# EO and SAR Constellation Imagery Collection Planning

Ella Herz[1]
*Orbit Logic, Greenbelt, Maryland, 20770*

**This paper will discuss various spacecraft and sensor models within Orbit Logic's Collection Planning & Analysis Workstation (CPAW), CPAW collection planning algorithms, and the CPAW approach to solving the satellite imagery collection planning problem. The paper will focus on how CPAW is able to meet this challenge for satellites constellations with various levels of agility and sensor types.**

## Nomenclature

| | | |
|---|---|---|
| *CPAW* | = | Collection Planning & Analysis Workstation |
| *EO* | = | Electro-Optical |
| *FOM* | = | Figure-of-Merit |
| *HGA* | = | High Gain Antenna |
| *LEO* | = | Low Earth Orbit |
| *OBP* | = | One Button Planning |
| *RGT* | = | Remote Ground Terminal |
| *SAR* | = | Synthetic Aperture Radar |
| *SSR* | = | Solid State Recorder |
| *STK* | = | Systems Toolkit (software developed by Analytical Graphics Inc.) |

## I. Introduction

By its very nature, the satellite imagery collection planning challenge is difficult. The solution space is extremely large – encompassing thousands of imaging orders and hundreds of variables related to the abilities of the satellites, sensors, and ground network. The complex system constraints include power, data storage, pointing, agility, sensors, etc. Yet there is a desire for "optimized" plans that maximize return from limited and expensive resources while balancing objectives for priority, area collected, resolution, cloud cover, and more. Satellite imagery collection planning systems must meet the performance demands of multiple planning sessions to cover constellations of spacecraft for 15 orbits per day for a typical LEO spacecraft while meeting the short timelines intrinsic to dynamic cloud forecasts and customer requirements for fast order turnaround.

Whether the satellite is a fully agile optical imager, fixed beam SAR spacecraft, pushbroom imager with limited agility, or a frame camera, Orbit Logic's Collection Planning & Analysis Workstation (CPAW) software solves the difficult problem of satellite imagery collection planning through a spacecraft simulator coupled with scheduling algorithms that generate high fidelity imagery collection plans for use in operations, analysis, or imagery ordering. CPAW covers everything from contact scheduling and recorder management to power and antenna modeling while accounting for clouds, terrain, timing constraints, platform agility, and sensor capabilities. Planning can be completely manual, fully automated, or anywhere in between to plan for anything from a single image on a single satellite to massive order decks collected by a mixed constellation of multiple EO and SAR spacecraft.

Orbit Logic's CPAW software is currently the only commercial software package that can generate coordinated imagery collection plans for fully agile, fixed beam, frame camera, and pushbroom satellites in a single integrated system. This multi-use capability is especially useful in a fleet with a variety of assets or for imagery customers that have access to multiple spacecraft from multiple operators. The synergy and efficiency of using a single planning system instead of separate, stovepipe systems for each type of satellite can bring significant efficiency and value to satellite operators, analysts, and imagery end customers.

The addition of satellites into CPAW is a quick and easy configuration process that does not generally require any new software development. The US Army Remote Ground Terminals (RGT) will be using CPAW to plan

[1] Chief Operating Officer, Orbit Logic, 7852 Walker Drive, Greenbelt, MD.

imagery collection for both SAR fixed beam and agile EO satellites. The Australian Defence Science and Technology Organisation (DSTO) uses CPAW for analysis on a proposed constellation of cubesats and nanosats with varying levels of agility (pushbroom, fixed beam, and agile). A customized version of CPAW is also deployed to support operational collection planning for DigitalGlobe's WorldView-1, WorldView-2, and GeoEye-1 spacecraft at DigitalGlobe's international ground station partner sites.

## II. Spacecraft and Sensor Models

Satellite imagery collection planning requires more than just line of sight calculations. In order to generate plans with the fidelity required for operations modeling must include: camera/imaging modeling, spacecraft agility/slew modeling, power modeling, data storage and downlink modeling, bright object constraint modeling, system timing rules, high gain antenna agility and constraint modeling, ground station location and obscuration masks, target access constraint modeling, space region constraint modeling, and restricted ground area constraint modeling. This level of modeling and simulation is also necessary for accurate collection feasibility and timeline assessments, especially when multiple targets, area collections, and satellites are involved. Different spacecraft operate in different ways and have different constraints. An off-the-shelf tool must be configurable to handle most or all of the common operations approaches and constraints, with an architecture that is modular and flexible enough to support updates when a new concept or constraint is inevitably encountered for a new spacecraft.

### A. Imaging Model

Typically the most complex model is the Imaging Model. The Imaging Model must take into account not only the capabilities of the sensor and various imaging modes, but also pointing requirements for the spacecraft during imaging. The common satellite imaging approaches in use today are listed below.

- **Line Sensor:** In this imaging mode a line sensor is moved across the target to form a swath image at any angle relative to the ground track as shown in Figure 1. This type of sensor often has a selection of line rates and the option for stereo imaging within a single pass. This imaging mode is used by the most sophisticated commercial imaging satellites.

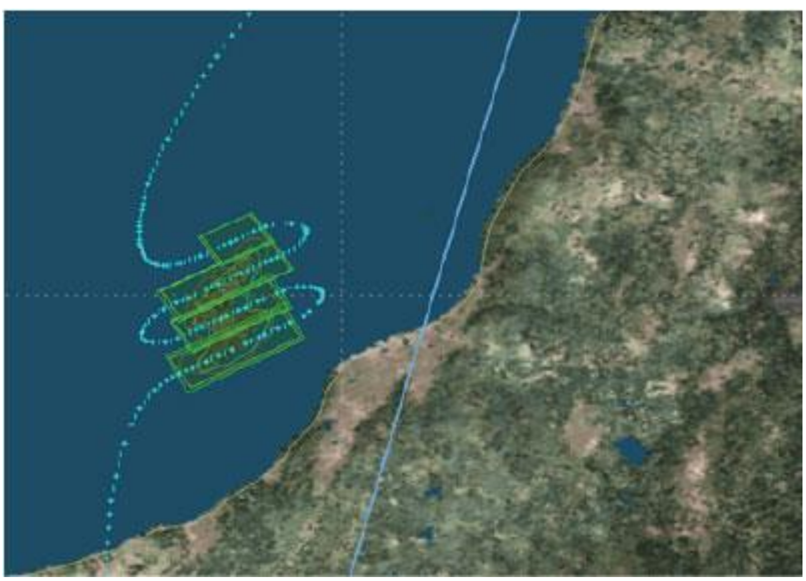

**Figure 1. Sensor boresight path of a complex maneuver for an agile high resolution optical satellite**

- **Beam Imaging:** This imaging mode is most commonly used in SAR satellite imaging, where one of several available "beams" are selected to image a fixed off-nadir "scene" area as shown in Figure 2. Mutliple scenes may be taken in line parallel to the ground track.

**Figure 2. Beam selection to collect the highest value area for a SAR satellite**

- **Pushbroom:** In this imaging mode the sensor footprint is swept across the ground (at orbital velicity and parallel to the ground track) while the spacecraft/sensor platform is maintained in a constant LVLH pointing attitude as shown in Figure 3. This mode is still in use by many commercial spacecraft.

**Figure 3. Slew and simple imagery collection for a low resolution Pushbroom satellite**

- **Frame Camera:** In this imaging approach the the sensor boresight is pointed at the target for a brief time and takes a "snapshot" photo. This mode is used by newer small spacecraft, sometimes to take a series of images of the same target to generate a short "video".

One of the unique features of CPAW is the ability to perform coordinated collection planning at operational fidelity for a mix of spacecraft types, each with different imaging modes and models. An instance of CPAW has been delivered for the US Army Remote Ground Terminal (RGT) which uses CPAW to plan commercial imagery collections by the Worldview-1, Worldview-2, GeoEye-1, and RADARSAt-2 satellites in a single system, supporting both SAR fixed beam and agile EO imaging.

### B. Slew Model

Slew Modeling can also be quite complex, simulating the spacecraft and/or sensor attitude before and after imaging events. The slew model is especially important for agile spacecraft in determining whether the spacecraft can maneuver sufficiently between successive imaging events. CPAW provides an interface to plug-in a separate slew model for each spacecraft. These slew models are typically provided by the spacecraft manufacturer (or developed based on manufacturer specifications) and usually have many configurable parameters that are adjusted to "tune" the slew model based on on-orbit calibrations and telemetry measurements. Configurable parameters may be adjusted using a GUI interface or by replacing or editing an XML file. Detailed slew models and plan visualization used during spacecraft and instrument development help find problems pre-launch and provides for smooth on-orbit checkout and transition to operations.

### C. Power Model

The Power Model within CPAW can be configured for low fidelity or more complex high fidelity power modeling, depending on system power constraints. Low fidelity power modeling is implemented through a simple duty-cycle constraint on the imager. Many satellites approach power limits with duty cycle constraints in operations. With the high fidelity power model, CPAW simulates power generation, accounting for the changing attitude of the spacecraft and solar arrays. Configurable parameters for the power draw include background power usage, communications, and imaging draw per imaging mode during sensor on times. With the high fidelity power model, the user can also specify the battery depth of discharge limit.

When duty cycle limits are selected and configured, CPAW algorithms respect the duty cycle constraints and generate imaging plans respecting those limits, which often means limiting the number of images collected. When high fidelity power modeling is configured, power is driven by pointing, and CPAW algorithms perform modeling and collection planning in concert, checking battery depth of discharge as the plans are built to ensure operation within limits. Battery depth of discharge issues are often resolved by algorithm selection of image collections (when available) that orient the spacecraft arrays towards the sun.

### D. Data Storage

Since Data Storage is often a limiting factor for satellite imaging systems, models for data storage and downlink are particularly important to overall planning. Recorder state tracking and downlink planning must take into account High Gain Antenna (HGA) agility, playback rates, file management protocols, and recorder timing constraints. Multiple configurable playback protocol options may be specified, including FIFO and priority-ordered downlink. Downlink limits may related to simultaneous imaging or lack of support thereof. In addition, individual tasking requests may specify specific ground stations (or multiple ground stations) for targeted file downlinks. Resolution of conflicts due to limited recorder space can be solved using one of two approaches; 1) eliminate planned imaging events that violate recorder capacity limits, or 2) remove lower priority images from the recorder (if any) to make room for higher priority image data.

CPAW has been used for operational planning on multiple satellite prorams over the past decade. While CPAW performs downlink planning and onboard data storage management with automated algorithms, the capability exists to manually adjust downlink plans. This capability has almost never been used in operations due to the extensive configurability and robust nature of the planning algorithms, and due to the volume of downlink events which can overwhelm an operator. Procedures and hooks are also available in CPAW for the redownlink of images with missing or corrupted data. Again, these capabilities have almost never been needed due to the robust nature of modern satellite communications.

### E. Bright Object Constraints

Bright Object Constraints for the sensor and for up to two start trackers may be configured and enabled for moon, earth, sun glint, and sun pointing limits. Plans which would point the imaging sensor or tracker within the configurable pointing threshold are rejected by the constraint-enforcing algorithms within CPAW and alternative plans are generated for scoring and ultimate selection and uplink.

In our experience, bright object pointing constraints are often defined very conservatively in the design phase and softened considerably during operations. CPAW provides the ability to reconfigure pointing threshholds at any time, or to set specific constraints as hard limits, warning (soft) limits, or even to ignore the defined constraint entirely.

### F. System Timing Rules and Blackout Periods

System Timing Rules include minimum time between images and minimum post-umbra buffer before the start of imaging. Over several years of CPAW development and deployments for various spacecraft, we have assembled several common system timing constraints within the software. These can be enabled/disabled and configured as needed for specific spacecraft within CPAW. On occasion, a new timing constraint type is encountered and added to the software product.

In addition to system timing rules, the user can also manually define blackout periods or service requests when a specific spacecraft or ground station is unavailable for operations. Algorithms automatically adjust plans around specified blackout periods.

### G. Communication Constraints

High Gain Antenna Constraints present themselves in a variety of ways for different spacecraft. Some spacecraft can image and downlink at the same time by using agile high gain antennas, while other spacecraft must maneuver to keep their fixed high gain antenna pointed at the ground station during downlinks and thus preclude simultaneous imaging, and some spacecraft use omni antennas (with lower downlink rates) and do not require pointing. Even with agile high gain antennas, there are often spacecraft pointing limits due to pointing mechansism constraints and spacecraft structure blockages. These constraints can sometimes be quite complex and involve multiple gimbals, hard stops, rate and acceleration limits, and detailed blockage masks. CPAW provides configurable options to cover all of these cases for each spacecraft defined in the software. As part of downlink modeling ground station location and obscuration masks are configurable for any ground station defined through user interfaces or XML file.

Planning algorithms need to support collection planning during downlinks, and make appropriate imaging and maneuver decisions to avoid downlink interruptions. CPAW supports this requirement and also provides the ability to define an imaging priority threshold above which downlink interruptions are acceptable.

### H. Area Constraints

Region Constraints define areas in space where imaging is precluded from. The South Atlantic Anomaly region is one example of a constrained area that could be defined. When the satellite is within a defined constrained region, then no imaging is allowed. Multiple region constraints may be specified in CPAW.

Restricted Area Constraints define areas on the ground where imaging is not allowed. These can be applied on a CPAW deployment-specific basis to control which imaging areas are allowed for various users or customers. These constraints are especially useful for shared systems where different users have different rights to image different areas. Because of this specific common use-case, it is important to make these controls secure from end-user modification.

### I. Forecast Weather Modeling

Weather Constraints are applied for only EO sensors. CPAW supports multiple standard cloud cover forecast formats including GRIB1, GRIB2, and others. The applicable cloud cover prediction is applied for each specific imaging opportunity. CPAW supports cloud-based tasking request filters as well as cloud cover scoring for each imaging opportunity considered by the planning algorithms or manual planner.

A global cloud cover forecast in GRIB2 format is available from the NOAAs National Center for Evironmental Predictions (NCEP). While the forecast resolution is sub-optimal (1/2 degree cells), this option may be chosen since the data is provided for free. High resolution global and regional cloud forecasts are available commercially from MDA Information Systems and other sources. Note that cloud cover forecasts are notoriously inaccurate more than 6 hours into the future, especially in some parts of the world and during certain seasons. The short range nature of cloud cover forecast accuracy is often the primary driver behind EO imaging satellite planning timelines.

## III. Collection Planning Algorithms

Within CPAW, multiple algorithms compete against each other to create an optimized collection plan within minutes. Each algorithm approaches the plan building and optimization differently, but all algorithms respect hard system constraints and support all imaging modes. Multiple algorithms can be run in parallel on multi-processor systems, so there is no limit to the number of algorithms that may be applied to the plan-building process. All algorithms start with the same input – a list of specific, single-image targets with pre-computed imaging opportunity windows. Large area targets are split (on an opportunity-by-opportunity basis) into individual swaths, scenes, or scene-groups (as appropriate for the imaging mode) to form the “single-image targets” (which are also referred to individually as “strips” within CPAW nomenclature).

The algorithms iterate with the various constraint, slew, and imaging models to generate valid plans. In addition, the current collection of algorithms within CPAW are all constructive in nature. This means that any algorithm can be interrupted at any point and still return and valid plan solution. However, if an algorithm is interrupted, the plan may not be as comprehensive as if the algorithm was allowed to run to completion. As each new image is added to the plan, it is validated by the constraint models within CPAW. Any constraint violation encountered by the insertion of this image to the plan causes the algorithms to adjust the tasking of the image within the plan (potentially removing it) before the next image is added. A timeout in the middle of this validation process causes the system to retrieve the [last validated] solution that does not include the latest image still under validation.

All algorithm plan solutions are scored using a common Figure-of-Merit (FOM). The highest-scoring solution/plan is returned for operator review in tabular and 2D/3D map and/or 2D/3D animation formats. Scores and statistics are provided for each algorithm run. The standard CPAW FOM includes factors for priority, area, cloud cover, resolution, price/cost, and more. Each factor may be weighted and normalized using configurable parameters available to the user through the FOM GUI. Because the FOM is only loosely-coupled to the algorithms (some algorithms use preliminary FOM scoring to assist in the plan optimization process), a custom FOM can be implemented fairly easily within the CPAW architecture.

## IV. Collection Planning Approach

A sample operations concept for CPAW shows how the various pieces of CPAW come together to perform all the necessary steps for collection planning.

Sample Ops Concept:

1. define orders;
2. create or receive contact schedule;
3. generate planning windows based on contacts, orders, sunlight, etc;
4. filter orders; based on access variables, priority, weather, etc;
5. divide orders into strips based on sensor parameters;
6. run algorithms to generate collection and downlink plans;
7. transmit plans to command system;
8. receive status from image processing system;
9. track order fulfillment (unfulfilled areas retained for future planning.

This full process can be run manually, fully automated, or partially automated for a single spacecraft or a fleet of imaging systems with varying sensors and capabilities.

### A. Order Definition

Order Management includes the ability to add, edit, review or delete point or area targets on the ground or in space. Orders can be imported via file in a variety of formats (kml, shp, etc.), pulled in from STK objects such as point targets, area targets or facilities, created in Google Earth, or even defined manually using lat/lon points.

Target Imaging Constraints may be defined separately for each tasking request (through the tasking request API or GUI). Imaging constraints include elevation/off-nadir angles, imaging azimuth angles, lighting constraints, resolution limits, cloud cover limits, and more. These limits are used both for initial imaging opportunity determinations and for final detailed image tasking validation. The Target Imaging Constraints for an order are specific to the phenomenology of the sensor (i.e. panchromatic sensors and SAR sensors have different options). CPAW provides order creation wizard capability that ensures imaging constraints are self-consistent with the selected phenomenology (polarization attribute is only for SAR requests, cloud cover applied only for EO, etc.). Other tasking attributes include the ability to specify stereo collection and/or recurring collection for any order, or to open up the imaging options and specify “consistent collect” limits to ensure that multi-pass images are collected in a manner that is supported by the user’s ground image processing software (all EO, all SAR, or perhaps all collected by a single satellite).

Order Management is one part of the planning system that is often useful to open up to end customers. Orbit Logic has extended the order management capabilities within CPAW to a web interface through a new Order Logic web application. Logins and configurable permissions ensure that users are limited the order management capabilities and data for which they are authorized.

## B. Contact Scheduling

Because recorder space is one of the key limiting factors in satellite imagery collection, the first real step in its planning is defining when the images can be downlinked. Recorder management and downlink planning are dependent upon a schedule of contacts between the satellites and ground stations. CPAW includes simple contact scheduling that is sufficient for small imaging constellations. CPAW contact scheduling takes into account the location, elevation, and obscuration mask of the ground station as well as the communication abilities of the spacecraft. Deconfliction is a simple first-come, first-served approach. Orbit Logic's STK Scheduler software can also be used to generate CPAW-compatible, optimized, deconflicted contact schedules for more complex configurations and optimization approaches – for instance with a very large constellation of satellites with multiple ground stations such that any ground station may have access to multiple satellites at any one time. CPAW also supports the used of externally-generated contact schedules via file import. Contact schedules include AOS and LOS times, elevation, and azimuth for each contact between a satellite and ground station.

The user has the ability to review contact schedules (regardless of the source) and edit them within the CPAW GUI as needed.

## C. Planning Windows

The amount of time to be planned (aka Planning Window) varies from customer to customer. CPAW provides a number of options for automatically defining Planning Windows for analysis or operations based on physical constraints. Most simply, Planning Windows can be auto-generated for each spacecraft based on the sun – either with the satellite or the earth (within the sensor FOR) being in the sun during the Planning Window. Planning Windows can also be auto-generated based on the target requests in the system such that CPAW only considers planning during times when there is a valid target collection opportunity. For operations, Planning Windows are often generated based on contact schedules such that planning would occur for the time period from one contact until the next. This Planning Window approach aligns with typical satellite command generation processes. With contact-based Planning Windows, the user can decide if planning should occur only in contact or between contacts and whether it should also consider lighting constraints for the earth or the spacecraft. Planning Windows can be viewed in 2D or 3D in STK or Google Earth showing the ground track and spacecraft swath as well as original and unfulfilled target requests as shown in the figure below.

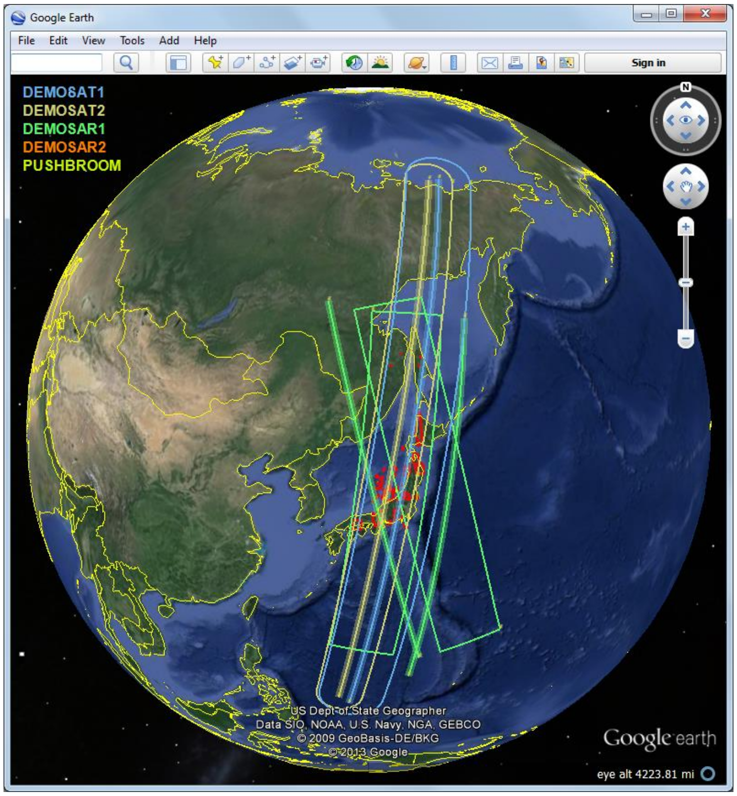


**Figure 4. Planning Window Visualization.**

**D. Filtering**

Once a Planning Window is chosen, planning for that window begins with figuring out what images can be taken during that window. First, large targets have to be broken down into “strips”. The size and orientation of the strip depends on the scan model, imaging constraints, spacecraft and sensor configuration, orbital geometry, and order parameters. The planning is actually done at this strip level, not for whole target areas. The figure below shows an target area order broken up into multiple strips, of which only a few (shaded) are included in the plan.

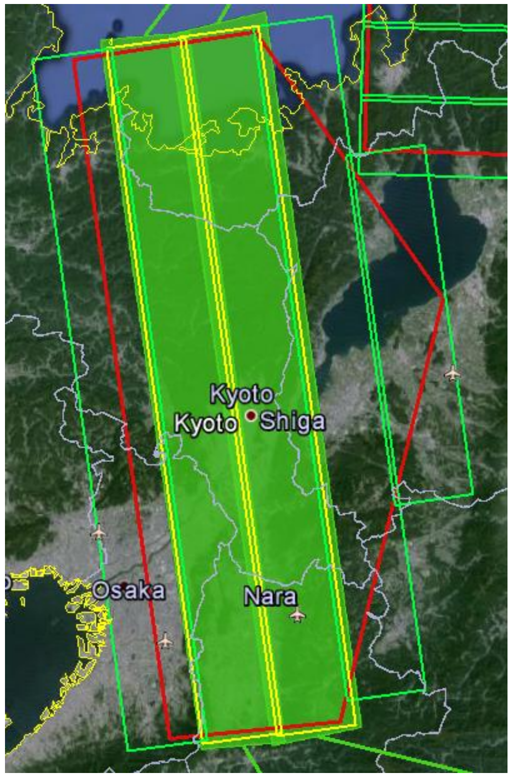


**Figure 5. Target Area broken into strips.**

Filters are applied to both the full order and to the individual strips. Orders and strips can be filtered based on factors including priority, location, line of sight, cloud cover, and/or off nadir angle. Only strips that meet all filter criteria, plus all other imaging constraints are considered for planning.

**E. Collection Plans and Data Storage Plans**

Once the Contact Schedule and Planning Windows are defined and the areas have been filtered, it is time to decide which strips to include in the plan. Algorithms run as described above to create an optimized, deconflicted, validated imagery collection plan and associated data storage/downlink plan. The user will be notified of any violations to soft constraints (algorithms will never create a plan that violates hard constraints). The user can manually adjust the plan by including or excluding images from the plan or changing imaging start and stop times or imaging modes. Each time a user changes the plan manually, the plan is validated and violations are displayed.

In addition to the collection plan, the user can also view the data storage plan. The data storage plan shows all events related to data storage including contact AOS/LOS, image capture, image playback start/stop, image deletion from the recorder, and HGA events. For any given event in the data storage plan, the user can also view state information that shows the images on the recorder at that time as well as recorder state data.

The output XML plan is then transmitted to the command and control system for the satellite. The file is merged with other operational procedures and translated into commands for the satellite.

**F. Order Fulfillment**

After the Collection Plan has been transmitted, CPAW assumes that the images included in the plan have been fulfilled and will not attempt to include those images in future plans unless a failure status is returned from the image processing system or from the command system. Because large areas are broken up into smaller strips, it may take multiple scans to fulfill a single order. Likewise a single strip may fulfill multiple orders provided that the image is collected within constraints of all overlapping orders. CPAW tracks the amount of area collected and the percent complete for each area. Order fulfillment can be viewed in 2D or 3D in STK or Google Earth as shown in the figure below. This type of order fulfillment visualization can be useful to demonstrate to customers on a day-by-day or pass-by-pass basis how their imagery orders are completed over time.

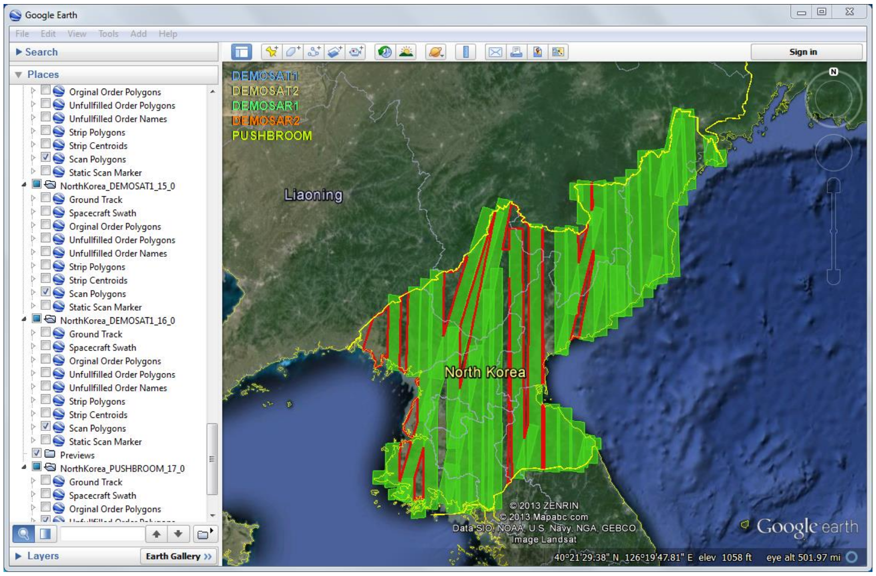


**Figure 6. CPAW Area Fulfillment Analysis**

## G. Constellation Planning & Automation

CPAW has unique automation features that support both operations and analysis for coordinated multi-satellite systems. Planning for each satellite takes into account planning completed for other satellites in order to avoid redundant area or target collections and to support collaborative multi-satellite collections of large area targets. While this can be done through manual planning in CPAW, a feature called “One Button Planning” (OBP) allows the user to execute planning for a specific period of time for all satellites. Planning Windows are auto-generated and unioned for all satellites based on computed valid target access times for the entire target deck, and the algorithms run on all windows. Order fulfillment is tracked as planning is completed to facilitate coordinated planning between satellites. A Google Earth globe is also updated with plan visualizations for each window during the planning run. Orbit Logic and its CPAW customers have used the OBP feature extensively for collection analysis purposes, often comparing results for a specified set of targets based on different satellite constellations or sensor/satellite capabilities. The Australian Defence Science and Technology Organisation (DSTO) used CPAW for analysis on a proposed constellation of cubesats and nanosats with varying levels of agility –pushbroom, fixed beam, and agile – to examine satellite imagery coverage of Australia with the smallsat constellation [Stepan 2012] and combined with other commercial satellite imaging systems [Cartwright 2013]. Figure 6, above, was generated with an OBP run with no manual intervention. The OBP feature is also very useful for imagery customers that have multiple sources for satellite imagery, allowing them to make more efficient use of those resources and make better decisions about sourcing requirements to various vendors. CPAW includes optional email interfaces for imagery ordering and status feedback. Orbit Logic has pre-coordinated email ordering specifications with several commercial satellite operators.

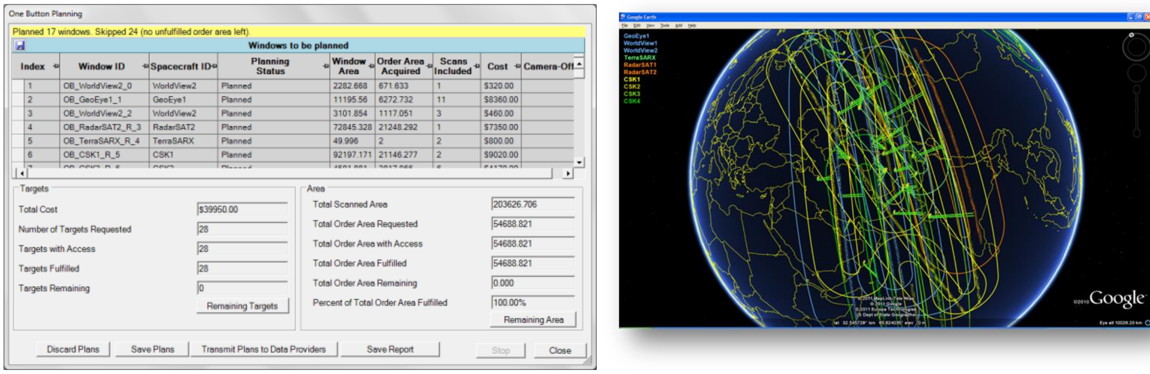


**Figure 7. CPAW OBP Metrics GUI and Associated Google Earth Visualization**

In addition to OBP, which is especially useful for analysis and imagery ordering, CPAW provides a light-out feature that is designed primarily for spacecraft operators. When CPAW lights-out planning is turned on, CPAW will auto-generate Planning Windows for all spacecraft based on the latest contact schedule and execute planning on a recurring basis based upon a configurable pre-contact start time. Window generation and planning will continue until disabled by an operator. No operator interaction is required while lights-out planning is enabled, and plans will be generated and transmitted for execution (and order fulfillment tracked) in time for uplink to the satellite on each contact. The latest order database, ephemeris, and contact schedules are used for the planning session for each Planning Window and can be updated at any time. Orbit Logic has applied years of operational experience to the lights-out planning process within CPAW, allowing satellite operators to reduce operations staff and dramatically shorten planning timelines while simultaneously improving the return from their satellite assets.

## V. Conclusion

The imaging satellite collection planning challenge requires a wide range of accurate modeling, high fidelity simulation, and advanced algorithms as described in this paper. Frequently, this challenge is addressed with satellite-specific software development. This approach, which is time consuming, technically risky and expensive, does not address the greater challenge of how to effectively use a variety of satellite assets with mixed capabilities to efficiently collect customer tasking requests. The manual coordination of multiple stove-pipe planning software applications (one for each satellite or satellite operator) is extremely inefficient.

By applying years of operational experience with imaging satellites, Orbit Logic has developed a robust and configurable application that can perform operational-fidelity planning for a single satellite or a constellation of satellites with a mix of sensor types, phenomenology, and imaging modes. Originally developed and deployed for satellite operators, the CPAW application has found useful application for imagery customers and engineers performing design and capability analysis. Because different customers have different approaches to operations and automation, CPAW configurability extends beyond the satellite models to also support different configurable levels of automation and multiple planning process flows.

Recent and ongoing work by Orbit Logic is extendeding CPAW through the development of a web-based order management application and the SpyMeSat mobile app for situational awareness, archive imagery ordering, and tasking.

## References

[1]Koppersmith, J. and Herz, A. "Sophisticated Collection Planning for GeoEye's High Resolution Imagery Satellites," SpaceOps, Rome, Italy, 2006.

[2]Cartwright, I. "Scheduling multi-spectral collection of the Australian landmass using a 6U cubesat constellation," AIAA/USU Conference on Small Satellites, Logan, Utah, 2013.

[3]Stepan, L., Cartwright, I., and Lingard, D. "Can a Constellation of CubeSats Create a Capability? Satisfying Australia's Future Need for Multi-Spectral Imagery," 6U CubeSat Low Cost Space Missions Workshop, Canberra, Australia, July 2012.