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LESS IS MORE:
CHANGING THE BATTLE
DAMAGE ASSESSMENT PARADIGM

by

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ABSTRACT

An important part of the execution of any military operation is the ability to quickly determine whether or not specific actions are having the desired impact on the adversary and making progress toward the commander's overarching goals. Experience in large-scale conflict over the past few decades suggests that the current Battle Damage Assessment (BDA) process has had, and will continue to have, difficulty keeping up with the pace of operations due to limited availability of required intelligence collection assets. Reliable assessment of the effectiveness and impact of military actions promises to become even more difficult as the speed and complexity of combat increases, and conflict spreads across multiple domains.

Models are in use today that attempt to mix past and real-time data to predict a customer's purchase activity as they are clicking through a website, to predict mechanical failures as aircraft are being serviced, and to predict the outcome of sporting events in progress. Similar models could be employed to examine available data from ongoing operations, along with testing or other past data, to determine the probable results of a strike when no traditional BDA is available. This study uses an evaluation framework, guided by traditional characteristics of "good" intelligence as evaluation criteria, to examine the prospect of predictive BDA.

While there are both advantages and drawbacks for predictive analytics, the conclusion of this analysis is that it could provide added benefit in situations where traditional information is lacking. The Air Force should begin a low-level investment in predictive BDA algorithm development and test its accuracy and sufficiency at every opportunity in training or combat operations, with the hope that predictive analytics can help provide leaders with a more complete picture to consider when making decisions.

INTRODUCTION

Overview of the Study

This study examines the implications, both positive and negative, of attempting to assess the effectiveness of a strike and the remaining capability of adversary systems using predictive analytics supported by only a limited amount of data. Joint and Service doctrine in the areas of Intelligence, Surveillance and Reconnaissance (ISR), Targeting, and Battle Damage Assessment (BDA) serves as the baseline from which any change must be evaluated. As such, this study begins with a review of this documentation. Next, the research will examine instances where predictive analytics algorithms are being used to combine small amounts of real data, past results, and computer-driven simulation to predict future events. This is currently being attempted across a wide swath of manufacturing, retail, entertainment, and other industries to anticipate everything from customer demand to mechanical failures.[1] With all of this as background, the use of predictive analytics to produce BDA for use in post-strike decision-making is evaluated, to include advantages and shortfalls, instances where predictive BDA may be more or less useful or appropriate, and considerations in presenting the information in a way that allows commanders to understand the information prior to making decisions. Finally, the paper will make recommendations for the use of predictive or extrapolated BDA based on the evaluation, and identify candidate areas for additional research.

Battle Damage Assessment Introduction

Traditionally, Battle Damage Assessment is an analysis of all-source intelligence data aimed at determination of the level of physical and functional damage sustained by a specific target, along with a functional assessment of the higher-level target system, resulting from the application of lethal or nonlethal military force.[2] This post-engagement analysis is a collaborative process that involves both operations and intelligence functions. The current paradigm, codified in joint and service doctrine, requires that this physical damage assessment comes from data provided by some combination of "aircraft cockpit video, weapons system video, visual/verbal reports from ground spotters or combat troops, controllers or observers, artillery target surveillance reports, signals intelligence (SIGINT), human intelligence (HUMINT), imagery intelligence (IMINT), measurement and signature intelligence (MASINT), or open-source intelligence."[3] However, the sensors and infrastructure required to collect this information are the same assets that are critical to the development of new targets, along with information about enemy formations and movements. More often than not, initial BDA reports must rely on visual observation of the target and are usually based on a single source.[4]

The Nature of the Problem

Experience in large-scale conflict over the past few decades suggests that the current BDA process has had, and will continue to have, difficulty keeping up with the pace of operations. Reliable assessment of the effectiveness and impact of military actions continues to get more difficult as combat has increased in speed and complexity, stretching over large areas and across multiple domains.[5] In its final report to Congress following Operation *Desert Storm*, the Department of Defense reported that "The BDA process at the theater level…had difficulty trying to keep pace with the size, speed, and scope of the air campaign."[6] Even with huge advancements in technology, the "assessment mission during both Operations *Enduring Freedom* and *Iraqi Freedom* was again overrun by the rapid operations tempo."[7]

Intelligence assets are generally viewed as high-demand/low-density assets. Air Force ISR studies have shown that this has held true for all recent conflicts, whether in the prosecution of fixed or emerging targets.[8] At the Combatant Command or Joint Task Force level, the collection manager must develop and execute a plan, guided by an intelligence strategy, for utilizing limited ISR assets to meet the commander's Priority Intelligence Requirements (PIRs) and be able to react and adjust quickly enough to keep up with the speed of combat operations.[9] This is a difficult task, but it is dictated by priority. Intelligence requirements assigned a low priority may end up falling off the list of those collections that can be satisfied. This was the case with BDA during Operation *Iraqi Freedom*, and as a result "very few BDA collections were achieved" during the conflict.[10] Following the campaign, some members of Air Force leadership identified BDA as an ISR system shortfall, failing to recognize the root causes of the low priority assigned to the collection for BDA along with "a lack of ISR assets given the large number of requirements."[11]

Even with the recent explosion of ISR sensors and capabilities, their availability for BDA remains an issue because of Combatant Commanders' seemingly unquenchable demand for ISR. At the Air Force Association's 2016 conference in National Harbor, Maryland, General Joseph Dunford, the Chairman of the Joint Chiefs of Staff, noted that "since 2007, the military has increased the number of ISR aircraft available to combatant commands by 600 percent. Nonetheless, the Air Force is still meeting less than 30 percent of commanders' stated requirements."[12] Gen Dunford went on to point out that "simply continuing to add more platforms and pilots is an unsustainable path," and that the military will need to "think really hard about how we collect, analyze and disseminate information at the tactical, operational and strategic level to feed decision making"[13] In a large-scale, fast-moving conflict, decision makers rely on prompt BDA to inform future plans. The problem is, BDA represents yet another draw on these limited ISR assets that leaders cannot often afford to re-task.

Commanders in recent conflicts in Iraq and Afghanistan have to some extent been spoiled by the relatively small scale and focused ISR support available to them. In a future large-scale conflict against a near-peer enemy, the ISR enterprise will be severely challenged to keep up with demand. In addition to the straightforward math of numerous intelligence requirements needing to be prioritized and assigned to a finite number of collection assets, the Air Commander is unlikely to have uncontested control of the skies from which to collect ISR. In both Iraq and Afghanistan, commanders have been able to task manned and unmanned airborne ISR assets almost at will. If the airspace is not safe for drones or U-2s, and support from space is limited, a predictive estimate may be the only BDA available to leadership when a reattack or other tactical decision needs to be made.

Purpose of the Study

This disconnect between the supply and demand of ISR resources means that every potential opportunity to improve the use of available capacity should be explored. Joint doctrine assigns the Joint Force Commander the responsibility of developing a plan that incorporates BDA into the overall intelligence architecture. "This plan must synchronize ISR resources and reporting to effectively/efficiently support timely BDA."[14] However, some analysts argue that "overemphasis on BDA collection denigrates the target acquisition effort because it consumes too many assets that can be used more proactively for surveillance and targeting."[15]

The purpose of this study is to examine a possible alternative to traditional target-by-target BDA that could limit the drain on ISR collection resources, while at the same time filling in information where otherwise none exists. If a small amount of actual BDA data could be extrapolated to make reliable assumptions about the success or failure of large-scale operations with the help of models and predictive analytics, then commanders could be provided with a more timely initial assessment of strikes or other operations during the chaos of combat. Given this type of data presented in the correct context, tight coordination between the BDA cell and the operations assessment team could be used to give a commander an evolving but reliable assessment of the air campaign at any given time. However, this data would still be, basically, an informed prediction. And so this study will also examine the potential that "unpredictable third-party actions, unintended consequences of friendly operations, subordinate initiative and creativity, and the fog and friction of conflict" might render these predictions unreliable at best, or even misleading at worst.[16]

The Research Question

Advanced models are running all around us attempting to predict systems as complicated as the weather, and outcomes as unpredictable as sporting events. Computers are already used to model military actions with no real data based solely on simulations and munitions effectiveness statistics. But the usefulness of data-driven predictions to Operational Commanders is uncertain. Could they be used to make targeting and other decisions when the intelligence is not available to conduct traditional BDA, and if so, how? Therefore, the research question for this study is, what are the operational implications of conducting battle damage assessment (BDA) using predictive analytics, supported by sampling and extrapolation, versus 100% post-strike confirmation?

Research Methodology

This research was conducted using an evaluation framework. Because implementation of these predictive techniques and the creation and testing of actual BDA algorithms would require operational plans, targeting techniques and system intelligence that are, in large part, classified, the actual creation and specifics of an algorithm is beyond the scope of this research. However, Battle Damage Assessments are, at their root, intelligence products and so the proposed use of predictive BDA is evaluated based on criteria identified in joint doctrine as desired attributes of intelligence in general. Specifically, the goal is for intelligence products to be "anticipatory, timely, accurate, usable, complete, relevant, objective, and available."[17]

LITERATURE REVIEW

Researching the Problem

Overall, the available literature suggests a basic need for evolution of BDA processes to better support Operational Commanders in decision-making during future large-scale conflicts, where ISR assets will likely be overtasked and available only for top intelligence collection priorities. This research begins by establishing a solid baseline understanding of how BDA is conducted and used by the Joint Force today. Current, published joint doctrine concerning Intelligence, Operational Planning, Targeting and BDA Methodology, along with Air Force specific doctrine derived from these joint publications, serve as this "as-is" literature. The level of detail in these primary DoD publications varies, and they give no insight into potential changes or improvements, but they are the baseline for military BDA today.

Recent literature concerning BDA seems to be scarce, possibly because in recent protracted conflicts the real-time decision-making required by operational commanders has been confined to a small set of targets at any given time, making BDA easier to fit into the overall execution of the ISR enterprise. But following larger-scale conflicts during the 1990s and early 2000s, BDA was a significant source of leadership frustration. An article by James Diehl and Charles Sloan describes the findings and recommendations from the Joint Battle Damage Assessment (JBDA) Joint Test and Evaluation Program, conducted under the cognizance of the Director, OT&E from 2000-2004.[18] "The JBDA charter was to enhance current joint BDA processes to provide more timely and effective assessments of fixed and mobile targets."[19] The article and the evaluation are over 10 years old, but they help establish the state of BDA and challenges that the military has faced and continues to face with regard to conducting effective and efficient BDA. Out of the evaluation came recommendations to improve C4ISR system interoperability, joint TTPs, and joint training. But the article also identifies a set of 'future' BDA challenges, many of which the military still struggles with today, such as integrating operations and intelligence functions, prioritization of collection assets, and considerations about collateral damage and media reporting.[20] Other articles have given some initial thought to the desire to provide BDA at a higher level than just "this target is destroyed."[21] Extrapolation could potentially be used to develop the type "Effects-Based Assessment" described in these articles, providing operational or even strategic BDA to higher-level commanders.

During any future large-scale conflict, ISR assets are likely to be again prioritized for use gathering intelligence data on new targets, with collection on anything but the highest value targets post-attack being secondary. One RAND study conducted under an Air Force contract focused on collection against and targeting of emerging or fleeting targets.[22] While it only briefly addresses BDA specifically, the report includes extensive analysis of current Air Force ISR capabilities and processes, along with operational trade-offs required in order to employ limited ISR resources against a variety of target sets. Because Commanders traditionally treat targets as operational until verified destroyed, this may very well to lead to unnecessary reattacks and/or overly cautious avoidance of risk that hampers mission effectiveness. So what to do about it? A collaborative research paper published jointly by the Air Force and SAIC for the 2004 Command and Control Research and Technology Symposium suggests that ISR would contribute to a Predictive Battlespace Awareness if used in a more anticipatory manner, focusing on confirmation of effects rather than discovery.[23] An Air Force Institute of Technology (AFIT) thesis from 2006 concentrated specifically on developing an effective BDA methodology to incorporate into the Army's CASTFOREM force-on-force model, the predecessor to its current COMBAT XXI model.[24] The research is focused on close combat and BDA as perceived by a ground soldier, but the methodology may be applicable on a wider scale that could be used to extrapolate BDA results based on modeling. While not specifically tied to BDA, several other studies have been completed that examine the ability to effectively draw conclusions about changes to military (or similar) systems based on sample data, and the errors that are involved in those conclusions.[25,26,27] Specifically, this research is focused on predictive analytics as a potential solution to produce reliable predictions. Scholarly publications from both industry[28] and academia[29] are used as a basis for understanding the possibilities and limitations of this evolving area of data analysis.

Battle Damage Assessment Doctrine Review

Joint doctrine defines Battle Damage Assessment as the timely and accurate estimate of damage resulting from the application of lethal and nonlethal military force.[30] BDA is a task assigned to Combatant Commander (CCDRs) as a part of their overall responsibility to evaluate and engage targets to meet their assigned objectives within their designated battlespace. Within each Combatant Command (CCMD), a Joint Intelligence Operations Center (JIOC) – which falls under the CCMD J-2 – is responsible for ensuring that target intelligence and BDA are produced by the appropriate echelon within the organization. If CCMD ISR assets are not sufficient to produce the required target intelligence, the JIOC has the authority and responsibility to coordinate with other DoD commands, Services, and agencies to request target intelligence or BDA information.[31]

A "target" can be defined as any entity (a person, place, or thing) "considered for possible engagement or action to alter or neutralize the function it performs for the adversary."[32] Of note, there exists an exhaustive process for maintaining Modernized Integrated Database (MIDB) records as a part of the Defense Intelligence Analysis Program (DIAP) for worldwide target development.[33] This paper does not advocate changing that established process or the participants, inputs or outputs involved. This study of predictive analytics would look to provide information to commanders in situations where traditional BDA is not available in the timeline or in quantity required to make time-critical operational decisions.

Joint Targeting is executed as a part of Joint Operation Planning and is characterized by a six-phase iterative process that "that methodically analyzes, prioritizes, and assigns assets against targets."[34] This process is known as the Joint Targeting Cycle (see Figure 1 below). The process is not rigidly sequential or timed. Some steps may be executed concurrently depending on the given situation, but the cycle provides a framework which describes "the steps that must be satisfied to conduct joint targeting successfully."[35] Battle Damage Assessment is actually a subset of what is notionally the last phase of the cycle, Combat or Targeting Assessment (name varies depending on the publication).

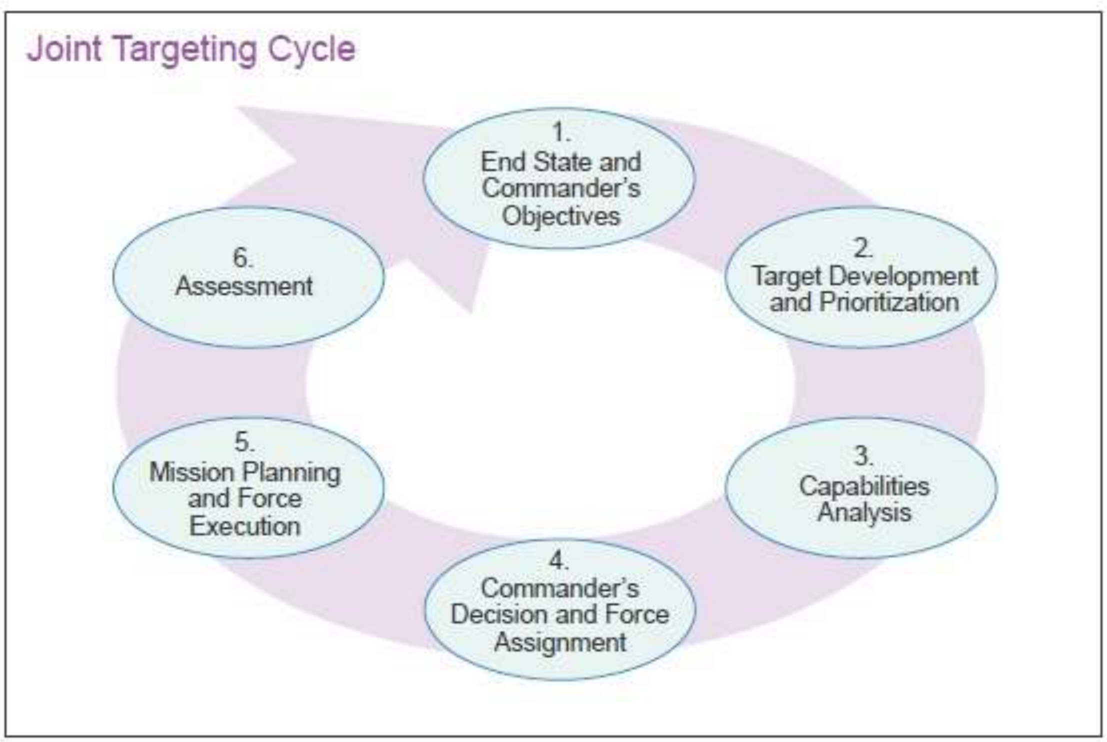

Figure 1: The Joint Targeting Cycle[36]

While BDA formally occurs during Phase 6 of the Joint Targeting Cycle (JTC), coordination and management of BDA occur throughout the cycle, and successful BDA is dependent on information developed in several other phases. This short review and consolidation of Joint and Service doctrine are focused specifically on BDA and how it fits into the JTC. A detailed explanation of each phase of the JTC is beyond the scope of this study but can be found in Joint Publication 3-60, Joint Targeting.

Clear, measurable, and achievable Commanders objectives from Phase 1 provide the basic criteria for the conduct of BDA during and following operations. BDA relies heavily on the target materials, including analytical decisions and supporting intelligence, which are produced during Phase 2. During Phase 3, target graphics that identify critical elements and aim point selection are generated, which are useful during BDA, as are collateral damage or collateral effects estimates. The intended targets and effects that are documented through tasking orders during Phase 4 serve as a starting point for BDA planning. During this phase, weapons, delivery platforms, and tactics are matched to targets or even specific target aim points, taking into consideration the realities of weapon and platform availability and collateral damage considerations. In Phase 5, the tasking, construction, and actual execution of missions are conducted. During this phase planned routes, in-flight reporting, aircraft cockpit or weapons system video of the engagement, or post-mission debriefings provide valuable BDA inputs.

The final phase, Assessment, is a continuous process that evaluates the effectiveness of the decisions made and the actions taken during the first five phases of the cycle. This assessment process helps commanders determine whether or not they are making progress toward achieving the required objectives. The assessment takes place at multiple echelon levels and across the range of military operations at the tactical, operational and strategic levels. In both combat and non-combat operations, it is important to measure progress against objectives. In fact, assessment can often be more difficult and complicated in non-combat scenarios. In general and for the purposes of this study, BDA is considered a part of the tactical level assessment, referred to as Combat Assessment. The Combat Assessment function within the JTC is focused on determining the results of target engagements outputs produced by the Combat Assessment function within the JTC are "BDA, munitions effectiveness assessment (MEA), collateral damage assessment (CDA), and reattack recommendations."[37]

The current process for BDA analysis and reporting occurs in three phases: target element analysis, target level analysis, and analysis of the target system. Target element analysis is a quantitative estimate of the physical damage done to a specific part of the target or aim point resulting from an attack. This report is due 1-2 hours after information is available, and includes assessment of "hit" or "miss" along with a combination of the assessed damage level (none, damaged, destroyed, or unknown – although there can be more specific terms depending on the target) and the confidence of that assessment (confirmed, probable, or possible). Target level analysis builds on the initial report to assess the amount of functional damage to the target (none, light, moderate, severe, destroyed, abandoned, or unknown). This report is due 4-6 hours after the information is available, and may include an estimated recovery or recuperation, and a reattack recommendation as appropriate. Predictive results could potentially provide information required for these first two reports, should they be required before any traditional BDA intelligence is received. Finally, an in-depth analysis of the effect on the target system is completed and reported. This extensive effort draws from all-source intelligence and may require days or weeks to complete.[38]

Predictive Analytics

Predictive analytics is the term used to describe the branch of data analysis concerned with the prediction of future probabilities and trends. In general, this involves the creation of a statistical model built on a large amount of data collected from past events or testing. Predictions are made, and the model is constantly validated or updated as additional information becomes available.[39] It makes use of a variety of analytical techniques and disciplines such as data mining, statistics, and game theory to use current and historical facts to make predictions about future events.[40] Predictive analytics has become more and more of an intriguing prospect in science and industry as collection and storage of data has become easier and cheaper and processing speed has increased. It is currently being applied in corporations across a wide swath of manufacturing, retail, entertainment, and other industries to anticipate everything from customer demand to component failures, as well as in a number of research areas including meteorology, security, genetics, and economics.[41]

The airline industry, in particular, is interested in predicting mechanical failures ahead of time in order to minimize flight delays and cancellations, which are costly and have a negative impact on customer attitudes. Along these lines, Microsoft has tested machine-learning models that are based on historical data, aircraft maintenance records, and flight route information. These models are applied in real-time and attempt to predict mechanical issues on a specific aircraft that will result in a flight delay or cancellation within the next 24 hours.[42] The airline can then conduct extra inspections and fix or replace parts while the aircraft is being serviced in order to reduce the likelihood of these delays. Similar predictive solutions are being developed for the oil and gas industry, where telemetry data is used to predict failures of electric submersible pumps extracting crude oil, manufacturing (predicting circuit board failures as they are being produced), and the financial industry (using customer behavior to predict credit defaults).[43]

These techniques are also being applied by the sports industry in real-time to predict the unpredictable. Most sports viewers have seen (and potentially criticized) ESPN's win probability analytics. The Network simulates out an entire game and then provides a running in-game updated prediction based on historical data of every outcome of teams in similar situations. Based off of these simulations, they estimate each team's win probability before and at any point during the game.[44]

Predictive analytics is often tied to the collection of 'big data,' the collection of massive amounts of information from multiple sources with the hope of using it to glean some new insight. But predictive analytics and big data are "less about size and more about introducing fundamentally new information to prediction and decision processes. This information matters most when existing data sources are insufficient to provide accurate or actionable predictions — for example, due to small sample sizes or coarseness of historical [records]."[45]

Predictive analytics is more than simply data extrapolation, which is a mathematical procedure that estimates the "value of a variable or function outside the tabulated or observed range."[46] At its most basic, this is essentially plotting data along a line or curve, then extending that curve into an area where you have no data. Extrapolation introduces a large amount of uncertainty because it assumes no changes in contributing factors over time, and it is difficult or impossible to determine the effect of variables that could impact the estimation but do not have a noticeable effect on the observed data. A simple example applied to BDA would be assuming that because you hit three identical targets with a 2000lb bomb and visually observed that they were destroyed, then a fourth one was likely destroyed as well. However, not included in the "known" data was the fact that all of the first three were under clear skies, but the reason there is no visual BDA available for the fourth is a very low cloud cover preventing visual observation of the target, which could have also affected the success of that particular strike. Predictive analytics would extrapolate known data, but could also take into account historical information, test data, training exercise results, and intelligence estimates about expected adversary actions and reactions, and would run continuously to incorporate traditional BDA or other information as it becomes available.

A large amount of data collection and analysis is already accomplished as part of the targeting process. During the capabilities analysis (phase 3 of the Joint Targeting Cycle described earlier) targets are analyzed for vulnerabilities and weapons are matched to targets and aim-points based on desired effects and efficient use of available resources. This actually includes the weaponeer's estimation of the most likely results of employing a capability against a specific target element.[47] In addition, intelligence analysts provide data on enemy intentions, capabilities and defensive posture in support of the Force Assignment phase of targeting (phase 4). Planners and weaponeers run models to estimate the probability that the striking platform will make it to the target and successfully release its weapon. The Defense Intelligence Agency (DIA), Joint Warfare Analysis Center (JWAC), and the Defense Threat Reduction Agency (DTRA), among others, have developed quantitative techniques that can be used to estimate weapon effectiveness as well as the risk of collateral damage with specific weapon-target pairings.[48] These models are also used to estimate the number of assets that may be required in order to create the desired effect using specific weapons and/or delivery systems.

Currently, if there is no post-strike data available for a particular target, "the assessment is usually left blank or unknown."[49] This risk-averse posture may restrict decision makers, potentially resulting in unnecessary re-attacks or avoidance of threat systems that may already be neutralized. It also adds restrictions to planners already dealing with a host of issues including weather, adversary operations, packaging and timing of required support assets, force protection concerns, rules of engagement, and laws of war.[50]

Post Combat assessments serve as a valuable tool to feed and improve BDA prediction algorithms. Where and when possible, the most accurate data on munitions effects is provided by teams made up of engineers, tacticians and intelligence analysts who are able to conduct a damage assessment on the ground. Often these are only possible once hostilities have ended, but these opportunities can improve the understanding and correlation of damage levels observed through sensor data and actual physical and functional damage to targets.

Predictive BDA could make use of all of the work done during targeting and the results of previous post-combat assessments to provide reliable estimations in instances where no traditional BDA is available. In fact, both Joint and Air Force doctrine allow for Estimated Damage Assessments (EDA) based on this upfront analysis. In instances where waiting on verification of strike results will "inordinately" delay assessments to decision makers, Air Force doctrine allows damage to be estimated based on weapons effectiveness estimates before BDA is confirmed, for all but high-priority targets.[51] The Commander of Air Force Forces, or the Joint Force Air Component Commander (JFACC), as appropriate, can provide additional guidance that identifies types of targets and target sets for which he or she is willing to accept EDA.

Ultimately, one of the biggest concerns with predictions of any type is that they almost always have some chance of being wrong. The ESPN in-game prediction mid-way through the 2017 Super Bowl gave the Atlanta Falcons, with a 28-3 lead, a 98.9% chance of beating the New England Patriots.[52] The Falcons had dominated every part of the game to that point. However, viewers that stuck around witnessed a historic comeback that apparently, based on history and other factors, had only a 1.1% chance of occurring.

ANALYSIS

Predictive Analytics Model

Much of the data, the sources of that data, and even some of the variables to be considered as part of a predictive analytics model for BDA would be classified. For that reason, the actual development, testing, or implementation of an operationally relevant predictive BDA algorithm is beyond the scope of this research. However, general principles for predictive analytics models are considered – particularly those that can be applied directly to the BDA discussion. Any effort to predict a future event with relative accuracy involves knowing what has happened in the past and understanding the current situation.[53] The key beginning step is deciding what data is actually relevant. Table 1 is by no means an all-inclusive list, but it shows data that may be available ahead of time and would serve as variable inputs to a model. This information is largely static during the course of an engagement, but could be updated if changes are made or observed.

Several relevant factors are controlled by decision makers during the targeting process. These are known variables that could be changed prior to the strike if required. These represent the best decision that can be made by the JFACC and his or her targeting team given the information and resources available in the time leading up to a strike. These include the choice of a weapon and the strike platform, the targets assigned, and specifics of the strike operation such as tactics or time on target.

Category	Factors that are ***known*** and can be ***controlled***	Factors that ***may be known***, but ***difficult to change*** in the short-term	Factors that are known but are ***uncontrollable***	Wild cards
Platform	Choice of aircraft or delivery platform	Delivery platform survivability		Aircraft mechanical failure
Weapon	Weapon choice	Weapon survivability Munitions Effectiveness Assessment (MEA)		Failure to separate/fuze/detonate
Target	Target and Aim point # of weapons assigned to target		Enemy defensive capabilities on route to and at the target	Unanticipated changes or movement Hidden target characteristics
Tactics	Blue attack vector / special tactics	Expected enemy reactions		Wartime reserve capabilities Unexpected enemy reactions
Time	Time of day / Sun angle	Transit time from base/tanker		
Other		Enemy defensive posture	Weather	

Table 1: Input Data for Predictive BDA Algorithms

Other information may be known and theoretically could be changed over time with outside influences, but would be difficult to alter significantly in the near-term. This data may itself be the product of modeling and simulation or test data, such as MEA or survivability. Tactical information about enemy tactics, capabilities or awareness would be based on intelligence analysis. New tactics or technologies could be developed to improve platform or weapon survivability or weapon accuracy. Additional fuel tanks could be added to increase range or allow a platform to travel faster (and be less fuel efficient). The enemy's defensive posture could be changed with politics or diversion. However, much of this would be difficult for a JFACC to change within the battle rhythm of an ongoing operation.

Some factors can be known ahead of time, but there is realistically nothing that can be done about them (other than possibly cancel or delay the operation). These would include weather (on route to or at the target site) or the enemy's defensive capabilities that could disrupt the operation.

Especially in the case of something as complicated as armed conflict, there will be wild cards that may or may not present themselves, but they must be considered when trying to predictively play out possible scenarios and understand the probability of those scenarios occurring. Any unexpected event or mechanical failure has the potential to derail even the best plans – "Murphy's Law" is alive and well. However, even for these types of factors, there is potential data available to make the model "smarter" and the BDA prediction more reliable. An aircraft could suffer a mechanical failure that no one could have predicted. But at the same time, related information like time or flight hours since the last overhaul, failures in other aircraft, or pilot reports of warning signals could help predict the unpredictable.

In addition to incorporating all available data prior to an operation, a predictive BDA model would be required to update calculations as additional data is collected. Real-time communications with the pilot regarding the success of target acquisition & weapons release, visual observations relayed from the aircrew immediately post-strike, and cockpit data and/or video recordings may all be available to confirm, refute or add information to predicted BDA results. Across the battlespace, this information may update predictions for similar strike operations and targets. For example, a pilot reports difficulty locking onto a target because of unexpected countermeasures or decoys. This information may lower the probability that similar targets were destroyed or damaged. Mission debriefs as well as actual BDA from IMINT, SIGINT, or other sources should also add to the predictions for targets and systems for which no BDA intelligence is available.

Evaluation Framework

As stated earlier, much of the data identified in Table 1 and the details of any real-world example that could be used to evaluate the use of predictive BDA would be classified. The idea is not that predictive analytics would replace traditional BDA entirely, but that it would supplement the process already in place for providing leadership with assessments of the level of success of ongoing operations, from which they can determine progress made toward overarching goals.

Joint Intelligence doctrine identifies the qualities of "good" intelligence, providing the evaluation criteria against which a predictive BDA model can be analyzed. Specifically, data produced by a predictive model would need to be "timely, accurate, usable, complete, relevant, objective, and available."[54]

Timeliness and Availability

If the information presented is going to be worth anything, it needs to be there when the commander requires it. Predictive BDA would theoretically be available at any point in time. Its main use-case would be an instance where a decision needs to be made, and no other information on the target is available. Even the required timelines published in Joint BDA doctrine, described earlier in this paper, could be frustrating for a commander who needs an assessment now. One consideration that would affect the timeliness and the availability of predictive results is the complication of the algorithms and the resulting lag-time for updating results incorporating new information. The desire would be for the model to constantly update and refine estimates and predictions as new information is made available and added to the system, but this comes at a cost.

There are two general methods that predictive models use to deal with streams of incoming data. The model can either make determinations based only on the newest incoming data points, incrementally build a picture from the data as it arrives, or it can re-evaluate the entire dataset each time new data points arrive.[55] A model evaluating only the newest data has the potential to fluctuate significantly, but it is useful if the newest data is more important, valuable, or indicative of the current situation than older data. Predictive models used by stock brokers place a high value on recent data so that they are able to keep up with the market conditions in real-time.[56] Where this is not the case and/or the desire is to use additional data dampen out fluctuations and zero in on a predicted result, the model should incorporate the newest data into an analysis of the entire dataset. This analysis is obviously more computationally intensive and therefore will tend to take more time.

Accuracy

Error or uncertainty propagation is a concern with any method of prediction, and it would represent a limitation in the fidelity and reliability that could be provided for BDA. The Navy utilizes a hierarchy of simulation models to support their acquisition process by providing campaign-level analysis built on platform design and mission simulations.[57] What this means in practice is that they use the output of one model as an input for another model. This is done for many reasons but primarily in order to provide Navy decision makers with information in a reasonable time and at a reasonable cost.[58]

Predictive BDA would rely on a similarly hierarchical build, as estimated BDA would be built using the results of other probability models such as the Munitions Effectiveness Assessment (MEA), weapon sensor predicted performance (probability of engagement), and weapon fuzing (probability of kill). A study completed at the Naval Post-Graduate School in 2015 tracked uncertainty propagation through a hierarchical submarine engagement scenario and determined that, while still statistically significant, uncertainty could be reduced by accounting for deviations in input values vice using only mean results.[59] What this means for BDA predictive analysis is that utilizing multiple outputs within the standard deviation of a probability model such as MEA, rather than a single straight percentage, could yield more reliable BDA results.

Completeness

Even given a substantial amount of time and computing power, predictive BDA will never be able to give the complete picture. If definitive evidence of BDA exists, the predictive algorithms are not needed. However, intelligence data is almost never complete, and predictive BDA may be able to serve as a piece that helps fill in where information is incomplete. However, at some point, additional analysis or algorithm execution offers diminishing returns. In general, joint intelligence doctrine states that "the need to balance timeliness and completeness should favor timeliness."[60]

Relevance

Intelligence is only valuable if it is relevant to the situation at hand and if it assists the commander in accomplishing the mission. In order to be relevant, predictive BDA would need to fill in gaps in traditional BDA intelligence and provide the commander information required to make operational decisions such as whether or not to reattack a target or alter another mission in the area due to the remaining assessed capability of a threat. Relevance would need to be further studied over time, through training exercises or other opportunities for commanders to become comfortable with the information. Predictive results would really only be relevant for things that are not already 'known.' If one of the strike aircraft has a malfunction or is shot down before reaching its target(s), the model should return a 0% damage to the target. But that report is probably irrelevant, and any predictions of what would have happened had the aircraft reached the target would be irrelevant as well. Again, the information provided must address the situation at hand.

The phase one Target Element Analysis by itself does not usually give enough information to use for a reattack decision. However, because it does not take up much space and may add to the overall picture, the notional displays in the next section do include a "hit/miss" indicator. If it does not add to a commander's ability to make decisions, it should be removed. The most useful predictive data will be the Target Level Analysis, which as discussed earlier, may take several hours to complete if traditional BDA data sources are available at all.

Usability

In order to make quick, informed decisions, commanders require useful information that can be rapidly consumed and comprehended. Predictive BDA would need to provide simple, useful information displayed in a manner that does not overstate the accuracy or the confidence level of results. This information must be provided so that it conforms to current BDA doctrine and complements traditional BDA results. With this in mind, Figures 2 and 3 below show notional displays for a specific target. Figure 2 shows a Target Element Assessment (phase 1 BDA), and Figure 3 shows a Target Functional Damage Assessment (phase 2 BDA). Once integrated into a display of the Common Operating Picture (COP), these predictive results could be nested such that they are only displayed when the target is selected (too much information reduces its usability).

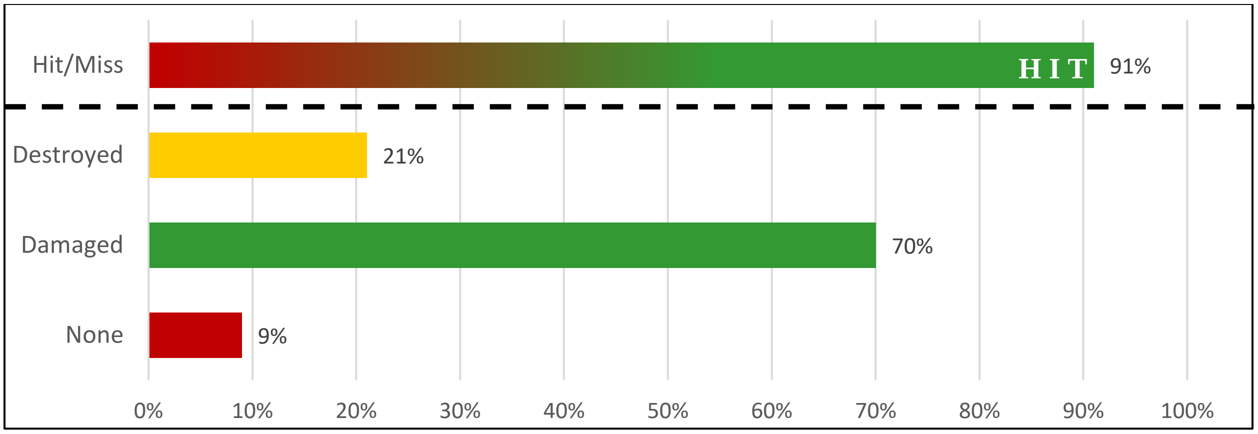

Figure 2. Notional Target Element Assessment Display

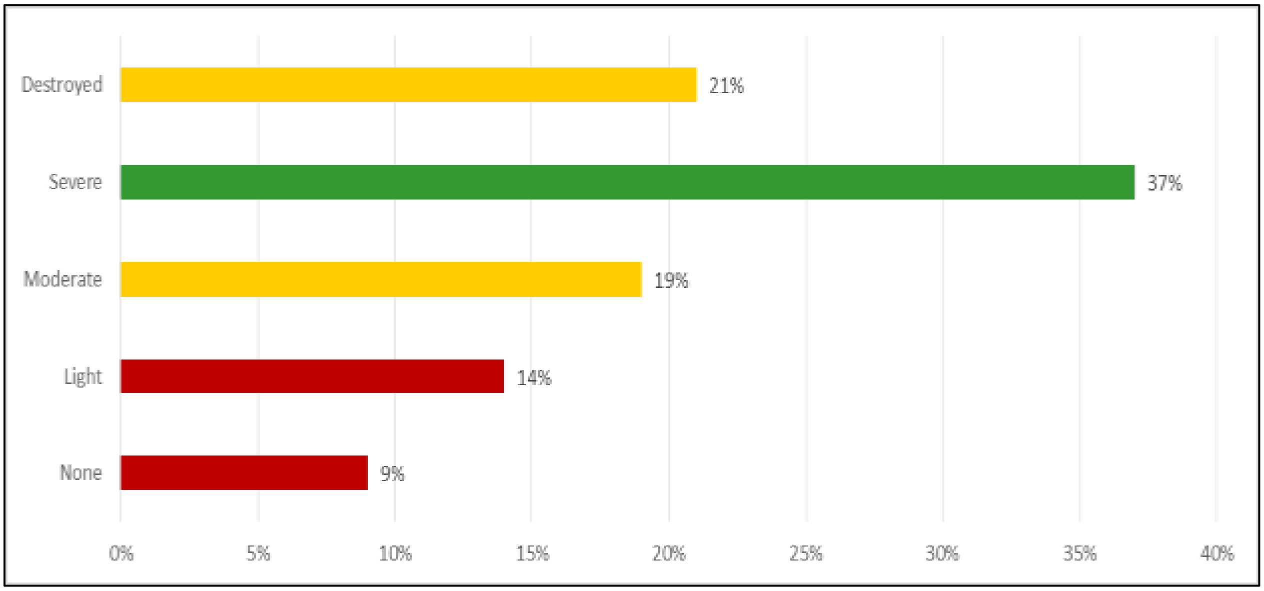

Figure 3. Notional Target Functional Damage Assessment Display

Objectivity

Humans by nature will tend to view information from their own perspective, and so intelligence analysts must be very careful to guard against biases that skew or slant assessments in a way that increases the appeal of a preferred COA. Assessments that have been altered or framed to fit a commander's preconceived notions also do not add value.[61] One of the great things about data analytics is that it provides information free of analyst emotion and bias (although some level of bias in the assumptions programmed into a predictive model may be unavoidable).[62] Predictive BDA would be purely data-driven, so the results would serve as a purely objective look at the information available. In fact, predictive BDA could potentially serve as an added sanity check against 'known' traditional BDA results.

CONCLUSIONS

Predictive analytics could provide an added benefit in situations where traditional BDA is not available. The most likely scenario where predictive BDA would be useful is a large-scale conflict against a near-peer adversary. The U.S. would likely not have uncontested control of the air or space domains from which to conduct intelligence collection, requiring prioritization of collection requirements that may not include a large amount of BDA data. Reliance on predictive analytics has its drawbacks, most notably that there may be no way to fully understand or anticipate an enemy's capabilities and actions at every target, and so no prediction would ever have a 100% confidence level. However, experienced leaders are accustomed to having to deal with a level of uncertainty as part of any intelligence assessment, and BDA is no exception. Applying sound logic to the combination of past results, expected performance, and available information about the current situation will provide another valuable tool to inform decision-makers, providing them with predictions that are timely, accurate, usable, complete, relevant, objective, and available. In the end, having some information that is based on rigorous predictive analytics will be more helpful than having nothing at all.

RECOMMENDATIONS

The recommendation of this paper is that the Air Force begin a low-level investment in predictive BDA algorithm development and test to compare against current, established methods of BDA at every opportunity. Industry is already working with predictive analytics, and those efforts should be leveraged to avoid reinventing the wheel. A massive program aimed at completely upending BDA processes would fail. This low-level approach will allow for steady algorithm improvement and an increase in leadership comfort and confidence with BDA that is based solely on predictive analytics. One difficulty will be that, thankfully, there is not an abundance of opportunity for testing in an operational combat environment. Training and perhaps some weapons tests could be considered a relevant environment that could provide real-world data which could be used to validate and/or improve predictive algorithms and models for BDA.

While it adds risk to the availability of data at any specific time, any predictive BDA model should conduct regressive analysis on the data set when new information is available vice a stock market-type incremental approach. This will prevent one-time abnormalities from significantly influencing results, while at the same time allowing for recognition and consideration of recurring events. This will add time and processing load to the data analysis but will contribute to improved accuracy of predictions since, in general, the most recent data is not necessarily the most representative of the current situation throughout the battlespace. In order to mitigate the impact to timeliness and availability, this regressive analysis should be limited to a specified subset of data.

This research proposes an effort focused on only BDA intelligence. It will be built on past efforts to predict situations or outcomes and make use of ever-increasing processing power and speed, along with emerging forms of data collection, but it should be limited in scope to solving this one problem. And regardless of how 'good' predictive models become, leaders will still be required to assess the situation and consider all available information in making decisions. As has always been the case, human insight and intuition will be the final measuring stick when faced with gaps in available intelligence.

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