Reducing Time Sensitive Target (TST) Prosecution Decision Time using Inference Processing and Intelligent Agents

Willard Ratliff and Gerard Mayer
Lockheed Martin Advanced Technology Laboratories
Cherry Hill, NJ
{bratliff, gmayer}@atl.lmco.com

Abstract

Automating the processes that make up the prosecution decision is critical to meeting the Air & Space Operation Center (AOC) Operation Requirements Document (ORD). The ORD necessitates assessments to be performed in under ten minutes. Meeting this stringent time requirement is difficult for human operators due to the complexity of the data set used in making prosecution decisions. Prosecution decision management for TSTs requires knowledge of several criteria including the threat level of the target, adherence to Rules of Engagement (RoE), weather factors, airspace de-confliction, consequences with regard to the civilian population and associated infrastructure, and availability of assets for making target assignments.

Lockheed Martin Advanced Technology Laboratories (ATL), under funding by the Air Force Research Laboratory, has been researching and developing decision support solutions that use efficient software techniques, such as knowledge-based systems, intelligent agents, and enterprise based retrieval services, to support the TST prosecution management within the AOC. At the core of ATL’s software solution is the use of a commercial inference engine along with ATL’s field-tested intelligent agents. The intelligent agents are used to gather essential elements of information (EEI) from systems of record such as the Theater Battle Management Core System, the Joint Weather Impacts System, and the JMEM Weaponeering System (JWS) and prepare the data for use by the inference engine. The key aspects of the inferencing tool include: 1) encapsulation of rules within rulesets according to domain, 2) rule-flows to define execution flow, and 3) rule templates used to define reusable rulebase components. The advantage of using the rule template paradigm is that portions of the rulesets can be published for review and augmentation by the operational user in real-time without requiring an application shutdown; therefore, application is much less fragile than traditional software solutions, which is critical in the dynamic battle management environment.

1. Introduction

Striking moving, high-value targets requires target prosecution decisions in under ten minutes. Decisions include asset-to-target assignment, ROE compliance verification, commander’s guidance compliance, collateral damage estimates, etc. The complexity of the data set used in making prosecution decisions and the requirement to share information within and outside of the Air Operations Center (AOC) are forcing the review of the role of human AOC operators in

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performing the prosecution management function. Although it is still necessary to keep final control of the overall prosecution directive in the hands of the operator, automation of many of the prosecution management functions is necessary and possible using today's advanced computer-based technologies.

The goal of the research at Lockheed Martin Advanced Technology Laboratories (ATL) is to shorten the kill chain with regard to these high value targets. The focus of the research has been to reduce the time spent in the Target and Engage portions of the kill chain to under two minutes. This means that the majority of decision points must be automated with almost no human intervention.

To accomplish these goals ATL has developed a hybrid software solution that employs rule-based reasoning, intelligent agents and enterprise-based data retrieval services. The data retrieval services and the intelligent agents are used to selectively pull and filter world environment information from Air Force Systems of Record for use by the inference process. The knowledge-based application developed by ATL has encapsulated a portion of the heuristics used within a Dynamic Target Cell (DTC) to perform the functions related to the TST prosecution management. ATL, with the collaboration of Lockheed Martin Integrated Systems and Solutions (IS&S) and the Air Force Research Laboratory (AFRL), has implemented the TST Dynamic Decision Enabler (TDDE) system.

Since beginning this research in 2003, Lockheed Martin has identified the key functions that the software must be able to perform to be considered successful. These key items are based on multiple reviews of Air Force Operational Tactics, Techniques, and Procedures documents and interviews with subject matter experts (SMEs).

The required functionality includes:

• **Activity validation** refers to determining that the target is time-sensitive in nature. This also includes determining that prosecution of the target adheres to the RoE and the commander’s military objectives.
• **Situation understanding** refers to understanding the current battlefield landscape. This includes knowledge covering the positions of friendly forces, infrastructure elements, no-fire zones, hostile forces, and other battlefield specific positional information.
• **Collateral damage estimate** encompasses understanding the destructive capability of a weapon to the specific target and the surrounding area.
• **Mission capacity** is understanding the availability of assets for prosecution purposes. This supports the weapon-target pairing function.
• **Threat analysis** determines the threat level to airborne assets based on hostile radar configuration and projected flight path to target. This supports the weapon-target pairing function.
• **Weapon-target pairing** determines which weapon and asset configurations are the “best-fit” for a specified target.

An additional capability key to this type of application is the ability for the operational user to augment the rule base, especially the RoE and the rules related to collateral damage estimation.
The solution developed by ATL satisfies this criterion with the use of rule templates that the operational user can modify as required when the military objectives change.

This paper is organized as follows. Section 2 provides a review of the current TDDE architecture. Section 3 discusses the data sources and agent retrieval services that support the inference processing. Section 4 summarizes the Rule Service components and their use. Finally, Section 5 provides the future transition and integration plans.

2. TDDE Solution Architecture
At the heart of the TDDE solution architecture is the rule service powered by a COTS Rule Management Tool called Blaze Advisor (see Figure 1). This tool was selected early in the program based on a trade study and evaluation and is produced by Fair Isaac Corporation. The rule service itself is encapsulated within a web service to accommodate parallel target processing and to allow the prosecution management processing functionality to be embedded within larger applications.

A requirement in developing any automated system is the ability to gain the user’s trust. In our software solution, the “thought” process of the inferencing cycle is recorded and persists for review by the operational user. The data preserved includes the trace of the fired rules and the values of the essential element of information (EEI) used in the decision. In addition, maps graphically display information used by the inference process. These include:

a) Asset location at the time of target instantiation/injection
b) Threat locations and asset ingress and egress routes
c) Area of Interest Kill Boxes, No-Fly Areas, No-Strike elements, etc.
The combination of reasoning drill back and graphical information will instill confidence in the prosecution recommendation provided by the system. With the increasing reliability of the system’s recommendations, the engagement of the TST can proceed at an accelerated pace.

The collaboration server provides the mechanism for persistently processing information to the data store. Target aggregate information and prosecution recommendations are provided to the application graphical user interface (GUI) through the collaboration server. This design provides a means for sending target object information to the user interface without creating a dependency between the rule service and the GUI. This allows the rule service and application GUI to be separate processes or operate on separate processors. The collaboration server accepts incremental and final processing results which are stored for later presentation to the user through the GUI.

The user interface is provided using a web browser. The use of a browser allows the GUI to be available on a large number of platforms with few installation requirements on the end-user’s system. The browser directly interfaces with the data store to present the processing information during run-time. The interface also allows the user to view previously processed TSTs.

The user interface is weapon-target pairing centric. Based on SME recommendation, the key criterion for providing Kill or No-Kill recommendations is based on whether the selected assets and thus, their weapons, meet the requirements to be used against the target. Asset availability and the ability to engage the target in a timely manner is the first hurdle to overcome to be considered for prosecution. Risk mitigation to the set of assets is another key criteria to be considered. The affects of weather on the platform and the weapon generate a pass/fail result. The associated weapon’s ability to meet or exceed the required probability of destruction and the potential for excessive collateral damage are all essential pieces of information that are conveyed to the user via a stoplight paradigm. The stoplight paradigm is also used to communicate the pass or failure of the asset and its associated weapon to meet the requirements to engage the target. This paradigm provides a color indication of success or failure of processing. Red meaning failure, yellow meaning partial success, and green meaning complete success.

3. Data Sources and Intelligent Agents
The TST process requires a significant amount of information to make prosecution decisions on high-profile, time-sensitive targets. Because of the need for large amounts of specific data, intelligent agents can be used to retrieve and disseminate the needed data. For the past ten years, ATL has been developing intelligent agent technology to perform tasks for users. The intelligent agent technology has been used on over 30 programs to provide information extraction and persistent monitoring for various data resources.

Using agents to selectively retrieve data also allows for information filtering so that only relevant data passes to the rule service for reasoning. These agents are standalone processes that act as service orientated components waiting to accept data requests from clients. The client, this case, is the rule service.

The application's core source of information about the tactical environment is provided by the Theatre Battle Management Core System (TBMCS). TBMCS provides web services which have
encapsulated the Air Tactical Order (ATO), Air Control Order (ACO), Friendly Order of Battle (FOB), and Modernized Integrated Database (MIDB). The services provide information related to theater specifics, such as:

a) Country border, kill box, no-fly area, fire support coordination line (FSCL) boundaries descriptions
b) Theater assets, weapon loadout, package and mission details, planned targets
c) Ground and Naval friendly asset information
d) Electronic threats
e) No-strike information
f) Air corridor boundaries.

This data directly supports weapon-target pairing and course of action selection for the prosecution management decision process.

Access to other data sources to assist in the collateral damage estimates and asset allocation is also required. The other data sources include the Joint Weather Information Service (JWIS), the Joint Munitions Effectiveness Manuals (JMEM) Weaponeering System (JWS), the Command and Control Personal Computer (C2PC) position databases, and the Integrated Many-on-Many (IMOM) application.

Access to the C2PC databases provides the current positional information for the assets delineated in the ATO. The locations of these assets in relation to the target are the first filter used to determine asset availability for prosecution.

Retrieval of the current weather picture through JWIS allows the rule service to assess the likelihood of both the platform and weapon to succeed in the prosecution of the specified target.

The system produces both the ingress and egress routes to and from the specified target for a candidate asset. This process interfaces with the IMOM application to determine the risk to the candidate asset. IMOM provides the analysis of the routes based upon the threat lay down in the vicinity of the target. ATL’s application then performs a threat analysis evaluation to select the route of less risk to the asset.

To estimate the collateral damage and determine the potential weapon effect on the target, ATL’s application interfaces with the JWS. Based on weapon specification, including warhead, fuse settings and projected weapon delivery criteria, JWS calculates the probability of destroying the target. This information is used to determine whether the weapon meets the commander’s intent for threshold guidance. In addition, JMEM provides a methodology for defining the level of expected collateral damage based on the weapon loadout and distance from the point of impact. The system uses this information to determine if any co-located no-strike elements exceed the commander’s intent for acceptability.

Access to the aforementioned data sources allows the population of the world model that the rules reason about. The ability to retrieve the data at run-time in a dynamic environment means that the rule service will provide a richer, more robust, and more importantly a more relevant context to perform its decision processing.
4. Rule Service Components
In 2003, Lockheed Martin performed an analysis of technologies to determine which would likely be the most successful in providing a solution to the prosecution recommendation problem. In the course of reviewing alternate technology approaches, it became clear that multiple technology strategies would be required to provide automated assistance to the TST problem. To determine the prosecution viability of a target many factors come into play. Information about the current air picture, tactical picture, asset capability, and collateral damage are all ingredients in determining the prosecution viability of a target. This implies that the application requires access to a variety of data sources and the need to interpret upper echelon doctrine in order to make prosecution decisions. With these criteria in mind the Lockheed Martin team reviewed several artificial intelligence related technologies in terms of their applicability to the domain space. The technologies reviewed included Bayesian Networks, Case-Based Reasoning, Neural Networks, Rule-Based Systems, and Intelligent Agents.

Bayesian networks use a directed graph model to represent events in the problem realm. For each Boolean attribute of a graph node a probability value is assigned. The network then performs processing that determines the likelihood of the end node/event based on the previous probability distribution. The assignment of the probabilities in terms of the TST domain would most likely turn out to be more subjective than objective process. It became clear during the review process that an Air Staff domain expert could not provide the set of probabilistic values required for the network, nor is it likely that another SME could provide the values.

The Case-Based Reasoning (CBR) system subscribes to a classification model that describes a set of problems and the known solutions. The CBR system, when confronted with an event, will perform a search of the problem set representations or cases to find the most similar cases. Because the TST process is dynamic, a set of a priori cases cannot be described.

Neural networks are used for problems that have large amounts of training data available so that the network can learn and produce the desired results. In the supervised learning paradigm, the wanted results are provided as well as the training data. This allows the network to process input data and produce fairly accurate results at great speeds. The TST process does not fit this model because, as previously mentioned, the environment in which TSTs are prosecuted is dynamic and complex.

Rule-based systems provide the means to encapsulate the knowledge used by domain experts in their respective fields. Through knowledge engineering, heuristics, or rules of thumb, can be extracted from a domain expert and encapsulated in a rule base. The staff personnel in the AOC rely on guidelines such as RoE and Command’s Guidance in determining which targets to prosecute. A rule-based approach was an understandable approach for the SME, and they can even examine the rules to determine if they match their intellectual process.

Today’s rule-based development environments provide many features that alleviate complexity in the development of rule-based systems. First is the use of regular “if-then-else” clauses to author rules. The second is the ease in which object model definitions can be imported and used in the system. Object definitions residing in Java classes, XML schemas, and UML design documents can be easily imported. The third advanced feature is the ability to publish portions of
a rule-set for maintenance by the end-user. It is this last feature that will enhance the robustness of the prosecution management software by allowing modifications of the system in real-time during operational engagements.

For the above reasons, the use of a knowledge base in combination with intelligent agents was selected as the technologies to be used on the problem.

The rule service is the central processing hub for the application. In essence, it is the nerve center, which acquires situational data from its agents and uses that data to produce informational prosecution recommendations. Processing is initiated by the web service instantiation of a rule agent from the rule server. Figure 2 shows the component interaction for the rule services. As part of the instantiation, the target unique identifier, its type, and location are passed as arguments.

The workflow of the rule agent is as follows:

a) Retrieve the world environment information as described in the previous section via intelligent agents.

b) Define the set of available assets based on distance from target and recent role information.

c) Perform asset/weapon viability based upon adherence to RoE, weather rules, collateral damage acceptability, threat analysis, and airspace deconfliction.

d) Push inference results to collaboration Server.

e) Build package/mission information.

f) Determine Kill/No-Kill recommendation.

g) Push prosecution recommendation to collaboration server.

h) Exit rule agent.

The above tasks are packaged as a set of knowledge clusters that use a combination of inferencing and procedural code to make the prescribed determinations and recommendations. A knowledge cluster is a group of related rules that represent different pockets of understanding.
and knowledge about different facets of the related domain. During the course of the development effort the rule sets used by these knowledge clusters have been refined based on ongoing interviews with domain experts. The result of this knowledge engineering process has been the capability to effectively execute in a more realistic and increasingly complex processing environment. This approach allows modular development and testing per knowledge cluster.

The application consists of a set of rule sets that work together to provide prosecution decisions to the warfighter. The method by which the application can be updated is to provide a mechanism for publication and modification of the rule sets. The Advisor tool provides a built-in mechanism to generate a web-based rule maintenance application based on templates described in the knowledge base. A portion of the rule sets related to theater RoE and collateral damage estimation have been developed as a series of user-configurable templates in order to meet the changing condition in the battlespace. The ability to modify or add rules can be restricted based on a prescribed change authority level.

The deployment manager, shown in Figure 2, provides the mechanism to detect changes to a rule set template. It is used to notify deployed rule services of updates; this is a built-in capability of the Advisor tool. The use of the deployment manager allows updates to occur without having to shutdown and restart the rule servers. The deployment manager is configured through a XML based configuration file. In the configuration file, the type and location of rule sets to load is specified, as well as the configuration specifies for change detection monitors and event monitors.

This development effort adhered to the classical knowledge engineering cycle of knowledge acquisition via personal interviews with domain experts, knowledge analysis and refinement, knowledge synthesis in detailing hypothetical situations, identification of underlying requirements, incorporation into prototypical models, and review by the original domain experts has been performed\(^2\). This has led to a scalable and distributed framework capable of handling multiple TSTs in the two minute time frame.

5. **Transition Plans**

The transition goal of this development effort is to install the application in the Project Integration Center (PIC) at the Air Force Research Laboratory’s Rome Research Site (RRS). At the RRS the application will interface with both the TBMCS and the JWIS services located at the site. The final delivery and integration is scheduled for November 2006.

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