Since spring of 2002 we have been working on a methodology, decision model, and cognitive support system to aid with effective allocation of anti-terrorism (AT) resources at Marine Corps installations. The work has so far been focused on the military domain, but the model and the software tools developed to implement it are generalizable to a range of commercial and public-sector settings including industrial parks, corporate campuses, and civic facilities. The approach suggests that anti-terrorism decision makers determine mitigation project allocations using measures of facility priority and mitigation project utility as inputs to the allocation algorithm. The three-part hybrid resource allocation model presented here uses multi-criteria decision-making techniques to assess facility (e.g., building, hangar) priorities, a utility function to calculate anti-terrorism project mitigation values (e.g., protective glazing, wall coatings, and stand-off barriers) and optimization techniques to determine resource allocations across multiple, competing AT mitigation projects. The model has been realized in a cognitive support system developed as a set of loosely coupled Web services. The approach, model, and cognitive support system have been evaluated using the cognitive walkthrough method with prospective system users in the field. In this paper we describe the domain, the problem space, the decision model, the cognitive support system and summary results of early model and system evaluations.

Introduction

The recent history of terrorist attacks on both military and civilian targets at home and abroad suggests a need for increased emphasis on effective implementation of mitigations to protect industrial facilities. The effects of attacks such as the 1996 truck bombing of the Khobar Towers housing complex, the 1998 U.S. embassy bombings in Kenya and Tanzania, and recent attacks on expatriate housing complexes in Saudi Arabia may have been diminished had more effective facility anti-terrorism mitigations been installed. Anti-terrorist mitigations are generally expensive, however, and deciding what, how, where, and when to allocate resources to protect critical infrastructure is a difficult problem. We have been working on a methodology, decision model, and cognitive support system to aid with more effective allocation of anti-terrorism (AT) resources at Marine Corps installations. Though our work has so far focused on the military domain, the methodology, decision model, and supporting tools are generalizable to a range of commercial and public-sector settings including industrial parks, corporate campuses, and civic facilities.

Anti-terrorism facility mitigations are designed to protect people and property from asymmetric attack by nontraditional hostile organizations. Anti-terrorism mitigations include measures such as blast-resistant glazing (windows are the major cause of injury and death in most bomb attacks), wall-hardening coatings, fences, vehicle stand-off barriers, enhanced lighting, video surveillance, and guards. Allocating available funds across different anti-terrorism mitigation projects, with the exception of guards, is a project selection and capital budgeting problem. Though a range of well-developed techniques to address such problems are used in both the private and public sectors, and are widely researched, the anti-terrorism domain presents some special problems that make many of these techniques unsuitable. Chief among these are the need to assess trade-offs between the cost of mitigations, the financial benefits of protecting valuable facilities and other assets, and the value of the people protected when mitigations are applied.

At the beginning of the paper, we provide some background on project selection and capital budgeting techniques.
commonly employed. We then describe the domain of anti-terrorism resource allocation and the hybrid decision model assembled to address some of the special problems that arise in the domain. In the next section we describe the cognitive support system that has been constructed to realize this decision model and give summary results from early field evaluations of both the model and system. We conclude with a discussion of some avenues for further work in the AT resource allocation problem space.

**Background**

Project selection is a critical task for many organizations including government funding agencies, universities, research institutes, and technology and capital-intensive companies. It is a complex decision-making process consisting of multiple stages, with multiple groups of decision makers, multiple and often-conflicting objectives, and high risk and uncertainty in predicting the future success and impacts of different project combinations (Ghasemzadeh & Archer, 2000). Among the methods employed to address project selection problems are unstructured peer review, scoring, mathematical programming, economic models, decision analysis, artificial intelligence, and portfolio optimization (Henriksen & Traynor, 1999). Multi-attribute utility methods are the basis for a number of project selection methods. Barabasoglu and Pinhas (1995), for example, describe a capital budgeting process using the Analytic Hierarchy Process (AHP) for resource allocation. The method uses AHP for prioritizing the different resources, and uses a linear program for allocating limited budget resources. Korhonen and Wallenius (1990) describe a dynamic decision support system for solving multiple linear programming problems by using the weighting technique of AHP.

Liberatore (1987) focuses on structuring the decision hierarchy so that the AHP can be successfully implemented in a capital budgeting decision problem. Thurston (1991) demonstrates the application of multi-attribute decision making for selecting the best design alternative, coupling optimization methods with multi-attribute analysis. The utility of each design alternative is evaluated, and the one that maximizes utility is chosen. Greiner, Fowler, Shunk, Carlyle, and McNutt (2003) describe how to integrate AHP with a 0–1 integer portfolio optimization problem for supporting decision-making activities in the military domain, which provides a screening process in selecting new weapons development projects.

Efforts to make these techniques more usable for a wider range of stakeholders typically involve development of computer-aided decision support systems to support project selection tasks (Bard et al., 1988; Kocaoglu & Iyigun, 1994; Ghasemzadeh & Archer, 2000). According to Liberatore (1987) most organizations use project selection and justification tools that embed standard financial analysis methods such as Cost Benefit Analysis (CBA) or Discounted Cash Flow (DCF).

Organizations in the commercial sector typically use one of four methods for capital project ranking: payback, net present value (NPV), regular internal rate of return (IRR), and modified internal rate of return (IRR*) (Brigham, 1989). Proctor and Canada (1992) provide an extensive summary of literature dealing with capital budgeting processes based on the discounted cash flow approach. These methods focus on the **financial return** obtained from a given course of action. Though terrorist attacks generally do have a financial cost, and potentially impact the ability of an organization to generate future revenue, the benefits of applying specific AT mitigations also include protecting people and providing an environment in which they can feel safe and secure, and ensuring that the facilities platform is available to support the organization’s mission. Though the financial costs of different AT mitigations are quite easy to derive, the benefits of these mitigations are much more difficult to determine given the low probability that a given mitigation will actually be used, and the intangible nature of their many benefits. The methods and tools described in this paper are one approach to effectively managing the AT resource allocation problem.

Traditional methods for project selection and capital budgeting have often been judged inadequate because they fail to account for nonquantifiable intangible factors and to establish the link between the capital investment decision and organizational priorities (Sullivan & Smith, 1990). Otley (1999), for example, points out that budget control mechanisms often hide or make implicit the organizational priorities and capabilities that they represent and identifies a series of challenges to be addressed when assessing true performance of available resources. Among the most relevant of these to the case of anti-terrorism resource allocation are:

- How are budgets figures related to strategic goals?
- How are resources allocated (budgeted) relative to strategic goals?

Among the approaches sometimes used to address such issues is Value Focused Thinking (Keeney, 1994), which involves iterative decomposition of an institution’s high-level values and objectives into successively more detailed and lower-level objectives. Empirical studies of VFT suggest that broader and high-quality decision alternatives (decision opportunities in the VFT lexicon) are identified when VFT rather than traditional, alternative-focused thinking approaches are employed (Keeney, 1994). Another approach is the Analytic Hierarchy Process (AHP; Saaty, 1980), which has been used in conjunction with more traditional, finance-based methods to solve project selection and capital budgeting problems (Varney, Sullivan, & Cochran, 1985; Wabalickis, 1987). Liberatore (1987) for example, describes a case in which AHP was successfully integrated into the capital-budgeting decision process.

**Anti-Terrorism Project Planning and Allocation**

It is important that designers of cognitive support systems ensure that the support they provide helps answer the “right” questions with respect to user requirements in the domain.
(Parker, 2001). Scenarios are one useful method for helping to negotiate and identify the concrete uses of a given decision model, and for showing how technology can be integrated in the task domain to the best effect. Scenarios take the form of narratives that describe the details of behaviors, tasks, and technology support in a design space (Carroll, 2000; Carroll & Rosson, 1992). Scenarios help to both envision new technology support and to evaluate how well envisioned or implemented technologies afford useful and usable advantages in their domain of use. The following are among the key scenarios driving design of our methodology, model, and cognitive support system and are provided to help portray how the model and cognitive system are planned for use.

**Allocating an Anti-Terrorism Budget Over Multiple Locations**

A United States Marine Corps (USMC) headquarters facilities planner apportions a “global” budget across a geographically dispersed, functionally heterogeneous installation set. In this scenario, the planner attempts to optimize organizational security and capabilities by funding mitigations in support of critical worldwide activities. The facilities planner begins with a mandated AT budget, assesses each individual installation’s contribution to these organizational objectives, assesses localized threats, and allocates resources accordingly.

**Allocating an Anti-Terrorism Budget Over Multiple Facilities at a Single Location**

The anti-terrorism team at a particular installation must allocate a fixed AT budget across facilities with varying priorities and concerns. The budget includes not only the amount allocated by USMC headquarters but also additional funds budgeted by the local commander. A crossfunctional team of personnel from public works, operations, and security reconcile diverse protection perspectives into a single prioritized list of facilities. Mitigation projects are then funded by priority until the budget is exhausted.

**Planning and Justifying an Anti-Terrorism Budget (Budget Programming)**

An anti-terrorism team is responsible for identifying the AT requirements for a given installation. Properly prioritized requirements are a budget-programming tool that the team can use to justify resource requests. When a set of such requests is compiled by USMC headquarters across all installations, it represents a snapshot of the resources needed to achieve a specific level of protection across the entire service.

**Resource Allocation Decision Model**

We conceptualize the AT resource allocation problem as consisting of three major components: prioritizing facilities and other assets to be protected, identifying the relative utility of different mitigations and mitigation projects (the latter are combinations of mitigations), and allocation of available resources (money, time, people) to protect the highest priority facilities with those mitigations providing the highest utility, subject to the constrained resources. A high-level view of this conceptualization of the AT planning problem space is depicted in Figure 1.

**Decision Model Rationale**

Designing a model for rational decision making in a complex domain such as AT planning involves resolving the need for accuracy in the results of the model with the cost of capturing the data needed for this increased accuracy. Models designed to provide “perfect” solutions often require “perfect” data to be useful. These may fail in practice when needed data are unavailable or the cost and effort needed to obtain them is unrealistic. A significant challenge to development of techniques and tools to aid anti-terrorism decision makers is the range of different data that potentially influence the decision process. The cost of identifying, collecting, and then merging or fusing this data to make it comprehensible to decision makers must be traded off against the increased accuracy of the system solutions as the amount of available data increases. A key tenet in the design of the decision model and cognitive system described here is that the system be useful with varying data availability. In other words, even with an incomplete data set the decision maker should be in a position to make decisions of a higher quality than when no data and no cognitive support system are available.

The approach taken here to resolving this trade off is to decouple or compartmentalize the problem-solving units or modules of the system such that each provides stand-alone support to the AT decision maker. For example, in cases where specific mitigation project utility data are unavailable,
the model’s prioritization piece can still be used to identify which facilities are most important to protect. If prioritization data are unavailable then the mitigation project utility piece can still be used to give an assessment of the relative impact of different mitigation projects. Anti-terrorism planners and decision makers may also use these model parts separately to perform rough assessments of an installation’s AT profile.

Two factors often used to determine where and when these mitigations will be applied include assessments of facility vulnerability and threat. Efforts to measure facility vulnerability are driven by factors such as location of the facility relative to an avenue of attack (e.g., public roadways), the actual or symbolic importance of the facility, and whether or not the type of the facility is one historically subject to terrorist attack. However, the actions of terrorist organizations are inherently unpredictable and adaptive; using vulnerability to drive the allocation of AT mitigations may only change rather than eliminate terrorist targets. The perceived threat to a facility is often a function of specific, time-sensitive intelligence data, but the latency of construction improvement projects and the relative rigidity of most capital-budgeting processes mean that decision makers cannot respond quickly to specific threat data. Both of these perspectives also focus solely on the current status of the facility to be protected and fail to account for the impact of different AT mitigation projects, in other words, how the situation improved once mitigations are applied.

Facility Prioritization

The first part of the AT resource allocation problem is facility prioritization. The primary objective of this component is to prioritize a set of identified assets—a set which itself is identified as all possible assets to protect, or some subset created using heuristics—based on a set of agreed-upon ranking criteria. The two most widely used methods in multicriteria ranking problems are the Analytical Hierarchy Process (AHP; Saaty, 1980) and the Simple Multi-Attribute Rating Technique (SMART; Edwards, 1977). Other alternative focused methods scoring methods are Simple Attribute Weighting (SAW), Weighted Product Method (WPM), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and ELECTRE (Hwang & Yoon, 1981).

The Analytical Hierarchy Process supports the incorporation of both objective, quantifiable data and the more subjective qualitative data into the decision process (Saaty, 1980). The Analytical Hierarchy Process also facilitates the support for the different phases of the decision-making process—intelligence, design, and choice (Simon, 1960). The process can also be used for individual and group decision making, a means for conceptualizing and communicating about the problem domain, which supports the building of a community with a shared vision.

To prioritize facilities, decision makers must choose from among alternatives based on potentially conflicting objec-
resource allocation problem of the Istanbul Water and Sewage Authority is formulated using AHP to help quantify the intangible, social factors that must be considered to most effectively allocate World Bank loan funds to a set of competing waterworks upgrade projects.

A weakness of the AHP approach is that the number of individual AHP comparisons required can become unwieldy as the number of criteria and/or alternatives being considered increases, and this issue is exacerbated when multiple stakeholders engage in the comparison process. Variations of the AHP approach exist that somewhat ameliorate this issue, but with trade-offs in consistency and/or accuracy. These will be explored further in the next phase of the project.

**Mitigation Project Utility**

The second component of the AT decision model is a benefit-cost assessment of different AT mitigation projects. This part of the model is an expression of the moderated benefit-cost ratio of a given mitigation as applied to a given installation asset (e.g., a building). For capital budgeting projects in the public sector, where nonfinancial elements may play a key role in determination of overall project utility, the benefit-cost ratio is a widely used measure to assist decision makers (Au & Au, 1992). Cost benefit analysis (CBA) is the principal analytical framework used to evaluate public expenditure decisions to allocate scarce resources in a more efficient way. It was developed during the 1930s when the U.S. government had embarked in several costly construction programs, such as dams in the West, and needed CBA to justify these expenditures to the public and to Congress. Cost/Benefit Analysis can be carried out using only financial costs and financial benefits and it is possible to include intangible items within the analysis. As a value must be estimated for these, it brings an element of subjectivity into the process.

An AT example, it determines the relative benefit of applying a hardening mitigation to the glazing of a certain building relative to the utility of applying other mitigations, or of the utility of applying mitigations to a different building. An early challenge to the development of this model is identification of the factors or attributes that should be considered as part of the calculation, or utility function. Among the elements currently included in calculation of mitigation project utility are the following:

**Benefits**
- People protected
- Equipment protected
- Facility protected

**Costs**
- Mitigation direct costs
- Mitigation indirect costs

**Utility Factors**
- Mitigation effect rating
- Mitigation interaction effects
- Risk data
- Vulnerability data

The purpose of calculating mitigation project utility is to evaluate the net beneficial output achieved by providing different mitigations to a facility or other assets.

What makes the utility function so difficult to model is that it requires specification of the relationship between the benefits of protecting lives and the benefits of protecting buildings and equipment. This specification may be a requirement in the military domain, where the mission importance of buildings and equipment cannot be completely discounted with respect to human life, but it may be the case that in civilian domains the number or people protected dominates or “trumps” all other benefits derived from a given AT mitigation project. To address this conundrum we are relying especially on the use of sensitivity analysis visualization tools to make apparent to decision makers the structure and content of the utility calculation behind each mitigation project. Further studies with users of the decision model and cognitive support system will, we hope, help tune this model further such that it more accurately reflects these important relationships.

**Resource Allocation**

The optimization engine for resource allocation is an integer program. The integer program is used to maximize the mitigation utility with the budget and mitigation project costs as the constraints. The problem is solved as an integer program, since partial allocation of budgets is not allowed. Two different approaches have been suggested for similar applications (Ramanathan & Ganesh, 1995). In the first, the AHP priorities are used as coefficients in the objective function of the linear program formulation. In the second, the benefit-cost ratios are used as the coefficients.

We combine the AHP and the benefit-cost ratio to form the coefficient to the optimization problem using the installation budget and the sum of mitigation costs for each project as the constraints. The solution to this yields project allocations with the highest aggregate utility to the highest priority assets. For AT resource allocation it is required that a particular mitigation project is either selected for resource allocations or not selected at all, i.e., there is no partial allocation of resources.

Incorporating 0–1 integer programming is the methodology for solving these types of problems. A 0–1-integer program is used to maximize the mitigation utility with the budget and mitigation project costs as the constraints (Kyparisis, Gupta, & Ip, 1996). These types of 0–1 integer programming models, commonly referred to as “knapsack problems,” are based on the premise that the decision maker wants to define a selection that provides optimal value while meeting a specific constraint, a budgetary constraint in this case (Greiner et al., 2003).
Facility Prioritization Example

The first step in the USMC AT/FP resource allocation model involves identifying facilities to be considered for protection and ranking them based on an agreed-upon criteria set. To prioritize facilities, decision makers must choose from among alternatives based on potentially conflicting objective performance measures. The next step in the AHP process is to perform a pair-wise comparison among the different criteria to arrive at a criteria weight score. Decision makers make comparisons of each pair of criteria using a 9-point scale; a representative set includes the five below.

Equally important = 1
Moderately more important = 3
Strongly more important = 5
Very strongly more important = 7
Extremely more important = 9
Intermediate scores = 2, 4, 6, 8

Using the 9-point scale, the decision maker must determine the importance, preference, or likelihood of each element when compared to every other element at the same level of the problem space hierarchy. For example, a value of 1 would mean two criteria are equally important, while a value of 7 means one criterion is very strongly more important than the other. Raw scores for the example criteria set are shown in Table 1.

Once the pair-wise comparisons have been completed, the criteria weight score is computed. This is calculated as follows. Each column is summed and the each cell value (column) is divided by the total to get the normalized values.

After the normalized values are calculated, the average row sum of normalized values is calculated. This value is the criterion score for that criterion (Table 2).

Mitigation Project Utility Example

A base project mitigation utility is an additive function and is calculated as follows:

\[ u = \frac{\sum b}{n} + \sum c \]

The raw mitigation utility, is thus the ratio of benefit to cost added to the utility factors for each project. This process is continued across all available projects. Utility factors include external factors like risk data, threat data, etc. These are quantified as accelerators and decelerators to the systems.

Table 4 below gives the priority weight scores of each of the alternatives. From the table it can be seen that maintenance has a higher priority than other facilities like training and supply.
Raw mitigation utility is the utility value that is obtained as a result of the benefit-cost ratio calculation. This value has to be normalized in the next step to avoid dominance of mitigation utility value over the others.

As there can be significant differences in the mitigation project utility values for different mitigation projects depending on the benefit cost ratios, it is possible that a particular project utility will be dominant. To avoid this situation, the mitigation project utility values are normalized as follows for each project:

Normalized mitigation project utility

\[ \frac{\text{Raw mitigation project utility for the project}}{\sum_{i=1}^{n} \text{Raw mitigation project utility}} \]  

where \( n \) = total number of projects.

Since different types of facilities (e.g., buildings, hangars, etc.) have associated priority weightings from the prioritization part of the model, the normalized mitigation project utility is added to the facility priority value. The sum of the priority weighting and the normalized mitigation project utility is the adjusted utility value for each project.

Adjusted Utility Value, \( u = \text{Normalized mitigation utility value (for the project)} + \text{AHP priority value (for the asset class of the project)} \).

Table 5 gives the result of the above calculations for the utility.

### Resource Allocation Example

Facility priority and mitigation utility are used as inputs to a commercial-off-the-shelf (COTS) algorithm that optimizes allocation of available AT funds across identified mitigation projects. Allocations are made subject to the mitigation project cost constraint with respect to the installation AT budget. The general form of the optimization can be summarized as follows:

\[ \text{Max} \sum_{i=1}^{n} u_i x_i \]

where \( n \) is the number of projects subject to:

\[ \sum_{i=1}^{n} c_i x_i \leq B \]

\[ x_i \in \{0, 1\} \]

Table 6 shows the allocations made to the different projects. ATFP-Proj2 and ATFP-Proj3 have the maximum values for the weighted utility. Each of these projects is allocated the costs required to fund these projects. ATFP-Proj4 has a much higher cost, and it cannot be funded with the available $65,000 budget. Thus, there is no partial funding for a project.

### Cognitive Support System Design Rationale

Cognitive support systems are systems designed to aid users with knowledge work in complex domains. Cognitive support systems for decision making focus on problem structuring, data collection and organization, and application of algorithms for decision analysis, mathematical programming and optimization, stochastic modeling, simulation, and logic modeling (Sprague & Carlson, 1982). Cognitive support systems therefore may embed a great deal of knowledge about how an organization, and groups and individuals within the organization, operate within a given domain (Manhiein, 1986; Turban & Watkins, 1986). Studies of human, naturalistic decision-making have uncovered a range of maladaptive behaviors that appear to be germane to humans (Klein, 1998; Tversky & Kahneman, 1974). The theory of bounded rationality, for example, acknowledges the human cognitive dimension of real-world decision scenarios and describes a process by which people strive to make decisions that are merely “satisficing,” or good enough (Simon, 1957). Much contemporary decision research focuses on the situated nature of decision making. Other research points to the highly adaptive nature of human decision-making and suggests that how decisions are made is dependent on both the context and scenario, and on the attributes of the individual making the decision (Crozier & Ranyard, 1997). A key objective then in the design and development of cognitive support systems is the extent to which such systems support careful consideration of all available information and use that information appropriately in decision-making tasks. When designed, implemented, and used appropriately, cognitive support systems can significantly improve the quality of an organization’s decision-making (Bhargava, Sridhar, & Herrick, 1999).

The system developed to support the approach and implement the decision model was developed based on three

<table>
<thead>
<tr>
<th>Mitigation project</th>
<th>Asset class</th>
<th>Benefit-cost ratio</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATFP-Proj2</td>
<td>Maintenance</td>
<td>13043.4</td>
<td>0.16</td>
</tr>
<tr>
<td>ATFP-Proj3</td>
<td>Admin</td>
<td>56595.2</td>
<td>0.83</td>
</tr>
<tr>
<td>ATFP-Proj4</td>
<td>Utilities</td>
<td>9.8</td>
<td>1.8E-4</td>
</tr>
</tbody>
</table>
key design criteria: usability, usefulness, and deployability. All of these criteria center on the idea of a user-centric design process. Each element of the decision model has been implemented as a discrete Web service, allowing elements to be used alone (e.g., for asset prioritization, or determination of mitigation project utility) or in combination as required for more complex scenarios and decision objectives. The system architecture is Web-based, distributed, and lightweight allowing it to support reliable, pervasive access including access from mobile devices.

Web services are discrete units of software functionality that are deployed to a URI and are discoverable either directly or through a Web-based broker such as UDDI and describable using standard, XML-based ontology languages such as WSDL. The attraction of Web services is their ability to integrate disparate systems, regardless of the platform on which they are deployed or the language in which they are written. Web services combine best practices from component-based development with emerging support for autonomous and semi-autonomous enterprise application integration (EAI). Extensible Markup Language (XML) is utilized as the basis for a range of application-specific dialects including SOAP, WSDL, RDF, and UDDI that provide a means for standardizing data formatting and encoding, therefore facilitating autonomous data exchange. Figure 2 shows how Web service technology has been used to implement the AT cognitive support system.

We have implemented the system using IBM’s Web Services Development Toolkit (WSTK 3.2). The development and deployment platform is Apache Tomcat. We use the open-source database management system, mySQL for persistent data. The linear programming functionality required for budget allocation is implemented using a COTS software component, the Lindo Java API version 2.0. Business logic for the core decision processing was developed using Java (JSDK1.4.1) and the Web-based user interface (presentation logic) was developed using Java Server Pages (JSP).

This loosely coupled, component-based architecture allows flexible use, combination, and recombination of the decision elements. This simplifies extensions to and maintenance of the components and allows distribution of system processing parts across multiple servers to achieve load balancing or fail-over capabilities. The prioritization, project utility, and budget allocation services are relatively generic, the Web-based component model supports building new presentation logic to re-badge back-end functionality for different applications, for example, a cognitive support system to help choose among research and development projects could be assembled easily using these existing parts. The Web services model also enables important future enhancements to the systems, especially the use of intelligent software agents to act as assistants and mediators between the human user and the different services.

Model and System Evaluation

Formal evaluations of the AT decision model and cognitive support system have been performed using the cognitive walkthrough method. The cognitive walkthrough (CW) method is an evaluation technique designed to investigate the usability and comprehensibility of a system early in the development process (Polson, Lewis, Rieman, & 1992; Wharton, Rieman, Lewis, & Polson, 1994). A key advantage of the CW method is that it is derived from a cognitive theory of how users work through a computer-supported task (Kahn & Prail, 1994). The method is based on a theory of exploratory learning (Polson et al., 1992), which posits that system users form goals, explore the actions available to them to make progress towards their goals, and continually assess whether the actions they take lead towards achieving their identified goals. Of particular interest in the case reported here was identification of points at which users’ mental models and their manner of performance of a given task differed from the model implemented in the system. These points form the basis for further analysis to determine whether either system changes or user changes to existing task practices might be implemented to more closely align cognitive support capabilities with the task that is to be accomplished.

The cognitive walkthrough method involves observing and recording the behavior of systems users as they work through a decision scenario using a cognitive support system. The objective of the method is to understand the cognitive fit, or comprehensibility of the system relative to the information and information processing requirements of the decision maker. Of particular interest are the breakdowns that occur during system use, in other words, where and when the system fails to adequately support the users model of the decision domain. We are particularly concerned that the system’s overall usefulness not rely on a single, inflexible model of the AT resource allocation task. Such prescriptive, rigid tasks models are both difficult to specify for a range of users and use scenarios and brittle over time as the context in which such systems are used evolves. Therefore,
the focus on the analysis was how each major system function (facility prioritization, mitigation project utility, and resource allocation) supported each of the decision maker's major subtasks.

The CW method involves identification of a set of tasks to serve as the basis for each participant walkthrough. In the ATP-CSS the baseline task is allocation of a budget among competing mitigation project alternatives. To clarify, this task can be further decomposed into the following set of subtasks:

1. Facility Prioritization
   a. Identification of prioritization criteria
   b. Relative weighting of prioritization criteria
   c. Identification of alternative facilities for mitigation
   d. Assessment of identified alternatives with respect to each of the identified prioritization criteria (AHP)
   e. Review and adjustment of calculated facility priorities
2. Mitigation Project Utility
   a. Identification of mitigation projects
   b. Specification of mitigation project costs
   c. Specification of mitigation project benefits
      i. Personnel protected
      ii. Key equipment protected
      iii. Facility replacement cost
   d. Specification of mitigation project benefit/cost accelerators (for example, facility vulnerability, facility risk, facility's current condition)
   e. Review and adjustment of calculated mitigation project utility values
3. Mitigation Project Budget Allocation
   a. Calculation of mitigation project budget allocation
   b. Review of calculated mitigation project resource allocations

Cognitive walkthroughs were conducted at six Marine Corps installations over 6 days, 3 days at installations in California in the spring of 2003 and 3 days at installations in North Carolina and Virginia in the fall of the same year. Walkthroughs were performed with a total of 21 prospective system users including anti-terrorism officers, provost marshals and other military police, public works officers (Navy engineers), base operations officers, and civilian facilities planners. In addition, the model and system have undergone 13 informal focus group design reviews with senior Marine Corps and other Department of Defense personnel. These design reviews were used especially in the early phases of the project, primarily as a means to clarify and refine system requirements. Once a complete working version of the system was available, a more formal study of system usefulness and usability commenced using cognitive walkthroughs with potential users in the field.

After answering a set of basic questions related to their role and experience in the AT domain, walkthrough participants were asked to work through an AT resource allocation scenario familiar to them using the task outline above as a guide. Walkthroughs lasted from 45 to 120 minutes and were generally uninterrupted, focused sessions. The section below outlines the most significant issues that emerged from the walkthroughs and where possible outlines future work to address identified issues.

Model and System Use Scenarios

Essential to the design of the decision model and cognitive support system is understanding the different scenarios of use where they are likely to be applied. Many reviewers reacted to the standard task scenario presented in design reviews by expressing that their ways of working and the context in which they perform AT planning tasks often differ from that used as the baseline. For many the AT planning process is a new priority for their position and many are still in the process of working through the best approach to addressed AT planning and allocation scenarios as they arise. In this sense development of the AT cognitive support system is not a matter of developing a system to best fit a well-understood, preexisting task, but one of co-evolution of the users' domain understanding and the tools to support their work.

This result suggests that the de-coupled architecture employed in cognitive support system development may provide significant benefit in allowing flexible recombination of the different decision components to map more closely to disparate scenarios. Going forward we plan to further our understanding of potential use scenarios through broader and more in-depth design and system reviews with potential users and other stakeholders. Our ultimate goal is to allow system users to specify some key attributes of the planning and allocation scenario at hand, and then use a software agent to actively construct and lead the user through a task model that integrates underlying system components into a scenario-specific application.

Explaining and Justifying System Results

Participants in both cognitive walkthroughs and informal design review frequently discussed the importance of how and why the system arrived at a particular set of resource allocation recommendations. This is a difficult problem in a complex, hybrid decision model since the elements of a given solution interact in a variety of ways. An important goal in development of a cognitive support system is working towards the best fit in cases where this fit is necessarily less close, for example, when the technology is not able to support a particular information need or inference process, it is important that the system has the ability to provide not only what and how information about the workings of the system but also why it works the way that it does. In decision systems exposing the inner working of a model and system is commonly achieved through sensitivity analysis. In a complex, hybrid decision model such as that described here, sensitivity analysis is complicated by the broad range of data and algorithms combined in the solution. In response to this result we are focusing primarily on the design and development of a minimalist training module (Carroll, 1990) and an integrated software assistant, a help facility, to guide users to a better understanding of how the system works. Also,
enhanced sensitivity analysis capabilities, in the form of pop-up dashboards that expose the underlying data and intermediate results for a given final result, are being designed and developed.

Problems Inherent When Placing a Value on Human Life

Valuation of human life and assessing the trade-offs between cost of facilities and equipment, and potential casualties is a significant complicating factor in the AT resource allocation domain. Utility models that include aspects related to the value of human life introduce unique difficulties in an otherwise rational mathematical model. This problem is not unique to the AT domain, there is little agreement across studies as to the best way to value the lives and injuries to people (de Blaeij, Florax, Rietveld, & Verhoef, 2000; Takeuchi, 2000). Much of the work in this area is highly domain and context specific, suggesting that organizations adopting AT resource allocation approaches will need to address this problem using criteria derived from their local value systems. In the case of AT planning and resource allocation at the USMC, these local value systems relate closely to command priorities and the nature of a given installation’s mission.

Availability of Model Data

A significant barrier to usability of the AT/FP cognitive support system is the overhead required to manually populate required data such as asset classes and assets, the utility factors associated with an asset (people, asset replacement cost, and the cost of equipment housed at the asset), and standard AT/FP mitigations. Several participants requested that the system provide a standard set of AT/FP mitigations with costs and effect ratings. This will allow the system to act as a knowledge base of AT/FP mitigation information and ease the task of creating mitigation projects. The ease of use and usefulness of the system would be enhanced considerably if these data were made available in the system through automatic data loads.

Analytical Hierarchy Process Scalability and Usability

The AHP criteria and alternative weighting user interface presents significant challenges for new users. Many reviewers found the matrix display used to weight prioritization criteria and alternatives confusing. Though the matrix may be the most efficient approach to representing this data, we are considering ways to provide more “natural” user interface mechanism for inputting prioritization weights.

Participants highlighted the difficulties inherent in the AHP prioritization process when considering relatively large numbers of criteria and alternatives. A well-known problem with the AHP prioritization approach is that as the number of criteria and/or alternatives increases, providing pair-wise comparison values to populate the model becomes laborious. In cases of large numbers of criteria and/or alternatives other prioritization methods such as SMART become attractive, even though decision fidelity is reduced. We are exploring ways in which the system could support methods for simplifying pair-wise comparisons as the number required increases.

Model Terminology

Much of the terminology used to label key model entities was obscure to many of the reviewers. For example, the term Problem Space, which describes an abstract entity that acts as a placeholder for a budget amount, was confusing to many reviewers. Unfortunately, in many cases where terms were obscure or confusing, no single, clear alternative was identified to replace the term with something more familiar. This suggests that customizable labels for model and system entities would improve the usability of the system.

Conclusion

The decision model and decision support system presented in this paper provides a rigorous yet practical approach to allocating anti-terrorism resources in military, commercial, government, and other public-sector domains. Though the design of the model and cognitive support system have emerged from the military, specifically Marine Corps requirements, the relative flexibility of the approach is easily adapted to nonmilitary domains. A central difference between military and nonmilitary AT resource allocation is the issue of acceptable risk and acceptable losses. Though one might assume that in nonmilitary domains acceptable risks and losses approach zero, in fact, society frequently makes implicit and explicit judgments of acceptable risks and losses, for example, in medical research allocations, transportation safety programs, and in seismic retrofits for earthquake damage mitigation. The approach described here combines the rigor of formal decision processes while at the same time explicitly acknowledging the limits human decision makers.

Decision model tuning and evaluation of cognitive support system performance and usability is an ongoing process. Additional system cognitive walkthroughs are planned with each incremental version of the system. Also planned is development to enhance application interoperability so that standing data such as facilities’ lists, individual facility populations, and standard mitigations can be loaded and made available to systems users without additional data entry. We expect that the Web services architecture employed in construction, with its XML-native data interchange formats, will ease this important and often time consuming task.

Results of model and system evaluations to date suggest a number of improvements that we plan to make going forward. These include development of sensitivity analysis and explanation facilities to help expose how and why the system makes the resource allocation recommendations that it does. We are currently researching approaches to provide users with intelligent assistance to aid with problem structuring, data gathering, and interpreting of the solutions.
proposed by the system. Though the loosely coupled decision model and cognitive support system architecture means that useful results can be obtained even when all data needed for a “perfect” solution are either unavailable or too expensive to capture, even in cases where this data is available the sheer volume of data potentially required by individual decision makers means that interfaces to existing Marine Corps legacy systems will be required to help automate data entry. Finally, we are planning continue work with cognizant groups in the Marine Corps on identifying a base of scenarios to represent the range of model and system use cases.

References


