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“Collective C2 in Multinational Civil-Military Operations”

GMTI Utility Analysis for Airborne Assets

Topics:
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Abstract

Proper requesting and tasking of airborne Ground Moving Target Indicator (GMTI) assets to satisfy specific operational needs is a complex problem due to the multi-dimensional nature of GMTI data collection. A high level of technical expertise is required to correctly determine GMTI collection parameters needed to satisfy operational mission needs. With an anticipated higher volume of GMTI collection requests than can be accommodated by available theater ISR assets, some form of prioritization and assignment of requests to specific assets that is achievable is needed. In addition, as the number and types of GMTI-producing ISR assets in theater increases, the challenge is to understand the resource utilization of each sensor type against specific mission objectives and to effectively assign collection requests to each asset. The GMTI community would benefit from tools and metrics to assist non-experts in requesting and tasking GMTI assets in a manner that will fulfill their mission needs and quantify GMTI collection utility.

We present a new Moving Target Indicator Interpretability Rating Scale (MTIIRS) metric for measuring GMTI data quality, and a suite of new tools for both requesting GMTI support and for selecting and tasking GMTI assets to achieve desired operational objectives. We have identified mission type, target type, and area of interest as a core set of parameters which define the GMTI collection requirements and give rise to an MTIIRS level (independent of a specific GMTI asset). Information needs are derived from a set of mission types, such as high value target-tracking, force protection, and facility monitoring. Each mission type corresponds to a predictive model used to compute GMTI collection utility for a given target type, area of interest and GMTI sensor.

1. Introduction

A fundamental challenge of Command and Control (C2) is to maintain awareness of the state of a fluid and dynamic battlespace environment. This is accomplished with Intelligence, Surveillance, and Reconnaissance (ISR) assets that are tasked to collect intelligence information and monitor the dynamic state of the battlespace in support of battlespace missions and operations. Such assets include airborne platforms equipped with video, electro-optical, infrared, signals detection, radar, and other sensing systems. Managing and tasking such assets to collect intelligence information in a manner that satisfies battlespace operational objectives presents a C2 challenge of its own – namely, the C2 of ISR assets.

Effective tasking and operation of ISR assets requires understanding which platforms are best suited for which intelligence gathering tasks and how assets should be operated to best accomplish the tasks. This problem of asset-task pairing is a complex, multi-dimensional problem that requires models and metrics of end-user operational needs (e.g., required data fidelity), models of sensor systems, and predictive models to assess the utility of pairing sensor system against end-user tasks. Systems based on such metrics and models are needed to streamline the process of formulating requests for ISR support and planning ISR missions.

Our research aims to construct such metrics, models, and systems with a specific focus on airborne GMTI (Ground Moving Target Indicator) platforms. GMTI platforms employ radar and other sensing systems to detect and track moving targets in an area of interest. The goal of a GMTI collection may be to simply categorize typical traffic patterns in an area of interest, or to track individual vehicles moving in an area. GMTI is a particularly dynamic type of intelligence collection that presents challenges for end-users in need of GMTI support and for collection managers who task assets to provide such support. In this paper, we present a new Moving Target Indicator Interpretability Rating Scale (MTIIRS) metric for measuring required GMTI data fidelity (Section 2) and a suite of new tools for both requesting GMTI support and for selecting and tasking GMTI assets to achieve needed operational objectives (Section 3). We also outline future directions of this research and the application of the approach to other sensing modalities (Section 4).

2. Mission-Based GMTI Sensor Planning

2.1. A mission model approach to the GMTI sensor planning problem

The first challenge in effectively tasking a GMTI asset is in simply understanding end-users' requirements for GMTI support. Given the complex, multidimensional nature of GMTI data collection, it is difficult for non-GMTI experts in need of GMTI support to clearly articulate their tasking requirements. Thus, there is often a divide between such end-users in need of GMTI support and collection managers who task GMTI assets.

One approach to bridge this divide would be to require GMTI requesters to articulate specific GMTI collection parameters, such as the required area revisit rate, needed to accomplish their operational objective. This approach is problematic for a variety of reasons. For one, end users often do not possess sufficient expertise to understand the relationship between GMTI collection parameters and operational objectives. For another, such collection parameters may be highly dependent upon a variety of contextual factors, such as the traffic density of the target environment and the specific GMTI platform employed. Collection managers and GMTI platform operators are still left with an insufficient understanding of the end-user's objective that would enable them to tailor platform tasking and operation to varying circumstances. As one platform operator lamented, "my hands were tied to a revisit rate and I didn't understand how the data I collected would be used."

We instead propose an approach that aims to elicit the mission (i.e., operational objective) the end-user intends to accomplish with GMTI support. Our approach then aims to elicit each of the elements a collection manager or platform operator would need to effectively task a GMTI asset against a support request. Moreover, we aim to also provide a modeling methodology for moving from the mission and other elements of the support request to the specification of collection parameters that account for the operational environment and the specific GMTI platform to be employed (this is the purview of our GMTI Planning Tool described in section 3.2).

To better understand the needs of end-users (the "requesters"), we first examined requests for GMTI support that had been previously made and identified which intelligence problems and objectives GMTI collections were being used to support. We then derived a set of standard GMTI mission types (defined in Figure 1) that include things such as "Track high value targets or individuals", "Monitor a border, facility, or other area of interest", and "Identify patterns of life in an area of interest". We also developed an associated set of GMTI-specific Essential Elements of Information (EEIs) that capture the types of activity or patterns of target behavior that are of interest to the requester. EEIs include things such as "identify traffic patterns", "identify milling activity", or "identify activity along established routes".

Mission Types:

1. Track high value targets: A mission to track high value targets for possible engagement. An example is tracking vehicles suspected of planting IEDs along a road.
2. Monitor a border or facility: A mission to monitor a border or facility for activity. An example is monitoring a border for vehicle crossings, or monitoring a facility for vehicles that come within a certain distance of it.
3. Perform force protection/convoy watch: A mission to monitor for targets that come within a certain distance of a troop or convoy location.
4. Maintain situation awareness in a region: A mission to monitor target activity in a region. An example is monitoring an area for any vehicle movement.
5. Identify patterns of activity in a region: A mission to identify common patterns of target movement in a region. An example would be monitoring a road to establish traffic patterns, or monitoring a facility to establish when vehicles typically come and go.

Essential Elements of Information (EEIs):

1. Baseline Movement: Determine normal activity in an area of interest, such as traffic patterns and human/animal movements, to detect activity outside of normal patterns.
2. Traffic Patterns: Detect movement along communications routes such as roads and trails which have been previously identified via intelligence analysis or global databases. Establish basic target information including target velocity estimates and number of targets.
3. Activity on Established Routes: Detect movement along communications routes such as roads and trails which have been previously identified. Establish basic target information including target velocity estimates and number of targets.
4. Activity on Non-Traditional Routes: Detect the appearance of activity in areas where no established routes have previously been detected or where no data was collected previously.
5. Post-Incident Backtracking (Forensic): Collect data at a level sufficient to support determination of the origination of tracks that may have been involved in an event of interest (e.g., an IED emplacement).
6. Non-Incident Backtracking (Forensic): Collect data at a level sufficient to support determination of the origination of tracks that may have been involved in an event of interest (e.g., an IED emplacement).
7. Milling Activity: Identify concentrated target movement in an area of interest. Data may not provide sufficient resolution to separate individual targets.

Figure 1: Proposed GMTI mission types and EEIs.

Having established a set of GMTI mission types and EEIs, we next examined other key elements that collection managers or platform operators would need to be aware of to effectively task a request. These elements are used to answer questions that include: “what do I look for?”, “where do I look?”, and “when do I look there?” (Figure 2). This gives rise to a need to elicit targets of interest (e.g., vehicles, watercraft), a region of interest, and the timing requirements for the request. We delve into each of these elements in more detail in Section 3.1 in the context of a software system for eliciting a request. In the next section, we discuss how key aspects of these elements are formalized and used in MTIIRS to describe required GMTI data fidelity.

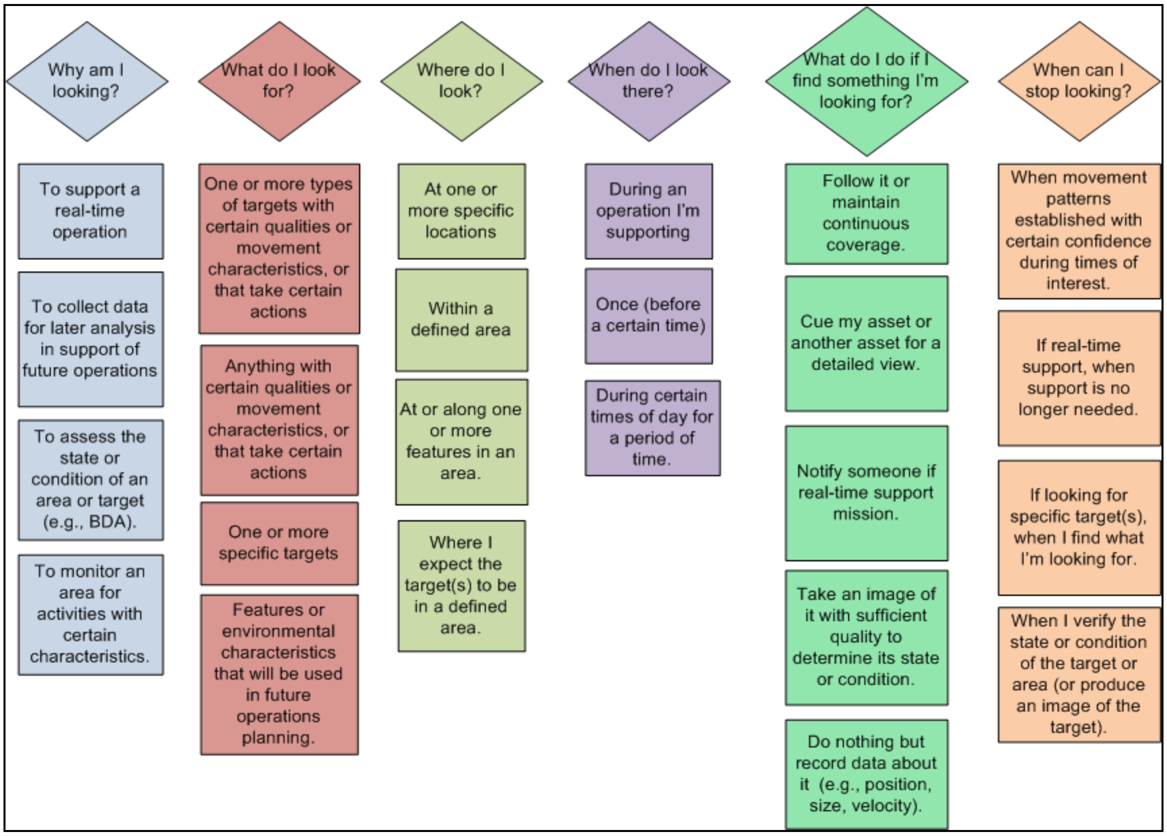

Figure 2: Collection manager tasking questions.

2.2. The Moving Target Indicator Interpretability Rating Scale (MTIIRS)

MTIIRS provides a common framework for defining both the fidelity required to support GMTI requests and for assessing the fidelity of previously collected GMTI data [1]. GMTI data fidelity can be defined as the relative ability to uniquely distinguish individual targets over a period of time. Increased data fidelity results in the ability to track individual targets, while low fidelity data provides a sense of motion or activity across the scene (e.g., to identify traffic patterns) but may not allow a tracker or analyst to associate individual entities from scan to scan [2]. Both high and low fidelity GMTI data can be of operational utility, and the ability to properly quantify the GMTI data quality needed for a specific mission, and to determine whether a particular sensor can provide data of this quality, will allow for more efficient use of limited sensor resources. Furthermore, when associated with archived GMTI data, this information will assist unanticipated (future) users in identifying data which can be used to satisfy their unique needs.

The impetus for such a scale was inspired by the National Imagery Interpretability Rating Scale (NIIRS). Specifying collections using a NIIRS scale number ensures that the right image quality is obtained for the intended mission requirement; likewise, the NIIRS scale has aided in the efficient allocation of imagery collection resources by providing a common language to describe image quality. Applying this approach to radar-based MTI data has been problematic due to the multi-dimensional nature of GMTI collection parameters. MTIIRS specifies quality levels of MTI data collection. The intent of creating this scale is to provide a common set of terms and conditions that allows for better tasking of GMTI platforms and an enhanced understanding of the usability of individual data sets to support specific mission needs. Standardizing terms and conditions will also pave the way for enabling collaborative GMTI mission planning in coalition C2 environments.

Historically and currently, GMTI data collection has instead been quantified using a metric (the “Hegyi” unit) based on the size of the collection area scanned per hour [2]. This metric is insufficient for a number of reasons. For one, it does not account for how the data will be used, so it could encourage and reward arbitrary collection planning whose only goal is to collect large volumes of data with no regard for the operational utility of the data. For another, it was developed without a careful analysis of the uses for such a metric or input from the GMTI community, and it does not allow for discrimination among the quality of different GMTI collections. Moreover, due to the nature of GMTI data, high rates of coverage will often result in data which is of no operational utility due to an insufficiently low update rate. Alternatively, one could quantify the data based on the number of GMTI reports collected. However, such a metric would also be problematic since a high density of GMTI reports can again render the data unusable as individual targets cannot be resolved across time.

Facilitated by the utility metrics working group at the Surface/GMTI community of practice, we collaborated with the GMTI collection and exploitation community to develop MTIIRS. There are as many approaches to the problem of quantifying GMTI radar data quality as there are disciplines within radar engineering, and these different approaches were examined at length. The working group ultimately agreed that a useful description of levels of data fidelity must be based upon the usability of the GMTI data and be understood by GMTI data exploiters and collection managers who may not have a high level of technical expertise in the physics of GMTI radar. We have chosen to represent these data quality levels on a linear scale, despite the multi-dimensional nature of the problem, because our goal is to provide a useful and easy-to-understand metric that will assist the community in both planning and exploitation and be straightforward enough to be universally adopted.

Our first goal was to standardize a set of GMTI mission types and EEIs. This enables the collection manager or platform operator to take into consideration the intended use of the data. The mission type gives rise to the required surveillance capability (i.e., a general understanding of the moving target environment [movement] vice tracking specific targets [tracking]). Other key elements include the targets of interest (vehicles vice dismounts) and their associated radar cross section (RCS) and maneuverability. Finally, the characteristics of the region of interest must be taken into consideration (i.e., the overall target density and terrain characteristics). Ultimately, sensor operation during the data collection must account for more specific factors associated with the target collection environment (e.g., relative target speed/density for the time of day of the collection; target maneuverability consistent with the indigenous road network; obscuration, etc.) [3].

The triad of required surveillance capability, target types of interest, and environmental characteristics gives rise to the required MTIIRS data fidelity level. The six draft MTIIRS levels are shown in Figure 3 and were developed to quantize the fidelity of localizing targets across a broad set of target and environmental factors. In the next section, we step through the formulation of a GMTI support request using the PRISM Input Tool and detail the formulation of an MTIIRS level from the request elements.

MTIIRS Level	Surveillance Capability	Environment	Target Type
1	General Movement	Rural or Suburban	Vehicular
2	General Movement	Rural or Suburban	Vehicular & Congregations
3	Tracking	Rural	Vehicles
4	Tracking	Suburban	Vehicles
5	Tracking	Rural	Dismounts
6	Tracking	Suburban	Dismounts

Figure 3: Draft MTIIRS levels.

3. Tools for Improved GMTI Asset Requesting and Tasking

3.1. The "PRISM Input Tool" for requesting GMTI support

The "PRISM Input Tool" is a web-based software tool that provides an intuitive, wizard-like interface to create requests for GMTI support [4]. Our aim was to make the tool usable by non-GMTI and GMTI experts alike. After first specifying a point-of-contact (i.e., the supported unit in need of the GMTI data), the user selects a GMTI-specific collection objective (i.e., the mission type) and an associated set of EEIs (Figure 4). Figure 1 provides the current set of collection objectives and EEIs used in the tool. The collection objective gives rise to the first aspect of an MTIIRS level – the required surveillance capability (one of "general movement" or "tracking"). EEIs enabled for selection are dependent upon the surveillance capability of the collection objective. In the case of the example in Figure 4, EEIs that require tracking are not enabled since the overall collection objective is to "Identify patterns of life in a region", which corresponds to a "general movement" surveillance capability.

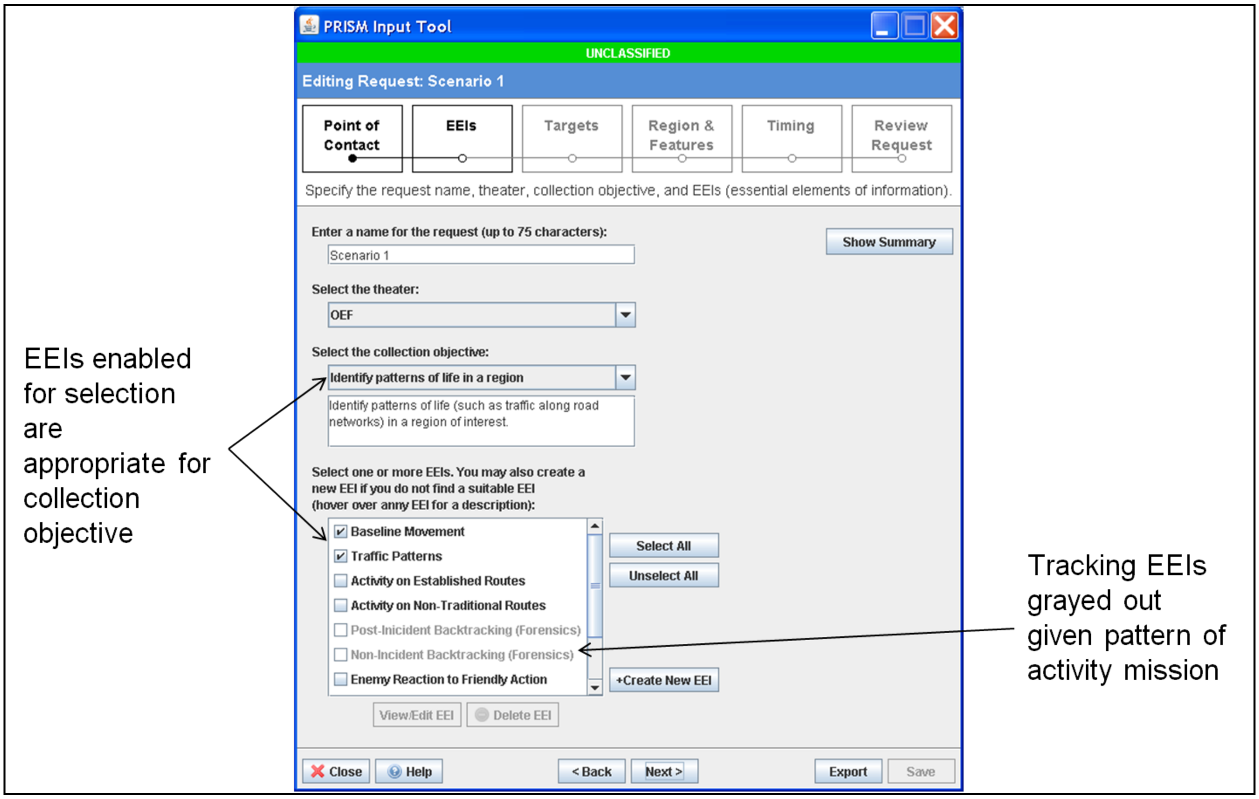

Figure 4: The PRISM Input Tool – Specifying collection objective and EEIs.

The user next indicates the specific types of targets that the requester is interested in monitoring or tracking. The tool currently contains the following breakdown of target types:

- Vehicles: small vehicles (e.g., cars), large vehicles (e.g., trucks), vehicle convoys
- Low-flying aircraft
- Watercraft: small craft (e.g., pleasure craft), large craft (e.g., commercial ships in excess of 300 tons)
- Dismounts (people and animals)

In formulating an MTIIRS level, the tool considers the target type selected with the smallest nominal radar cross section. For the purposes of MTIIRS, the radar cross section is categorized as either large (e.g., vehicle-sized) or small (e.g., dismount-sized).

Next, the user specifies the geographic area of interest and any specific features in the region (e.g., a road, location, etc.) that are of particular interest to the requester. For example, a requester may be primarily interested in monitoring activity at a boathouse (the "feature") in a region that encompasses an entire lake. Currently, the user must also specify the environmental properties of the region of interest, including the traffic density (one of "rural" or "suburban"). The traffic density is the final aspect of the request used in the MTIIRS formulation. In the future, the time-dependent traffic density of a region should be available in databases that maintain dynamic aspects of a target environment gathered from previous data collections.

Finally, the user specifies the timing requirements for the request. Requests may be "one-time" in nature, where the collection is performed once in support of a particular operation (e.g., force protection), or they may be "recurring" in nature, where the requester needs to monitor a region for a period of days or weeks to establish patterns of activity. Figure 5 shows the final screen in the tool that provides a formatted paragraph summarizing the elements of the request. The ultimate goal is to integrate the PRISM Input Tool with the PRISM system of record, a system for managing ISR collection requirements across a variety of sensing modalities [5].

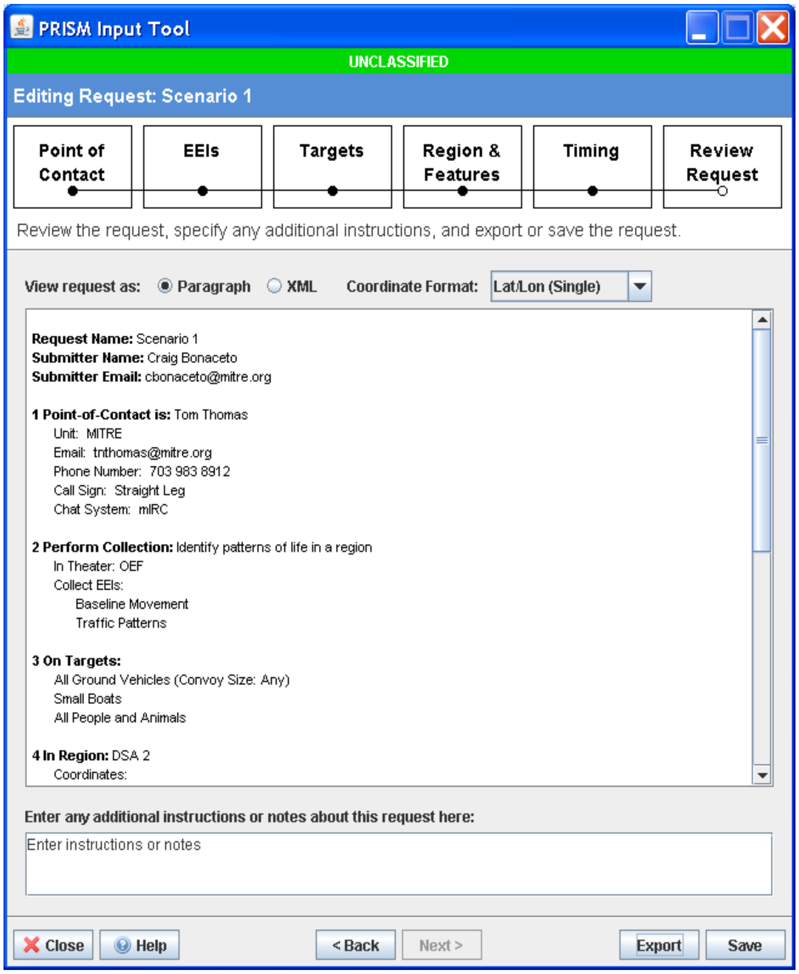

Figure 5: The PRISM Input Tool – A formatted summary of a GMTI support request.

3.2. The GMTI Planning Tool for developing GMTI collection plans

Given a set of requests for GMTI support at varying levels of MTIIRS fidelity, it is now the job of the collection manager to effectively task GMTI platforms against those requests. This is a complex problem that requires the use of sophisticated models of sensor collection capability to relate support requests to GMTI collection parameters needed to satisfy the requests and achieve the required level of fidelity.

In order to properly relate requests to sensor tasking, it is necessary to first develop a rigorous basis for quantifying collection requirements. GMTI collection characteristics can largely be described as a combination of three interrelated performance parameters: persistence, target state estimation, and tracking fidelity. By persistence we mean the frequency with which an area of interest must be interrogated or sampled and the time duration over which this sampling needs to occur. This could be a sensor revisit as often as every few seconds for high value target tracking, or scans as infrequently as once every few days for long term pattern of life analysis. Target state estimation is the ability to judge a target's true position and velocity, and is a function of sensor accuracy, collection diversity, and update rate, among other factors.

Tracking fidelity is computationally the most difficult of these three collection performance parameters to estimate. The GMTI target tracking performance model we have selected was first proposed by Mori, Chang, Chong and Dunn: Probability of Correct Association (Pca) [6]. Research efforts at the MITRE Corporation have extended the basic Pca concept outlined in this foundational paper to account for the particular characteristics of target tracking based on GMTI radar data. We have used the results of that research in our development of the GMTI planning tool. Pca is defined as the relative probability of correctly associating a target return to its associated track between successive GMTI updates. Pca is intended to account for the uncertainty in identifying a specific target in successive sensor scans for a given set of independent variables, including average target speed, relative maneuverability, traffic density, and sensor error. The required minimum Pca value can be associated with differing mission requirements, e.g., large area situational awareness (SA); small area SA; force protection/overwatch; tracking of specific targets, etc.

In summary, our modeling methodology derives a Pca value required to meet the collection objective and EEIs of a request, and this Pca value, in combination with the expected speed and maneuverability of the target types of interest and the traffic density of the region of interest, is used to derive a maximum revisit time for a specific GMTI sensor needed to satisfy the requirements of the request. The maximum revisit time and size of the area of interest govern the utilization of a specific GMTI sensor (i.e., the amount of its available timeline that will be consumed performing the collection).

This modeling methodology underpins our GMTI Planning Tool (Figure 6), which, given a set of requests for GMTI support and a set of available GMTI platforms, derives the anticipated performance of each platform against each request. The result is a platform-to-request performance matrix that enables the collection manager to see at-a-glance the expected performance of each GMTI platform against each GMTI request (Figure 7). The matrix concept was developed using principles of structure mapping for decision support design, which entails mapping the structure of the planning problem to the visual elements in the display [7]. The cells in the performance matrix show the expected area coverage, the quality of the coverage given the fidelity requirements of the request (color-coded green, yellow, or red), and the utilization of the platform’s sensor.

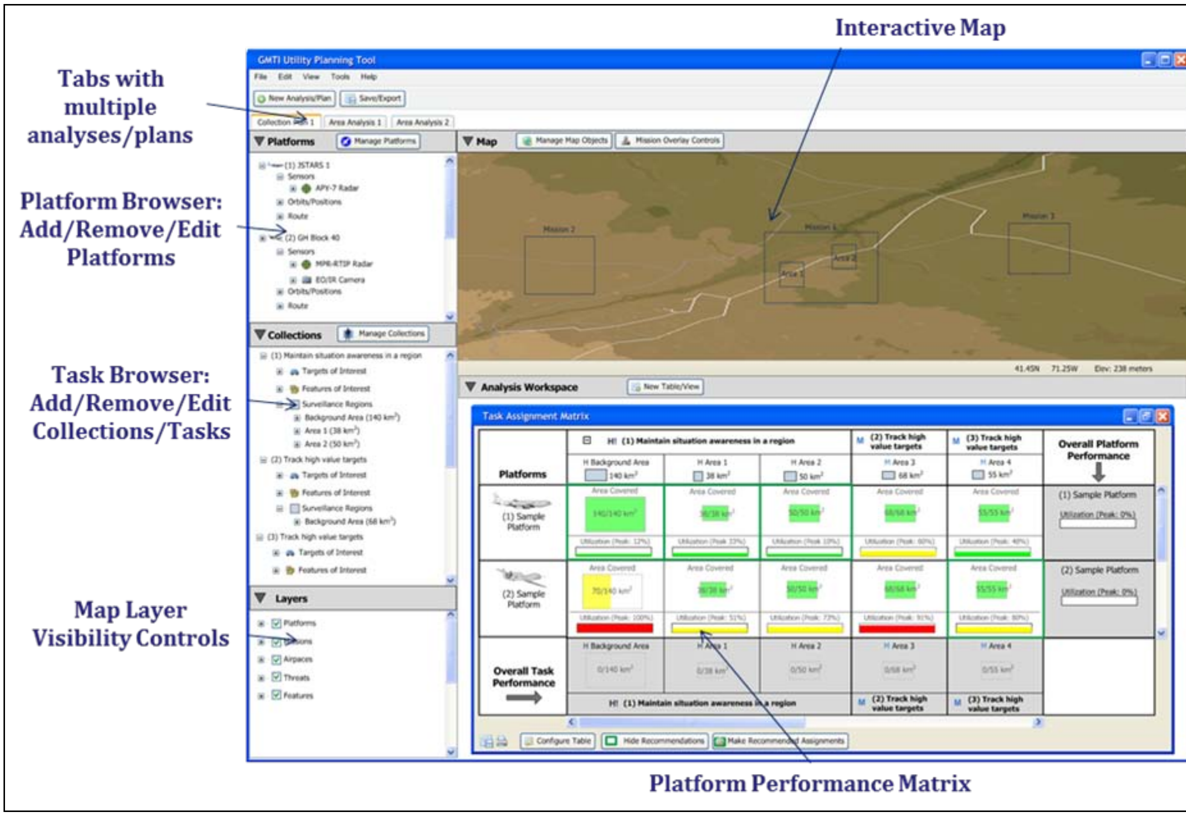

Figure 6: GMTI Planning Tool – Overview.

In the example in Figure 7, the first column in the matrix shows the performance of two sample GMTI platforms against a sample collection request in a 140 km^2 region. In this notional example, Sample Platform 1 is able to cover the entire area with sufficient quality while utilizing 12% of its available timeline, while Sample Platform 2 is able to cover half the area with mediocre quality while utilizing its entire available timeline.

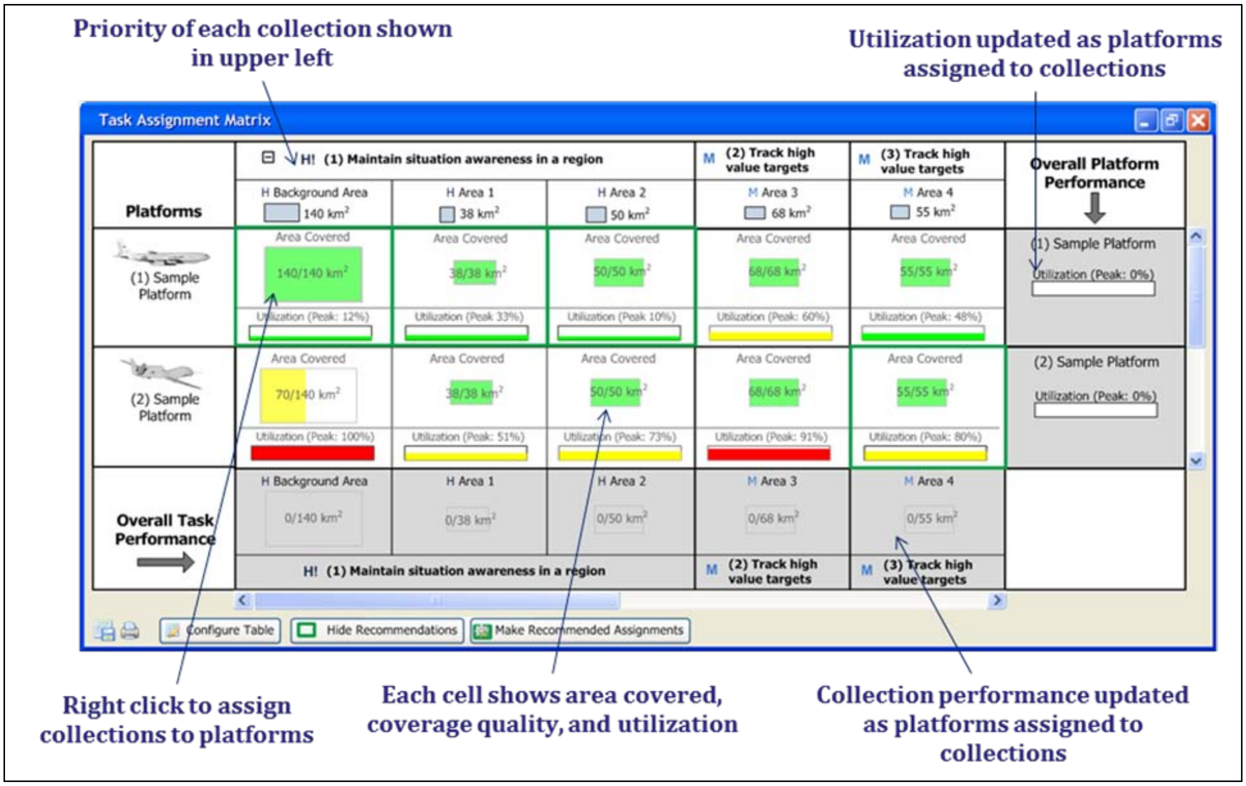

Figure 7: GMT Planning Tool – Platform performance matrix.

The collection manager clicks cells in the performance matrix to construct an assignment of platforms to requests. The tool then updates the overall utilization of each platform and the overall performance against each request based on the assignment of platforms to requests (Figure 8). Armed with this initial assignment of platforms to requests, the collection manager now has a rough cut at the collection deck for each platform. The collection manager may then use the interactive map to position platform orbits and evaluate terrain screening (Figure 9). As the collection manager manipulates a platform orbit, the tool updates the performance of the platform against each assigned request. Thus, the collection manager may perform a more detailed assessment of platform-request performance given an orbit and the actual terrain in the area of interest. The end result is a collection deck, and possibly an orbit, for each platform.

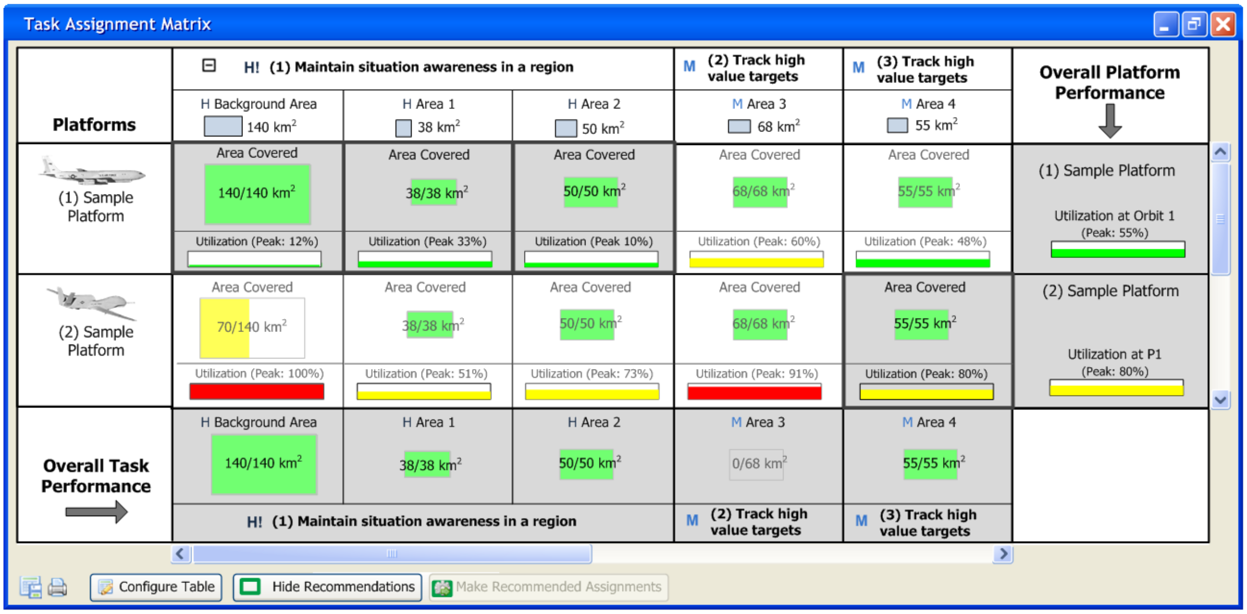

Figure 8: GMTI Planning Tool – Platform performance matrix after assigning platforms.

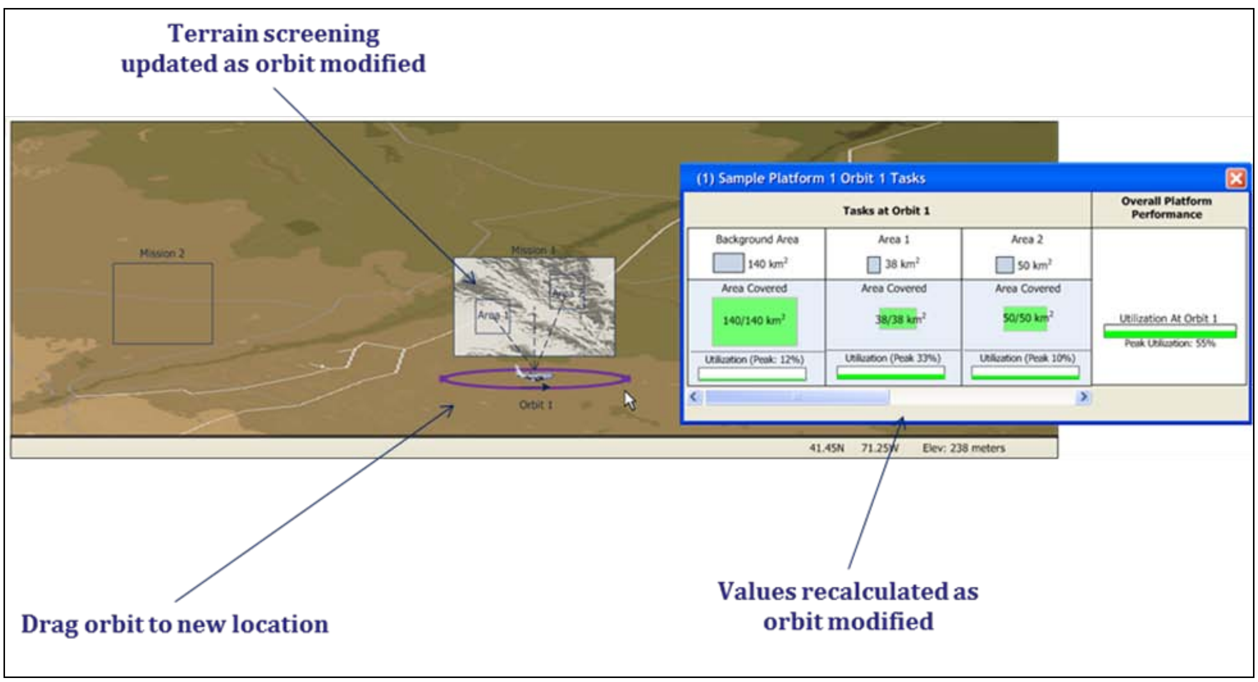

Figure 9: GMTI Planning Tool – Orbit analysis.

4. Conclusion and Next Steps

We have demonstrated an integrated approach that aims to standardize the process of requesting GMTI support and tasking GMTI platforms while overcoming the complexities of GMTI data collection. We presented a methodology for requesting GMTI support based on operational needs, a new MTIIRS metric for assessing required GMTI data fidelity, and a planning tool to relate GMTI requests to platform performance and plan effective GMTI collections. Such a holistic approach to GMTI planning can go a long way toward bridging the divide between end-users in need of GMTI support and collection managers and platform operators who provide such support. Moreover, the adoption of a standardized set of GMTI mission types and planning methodology can also help establish common ground and enable improved inter-service and coalition GMTI support and planning. We intend to next investigate the application of this methodology to other sensing modalities (e.g., full motion video, signals intelligence). In the GMTI domain, we also intend to extend this methodology to comprehend cross cue requests that require the coordination of GMTI and other sensor types.

5. References

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