the selection of the three "best" options for presentation to the users. This approach is partly inspired by Google Maps and SWIC, as discussed in Sections 3.3.3 and 3.4.2. The three selected options are:

- **Soonest:** the option that gets an acceptable aircraft at the FRFE site soonest
- **Best Dwell:** the option that achieves the best time-integrated payload value on the FRFE site.
- **Least Ripple:** the option that achieves and acceptable effect with least ripple effect.

A. Acronyms and Abbreviations

1Cdn Air Div	1 Canadian Air Division
ACCE	Air Component Coordination Elements
ACUMEN	Advanced Capability for Understanding and Managing Effects Networks
ADA	Air Domain Awareness
ADM-IM	Assistant Deputy Minister for Information Management
ADS-B	Automatic Dependent Surveillance – Broadcast
AFC2	Air Force Command and Control
AFRL	Air Force Research Lab
AOC	Aerospace Operations Centre
API	Application Programming Interface
ATO	Air Tasking Order
C2	Command and Control
C2Core	Command and Control Core Ontology
C2PC	Command and Control Personal Computer
C2RPC	Command and Control Rapid Prototyping Continuum
CAE	CAE Professional Services (Canada) Inc.
CAOC	Combined Aerospace Operations Centre
CBR	Case-Based Reasoning
CF	Canadian Forces
CFACC	Combined Force Air Component Command

CFS	Canadian Forces Station
COA	Course of Action
COP	Common Operating Picture
CORBA	Common Object Request Broker Architecture
DL	Description Logic
DND	Department of National Defence
DoD	(US) Department of Defense
DRDC	Defence Research and Development Canada
DSS	Dynamic Scheduling System
DWARP	Distributed World-Wide Aeronautical Planner
ETA	Estimated Time of Arrival
FAA	(US) Federal Aviation Administration
FE	Force Employment
FG	Force Generation
FLIR	Forward-Looking Infrared
FPCON	Force Protection Condition
FRFE	Fuzzy Request for Effect
GCCS	Global Command and Control System
HTTP	Hypertext Transfer Protocol
IFF	Interrogation Friend or Foe
IM/IT	Information Management and Technology
ISS	Intelligent Software Solutions
ISTIP	Intelligence Science and Technology Integration Platform
JAOD	Joint Air Operations Directive
JCDS	Joint Command and Decision Support

JSON	Javascript Object Notation
KML	Keyhole Markup Language
LCol (ret'd)	Lieutenant Colonel (retired)
LGen	Lieutenant General
MAAP	Master Aerospace Action Plan
MHCB	Mission Hockey Card Browser
MDA	Maritime Domain Awareness
MICTB	Multi-Intelligence Capability Test Bed
MOE	Measure of Effectiveness
NAPP	National Aerospace Planning Process
NAPPIC	NAPP Integration Capability
NATO	North Atlantic Treaty Organization
NAVCAN	Navigation Canada
NCDS	Net Centric Data Strategy
NDHQ	National Defence Headquarters
NEP	NAPP Enhancement Prototype
NFE	Non-Forecast Event
NORAD	North American Air Defence
NOTAM	Notice to Airmen
OWF	Ozone Widget Framework
OWL	Web Ontology Language
RAP	Recognized Air Picture
RCAF	Royal Canadian Air Force
RCAT	Rapid Course-of-Action (COA) Analysis Tool
REST	Representational State Transfer

RFE	Request for Effect
RWS	Remote Work Station
SC	Supported Commander
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SOW	Statement of Work
SWIC	Strategic Worldwide Integration Capability
SWRL	Semantic Web Rule Language
TARM	Total Air Resource Management
TBMCS	Theatre Battle Management Core Systems
TOI	Track of Interest
TSD	Traffic Situational Display
UCore	Universal Core Ontology
URI	Universal Resource Identifier
US	United States
VA	Visual Analytics
VOiiLA	Visionary Overarching Interaction Interface Layer for the Analyst
W3C	World Wide Web Consortium
WIDE	Work-Centered Interface Distributed Environment
XML	Extensible Markup Language
YAOD	Yearly Air Operation Directive
YFR	Yearly Flying Rate

B. Minutes from the CAOC Visit

Date:

2013 Feb 6

Location:

1 Canadian Air Division HQ, Winnipeg

B.1 Morning Presentation

Attendees:

- Major Lisa Baspaly, A2 (intelligence) Plans
- MWO Bruce Chartrand, CAOC Mission Support
- Major John Cowan, A3 Strategic Plans
- MSgt Joe Behun, A2 - ISR Ops
- Ted Skoczylas, A6 C2/S 2
- Major Shaun Bakker, A6 CRIP / A6 C2IS
- Capt Jamal Oromo, A6 CRIP
- Maj Jacques Robitaille, A5 / A7
- Sqn Ldr Dez Foster, CAOC CPD Chief
- LCol Dixon, Chief Combat Ops
- Jean Berger, DRDC Valcartier
- Abder Sahi, DRDC Valcartier
- Doug Stroud, Saxon Bay
- Mike Davenport, Salience

Presentations

- Jean presented a summary of DRDC's program
- Mike presented a draft description of the "User Experience" for the Napp Enhancement Prototype (NEP).

Comments

Scope of operations:

- Strategic Worldwide Integration Capability (SWIC) (from ISS) supports 3000 lines of tasking. A line of tasking corresponds approximately to the lines in the Gantt

Chart

- Operational software must be deployable
- Typical NATO-type CAOC is 600 people surging to 2500

Ripple Effect:

- Ripple effects of 3 weeks should be OK – but it depends on the Operational Tempo. E.g. during an exercise, ripple effects will be more severe.
- NAPPIC has an internal model of cause-and-effect, but the CAOC does not use it because there is no data feeding it.
- Ripple effect can be described in terms of each "contract" established between the CAOC and the Wings. If a resource is re-assigned due to an un-forecast effect (UFE) requirement, then the ripple effect appears as assertions that "Contract XYZ cannot be fulfilled"
- In NAPPIC a "contract" is a pairing of two missions (e.g. tanker mission and fighter mission)
- Right now, resource re-assignment (or an external event such as weather) causes the planners to "re-roll all the missions" to identify ripple effects.
- Theater Battle Management Core Systems (TBMCS) provides planning and operational support

Deconfliction of Air Space

- Re-planning also involves deconflicting of air space.
- Air space deconfliction involves setting up 4D "maps" of air operational areas
- US does 96h deconfliction, which is "standard" Force Employment planning timeframe
- NAPPIC does deconflicton of air space
- NAPPIC has a time-slider on a map portraying where all aircraft should be in the future

Flight Pro

- Flight Pro 7 is used in the Wings by Squadrons. .
- Key elements of FP7 are "decision points"
- Flight Pro was designed based on TBMCS instead of NAPPIC

Air Domain Awareness

- NAPPIC can suck-in the weather.
- "Stoplights" are used already as part of the brief every morning
- "Friendly Order of Battle" should describe the disposition of all friendly force employment: land, sea, and air assets.
- The AOC needs to visualize Threat and Risk (e.g. they now use Threat Rings in the

ADA display) – the "Red COP"

- NAPPIC has an Enemy Order of Battle capability
- Updates to tasked missions manually pushed from the tactical level to the AOC or pulled by AOC from the tactical level
- CAOC often does not know where aircraft are, which is critically important. This may be a critical deficiency of the current system. Lack of visibility into the location and readiness of both tasked force employment aircraft and force generation aircraft (i.e. under training) articulated by previous Commanders and captured in the CAE Report has been repeatedly flagged as a problem to informed decision making.

Communications

- Domain Awareness needs to include communications
- Airbus has a datalink to base because of its heritage as a commercial aircraft, but it is underutilized

Planning

- Q: Does NAPPIC provide a <u>visual</u> ATO?
- A: Use the Air Operations Directive (AOD) to encapsulate the commanders' priorities
- NAPPIC accepts a description of the AOD
- Currently they use Word, Excel, etc for the AOD
- Vision: have a NAPPIC unit that accepts AOD and interprets it
- ISS spent hundreds of millions of dollars to map out dependencies within the planning process
- Also NAPPIC generates ATO's and ACO's and does airspace deconfliction, based on what was shown in the demo.
- No interaction between NAPPIC and MIDB (Modernized Intelligent DataBase)

Replanning

- NAPPIC can block re-planning if the new plan is not viable
- The scope and spectrum of air operations is very broad
- During exercises, the tempo of operations is too high to do things the way RCAF normally does – in that situation we need dynamic re-tasking of assets.
- In battle, the priority system can be trumped by analysis of risk

Software Options

- There are no systems designed for non-combat CAOCs, so NAPPIC is a bit of a square peg in a round hole
- NAPPIC has hooks for GCCS, MS Office, and Google Earth, for example
- CF paid to remove bomb-dropping elements of NAPPIC

- ADM-IM is working on data integration
- “What if” analysis can be done with “White Board” software
- The US budget for sustainment of 18 systems of systems is $1.5 B
- ISS is selling ACUMEN, which might cover the NEP goals

Requirements

- The types of information displayed must be linked to the log-in identity of the operator.
- Need support to visualize joint situations (air force, army, special ops, navy)
- The low-hanging fruit right now is integration of data – ideally across both unclas and classified networks
- “The GUI is the easy part; organizing the data for data exchange and replication is the hard part”
- All the ADA and planning information visible in the CAOC must be accessible by the Wings

Scenario

- The Arctic mission scenario is a “no brainer” because there is a priority system, and the Staff College mission would have a lower priority than the Arctic mission
- A good scenario would involve humanitarian relief

What the NEP Should Focus On

- CAOC CPD Chief suggested: The final NEP demonstration should say “here is what we have, here is what we could have, which is 10% better”

B.2 AOC Tour

Attendees:

- LCol Dixon, Chief Combat Ops
- Jean Berger, DRDC Valcartier
- Abder Sahi, DRDC Valcartier
- Doug Stroud, Saxon Bay
- Mike Davenport, Salience

Observations:

- Use the term AOC for the 24h Operations Centre, and CAOC for the whole analysis team
- Two of the three main displays are geographic, similar to Google Earth
- NASA World Wind http://worldwind.arc.nasa.gov/features.html provides a similar capability to Google Earth
- No “what if” capability in the AOC

- No dynamic and fused display of sensor coverage
- They get a MET feed that can be displayed as text on the screen

B.3 NAPPIC Demonstration

Attendees:

- Sqn Ldr Dez Foster, CAOC CPD Chief
- Two NCOs who work with NAPPIC
- Jean Berger, DRDC Valcartier
- Abder Sahi, DRDC Valcartier
- Doug Stroud, Saxon Bay
- Mike Davenport, Salience

Observations:

- NAPPIC resides on a classified system
- There are two versions of NAPPIC (full and lite)
- Navy and Land Forces have the lite one to be able to read ATOs and ACOs
- Request for Effects data resides on classified and unclassified systems
- Requests for Effect data is imported into NAPPIC from an Excel spreadsheet that captures data exported by the RFE database. Of note, the RFE database is not currently "supported", which could result in "problems" until the right skill set is applied to the problem.
- NAPPIC can read airlift data from the Dynamic Scheduling System (DSS)
- NAPPIC cannot pull data from the Special Events database, which captures unclassified requests for aircraft to support airshows
- The Mission Manager screen uses one line for each mission, colour coded by status
- There is a Strategy Manager
- You can create templates for modifying missions, for example "Add Refueling Request"
- NAPPIC provides no visualization of "what if" scenarios
- No connection between NAPPIC captured flying time and unit flying and aircraft maintenance logs

NAPPIC User Guide

- Version 1.0, 2 August 2010, Intelligent Software Solutions

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