Decision Support System Engineering for Time Critical Targeting

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Abstract

Effective decision support for complex military operations requires more than the development of sophisticated decision aids. A decision aid must be integrated into a decision support system that brings to the decision aid the right information at the right time at the right level of detail. The user must have confidence in the tool's results. This paper describes decision aids being developed for Time Critical Targeting applications and discusses the additional factors influencing effective decision support system engineering for these applications.

Introduction

The actions of Iraq during the Gulf War forced the military to confront the threat posed by an enemy's capability to deliver warheads, possible containing weapons of mass destruction, through the use of theater missiles. Many potential enemies of the United States and its allies either already possess theater missiles or could easily acquire them. The potential for theater missiles to be employed in future wars, even small scale conflicts, has provided the motivation to develop strategies to counter these weapons.

While much of the effort and attention has been given to programs whose goal is to shoot down the enemy missiles themselves, there has also been considerable thought put into ways to get to the missiles before they are even launched. The number one challenge is how to target the missile during the short time it is exposed pre-launch. In the course of performing that targeting

a number of decisions have to be made, such as whether an object on the ground is a "time critical target," or which weapon should be tasked to destroy the target. The underlying assumption of decision aid development for time critical targeting is that by reducing the time needed for decision making, the overall time needed for responding to the time critical target is reduced. This reduction, along with improvements in other aspects of time critical targeting, will hopefully be sufficient to enable the response to be executed while the target is exposed.

We have been involved in the development of decision aids for time critical targeting. Much of our experience confirms the obvious: e.g., the decision algorithms have to account for the entire decision space, data must be formatted and stored properly, the human-machine interface needs to be user friendly. But we also encountered some unexpected challenges. As our decision logic became more sophisticated, so did the data needed to apply the logic to battle situations. As the aids performed greater battlespace analysis, the gap between an aid's output and a user's intuitive notions widened. We found that decision aid development went far beyond the confines of the aid itself to having to engineer the environment supporting the decision aid.

To appreciate the role support system engineering plays in decision aid development for time critical targeting, we'll provide a little more background on the problem space and describe some examples of the decision aids we deal with. Then we'll discuss the lessons we learned during the course of developing these decision aids regarding support system engineering and the selling of the aid's capabilities to the users.

Background: Time Critical Targeting

Time critical targeting will be discussed in the context of theater missile defense, which is conventionally divided into three primary areas: Active Defense, Passive Defense, and Attack Operations (AO). Active Defense refers to the process of destroying Theater Ballistic Missiles (TBM) in flight. Active Defense systems include the Airborne Laser, the Patriot missile system, and Theater High Altitude Air Defense (THAAD). Passive Defense refers to those steps taken to protect friendly assets and territory. Employment of early warning systems to alert populations to potential attack, and moving or fortifying critical assets in response to enemy threats are examples of passive defense measures. AO refers to the process of destroying the TBM delivery system and its related infrastructure, preferably before the TBM launches. Time Critical Targets (TCTs), as discussed in this paper, are a subset of the AO target set. Typically, they have short exposure times and are mobile. The Transporter Erector Launcher (TEL) is an example of an AO TCT. Other AO targets, such as weapon factories, usually are not time critical and are prosecuted as any other ground target via the established targeting process (i.e., Air Tasking Order or ATO).

TCTs challenge the standard operating procedures. A TCT's exposure time is short, typically less than an hour and a half, and, if it is mobile, it must be located before it can be attacked. Thus, the standard 24-hour ATO cycle for prosecuting targets at known locations can not be used for TCTs. During the Gulf War, fighters dedicated to countering TCTs, known as Combat Air Patrols (CAPs) were used. However, CAPs have considerable drawbacks. CAPs tie up aircraft, people, weapons, and fuel, making them unavailable for other missions and limiting the Commander's ability to execute the air campaign.

The steps needed to prosecute a TCT are the same as those needed for any target, but many of those steps must be accomplished within the target's short exposure time. The target must be within a sensor's coverage, must be detected, and, if moving, must be tracked, which could involve more than one sensor or sensor type. After the target is detected, it must be identified, and, if the target is time critical (e.g., the target meets predefined rules) it will be nominated for immediate prosecution. After the target is nominated, an appropriate weapon must be selected, coordinated among service and command elements, and tasked to prosecute the target. Finally, the weapon system must find and attack the target. All these steps must occur within the TCT's exposure time, which might be as long as an hour and a half, but may also be significantly shorter.

The Joint community recognizes that new approaches to target development and prosecution need to be explored in order to counter TCTs effectively. The Air Force's approach to the TCT challenge is identified in the AF Concept of Operations (CONOPS) for C2 Against TCTs [ACC, 1997]. The CONOPS recommends a system-of-systems approach, leveraging off of the strengths of the Theater Air Control System (TACS) nodes, such as the Airborne Warning and Control System (AWACS) and Joint Surveillance and Target Attack Radar System (JSTARS) aircraft. Dynamic Battle Management (DBM), a key element of the CONOPS, involves allocating responsibility for TCT prosecution, which in current doctrine is centralized at the Air Operations Center (AOC), to the TACS nodes. DBM stresses the importance of shared information, wide area connectivity, and, significantly, automated decision aids. It draws from objectives-based planning, using Intelligence Preparation of the Battlespace (IPB, i.e., the knowledge of the enemy's assets and tactics, techniques, and procedures), the rules of engagement, and commander's guidance to structure the battlespace for successful TCT prosecution.

Examples of Decision Aids for Time Critical Targeting

Several decision aids for time critical targeting, including Time Critical Targeting Aid (TCTA) and weapon to target pairing aids, have been developed and evaluated in recent exercises, including DBM simulations and Roving Sands. They and other aids under development, such as Joint Targeting Execution (JTE), Attack Operations Decision Aid (AODA), Advanced Field Artillery Tactical Data System (AFATDS) and the Joint Continuous Strike Environment, are proposed for inclusion future experiments. These decision aids are designed to organize, sort, and present information so better TCT decisions can be made. They are described individually in the following sections.

Decision Aids for Surveillance and Target Assessment

The Air Force's Time Critical Targeting Aid (TCTA) and the Army's Common Ground Station (CGS) are decision support aids designed to facilitate the surveillance and target identification phases of time critical targeting. The aids are similar: they are hosted on the same platform, share many functions, and will be merged into one product in the future. Both aids enhance the user's capability to manage and manipulate large quantities of sensor data, and to visualize this data with respect to the battlespace. The man-machine interface can display multiple types of sensor data along with intelligence information, enhancing the utility of data from multiple sources, any one of which is too uncertain or insufficient for target assessment.

TCTA and CGS are decision aids that track ground targets using JSTARS and other Moving Target Indicator/Synthetic Aperture Radar (MTI/SAR) data. They have specialized display capabilities for launch, imagery, area delimitation, overhead reconnaissance, and other data associated with ground targets. They provide data manipulation aids for targeting TCTs. Figure 1 shows a typical TCTA screen.
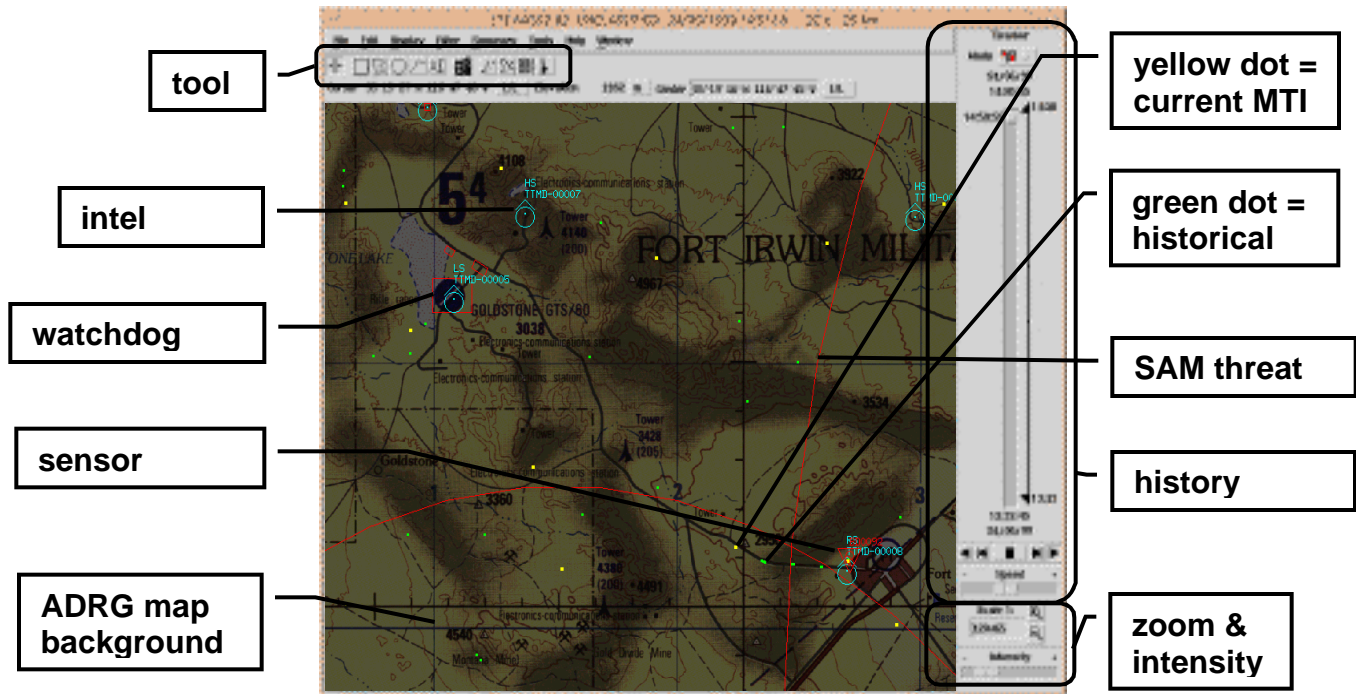

Figure 1. TCTA Screen

The basic job of TCTA and CGS is to display Moving Target Indicator (MTI) hits with enough context to allow the operator to identify patterns and potential targets. That context includes a map background (showing the road network), electronic intelligence (ELINT) reports, and previous MTI hits. The operator can also set up "watchdog areas" that will alert him when tracks enter or leave the area.

These aids support determination of TCT selection according to theater rules of engagement. Facilitating the operator's ability to rapidly nominate TCTs to the weapon selection process is essential to allow targeting within TMD timelines. TCTA can also be used to support Intelligence Preparation of Battlespace (IPB) production, to review battlefield activity over extended periods of time, and to use SAR, imagery, and traffic patterns to help identify temporary garrisons, loading points and hide sites.

Course of Action Decision Aids

The Air Force's Attack Operations Decision Aid (AODA) and the Army's Advanced Field Artillery Tactical Data System (AFATDS) are designed to help the user determine appropriate courses of action and optimize asset allocation. The aids primarily address difficulties with making quantitative judgements, performing complex tradeoffs, and analyzing complex situations within the short time critical targeting timeline. The aids also address user problems in managing large amounts of information, such as the status of friendly and enemy assets.

Attack Operations Decision Aid (AODA) is designed to optimize the pairing of Air Force weapons to TCTs in a many-on-many situation. Figure 3 shows a typical AODA screen. AODA's algorithms are based on operations research techniques. A commander makes similar decisions using a heuristic approach which, while adequate in a non-stressing (few-on-few) environment, can not efficiently handle complex situations. AODA assesses the tradeoffs among original target value and new target value, available weapon capability, asset survivability, and probability of destruction. AODA then provides the operator with a list of recommended weapon target pairings.

AODA's algorithms require that the values of targets and assets be captured numerically. Although subjective valuations of this nature are made by commanders during the decision process, they are not quantified to the level required by the decision aid. To fully support the aid's algorithms, commanders will have to explicitly state the values they place on targets and assets.
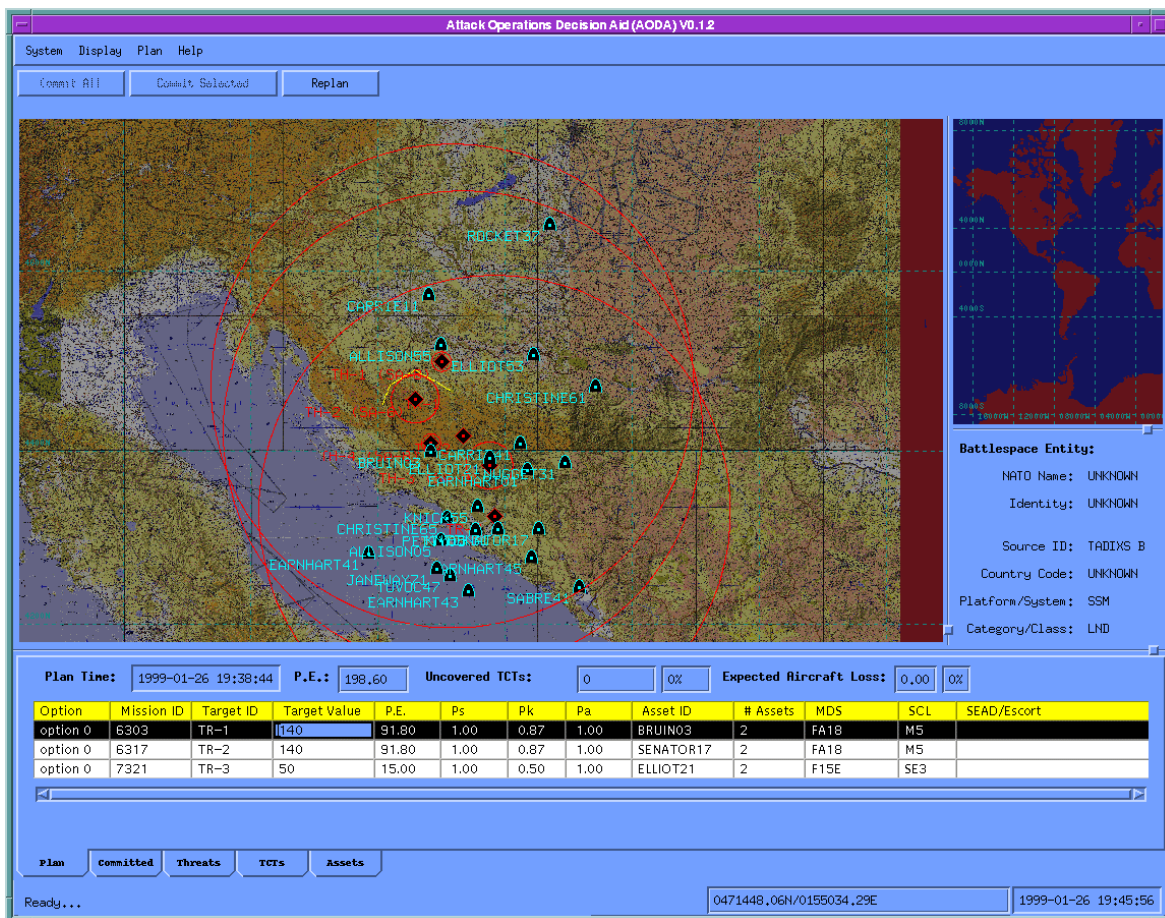
Figure 2. AODA Screen

Advanced Field Artillery Tactical Data System (AFATDS), illustrated in figure 4, is a multi service automated command and control system of mobile, multifunctional nodes providing automated planning and execution capabilities to fire support Operational Facilities (OPFACs), and Independent User Centers (IUCs). AFATDS will operate at the Fire Support Element (FSE) and Fire Support Coordination Centers (FSCC) of the supported maneuver force, and Field Artillery Command Posts (FACPs), Fire Direction Centers (FDCs) and selected Field Artillery (FA) elements throughout the command structure. It is designed to interact with different intelligence and command and control systems, e.g., ATCCS (Army Tactical Command and Control System), JSTARS, and the coalition systems.

AFATDS provides the singular Command, Control and Communications (C3) solution to the complex problem of integrating and controlling fire support assets. It provides the commander with integrated, responsive and reliable fire support.
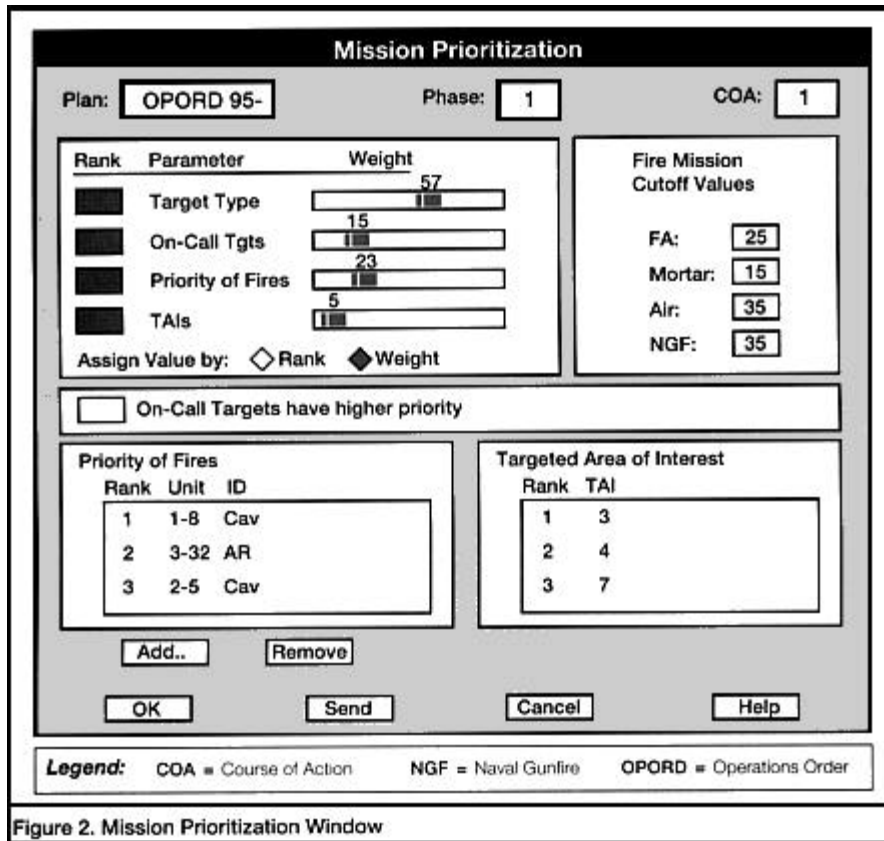
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Figure 3. Sample AFATDS Screen

AFATDS uses detailed targeting guidance and attack criteria and employs sophisticated decision algorithms to automate fire mission processing. The aid allows the user to specify decision criteria such as commander guidance, target value, and fire priority information using a user-friendly graphical interface. Another feature is a distributed database for all operational facility systems, which insures that they are all operating with the same information.

The system is intended to provide the ability to attack the right target, using the right weapon system, with the right munitions, at the right time.

Evolutionary TCT Decision Tools

Joint Target Execution (JTE) is an aid proposed for the TCT problem. It is currently an early prototype system that addresses the surveillance, assessment, and course of action phases of time critical targeting. It provides a common architecture for collaboration within and among services to detect, identify, and attack a TCT. The aid addresses difficulties in managing large amounts of information, visualization, performing tradeoffs, analyzing complex situations, and making quantitative judgements. The surveillance and assessment component is based on the CGS and TCTA, enhanced to support collaboration across multiple nodes, increasing confidence and providing more complete target information.

JTE includes target development as well as weapon target pairing, and encompasses assets from all the services. The JTE approach, illustrated in figure 2, involves sharing target information (but not detailed weapon information) among command and control nodes (not necessarily the actual weapon unit). For distributed weapon target pairing, each C2 center is responsible for deciding whether its weapons are capable of hitting the target (e.g., based on reachability, weapon effectiveness), and whether local needs prevail (e.g., self-protection, inventories). This approach is in concert with the usual military practice of maintaining local control over sensors and weapons. JTE is used to compose a mission nomination that can be shared with other JTE nodes. The JTE nodes perform weapon target assignment (choosing among the nominated missions) and share the results. The C2 centers then prosecute the missions as usual.
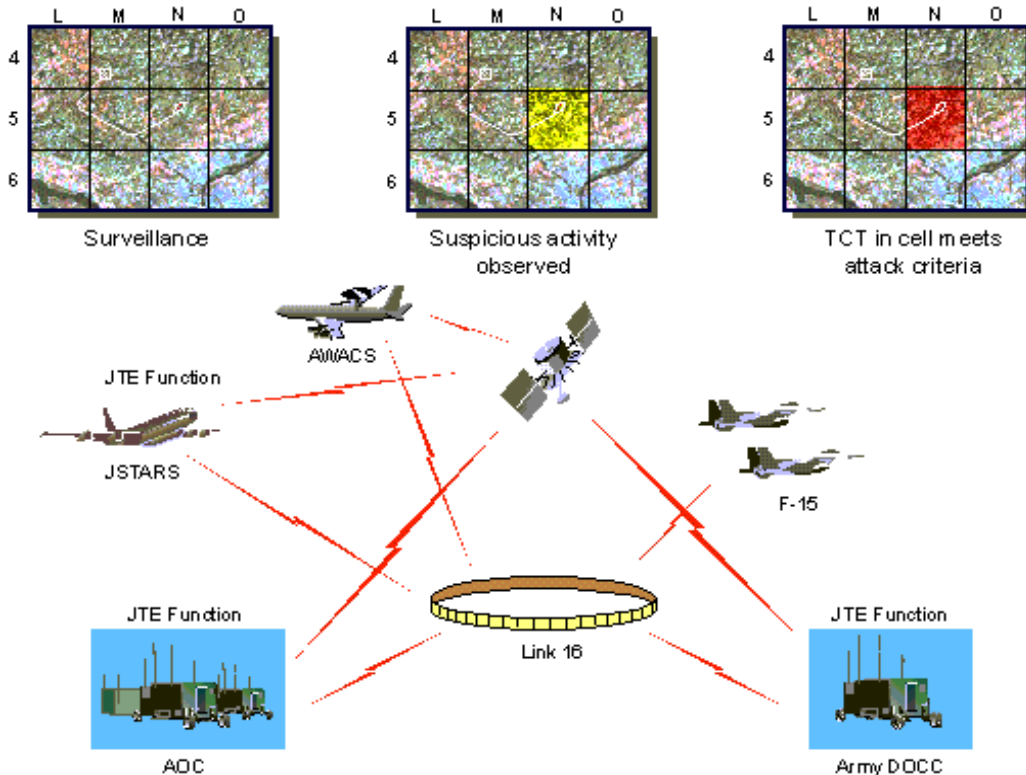

Figure 4. JTE

Decision Aid Support System Engineering

Our experience with these decision aids has underscored the value of sound decision aid support system engineering. Typically, developers focus on the components of the decision aid itself: algorithm selection, data manipulation and management, and the human machine interface. However, none of the systems described above operates as a stand-alone system. Each of these decision aids relies on a much larger environment in which the decision aid operates and that provides the data the decision aid needs. We refer to this environment as the decision aid support system. Just as the proper design of the decision aid itself depends on adherence to good

systems engineering principles, so, too, the usability of the decision aid depends on adhering to good systems engineering principles in the design (or, more likely, modification) of the decision aid support system. Our work with time critical targeting decision aids has provided valuable lessons in the areas of supporting data, connectivity, and placement.

Supporting Data

A time critical targeting decision aid will require data about the time critical targets, friendly capabilities, etc., in order to perform its decision processing. If the required input data is readily available, the engineering involved in design of the decision aid support system is primarily one of ensuring timely connectivity. But what if that input data is not readily available? A simple case occurs when data is not in the proper format. For example, data units might not be compatible between the input data and the needs of the decision aid. The input might, in one case, describe location by latitude, longitude, and altitude above mean sea level, while the decision aid may do its processing in an earth centered cartesian coordinate system. In another type of format discrepancy, the range of valid values of the input data might fail to meet the decision aid's expectations. When discrepancies between the decision aid's and input data's formats occur, one of the formats must change to the other's or valid conversion techniques must be developed.

A more stressing situation of input data not being readily available can arise when the decision aid uses more sophisticated methods than those currently employed, that in turn establishes new input data demands. For example, the AODA optimization algorithm uses the weapon's effectiveness (probability of kill) against the target in its calculations. However, the Air Operations Database (AODB), which provides AODA with weapons data, frequently indicates a platform's weapon type as "best available," which has no effectiveness associated with it.

Arranging for input data that is not readily available depends on the type of data that is needed. *Static data* is information that is known in advance and changes infrequently. Examples of static data include the location of stationary entities, such as airfields, and fixed characteristics, such as weapon fly out ranges. Access to static data is often, in the case of military data, through subscription to standard databases, such as the AODB. If required static data does not reside in existing databases, the appropriate production organization must be identified and arrangements made for them to produce the necessary information.

The developer needs to verify that the data definitions used by the information producers are the ones the decision aid is using. Variations in data definitions abound both within an individual service and among the various services. For example, the "window of vulnerability" may refer to a target's total exposure time, or to the time window for attack. Data definition agreement among the decision aid's developers, users, and data procurement agencies is required.

The production organization must also take the necessary steps to ensure that the new data has been validated by appropriate agencies. It is also necessary to work with the controllers of the database schema to ensure that the required fields are allocated and that the newly produced data is included in the database.

Dynamic data is data that is unknown prior to the system's deployment, or is subject to frequent changes during the mission. Examples of dynamic data include an aircraft's fuel status or the location of mobile units, such as missile launchers. If dynamic data is not readily available to the decision aid but can be carried by a message; the developer must work with the information producer to get the desired information, in the proper format and with the desired quality, into a message. If existing message sets can not readily accommodate the new information, the decision aid developer must work with the user community to modify the message standards to produce the information. Again, data definitions must be identical with the ones used by the decision aid, and all newly produced data should be validated as appropriate. If the required information can not be obtained through message exchange, the decision aid must allow the operator to manually enter the information, which can reduce speed and accuracy.

A change in input data preparation frequently initiates process changes. For example, requiring target priorities to be conveyed as numeric rather than alphanumeric values can require changes in the tactics, techniques, and procedures (TTPs) of target analysts. On the other hand, a change such as the timely update of critical data base values requires that current TTPs be rigidly followed.

Connectivity

The ability to transfer required information between production and user facilities must also be assessed. The impact of new dynamic data on information delivery times, for example, has to be analyzed, especially for time stressing situations such as attack operations, to ensure that needed information will be delivered to the decision aid in time to be useful. Are the production and user facilities connected? Will the existing network architecture support timely exchange of information? To support these questions, careful analysis of the aid's information exchange and throughput demands is required.

Remote ground sites in underdeveloped countries may lack the communication resources to fully meet the data requirements of an aid. Software that is to be hosted on board aircraft faces additional challenges, because aircraft may have limited connectivity. The aid developer must be aware of these limitations, and design an aid that will function any place it is deployed.

Placement

Where should a decision aid be placed so that it can be employed at the right command level to be useful? Where should the aid's output be available? For example, AODA is needed in the TCT cell in the Air Operations Center, to aid the battle manager with weapon-target pairing. When the weapon is an aircraft, however, a weapon controller, who is not part of the TCT cell, does the weapon tasking. The support system design should include, at the very least, giving the weapon controller access to the weapon-target pairing decisions made in the TCT cell. When similar conflicts arise, careful placement of decision aid functionality is necessary.

The developer also has to think about the environment the aid will be used in. Aircraft, for instance, often have insufficient space and/or energy resources for the introduction of new hardware. New decision aids frequently have to be integrated into existing hardware and

software systems. On AWACS, for example, a decision aid's displays must be integrated into existing displays. Decision aid developers must work closely with a platform's engineers to ensure that the decision aid can be accommodated.

User Acceptance

One paradox we encountered in decision aid development is that the very users who could benefit most from the aid often reject it. The aid's users must buy into the aid's usefulness and must have confidence that the aid will work as advertised. If the users don't believe that the aid is necessary, or don't believe that the aid "works right," they most likely won't use it, or will automatically reject the aid's results when they are counter intuitive. "Selling the users on their own product" often depends on a combination of sound decision aid engineering and user education/training.

Considering the User during Decision Aid Design

Design of a decision aid should conform to some obvious, but nevertheless often overlooked, principles. The decision aid must meet the user's perceived needs and incorporate those factors that the user feels are critical to a correct decision. It is imperative to determine what the user thinks the decision support needs are, the conditions under which the aid is needed, the features that are needed, and the factors that the aid's algorithms should consider. A decision aid should be built with a clear understanding of the users' expectations and level of expertise as well as the operating environment.

Decision aids may support various levels of command. At low levels, decision aids may simply help the operators to recognize a critical situation, so that pre-planned appropriate action can be taken and important information can be elevated to other command levels. Decision aids that support a commander responsible for the execution of the campaign plan, may need to gather all the available data, organize and present information clearly, and recommend options that facilitate decision making. A decision aid's support level of sophistication needs to be geared to the user's training, educational level, and background, which varies with the command level.

The operators of related and support systems must also participate in decision aid development to ensure that requisite changes in, for example, data preparation or in other TTPs, are implemented in a manner that best supports the decision aid. Exposure to the aid, by both system and support system users, through participation in requirements identification, development, design reviews, and exercises, will facilitate a mutual understanding between users and support system personnel of any needed process changes.

Another way in which developers assure that the aid complies with users' expectations is through verification and validation. Verification assures that the aid's algorithms are implemented properly. Validation assures that the aid provides the decision support it claims to provide. When users participate, validation is more effective in promoting acceptance of the decision aid.

Education and Training

Even developers with the best of designs and the best of design practices sometimes encounter resistance on the part of users to employ an aid. This can come about when those "users" who specified (or helped specify) the system aren't the people who ultimately use the aid after development. For example, those specifying the system might have been officers from the warfighting command, while the "operators" of the aid are enlisted personnel or augmentees. Another possibility is that during the development period the "original users" moved on to other assignments, and the "current users" are unfamiliar with the trade-off decisions their predecessors have made. Even if the same users have been integral to the development of the aid throughout, they might not appreciate how their requirements have spawned the sophisticated processing in the aid. In some cases, the users' expectations may be limited to what can be done without decision aids. In other cases, it might not be obvious that the aid has considered everything that user would have in making the decision. For example, when AODA was first discussed with a potential JEFX 99 user, his first reaction was, "I couldn't use a aid to make a divert decision. I have to consider the assets, weapons, safety, and original target." Only after finding out that AODA considered those factors, and that AODA allowed the operator to set weights to reflect each factor's importance, did the user decide the aid could be helpful.

Our experience with AODA in JEFX 99 can be generalized. The developer needs to work with the user to realistically change expectations and to educate the user about the advantages that the aid and technology improvements provide.

After the users are convinced of the potential value of a decision aid, they need to be properly trained. Good training can facilitate an aid's acceptance by the user community. Users are more likely to employ an aid when they understand how, when, and why the aid works, and they develop confidence in their ability to use the aid to consistently achieve positive results.

The developer needs to work with the user community to produce training materials that are appropriate for operators' command level and background and that convey the aid's complexity. Materials should focus not only on the mechanical aspects of running the aid, but should also describe the aid's capabilities, limitations, and valid usage. Most decision aids will require a variety of training materials including documentation, on-line help, test scenarios, and exercises. Test operators should be used to validate the training materials and to develop realistic training programs and timelines.

Depending on the aid's complexity and frequency of use, several levels of training, including those who work on the support system, may be required. For example, if notification of a TCT requires manually setting a new message field, the cognizant personnel have to be taught when and how to set the field.

Conclusion

The Air Force and other services are making good progress in addressing the difficult challenges posed by time critical targets. Effective decision support for time critical targeting will require advanced algorithms, data management, and human machine interface. But it will also require

extensive user participation throughout all stages of development and the engineering of the decision aid's support system. And even with all that, the decision aid might have to be sold all over again to the next generation of users. But this effort has to be expended. The threat posed by time critical targets is real, and the technology is in hand to address the threat. Sound system engineering, taking advantage of the experience and lessons we have learned to date, must be applied to bring the technology effectively into the hands of our military.

References

[ACC, 1997] "Combat Air Forces Concept of Operations for Command and Control Against Time Critical Targets" HQ ACC/DRAW, Langley AFB, VA, 8 July 1997.