Technical Report PTR 002-05

Tactical Group Decision Analysis System (TGDAS) For Distributed, Collaborative Planning and Support

SBIR Phase I Final Report
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1. INTRODUCTION

1.1 Summary of Accomplishments

This report presents the results of the DARPA SBIR Phase I project "Tactical Group Decision Analysis System (TGDAS) for Distributed, Collaborative Planning and Support." TGDAS is a complete, end-to-end software system that supports collaborative teams in tactical decision making, using advanced cognitive science and decision analytical methodology. Phase I has resulted in four major sets of accomplishments:

1. We have innovatively and successfully combined cognitive science and rigorous decision analysis in a full-scale, end-to-end system for collaborative team support. Our solution bases the computer support process on a rigorous, model-based decision analytical foundation that has previously proved successful, and augments this basic approach with the latest research in cognitive decision aiding -- including influence diagrams, mental models and critical thinking concepts. In particular, our technical approach builds on a seminal DARPA-sponsored R&D project on computer-based group decision aiding performed earlier by Perceptronics Solutions personnel.
2. We have identified and established a firm working relationship with a committed TGDAS user in the Special Operating Forces, and to specified an initial scenario and task sequence that meets that user's needs via a connection to the DARPA-funded SOFTools program. By adapting the TGDAS concept to the specific situation of our SOF user in Phase I, we have gained the knowledge necessary to develop a generic system suited to a broad range of users in Phase II. In addition, by satisfying the initial SOF customer, we will have achieved an essential transfer goal, and paved the way for wide dissemination of the product in Phase III.
3. We have provided a proof-of-concept demonstration, in which we were able to show a fully interactive user interface and to exercise the system in its several main functionalities before actually building the back-end programs and algorithms. Initial demonstration of the system to the potential SOCOM user resulted in highly positive responses, providing additional confidence for our construction of the complete Phase II prototype. Further, this demonstration formed part of the IPTO booth and exhibits at the 2005 DARPATech.
4. Finally, we have established a unique Phase II development plan that includes significant contributions from the three other groups who have participating in the DARPA/IPTO Tactical Group Decision Analysis Support System (TGDASS) Program as Phase I contractors. Their participation will permit us to add highly useful functionality to the TGDAS prototype intended for our SOCOM customer, as well as to continue the development of group decision aiding features of general utility to a variety of users.

1.2 Problem Statement

The need for distributed, real-time, collaborative tactical planning and decision-making is at the center of today's military and security command and control operations. This need is associated with rapidly changing events as well as with response to asymmetric warfare and counter-terrorist operations. Of particular concern is collaboration across services, agencies and organizations, or in operations involving coalition partners dispersed in different geographical locations. Associated with this critical need is the problem of aiding and enhancing the capabilities for tactical decision making by such distributed collaborative groups. It is clear that computer support systems provide the logical path, but prior to now no fully satisfactory solution has emerged -- in large part because current solutions have focused primarily on the *decision process* and not on the *decision product*.

A clearly related and equally critical problem is that of supporting and enhancing the tactical decision making capabilities of distributed collaborative groups. Decision support would effectively fit into in the evolving command, control and intelligence network-centric collaborative infrastructure. An example is the

Command Post of the Future (CPOF) developed by DARPA, which connects the division staff with each of its brigades and separate battalion headquarters. The CPOF is currently being introduced in Iraq, where group decision analysis technology could exploit the information-rich environment with an added capability to improve decision quality.

While it is clear that computer systems provide a logical approach to tactical decision support, to date no fully satisfactory support solution has emerged. The field of group decision support systems (GDSS) is committed to developing interactive computer-based systems which facilitate the solution of unstructured problems by decision makers working together as a team. But the main objective of current GDSS has been to augment the effectiveness of decision groups through interactive sharing of information among the group members and with the software applications. Accordingly, the focus of these systems is almost purely on facilitating group interaction, brainstorming and communication. Virtually no attention is paid to underlying decision analytic principles or to support of normative decision making.

1.3 Group Decision Aiding Benefits.

The benefits of computer-based group decision aiding were dramatically demonstrated in a pioneering DARPA-funded R&D project performed by current team members [3]. The Group Decision Aid shown in Figure 1-1 was designed as a complete, interactive stand-alone system to support military and business decision making. Using the minicomputer technology of its time, the Group Decision aid made the proven methodology of decision analysis available to command or management groups. The system featured simple hand-held data entry devices for the participants, a separate terminal for the facilitator/operator and a large-screen, high-resolution color monitor for display to the total group of the computer-generated information. The 'portable' system was intended for use in a command center or conference room as a complement to other information management and automation -- and was in fact adopted by several military and industrial organizations.

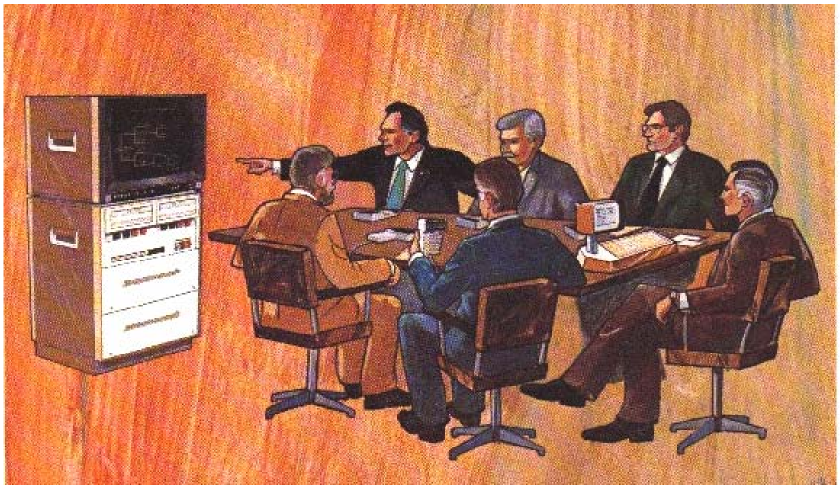

Figure 1-1 Perceptronics Group Decision Aid

The Group Decision Aid was experimentally evaluated by comparing the decision making performance of groups using the Aid with groups not using it in a complex (and eerily prescient) scenario involving a downed U.S. nuclear bomber, a hostage and WMD situation in an unstable nation and the need to rapidly plan a counter-terrorist response. The four types of measures examined were: decision analytical measures, participation measures, decision quality measures, and satisfaction measures.

On the average, the aided groups considered 65% more attributes in their deliberations and generated 60% more potential actions compared to their unaided counterparts. The aided groups also showed superiority both in decision content (the judged comprehensiveness of the information considered) and decision breadth (the judged completeness and appropriateness of the alternative set generated). The aided groups also produced more detailed recommendations, with significantly greater numbers of actions and events in their recommended course of action. 77% of the aided participants fully supported the group's chosen course of action, while only 53% of the unaided participants did so. The aided group members were also significantly more satisfied with their group decision making experience.

The real value of the Group Decision Aid, however, was in the markedly different distribution of time spent in various activities by the two types of groups. The average non-aided group spent approximately 91% of its time exchanging information and discussing actions and events, and less than 9% of its time on quantitative analytical activities. The average-aided group, on the other hand, was much more balanced; spending as much time in quantitative value and probability estimation (28%) as in action and event generation (26%). Attribute listing and weighting constituted 18% of the aided groups' time, and conflict resolution procedures accounted for another 18%. In summary, the aided groups spent the majority of their time productively. In contrast the unaided groups tended to divide early into factions which would then attempt to buttress their position by qualitatively enumerating all available favorable evidence. *Less than 10% of the unaided groups' time was spent in quantitative analysis.*

This seminal R&D project showed that computer-supported, model-based decision aiding yields better group decisions and also more satisfied group members. The drawbacks at the time were the needs for (1) physical co-location and (2) a trained facilitator or moderator. Since then, progress in distributed collaboration and agent technology has removed the requirement for co-location and made it possible to automate the facilitator, thus allowing deployment of the methodology into real-world tactical units.

1.4 Technical Approach: Model-Centered Support.

In the Phase I effort, we have extended our original research by developing a new model-centered Tactical Group Decision Analysis System (TGDAS) that combines a rational analytic modeling framework, a cognitive support environment, facilitator-free collaboration support, and a scheme for integration of contextual tools. The main elements of our technical approach are:

- **Decision Analysis.** A comprehensive analytical modeling capability simultaneously addresses logical, computational, pragmatic, and cognitive constraints at both individual and group levels. The modeling capability satisfies four main requirements: (1) rigor, a logically rigorous framework for decision making in accordance with proven decision analytic principles and methodologies; (2) versatility, that is, capable of modeling a variety of different types of decision problems; (3) efficiency, computationally efficient methods for operating with rich and complex models in real-time; and (4) usability, natural and easy-to-understand interfaces for anticipated users who are not experts in decision analysis.
- **Cognitive Aiding.** The cognitive support environment supplies a rich set of tools and measures to assist users in the tasks associated with decision analytic modeling. In a group context, members may differ not only in areas of expertise, constituent interests and substantive opinions about critical uncertainties, but also in the ways they organize knowledge, frame decisions, and solve problems. Therefore, the cognitive layer is designed to ensure that all users (1) provide inputs that are both relevant to the problem and accurately tap their knowledge and preferences, (2) effectively integrate competing stakeholder interests, complementary knowledge, differing points of view, and different styles of reasoning among members of the group, (3) understand and evaluate the knowledge and reasoning principles used to infer model outputs, and (4) under-stand, accept, and apply conclusions.
- **Information Environment.** A distributed infrastructure leverages the availability of robust COTS tools for online distributed collaboration. The infrastructure supports both real-time synchronous and asynchronous collaboration by rapidly formed multi-organizational teams, and provides a flexible environment for embedding decision models and problem structuring templates and tactical decision support tools.
- **Petri Net Automated Facilitation.** An automatic facilitator capability structures the group decision process by expanding established AI-based, concepts and experimentally-proven methodologies for autonomous facilitation [5][8]14]. Petri Net discrete event formalism allows a common representational structure for the decision process at all levels. Reuse of previous DARPA investments in Petri Net technology for manufacturing [4] and C2 decision making [10] as well as of recent applications to dynamic workflow control [12] will make this solution practical as well as innovative.

- **Data Agents.** Agent technology is used to monitor and update critical data bases and update the system on policy and business rule changes, mine relevant information from context data bases to help participants find critical information, and classify the large amount of text generated by the group using unsupervised machine learning algorithms such as Self-Organizing Maps (SOM) to generate shared graphical representation of textual data [9].

Figure 1-2 illustrates the resulting TGDAS concept. The system is structured around the four mechanisms required to support group decision making: (1) process support, (2) task structure, (3) task support and (4) process structure. We also include a fifth mechanism for continuous post-decision tracking.

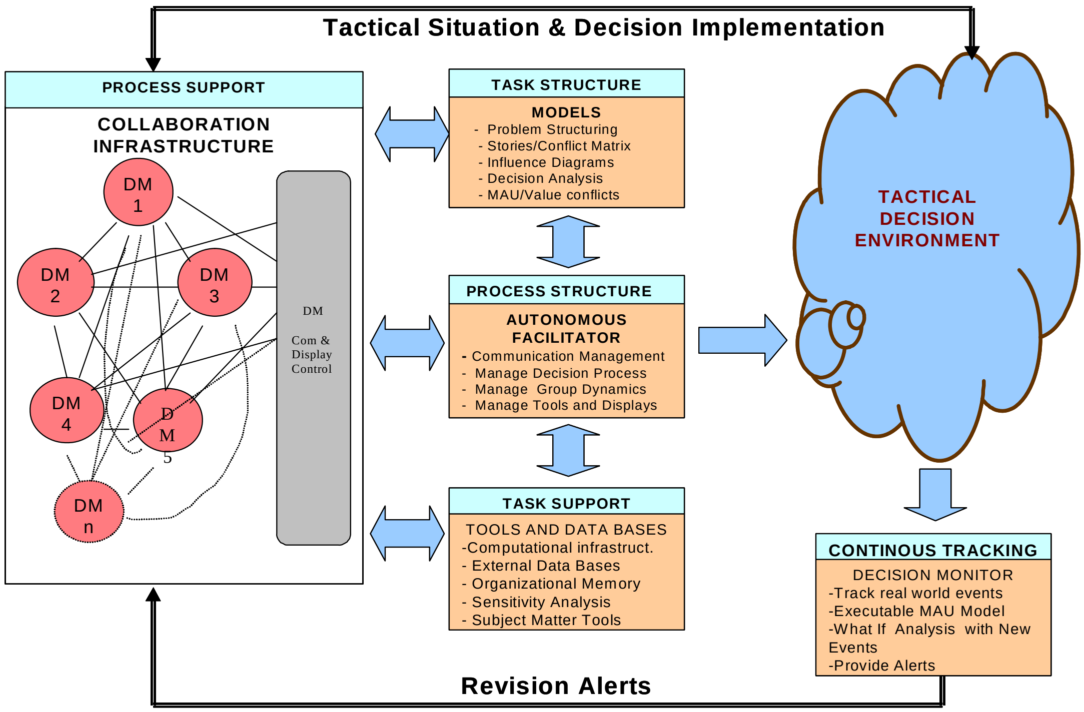

Figure 1-2 TGDAS Overview

In short, we conceive of our system as a facilitator-free group decision support system embedded in a collaboration framework using a scaleable and modular multi-tier architecture. The system concept features innovative built-in elements for accessing, integrating and analyzing information, including: a scaleable and modularly configurable Web-centric information sharing infrastructure which supports real-time group collaboration with a variety of media; an human factored graphical interface which makes complex cognitively-based decision support tools available to tactical users in an easy-to-understand operational context; and software agents and visualization tools that assist in accessing information, making inferences and determining new information gathering and fusion requirements.

1.5 Continued Work

The primary objective of Phase I has been to validate our TGDAS approach by designing a complete system implementation and showing that it is both usable in general by military personnel and useful in particular to a representative military customer. This we have done by identifying a potential customer in the Special Operating Forces (SOF) community, analyzing the system requirements both in general and for this specific user, establishing a comprehensive system architecture, and showing the feasibility of use by a SOF decision team through a detailed task flow analysis of a typical decision scenario and an interactive proof-of-concept demonstration that exercises the complete functionality of the system.

The focus of our subsequent development and commercialization strategy will be transformation of our Phase I results and our planned Phase II prototype software into a suite of software modules for use in a variety of military and non-military group decision support system applications.   The software product will be optimized to meet military as well as non-military market requirements. We will tailor the product to overcome significant barriers to entry. Product features will include: (1) instant operational utility and usability through familiar Web and graphical based interfaces; (2) flexibility to integrate with each customer's organization and procedures and to change as the responding organization evolves; and (3) no requirement for special hardware or software. The product will be offered for sale and/or license primarily to commercial companies already in the GDSS business to DOD prime contractors, as well as to civil organizations that are concerned with optimizing their decision making processes.

2. SOCOM Use Case and Scenario

2.1 Collaboration with SOCOM

We have developed the Phase I proof-of-concept demonstration in collaboration with the SOCOM Joint Special Operations Task Force (JSOTF), which has expressed a strong interest in becoming a user of the completed TGDAS. The point of contact has been LTC Jon W. Campbell, Fort Eustis, VA, who is Product Manager for Special Operations Mission Planning and is responsible for all echelons of mission planning with SOCOM, including both operational and tactical. TGDAS project team members have worked directly with LTC Campbell and his staff toward integration of the TGDAS technology with SOFTools (a DARPA Active Template application) and development of a typical JSOTF use case scenario.

SOFTools has an identified lack of decision support tools for planning and re-planning at specified decision points. Our intent is that TGDAS will enhance SOFTools by providing a new capability for model-based and cognitively-aided decision support to JSOTF tactical decision making teams. LTC Campbell has provided the required SOFTools software and has assisted in the definition and development of the TGDAS with subject matter expertise and application context support to facilitate the demonstration of collaborative decision support in the SOF environment.

Our JSOTF requirements analysis revealed that the SOFTools system produces Op Plans that include designated Decision Points. JSOTF HQ assigns a Decision Team (DT) to each Decision Point Specified in the Op Plan. The DT members come from appropriate staff sections, and the DT Leader is usually designated from J-3. The primary Decision Team task is to present option recommendations and rationale at decision briefings. Consequently, the primary requirements for the TGDAS prototype are to: (1) be accessible via SOFTools Operations Plans, and (2) help the Decision Teams analyze data relevant to Decision Points and recommend decisions.

2.2 Use Case Scenario

Our SOCOM scenario contains the following elements:

- The scene is Libya, and the background is an apparent renewal of a Libyan nuclear weapons effort.
- Allied agents have made contact with a disenchanted ex-soviet Muslim scientist currently working as part of this effort.
- The scientist has requested extraction for himself and his wife, and has offered to provide critical documents and other materials of proof in return.
- There is a pending Pan Arab scientific conference to be held in Tripoli and nearby locations.

Figure 2-1 SOCOM Scenario Locale

- The current Op Plan is to extract the asset, his documents and his wife during conference.
- New information has been received that impacts this previous plan.
- The immediate decision is: *Stay with original plan, or switch to an alternative option*?

3. TGDAS Description

3.1 Models and Algorithms

One of the early and overarching results of our Phase I R&D effort has been a better under-standing of exactly why our TGDAS concept represents a highly innovative and unique contribution to the field of decision support. This contribution is expressed schematically in Figure 3-1.

Our approach provides a schema and a practical framework for merging the principles of naturalistic decision making and cognitive decision representation with those of normative decision modeling and analysis. The innovative aspect of the approach is that it facilitates capturing the decision makers' ideas about the decision problem in the natural form of "stories" transforms the stories into formally correct but easily interpretable influence diagram representations, and then converts the latter into normative models that can be used for quantitative evaluation of options.

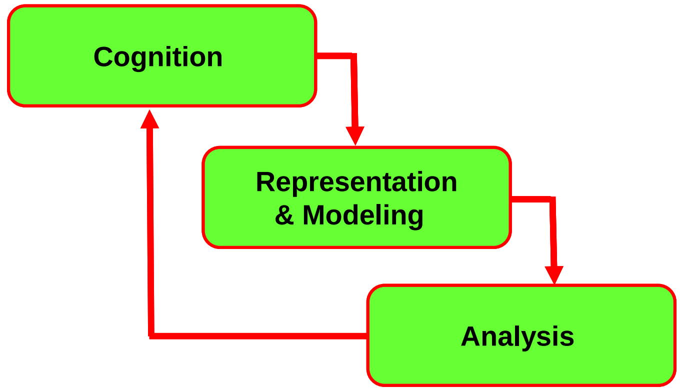

Figure 3-1 TGDAS Support Combines Cognitive and Analytical Decision Elements

In other words, we have created a fully supported collaborative process for transitioning from stories through systematic representation to decision modeling. The modeling provides the basis for rigorous analysis in terms of decision sensitivity to uncertainties and impact of new information. The information generated by the analysis provides feedback which stimulates critical thinking, which leads in turn to changes and refinements of the stories, further tuning of the model, and more refined analysis.

Implementation of the approach is discussed in the following sections, which first present the functional requirements and resulting software architecture, and then describe – by following the interface actions through the selected use case -- how the system elicits story matrixes from the stakeholders, how stories are transformed into an influence diagram representation, and how the decision trees associated with the influence diagram is used for analysis and feedback followed, optionally, by another cycle of critical thinking and model improvement.

3.2 Functional Requirements

The top level requirements for the TGDAS methodology and a supporting tool set are:

- Rapid transition to formal representation of problem and decision attributes to model-based decision representations via:
  - Stories
  - Influence Diagrams
  - Decision Trees
- Automation of facilitation functions and user data collection by:
  - Workflow and time management
  - Enforced user input and group collaboration
  - Consistency checking and input validation
  - Sensitivity analysis and reaction to new information
- Asynchronous and synchronous stakeholder collaboration

3.3 System Architecture and Core Infrastructure

Figure 3-2 shows the high level TGDAS architecture in terms of data flows. The architecture is divided into three structural and functional tiers: User Tools, Automated Facilitation and Services and Data. The User Tools are described in the following section, the two other functional tiers are described below.

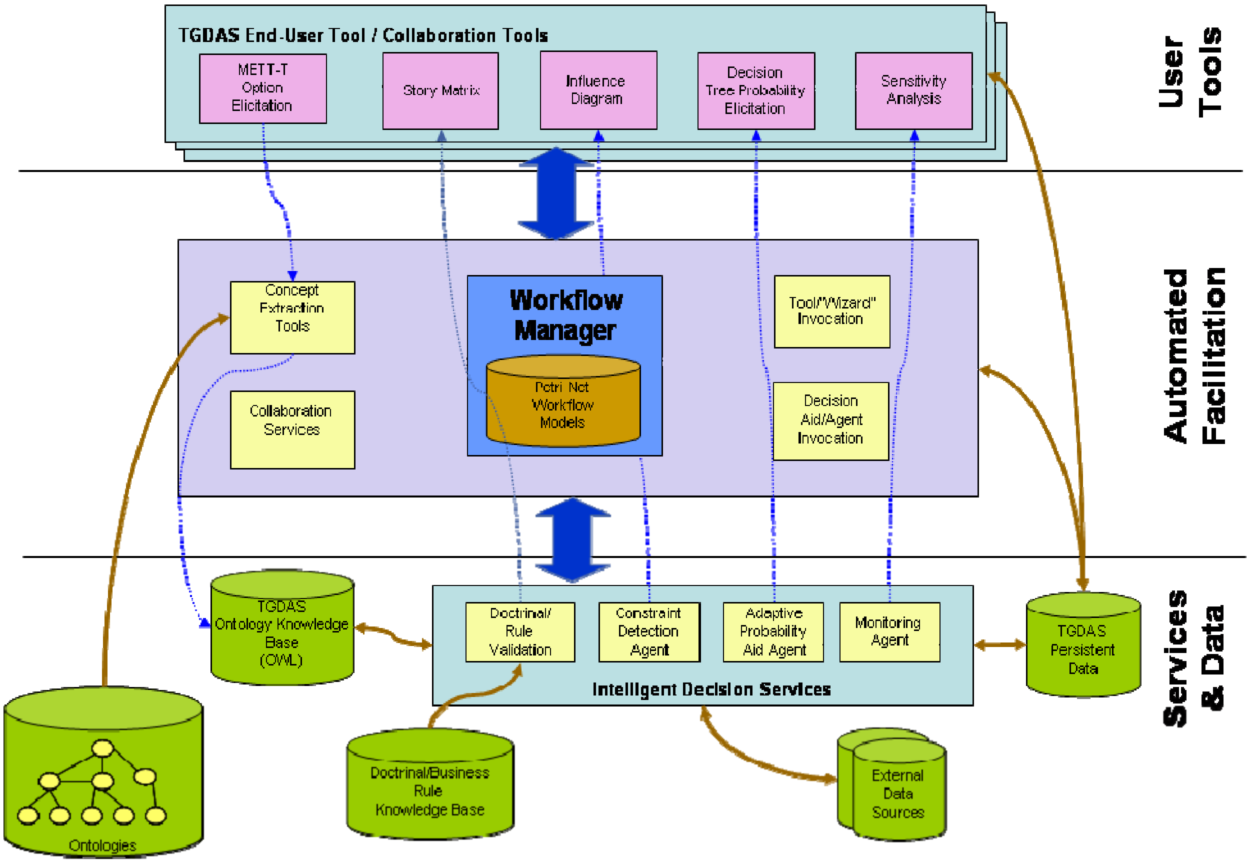

Figure 3-2 TGDAS High Level Data Flows

3.3.1 Automated Facilitator.

The Automated Facilitator (AF) is an intelligent workflow mechanism which drives the decision process by performing the following core functions:

1. *Workflow Control* – Maintain and control the overall state of the decision process and guarantees that the proper decision process and methodology is being adhered to as well as prompting the users for inputs to ensure time constraints for arriving at a decision are met.
2. *Tool/Wizard Invocation* – Guides users through use of tool by invoking wizards to help extract the necessary information for a given step in the process
3. *Intelligent Aid Invocation* – Invokes the intelligent decision aids to assist in the process or to gather information from external data sources which may influence the decision process.
4. *Collaboration Management* – Prompts users to use collaboration capabilities to resolve conflicts

The AF is controlled by rules encoded in a workflow model using Modified Petri Net (MPN) formalism. The MPN model provides the following core benefits:

1. Provides rich expressive capability for codifying workflow rules using a directed graph representation of activities(places) and transitions
2. Allows workflow to be not hard-coded in the system but to evolve with system use
3. Can be constructed and refined by domain experts (decision experts, not programmers)

Workflow Phases. The following summarizes the functions of the Automated Facilitator in the context of phases of the process; this is intended also to exemplify rules which may be encoded in the MPN formalism to drive the workflow.

Phase I

1. AF collects basic information from the Decision Leader to initiate the process.

    1. AF collects the names of the Decision Team members and e-mail addresses, if not already in the system
    2. Collects information on the preliminary time target for reporting on the best option (e.g. 1 day, 2 days, etc.)
    3. Generates a system-suggested time schedule to meet the time target, based on previous experience with the system and the size of the group (e.g., 3 hours on story development, 2 hours on ID, etc.) This schedule may or may not be disseminated to the Team members.
    4. Customizing (if necessary) and disseminating to the Team a brief previously-prepared tutorial on the decision making process, including its goals and expectations, its procedures, and the methods for accessing generally available information as well as communicating among participants.
    5. Scheduling and assigning the first Task of identifying relevant decision factors. In our use case, we use the military standard and highly familiar METT-T format (mission, enemy, troops, terrain, and time) as the framework for organizing the decision information. Accordingly, team assignments would likely follow standard procedure, i.e., S-3 for Mission, S-2 for Enemy, etc.

1. Based upon the time target, AF sets milestones (subject to modification by group leader) for each phase, based upon prior experience (in a database) including size of group, complexity of the task, time to final decision, etc.

Phase II

Group members enter complete METT-T form or enter narrative "story." AF monitors time taken during the phase. AF posts a "countdown" clock on each user screen for final decision and end of each milestone. Individual group members can use a meter or other entry method on their computer to indicate their willingness to move on (polling). When a certain threshold is reached (e.g. 80% of the group have indicated a 70% willingness to end the phase), the AF will stop the session (sending a warning message first, e.g. "The current phase will end in 2 minutes. Please finish your narrative now.") Then, AF terminates the phase and moves on to the next phase.

Phase III

AF automatically consolidates individual narratives to build a story. After the text file is consolidated (or simultaneously), a story matrix is compiled based upon keyword analysis. This draft story matrix is then edited by the group collectively, by a subset of the group, or designated individual.

When is extraction?	Cooperation of asset?	Asset surveillance by security forces?	Number of security forces available?	Mission outcomes?
Before conference During conference Afer conference	Asset motivated Other influences may get to asset Asset may lose interest in defection	Forces on alert before conference Forces distracted during conference Forces relaxed after conference	Force build-up before conference Maximum force levels at conference Force dissipation after conference	Successful extraction Maintain secrecy Minimum collateral damage

If categories are not pre-defined, two iterations of text analysis (clustering) could be done. First, cluster to identify central topics. Using these clusters, group members (or group leader) identify categories (with associated key words), and AF clusters again under these categories. Group members make final modifications.

The Automated Facilitator also flags areas of the story matrix which may reflect conflicts in the user's stories. Figure 3-3 below illustrates the process of conflict detection and resolution. Attachment E provides a table of Conflict States and Actions for the automated facilitator.

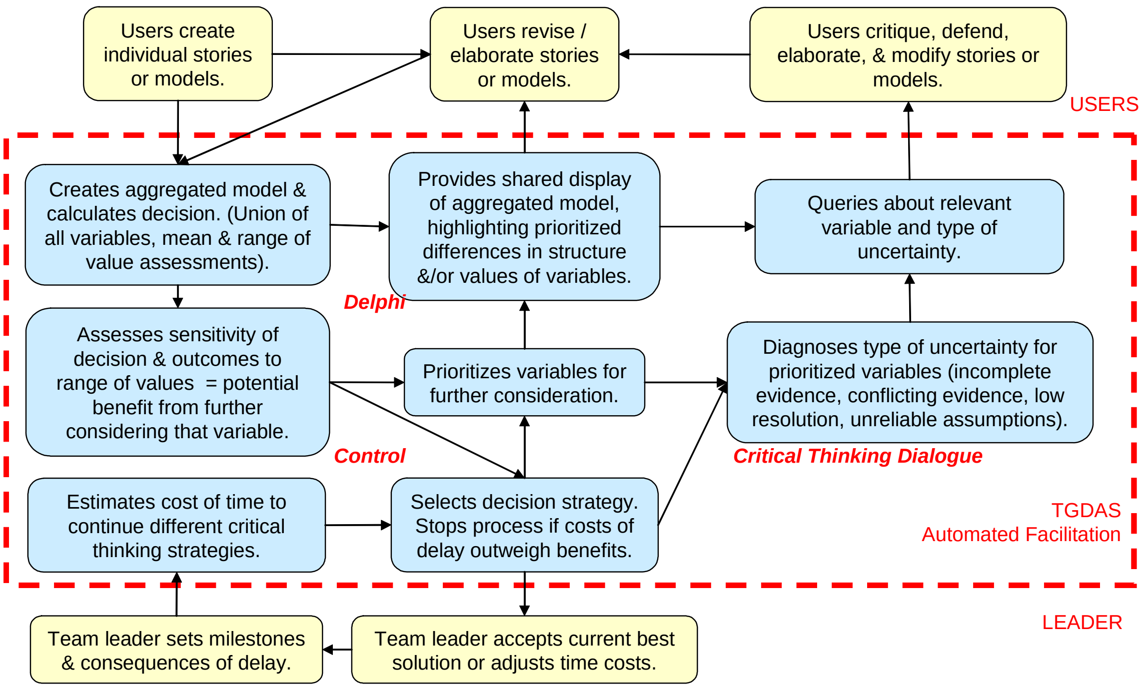

Figure 3-3 Automated Conflict Resolution

Phase IV
AF builds a graphical representation of the story matrix with nodes representing categories and relevant text available by clicking on the nodes. Individual group members draw influence arrows and assign values (probabilities). AF checks for circular references and other inconsistencies

Phase V
From the influence diagram, AF builds a decision tree and combined influence diagram. AF invoked services for sensitivity analysis & calculates best option based upon user input. The decision tree is generated based on the following heuristic:

1. For a given node, the set of nodes upon which the node is dependent as indicated in the influence diagram are determined.
2. All possible combinations of the dependent node outcomes and are considered as paths into the node for which the tree is being generated.
3. A unique tree is generated for each node, with probabilities assigned at the leaf branches.

3.3.2 Intelligent Decision Services and Data. Intelligent Decision Services are a set of "context aware" agents and AI utilities which enhance the model based decision tools which adaptive and semantic analysis capabilities.   The Intelligent Services are facilitated through an ontology based knowledge representation of the problem and decision attributes. The initially proposed set of Intelligent Services is:

1. *Doctrinal Rule Validation and Analysis* – This module assesses the doctrinal validity of data entered into METT-T. Based on the METT-T attributes the appropriate doctrinal template can be identified and used to build the Story Matrix.
2. *Constraint Detection Agent* – This agent attempts to access external databases to determine whether constraints (such as resource requirements) modeled in the influence diagram can be satisfied. For example, if a particular action requires 10 Blackhawk helicopters, but according to the METT-T summary only 5 are currently deployed in the Theater of Operation, the Constraint Detection Agent will alert the users.
3. *Adaptive Probability Aid Agent* – This agent uses machine learning capabilities to assist in assigning default probabilities to a decision tree.
4. *Assumption Monitoring Agent* – Monitors for new information that impacts key assumption in the decision and alerts the users of changes

Concept Extraction. The creation of a rich representation of the METT-T model enables the capture of the model's concepts and entities. An XML-based representation could represent the basic concepts of the METT-T but a more expressive language is required to associate the concepts and entities together in a machine-understandable format. For example, certain elements of the Troop section may not be associated with all possible Terrain elements. Establishing this relationship in a highly structured manner provides clarity and enables robust computing techniques. The Web Ontology Language (OWL) is an emerging standard of the W3C that supports the creation of formal domain vocabularies (ontologies) which provide the desired level of expression. The DARPA Agent Markup Language (DAML) program has supported the development of this standard and ISX has been involved in the program from its inception.

Extraction of the mission models concepts and entities uses commercial entity extraction technology. ISX has used the Inxight Smart Discovery suite to extract and transform textual information to form OWL statements. The representation of these extracted entities in the domain ontology creates a link from an abstract mission plan concept to a concrete instance of the mission force. Theses instances are stored in a local repository and provide a method to map realized mission elements to discrete decision points, such as those represented in the missions influence diagrams. This is shown in Figure 3-4 below.

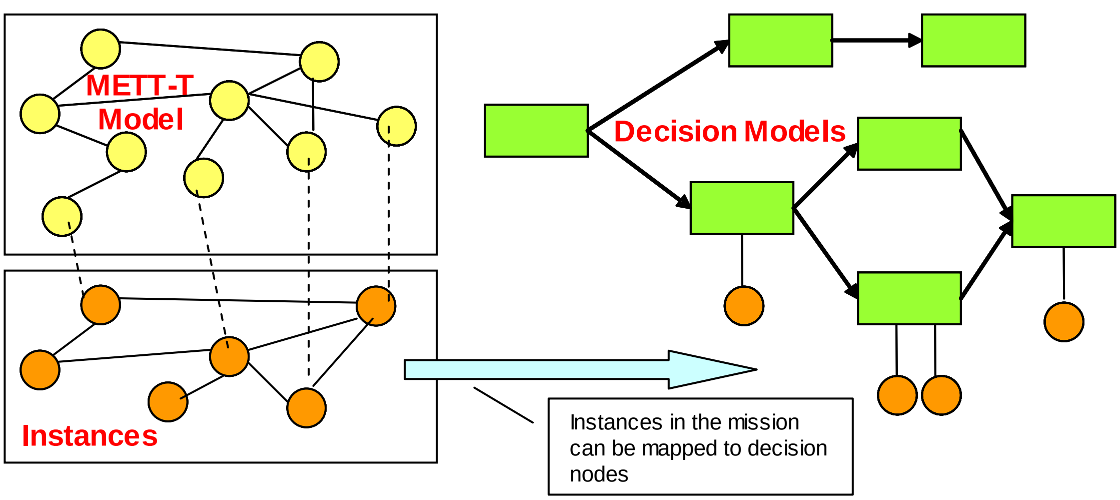

Figure 3-4 Mapping of Mission Instances to Decision Nodes

Rules Validation. Business rules can be analogous to military doctrine. In the business community, there are rules to describe transactions, how the actors are involved in the transaction and the flow of the process. In the military arena, you may have mission steps, executing forces and rules of engagement. These engagement rules may be derived from military doctrine or they may be mandated by non-military policy makers. The capture of these rules in a structured manner, such as CLIPS (expert system) statements, will allow for successful mission planning and enhance the decision making process.

Forming the mission model using a machine-understandable language such as OWL enables the creation of discrete actions that describe the mission. OWL supports the definition of classes and sub-classes of concepts as well as associations between the various concepts. This allows for a concept such as “city” to be associated to the broader concept of “country”. While theses facts are explicit in the ontology, they are not direct facts. Agents can use a rules engine, such as JESS, to make these facts external to the ontology representation and consumable by themselves and other processes. The evaluation of this fact set against the doctrinal/business rules provides a means to validate the mission elements. ISX has previously used JESS and rules describing OWL relationships to generate new facts.

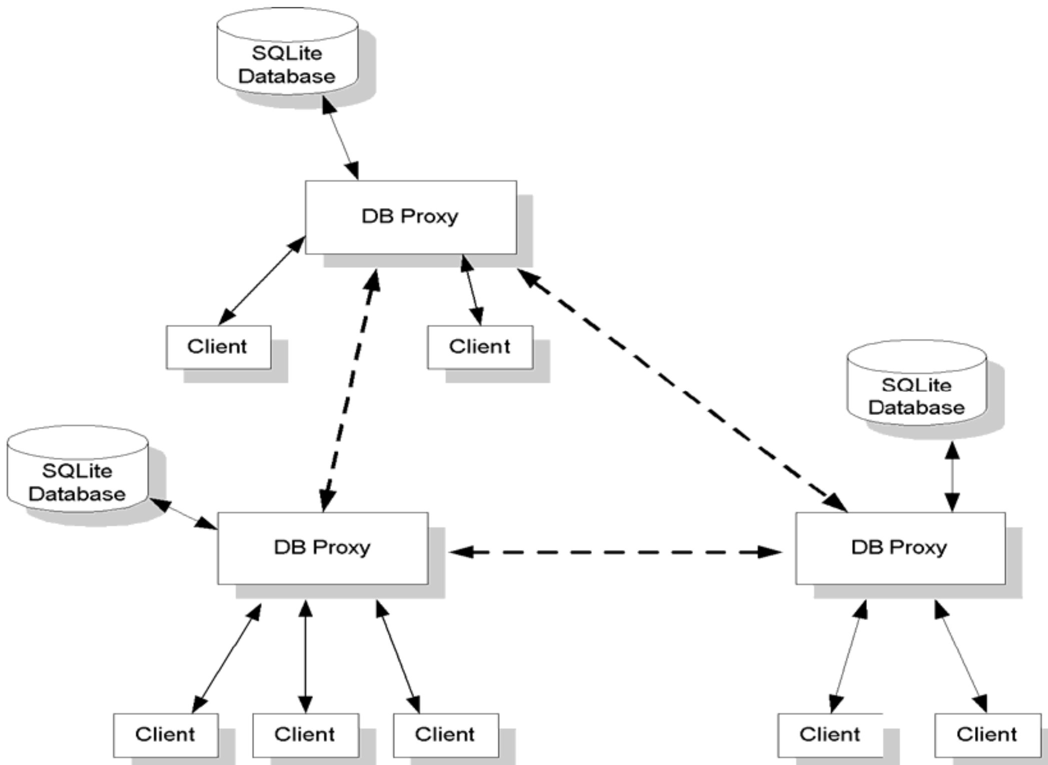

Figure 3-5 Typical DBProxy Topology

3.3.3 Asynchronous Collaboration. As the proposed prototype implementation is intended to be designed for use with the SOFTools toolset. Collaboration will be facilitated using the components of the SOFTools framework. SOFTools facilitates asynchronous sharing of data by utilizing a shared distributed database called DBProxy. DBProxy allows persistent data objects to be shared in a Peer-to-Peer manner over a distributed network. Figure 3-4 above shows a typical DBProxy topology.   The persistent data object for a given system including, background data, story matrices, influence diagrams, decision trees etc. Will be stored in local databases which will replicate to the various other users, AF and Intelligent Decision Services, using the DBProxy.

4. Proof-of-Concept Demonstration

4.1 Demonstration Requirements

Our analysis of the demonstration requirements focused on specification of a graphical user interface (GUI) that would provide continuity for the work flow steps involved in using the TGDAS. Consequently, the initial TGDAS GUI has been designed with the following design objectives:

- Familiar to any Windows™ user.
- Follows the general layout of the SOFTools interface, so as to permit a contextually logical movement between the two applications. (As the TGDAS prototype is being designed to operate within the context of SOFTools used by a JSOTF Decision Team, the objective was the make the TGDAS GUI compatible with that of SOFTools.)
- Allows users to move from any major process in TGDAS to any other at will and not force a single path to execute a task.
- Optimized for asynchronous collaboration, although real-time collaboration is also accommodated.

Our initial interface design, as described in the following, embodies these principles. It allows the user to select from the several utilities depending on the task at hand, and to move readily from any one to any other. Within each utility a “wizard” makes available to the user additional guidance if required, indicates whether all of the steps in exercising that utility have been completed, and recommends the next task to be performed. Using the proxy server functions of SOFTools and emails/chat, the interface can also present a user’s inputs to the others and track the progress of the process, as well as time remaining and tasks to be completed.

4.2 TGDAS Task Flow

Figure 4-1 is a task flow diagram that provides overview of the TGDAS decision support process as exemplified by the prototype system being developed for SOCOM. Consequently, the input to the system is from the SOFTools OP Plan, which contains an identified decision point.

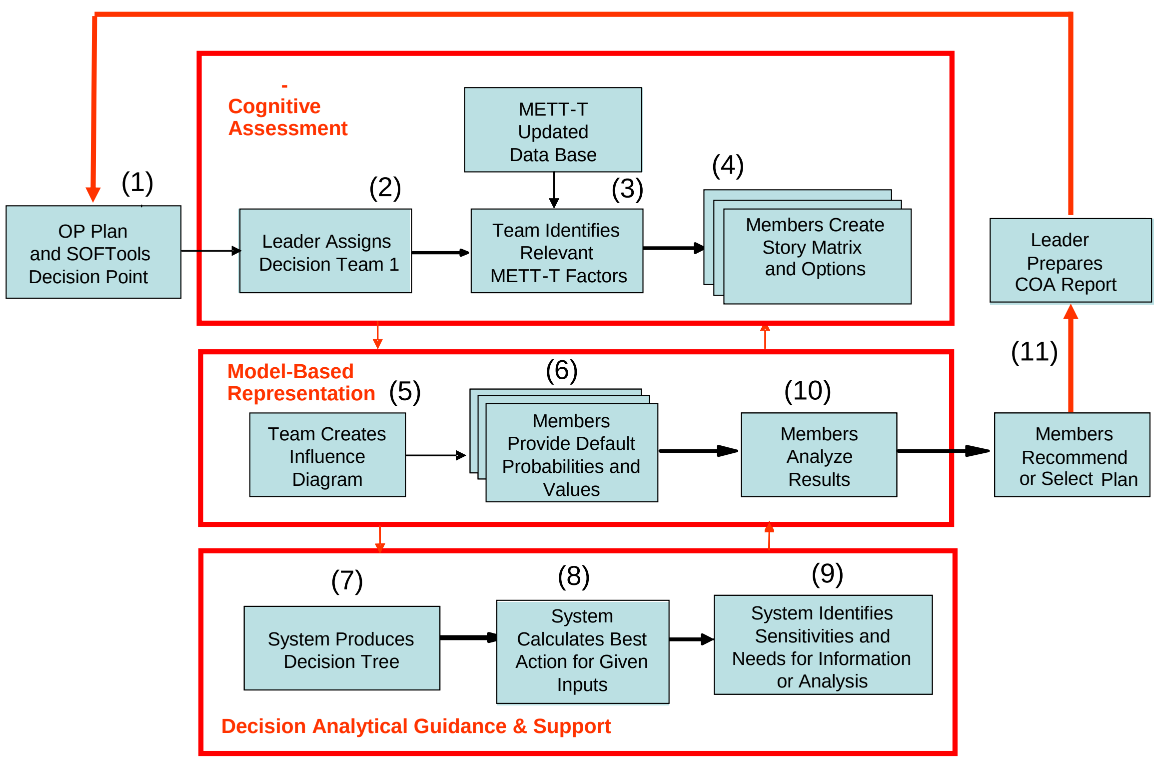

Figure 4-1 TGDAS Task Flow

The TGDAS decision support elements are divided into three major modules, corresponding to cognitive assessment actions, model representation actions, and decision analytical guidance and support:

1. Cognitive Assessment initiates the TGDAS process and enables the Decision Team to formalize its assessment of the decision situation and the options available using the familiar information format of the military METT-T summary of Mission, Enemy, Terrain, Troops and Time as well as a natural story matrix format derived from cognitive research
2. Model-Based Representation supports the Decision Team in formulating the Influence Diagram model, containing relevant probability and value parameters, from which is derived the recommended or selected plan of action – which goes back into the OP Plan.
3. Decision Analytical Guidance and Support is for system guidance and support based on decision analytical models, specifically the decision tree, which is derived from the previously defined influence diagram. This module includes sensitivity analysis which helps determine if more information is needed. There is a continual interaction and feedback between Module 2 and Module 3.

It is important to emphasize that the system itself does not decide on the best option; rather, the system provides tools that support the Decision Team in recommending a Plan or COA for the Commander's final choice.

4.3 Decision Support Process

In the following description of the decision support process, the various steps involved correspond to the tasks shown in the flow diagram of Figure 4-1.

4.3.1 OP Plan and SOFTools Decision Point. Figure 4-2 shows how the TGDAS decision support system is launched from the SOFTools application. TGDAS is evoked when a SOFTools Decision Point (DP 1) requires analysis further analysis, and is launched by double clicking on the DP 1 icon in the SOFTools Temporal Plan screen.

The resulting Decision Point Properties screen is the entry to TGDAS, and allows the TGDAS user group to characterize this particular decision point in terms of decision type and decision deadline, to set some look-and-feel parameters for the decision support system, and to append notes and links to the decision point, which can be updated as the decision process continues. Launching from an overarching program provides a familiar contextual setting for the new technology and minimizes training and adoption problems. When the Properties are completed the user hits OK.

4.3.2 Leader Assigns Decision Team 1. TGDAS presents the decision team leader with an interface that supports a range of users from novice to expert. The Set Up screen shown in Figure 4-3 allows the leader to select the following variables which determine how the TGDAS will guide the group members in their decision making process.

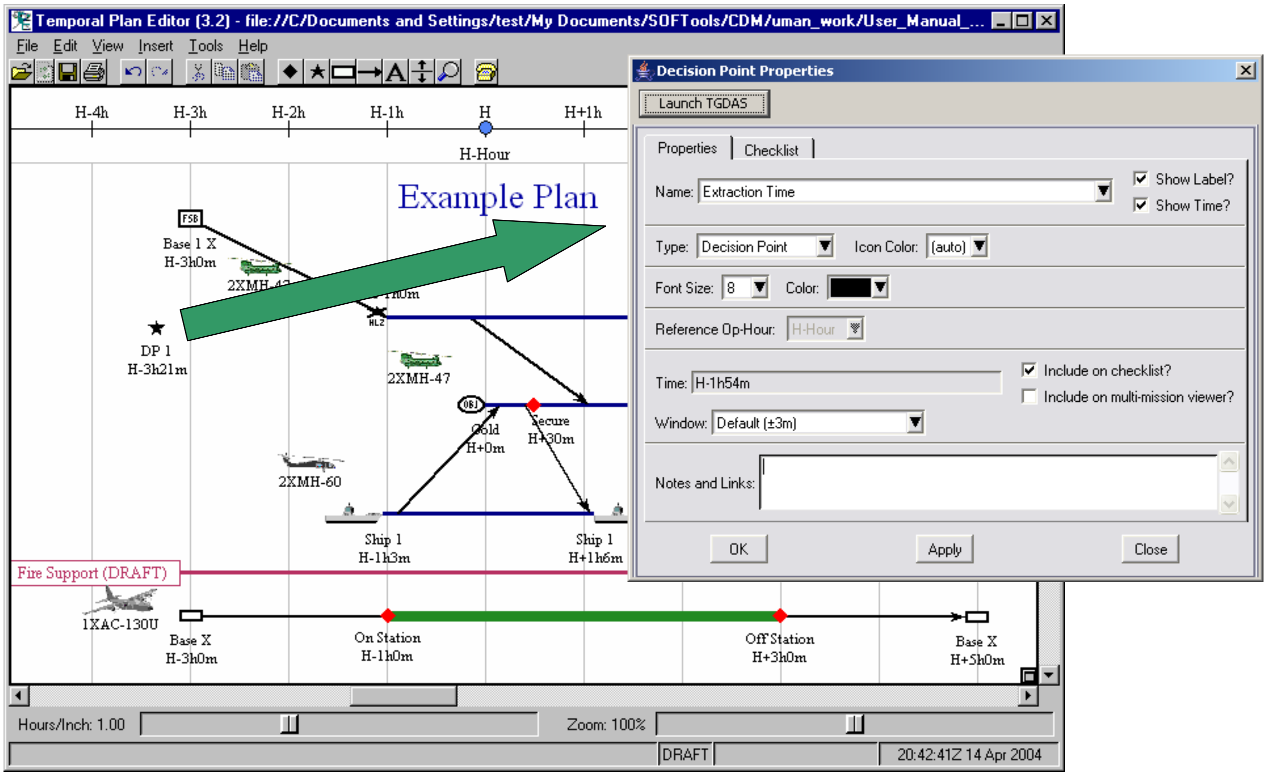

Figure 4-2 Launching TGDAS from SOFTools Application

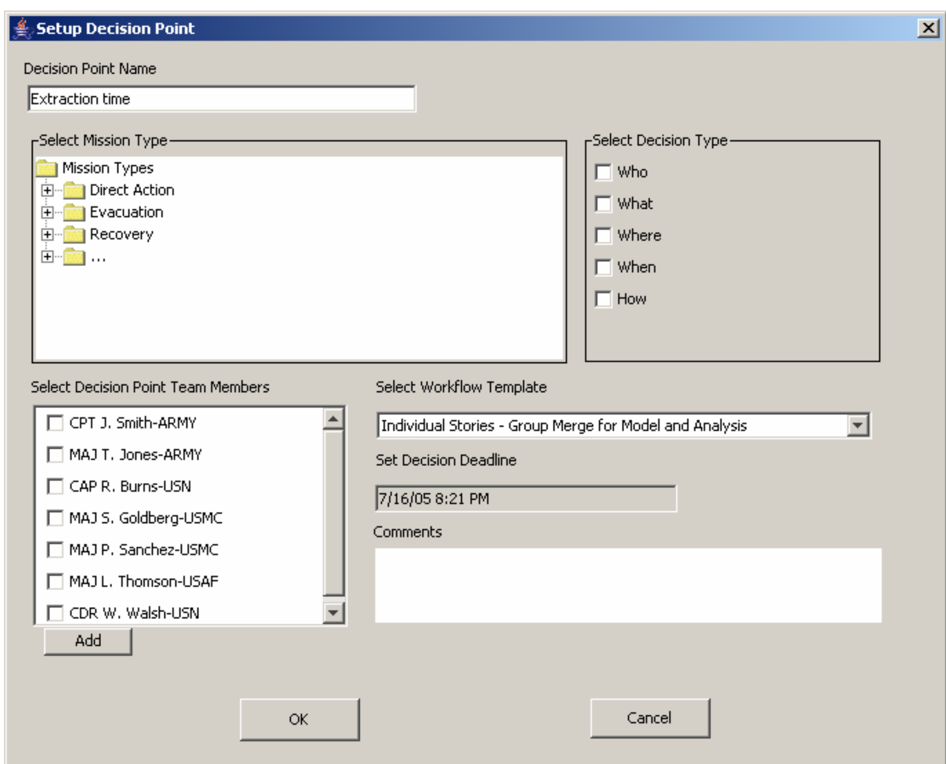

Figure C5-3 TGDAS Set Up Screen Configuration

The Set Up variables are:

1. Mission Type – The tactical situation in which the decision will be made
2. Decision Type – The kind of decision to be made in the tactical situation
3. Workflow Template – The specific process to be followed in TGDAS operation

In the example use case, the Mission is ‘Extraction’, the Decision Type is ‘Time’, and the Template is ‘Group Merge’.

The Set Up screen also allows the leader to perform the following tasks:

4. Select the Decision Team Members – from among pre-registered or new individuals
5. Set Decision Deadline – the time by which the decision must be made, which will guide the process
6. Comments – Add comments that annotate this particular decision

When Set Up is completed the user hits OK.

4.3.3 Team Identifies Relevant METT-T (Decision Data Base) Factors

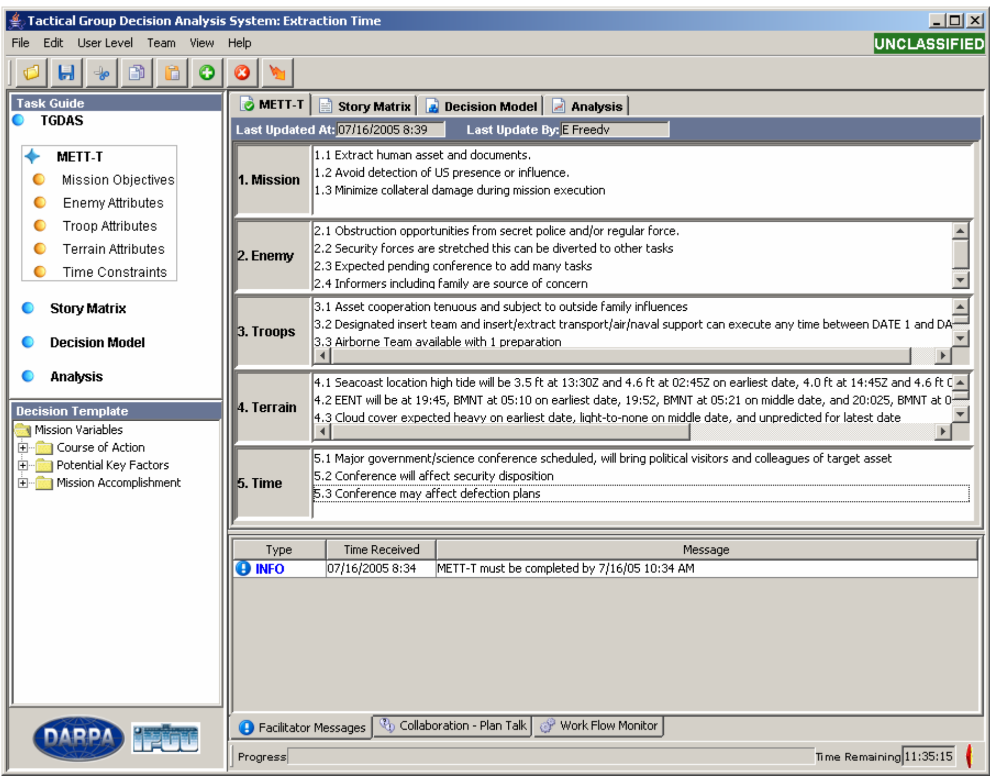

Figure 4-4 METT-T (Decision Data Base) Screen

The METT-T (Decision Data Base) screen provides several operating functions to the entire decision making team:

1. Task Guide – Summarizes the decision process and shows the current point in the process.
2. Decision Template – Provides guidance regarding the important factors
3. Communications – Shows messages received from other team members and from the Automated Facilitator
4. Decision Data Base – Provides the basic information on which the decision process will proceed. Pre-stored templates are associated with each decision type and provide a checklist of potentially

relevant information for that type of decision. In the present example, the mission involves extraction of a human asset (a scientist) together with documents and equipment from a hostile country. The decision point involves reconsideration of previously developed contingencies for the timing of the extraction, triggered by an unexpected development. The relevant information is displayed in a METT-T summary that can be supplied from outside the team and/or supplemented by team members. Information in the METT-T summary can be linked to text in other documents, such as IPB, spot reports, or other messages. As a result, users can examine the basis for a particular answer, and alerts can be generated when and if the supporting information changes.

When the Data Base summary is satisfactory, the team moves to the tabbed Story Matrix function.

4.3.4 Members Create Story Matrix and (Decision) Options

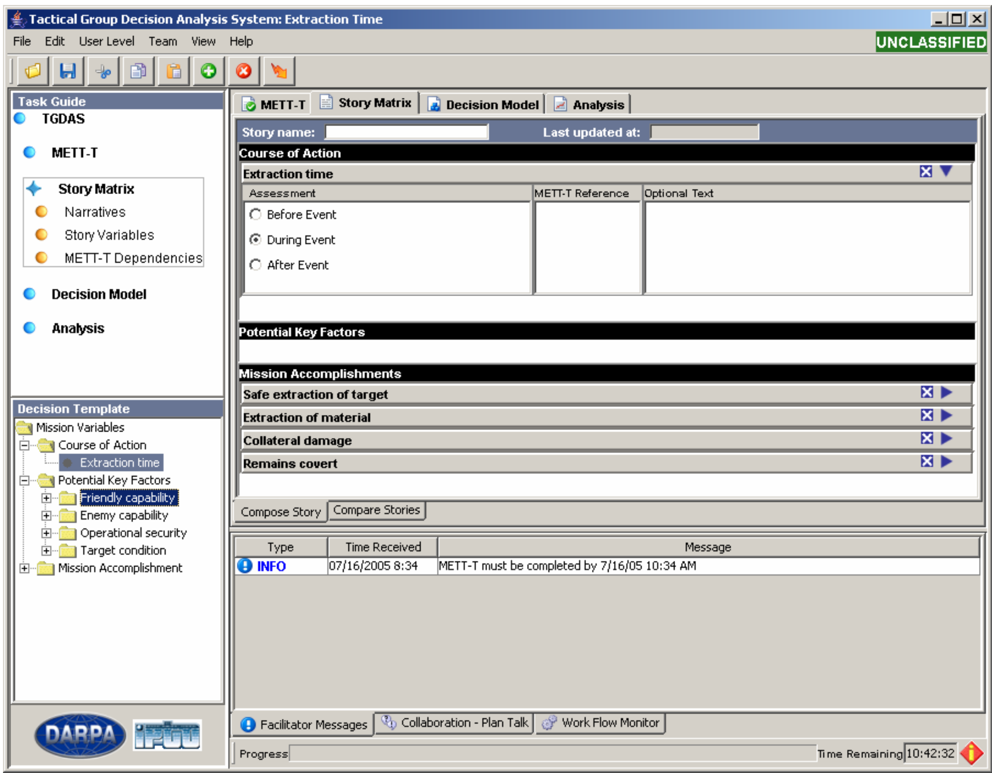

Figure 4-5 Individual Story Matrix Screen

The Story Matrix screen presents the framework for each member of the decision team to "tell the story of the decision and its outcome" in natural, narrative form. Story Matrix has two primary modes:

1. Compose Story, shown in Figure 4-5. The team members are guided by a stored Story Format and Decision Template based on the type of decision being made. In the example decision, the Story Format contains Course of Action, Key Factors and Mission Accomplishment, and the Decision Template provides further detail under those headings. The user can refer to information in the Decision Data Base (METT-T in the example) to provide references and text for the story.
2. Compare Story, shown in Figure 4-5a (following page). The progress of the collaborative team is displayed in terms of the major variables. Each member's story is summarized in the form of key variables as part of the Team Matrix, and the variable details of the individual stories are available in narrative form by clicking on the particular cell of the matrix.

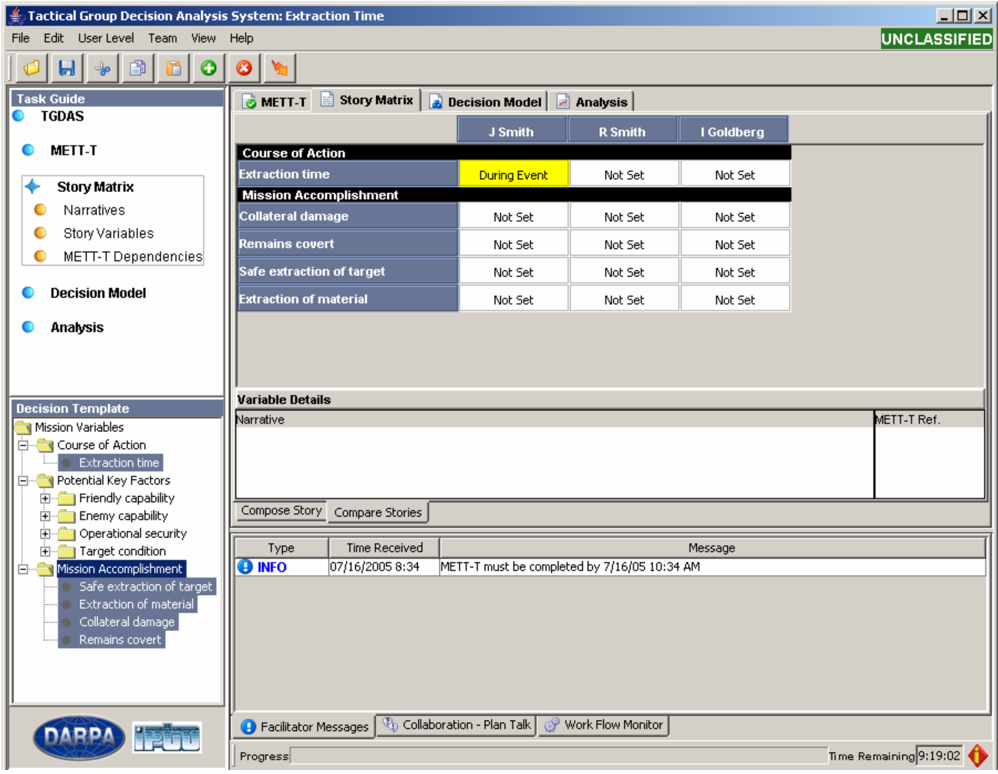

Figure 4-5a Team Story Matrix Screen

The Automated Facilitator (AF) function determines when new variables must be added to the matrix as a function of individual team member inputs, and also helps resolve conflicts within the team concerning variables.

When the Story Matrix is complete, the team leader moves the team to the decision modeling function by selecting the Decision Model Tab.

4.3.5 Team Creates Influence Diagram. The TGDAS Automated Facilitator automatically generates a decision model in the form of an Influence Diagram, shown in Figure 4-6, which is generated from the Story Matrix variables jointly determined by the decision making team.

An Influence Diagram is a more formal representation of what is going on in a story. It helps explain why a story unfolds in the way it does by representing causal and value relationships among story variables. The AF adopts a general, default assumption that the values of intermediate story variables will be influenced by the decision variable, and that aggregated value will be influenced by mission elements. Additional links among variables will be pre-specified in the template for the type of decision under consideration.

In the example , the node at the left of diagram represents the key decision variable (time of extraction), the central nodes represent uncertain events or states of affairs (extraction of target, extraction of material, etc.) and the diamond node at the right represents an overall measure of the goodness of the several decision options.

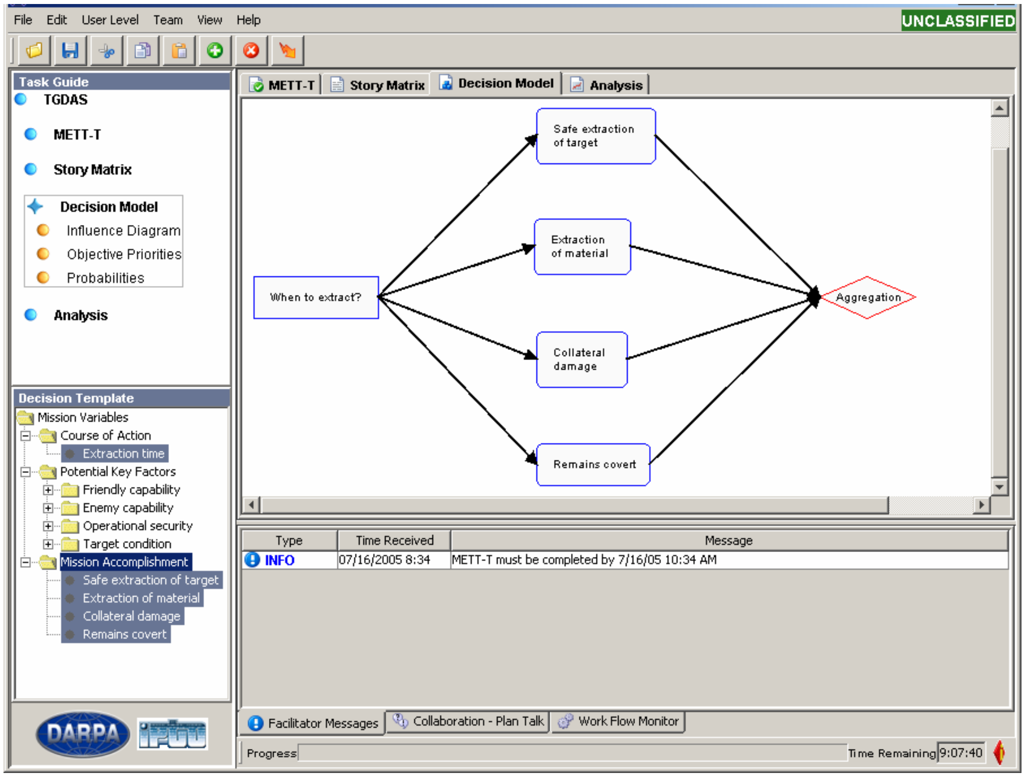

Figure 4-6 Decision Model Screen

4.3.6 Members Provide Default Probabilities and Values

The individual team members interact directly with the Influence Diagram in order to input the relevant probabilities and values:

1. Probabilities. Users estimate the probability that a particular state of affairs will be achieved by a particular decision option in a Probability Window, as shown in Figure 4-6a, obtained by double clicking on the Influence Diagram block for that state. In the example, the user is estimating the probabilities that safe extraction of the target will ('yes') or will not ('no') result from extraction before the conference, during the conference or after the conference. Estimates are entered by moving either the 'yes' or 'no' slider to the estimated probability. The complementary probability is automatically calculated and entered.

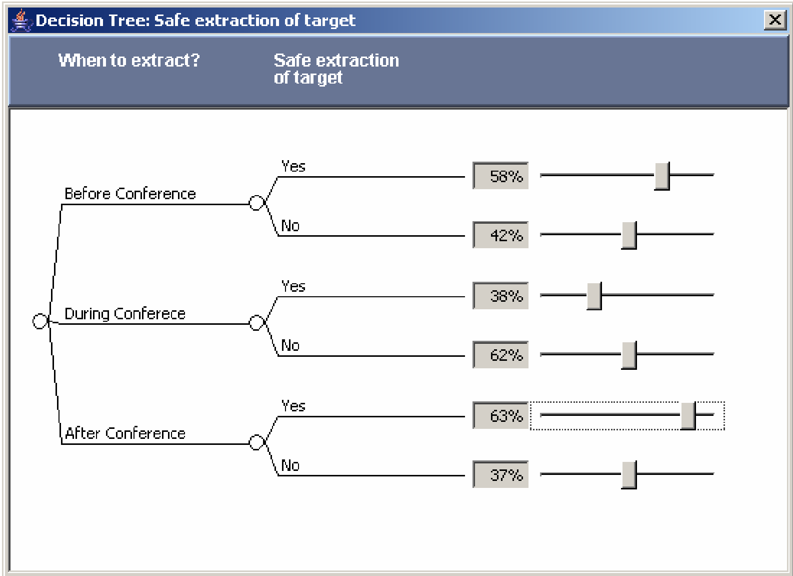

Figure 4-6a Probability Window

2. Values. Users estimate the relative priority of the mission objective using a Relative Priority Window (Figure 4-6a) obtained by double clicking on the Aggregation icon in the Influence Diagram. In the example, collateral damage has a low relative priority, safe extraction of the target has a medium relative priority, and extraction of material and remaining covert have high relative priorities.

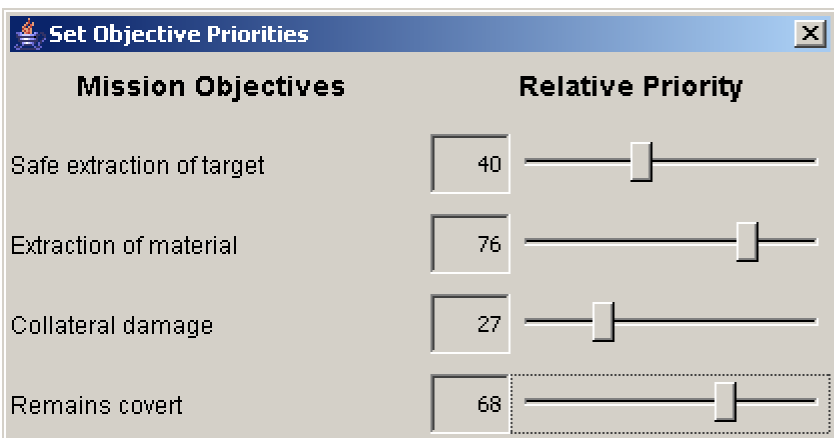

Figure 4-6b Relative Priority Window

The use of interactive graphic 'sliders' for these estimating operations is new and unique, to the best of our knowledge, and provides a cognitively effective way of entering the data by turning the conventional entry of an absolute number into a more natural positioning of a marker along a line, thus dividing it into two segments.

Probabilities and values for the entire decision making team may be merged using one of a number of algorithms, depending on the merge approach selected initially. Likewise, conflicts among team members – for example, where team members have widely differing estimates of probability or of relative priority, are flagged by the Automated Facilitator, which also provides methods for their resolution.

4.3.7 System Produces Decision Tree. The TGDAS calculates a full Decision Tree for the decision model represented by the Influence Diagram. In general, the Decision Tree remains in the background and unviewed during the decision support process, but it can be accessed and examined if desired.

Figure 4-7 shows a portion of the decision tree associated with our example. With a total of well over 500 paths, the full tree is too complex to display even for this simple problem. Instead, the decision tree functions as a computational device. The TGDAS uses it to calculate an expected value at every node (boxed numbers), which reflects how good the situation looks on arriving at that node and facing the branching future possibilities on the right. (The expected value at a node is the probability-weighted average of the values or expected values at the ends of its branches, and is computed by averaging and rolling back the tree from right to left.)

The Decision Tree represents all the possible scenarios, or sequences of events, that might be generated by the causal model in the influence diagram. Branches emerging from chance nodes are possible values of the variable at that node. Numbers on the branches are conditional probabilities of the values given the values on the branches traversed to get to that node. A complete path through the tree starts at the root node on the left and ends with a terminal node on the right. Each path describes a possible scenario, or sequence of events, and is associated with a specific payoff or value, indicated by the boxed number next to the diamond.

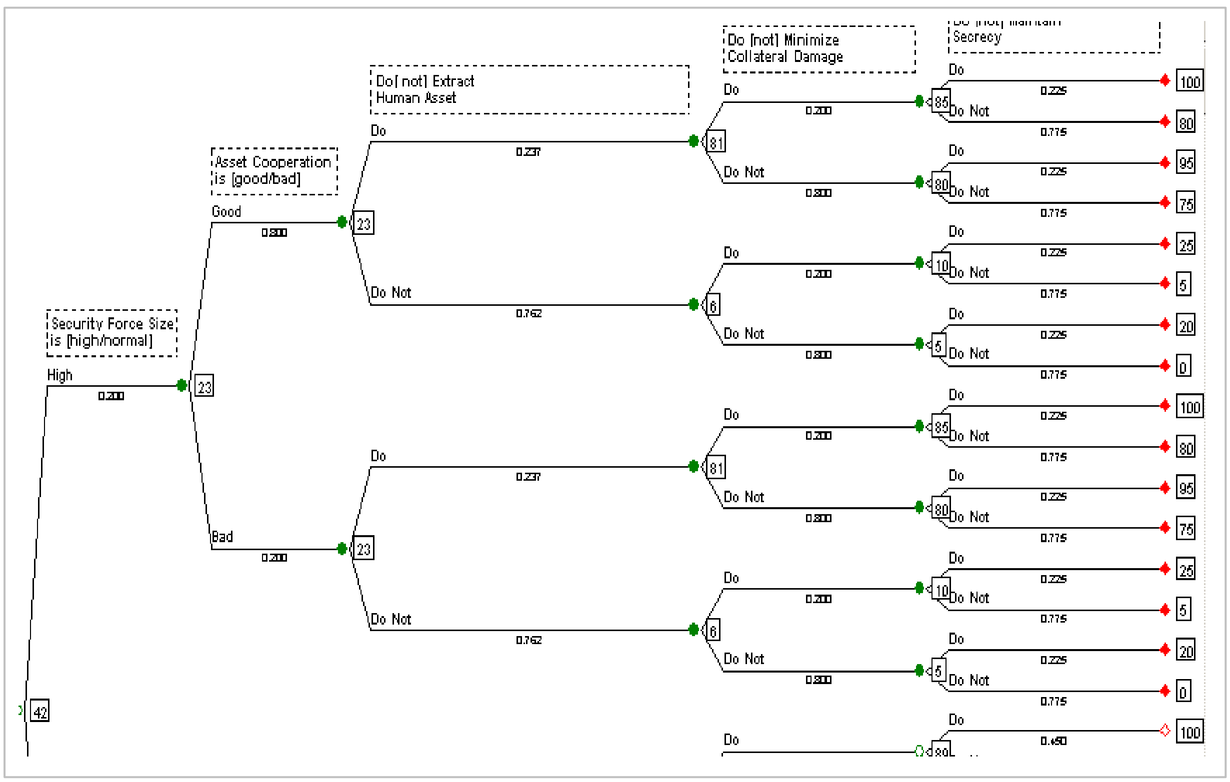

Figure 4-7 Portion of Full Decision Tree

4.3.8 System Calculates Best Action for Given Inputs. The decision team accesses the "best course of action" calculation by moving to the Analysis tab and selecting 'Evaluate COAs' in the Select Analysis View pull down menu. In Figure 4-8 the total decision tree has been "rolled back" to its initial node to display the value (or utility) associated with each of the three options. In this example, extraction before the conference has the highest utility of 62, while extraction during or after the conference have almost the same utilities, that are approximately half those of the leading option.The TGDAS also provides additional information on the derivation of the 'rolled up' utility values. This is obtained by double clicking the particular value. For example, Figure 4-8a, which shows the constitution of the lead value, indicates that the value of 62 is actually obtained by averaging several quite low values with several very high values. This means the numerically leading option is actually a somewhat risky proposition, for which there might be a very low payoff or a very high payoff. A group seeking a less risky approach might select another option for which the average payoff was somewhat less but the chances of obtaining that payoff were greater – that is, the constituents numbers were clustered more closely to the mean.

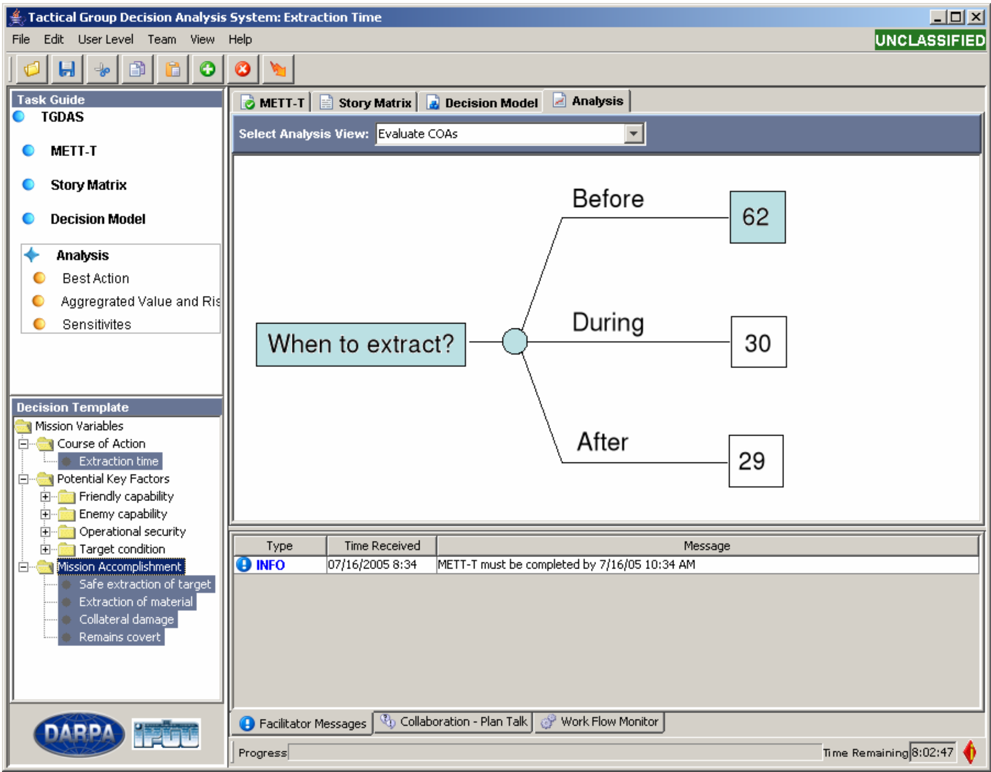

Figure 4-8 Best Course of Action Screen

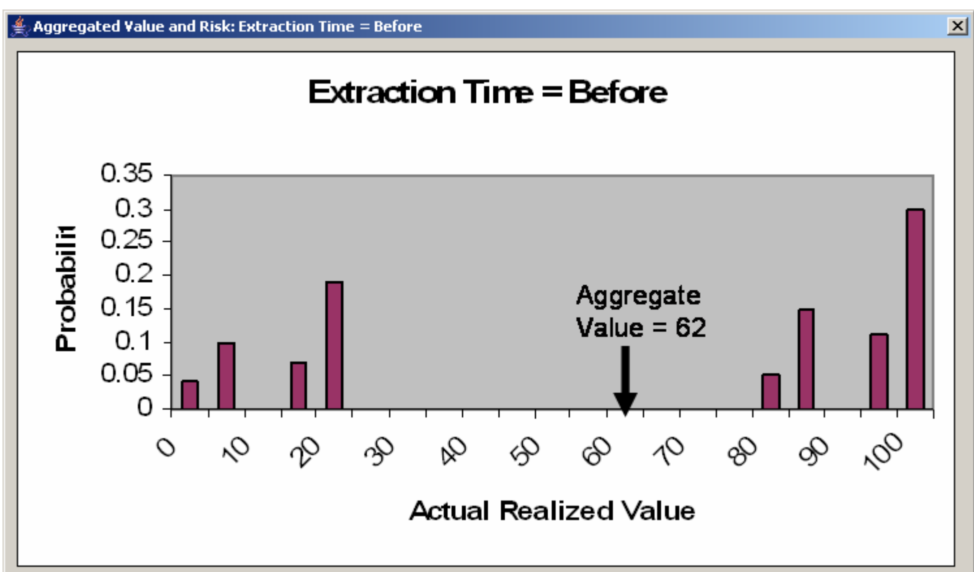

Figure 4-8a Constitution of Aggregate Value for 'Extract Before the Conference'

4.3.9 System Identifies Sensitivities and Needs for Information or Analysis. The TGDAS Analysis View allows the use to select the following displays :

1. Evaluate COAs (discussed previously)
2. One-Way Sensitivities Summary
3. One-Way Sensitivity (with Value of Information) for one Variable
4. Two- Way Sensitivities

One-Way Sensitivities Summary. Figure 4-9 shows the One-Way Sensitivities Summary in the form of a "Tornado Diagram." (The graph looks like a "tornado" with the largest bars at the top and the smallest at the bottom.) Tornado diagrams provide a broader view of how parameter values affect both Aggregated Value and decisions. The abscissa measures Aggregated Value, and each bar corresponds to a particular parameter. The width of the bar represents the potential influence of changes in the parameter on Aggregated Value. More specifically, it represents the change in Aggregated Value that results from changing the parameter setting from its lowest to its highest level, leaving all other parameter settings unchanged. Parameters are arranged from top to bottom in order of their influence. The vertical line is Aggregated Value given current settings for all the parameters The Tornado Diagram of Figure C5-9 has the additional benefit of showing the proportional value of additional information (red part of bar) vs. the currently available information (blue part of bar).

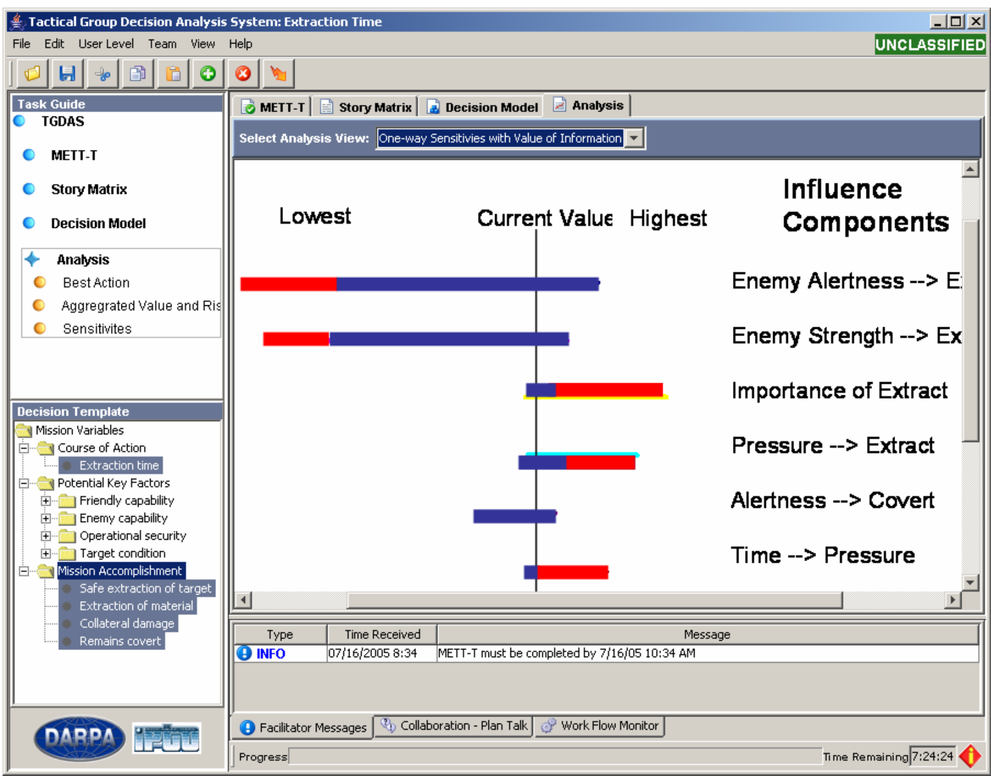

Figure 4-9 One-Way Sensitivity Summary (Tornado Diagram) Screen

One-Way Sensitivity Analysis. By clicking on the corresponding bar in the tornado diagram, team members can open a window for a particular parameter to view its graphical one-way sensitivity analysis. In the example of Figure 4-9a, they are viewing graphical one-way sensitivity for the most influential parameter, probability of mission element success for best case enemy capability. The analysis indicates that at the current value assigned by the group to the influence of alertness on extraction (0.1), extraction before the conference is clearly the preferred option. But if the estimate of this influence would change to 0.5 or above, the best course of action would be extraction during the conference.

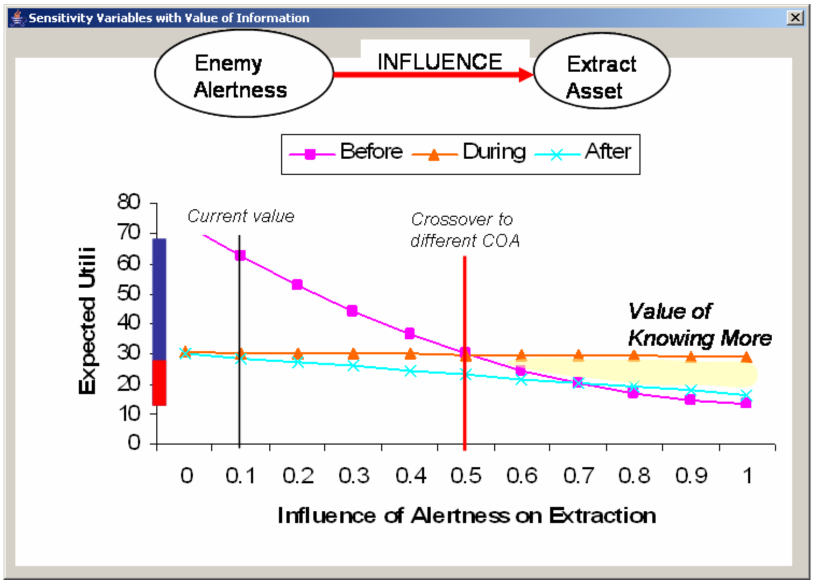

Figure 4-9a One-Way Sensitivity Window (Asset Extraction to Enemy Alertness)

Comparison of the one-way sensitivity analysis with the relevant bar in the tornado diagram shows that the height of the bar is the same as the difference between Aggregated Value when the parameter is at its lowest level and Aggregated Value when the parameter is at its highest level – given that the best option is chosen for each parameter setting. The value of additional information is the maximum difference between the best alternative option and the current option.

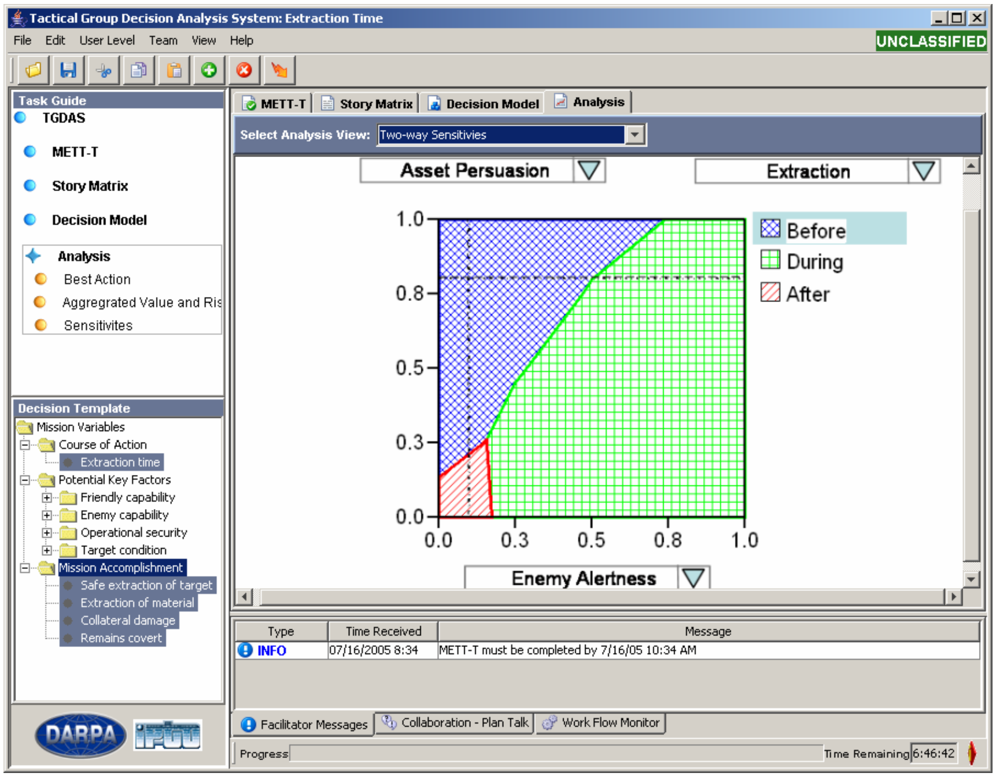

Figure C-9b Two-Way Sensitivities Analysis Window

Two-Way Sensitivity Analyses. Selecting the Two-Way Sensitivities Analysis view opens a window that allows the decision team member to analyze the effect on the choice of an option of variations in the influence of any two selected variables on a selected mission objective. In the example of Figure 4-9b, the user is viewing the combined effect on option selection of the influence of:

1. Asset Persuasion on Asset Extraction (currently estimated at 0.84)
2. Enemy Alertness on Asset Extraction (currently estimated at 0.10)

The graph of Figure 4-9b shows that the intersection of the currently estimated values falls in the domain of the 'Extraction Before the Conference' option (which is accordingly highlighted), and that the estimates of these two influences would have to change significantly before the domain of another option was entered. For example, if the Decision Team changed its estimate of the influence of Enemy Alertness on Asset Extraction from a low values of 0.10 to a high value of 0.7, the intersection of the two influences would then fall into the region of 'Extraction During the Conference' and the corresponding option would be highlighted.

The team member can interactively explore the entire sensitivity space by dragging the 'current value' lines and by selecting other variables from the three pull down menus. This hands-on capability should give the Team an enhanced understanding of the effects of the decision variables on the recommended decision.

4.3.10 Members Analyze Results. Decision Team members are able to use the full capabilities of the TGDAS to analyze the results of the AF-guided decision making process. If the deadline is imminent, the analysis will likely be based on the results of a one-pass COA and Sensitivity Analyses. If time allows, the Team may cycle through the process again, using guidance from the critical thinking agent, as described in Section 4.3.12 below.

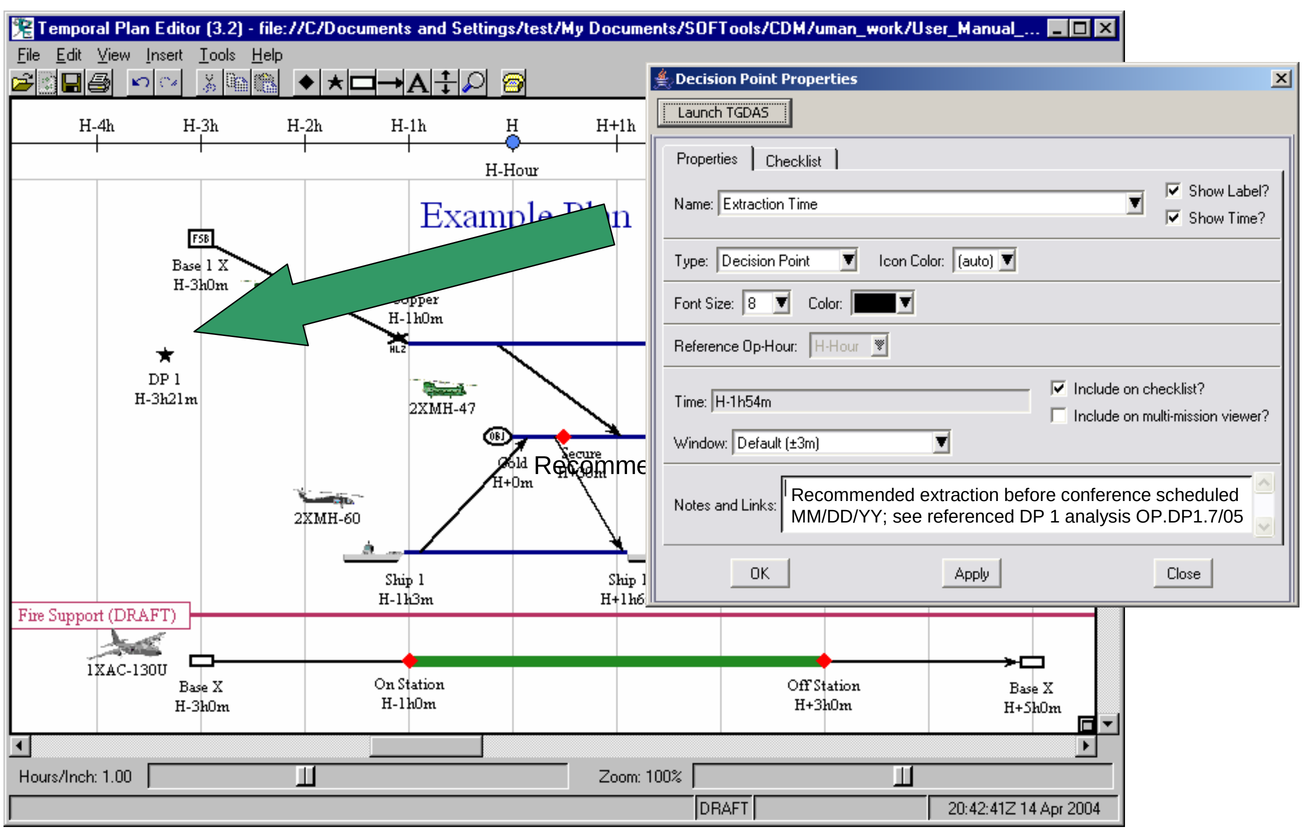

Figure 4-10 Decision Point Properties Contains TGDAS Results

4.3.11 Members Recommend or Select Plan and Leader Prepares COA Report. Depending on the organizational protocol, the group members will select or recommend a course of action by using a consensus method or by assigning the final decision recommendation to the Decision Team leader.

The Decision Team leader will then prepare a Course of Action report for the record or for the next organizational level using a format suggested by the TGDAS or another standard format. He or she may assign portions of the preparation to other Team members. In the case of the SOFTools example, the recommended decision will be inserted into the Decision Point Properties window that is associated with the corresponding decision point icon (DP1) along with references and links to any TGDAS analysis record or report, as shown in Figure 4-10. Likewise, the decision process itself will be retained in a computer file for future reference and/or updating as required.

4.3.12 Stimulation of Critical Thinking. If time is available, the decision support process need not stop at the steps described above. Instead, the Automated Facilitator may use a variety of methods to stimulate continued critical and creative thinking. For example:

- An *infallible crystal ball* announces: "I deduce this plan will not work. Tell me why."
- MAJ Brown responds: "The asset is a human being. He may lose interest in defecting if we wait too long. Especially during the conference, he will have contact with colleagues who may influence him, as well as other intelligence services."
- A new column header is added to the story matrix: Cooperation of asset. Both existing stories depend on the assumption that the asset will be maximally cooperative!
- MAJ Brown introduces new story, in which cooperation is likely only if extraction occurs *before the conference*.
- A new influence diagram is generated from this expanded story matrix.
- The Facilitator requests assessment of two parameters: 1. Current sincerity of asset. 2. Chance that cooperation will cease during a given block of time (before, during, after conference)
- With the new information, the collapsed Decision Tree shows that extraction before the conference now has the highest calculated value while the other options are nearly tied.
- New sensitivity analysis shows that extraction after conference is best only if the chance of loosing cooperation is very low or very high.

5. Project Continuation

5.1 Phase II Plan

Our major planned tasks for the Phase II continued development and evaluation are:

- Detailed System Definition and Design
- System Implementation (Spiral Development)
- Test and Modification
- System Demonstration
- Operational Evaluation
- Commercialization Plan

5.2.1 Cognitive Process Models and Algorithms. Of particular importance in our planned system implementation will be the detailed definition and design of the cognitive process models and algorithms. In the TGDAS, the cognitive process models and algorithms are implemented by a set of tools and agents that support the Decision Team functions in the process flow described above. Figure 5-1 shows how the major planned tools and agents will interact with the key process flow steps. The components are:

- Doctrine Template
- Information Selection Agents

- Constrained Resource Agents
- Probability Elicitation Tools
- Conflict Resolution Tools and Agents
- Monitoring Agents

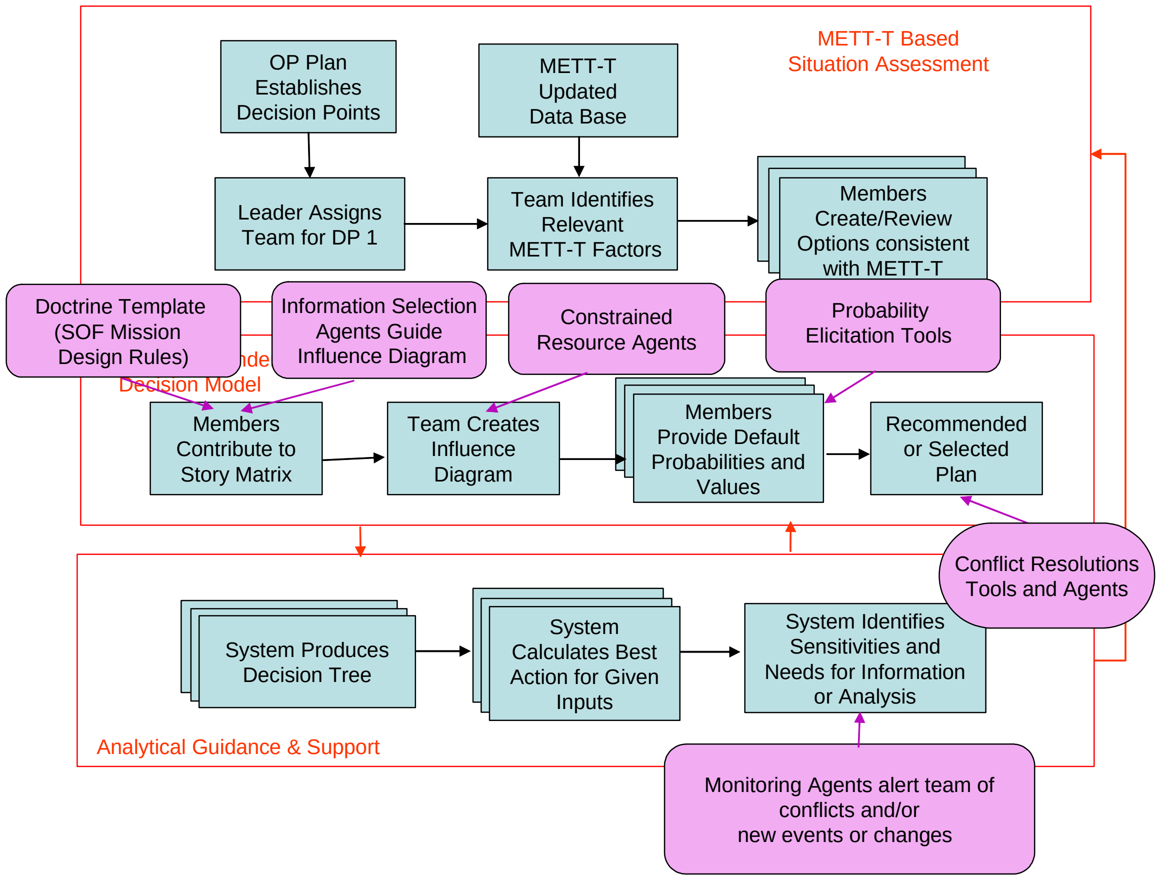

Figure 5-1 TGDAS Key Supporting Cognitive Tools and Agents

5.2.3 Commercialization Plan. Also of critical importance in Phase II will be the full development of a plan to commercialize of the Phase II product. Our preliminary plan is outlined in the following.

Product Description. The focus of our commercialization strategy will be transformation of the Phase II prototype software into a suite of software modules for use in a variety of group decision support system applications. One version of the Phase II prototype will be configured specifically for direct transfer to our identified SOCOM customer. At the same time, we will create a prototype version for more demonstration in more general applications.

Accordingly, the planned software product will be optimized to meet military as well as non-military market requirements. It will be offered for sale and/or license primarily to commercial companies already in the GDSS business to DoD prime contractors, as well as to civil organizations that are concerned with optimizing their decision making processes, particularly in the emergency preparedness sector. In that regard, we plan to explore the application of our group decision support system as a commercial tool for helping military and non-military homeland security and emergency response teams plan and execute their various mission, for example, in a bomb disposal situation, a contaminated urban area, a search in a dangerous environment, etc.

IP Protection. In order to enhance and protect our competitive position as decision support system innovators, we have submitted a U.S. Patent Application for the new and novel aspects of the TGDAS technology. The submission has been notified to the DARPA SBIR office and to the project PM. Assuming the patent issues, it will provide valuable IP protection in addition to the data rights provided as part of SBIR contracts, and will not affect the Government's rights in the project's technical data and software as provided in paragraph (b)(4) of the Rights in Noncommercial Technical Data and Computer Software – Small Business Innovative Research (SBIR) Program clause contained in our contract.

Marketing Strategy. At the highest level, the market for group decision support software can be considered a sizeable part of the many-multi-billion dollar worldwide market for management information systems. In that market, Decision Support Systems (DSS) are defined as the class of computerized information systems that supports decision making activities, and are primarily intended to help decision makers use communications technologies, data, documents, knowledge and/or models to successfully complete decision process tasks. As pointed out by Frost & Sullivan, a major market analysis firm, "The growing prevalence of the Web as an interface to business applications provides an important opportunity for market participants. Because the Web interface is familiar to workers, utilizing this interface with DSS software can reduce the employee training period." Frost & Sullivan also says that "Small and mid-sized DSS vendors will have to select markets in which they already have expertise or consider forming partnerships with acquire the necessary industry knowledge." As described below, this is also the approach we favor for our commercialized SBIR product.

We will tailor our product to overcome significant barriers to entry. Product features will include:

- Instant operational utility and usability through familiar Web and graphical based interfaces
- Flexibility to integrate with each customer's organization and procedures and to change as the responding organization evolves
- No requirement for special hardware or software

We will focus initial sales and marketing efforts on standard setters. Our market segments are dominated at the top by institutions, which have a significant influence on the policies and procedures adopted by all the other entities in that segment. Our initial marketing focus will be to deploy our technology in the headquarters and test units of these organizations. In pursuing sales to these key early adopters we will seek to partner with one or more of the big IT and aerospace companies that are moving into the DDS space, and leverage the channels they already provide, helping them to present us as a part of their enterprise solutions.

Competition is expected, primarily in the military sector, due to the strong and growing emphasis on DDS and GDSS. While we are not currently aware of any products and/or developments precisely like our planned model-based decision support system, there are numerous commercial MIS and GDSS products which must be considered as competition in that they involve some form of software for aiding decision makers and will likely compete for the same budget dollars. We plan to counter competition by developing a product that combines (1) a rigorous decision model based framework with (2) ease of use leading to (3) an actual decision outcome. These are not features of the vast majority of current DSS and GDSS products.

We estimate that the requirement for funding to turn the Phase II prototype into a fully supported product and take it to market will be on the order of $500K to $1 million. We will seek such funding from several sources, but our preferred source will be strategic partners who wish to extend their capability in the large and growing market for command and control and robotic management solutions. Our funding and partnering plan includes:

- At the beginning of Phase II we will approach potential strategic partners in the commercial, aerospace and defense contractor community with a business plan that offers them rights to market our system as part of their solutions for large customers, as well as rights to use our technology in other products (such as military C4I systems) in return for development funding.

- We will also – in parallel – attempt to negotiate contracts with early adopters wherein they fund some of the special system features in order to expedite their availability, without our relinquishing our intellectual property rights.

Commercialization Experience. Perceptronics Solutions' commercialization team consists of Dr. Amos Freedy, Dr. Gershon Weltman and Jim McDonough. Drs. Weltman and Freedy have a solid record of commercializing R&D products, including a software product from an SBIR Phase II contract. In addition, they are experienced in forming strategic partnerships for shared development and marketing of such commercialized products. Under their leadership Perceptronics, Inc. achieved a worldwide reputation for its ability to move rapidly from an innovative technical concept to an effective R&D program, and from the R&D results to a fully-integrated and supported commercial product. *Together, DOD R&D products commercialized by the Perceptronics Solutions team have accounted for over $70 million in product sales and over $15 million in equity investment.*

Dr. Amos Freedy has directed the successful commercialization of several decision support products developed under DOD contract. This includes the original Group Decision Aid, the PERCNET knowledge-based simulation environment for modeling human-machine tasks; and the CACE Petri net based process modeling and simulation tool; and the IC3D peer-to-peer framework for Internet collaboration. Similarly, Dr. Gershon Weltman directed the successful development and commercial-ization of the OneView® software for Internet collaboration from SBIR Phase I, interim and Phase II contracts.

5.2 Phase III Activities

Our main Phase III commercialization and transition objectives are:

- Strategic Partnering
- Military /Aerospace Marketing (Special Ops and Battlefield C4I)
- Non-Military Marketing (DHS and Corporate Management)

5.3 Transition Progress

In our Phase I proposal, we identified the following 5 elements as essential for successful technology and product transition:

- ✓ Assign transition responsibility
- ✓ Selection of transition path and strategy
- ✓ Chum the waters
- ✓ Rapid Prototype demonstrations
- ✓ Continuous marketing follow-through

We have made significant progress on all 5 of these elements, particularly in finding a transition path and strategy that includes early cooperation and potential operational use by a Special Operations Customer, and we are on schedule to have all of them further under way by the start of Phase II.

6. Conclusions

6.1 Task Accomplishment

We have successfully met and exceeded the research objectives originally planned for Phase I; and on the basis of the Phase I results, we are fully confident of successfully completing a complete system prototype during Phase II, including potential new technical contributions from other outside contractors.

6.2 Concept Validation

6.2.1 Proof-of-Concept Demonstration. The proof-of-concept demonstration, which included working through a complete system task flow process as described in Section 4, has validated the basic TGDAS concept and provided empirical evidence that it will be highly useful in actual operational settings.

In terms of our contribution to decision support, Figure 4-1 illustrates how the major components of our process underlie the unique combination of *Cognition, Representation & Modeling and Analysis* represented by the TGDAS.

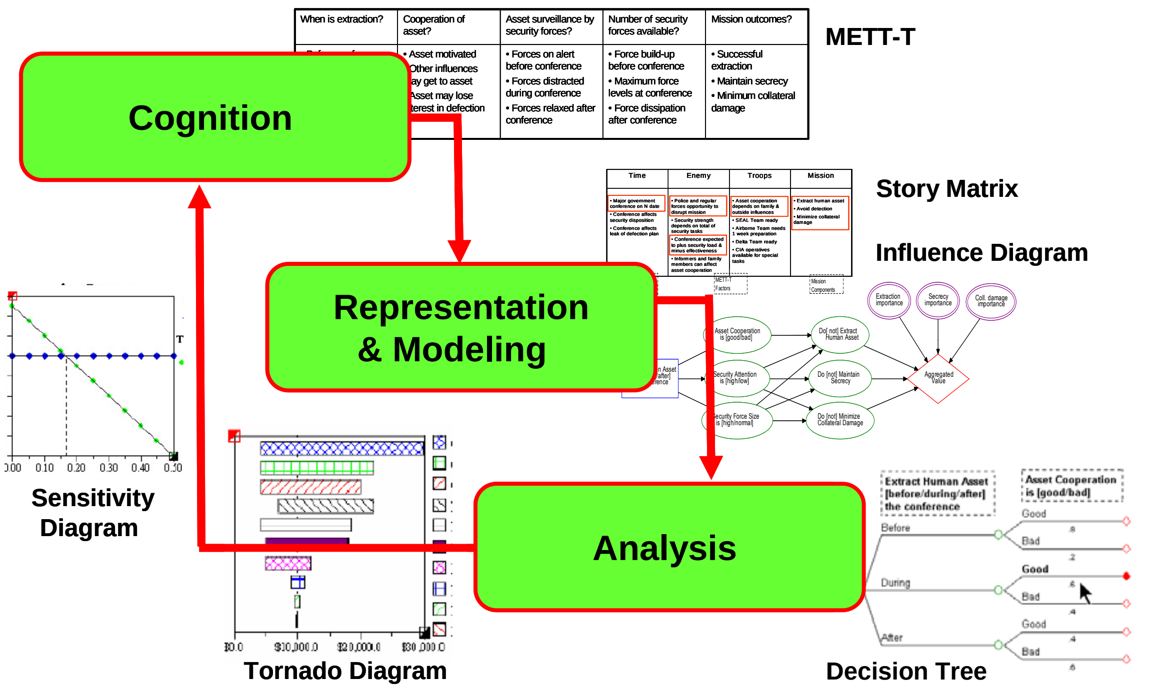

Figure 6-1 TGDAS Elements Support the Combination of Cognitive and Analytical Methods

6.2.2 Theoretical Validation. Theoretical benefits clearly arise because the TGDAS:

- Uses the familiar METT-T format to define and describe the decision environment
- Uses naturalistic story telling methods to create plausible options
- Uses rigorous, model-based analytical methods to calculate the best option, identify the most sensitive decision elements and flag future information related to these elements
- Incorporates the inputs of all Decision Team members
- Provides a logical progression of user friendly Decision Team tasks that lead in reasonable time from a broadly defined decision requirement to reportable and rigorously supportable results.

6.2.3 Empirical Validation. Empirical benefits of the model-based, structured TGDAS approach were also observed in two important cases:

Internal Validation. The development team of Amos Freedy, Jim McDonough, Elan Freedy, Marvin Cohen and Gershon Weltman has met several times to work through initial versions of the TGDAS flow process. During the course of the process, talking the chosen scenario through the process flow steps and applying such computer analytical tools as were available definitely:

- Improved our understanding of the decision situation,
- Helped develop credible options,
- Revealed factors in the options that were not immediately evident, and
- Guided the Team to a recommended course of action that had the support of all its members and was likely not the course of action most of the members would have chosen immediately.

This early "mockup" version of the TGDAS performed for relative experts much as we anticipate the final, fully-realized computer system will perform for relative newcomers.

External Validation. Initial run-throughs of the task flow steps for the selected scenarios with representative of the SOCOM customer produced enthusiastic responses. The SOCOM personnel were able to understand and participate fully in the process and to add helpful suggestions despite the first time exposure. This is a positive and highly encouraging finding.

6.3 Anticipated Benefits.

7. Bibliography

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Attachment A
Story Matrix Development

This section presents the full development of an integrated story matrix that accommodates all of the collaborative inputs of the Decision Team. The steps are described in more detail in the following sections.

A.1 First Story

The system keeps track of contributors either by name or anonymously (as in the Delphi method), to avoid undue influence by factors such as rank or status. In this case, MAJ Smith is called "A." In Figure A-1, text entered automatically by the TGDAS is bold sans serif, to contrast with text entered by team members.

According to METT-T, enemy security forces are a major obstacle in this mission. One team member, MAJ Smith, sees the upcoming conference as a window of opportunity during which the security forces will be distracted.

As shown, MAJ Smith types "Extraction during conference" in the option column for Story #1. In the blank column, MAJ Smith writes that distraction by other tasks during the conference will reduce the attention given by security forces to individual surveillance. He links this claim to supporting text in the METT-T Summary (e.g., by selecting one or more blocks of METT-T material, clicking on the *Link* command button, and then clicking on a cell in the story matrix).

This linkage has three consequences: (a) Since the information comes from the Enemy and Time sections of METT-T, the system automatically generates a column header "Enemy-Time." Team members will refine this header as the process continues and other enemy factors are introduced. (b) Any subsequent change in the selected METT-T information will be propagated to this model element and team members will be alerted. (c) Other team members can click on this story element and see the METT-T elements that motivated it. New METT-T information can be linked to this item by other team members at any time.

MAJ Smith expects that distraction of security forces will improve chances of success on all three mission elements, so he accepts the default answer, "*yes*," in each mission element column.

A.2 Working Independently

CPT Jones is also concerned about enemy security forces, but sees the conference as an obstacle rather than an opportunity. The size of the force in the town has already increased and will reach a maximum during the conference. Figure A-2 shows CPT Jones' independent contribution to the story matrix.

CPT Jones initiates a story in which extraction occurs after the conference, when the size of the security force will have returned to normal. He links this item to text in METT-T (not shown), and the system generates the column header, "Enemy-Time." The system logs this as Story #2, and refers to CPT Jones as Participant B.

Group solutions are often improved if team members work independently on the problem before viewing one another's work. By avoiding mutual influence at the beginning of the process, team members are more likely to bring complementary viewpoints to bear, to devote energy to their own solutions, and avoid bandwagon effects. Thus far, CPT Jones and MAJ Smith are unaware of one another's contributions.

The Automated Facilitator will recommend that each phase of decision making end when specific criteria are satisfied. These may include, for example: a high percentage of team members' indicating readiness to move on, slow down in rate of typing, and/or completion of appropriate tasks. The commander or team leader will be able to preempt or override this recommendation at any time.

A.3 Integrated Story Matrix for Collaborative Work

When the team is ready to begin collaborative work, the system constructs an integrated display for stories created by different team members, as seen in Figure A-3.

To integrate the diverse stories, the system standardizes inputs by transforming column headers into *variables* and story elements into *values* of variables. A variable is a question with a specified set of answers (or values) that are mutually exclusive and that exhaust all possibilities. The transformation is largely automatic, with the help of a few Facilitator queries. The participants' answers will clarify the structure and further evolve their understanding of the problem.

Participants are first asked to specify possible values of the decision variable (*extraction time options*). They can do so either by selecting appropriate text in the story matrix or by typing in new text. The values of the decision variable are *during conference*, *after conference*, and *before conference*, respectively.

In this example, both A and B have provided story elements under the Enemy-Time heading. Thus the system asks A and B whether the relevant story elements are mutually incompatible answers to the same question, hence, values of the same variable. A and B answer that both answers may be true simultaneously. The TGDAS therefore interprets them as values of *different* variables and creates two story matrix columns. The participants are then asked to refine the column headers to distinguish the two variables. They do so by adding *attention* and *size of security forces*, respectively. Participants are also asked to explicitly label values of these variables.

The three levels of attention designated by A are *high*, *low*, and *normal*, and three levels of force size designated by B are *higher*, *highest*, and *normal*. The system asks whether these values cover all possibilities, and if not, requests additional values.

A.4 Conflict Recognition

After the decision variable is precisely specified, the system knows that A and B have recommended different options. The extent of their disagreement, however, is still not clear. For example, they may both think that either option would be okay. This leads to additional probing via the Automated Facilitator.

The Facilitator polls the participants regarding mission element success contingent on each proposed option. As shown in Figure A-4, A and B have different opinions. A feels that B's option will fail to achieve any of the three mission elements, and B is similarly pessimistic with regard to A's option. The Facilitator concludes that there is genuine disagreement about options and outcomes, and flags differences of opinion as *conflicts*. The Facilitator now begins to probe for causes of the conflict.

The system polls A and B to determine whether they agree on the two security force variables, attention and size. In fact, they do agree: Both A and B predict that force size will be rising before the conference, at its maximum during the conference, and back to normal afterwards. They also agree that attention to individual surveillance will be high before the conference (due to absence of distracting tasks), low during the conference (due to preoccupation with other tasks), and back to normal afterwards.

The disagreement between A and B is as yet unexplained. It will be clarified and possibly be resolved by more complete and precise modeling of the relative impact of attention and size.

Mission	Enemy	Troops	Terrain	Time
• Extract human asset & documents • Avoid detection of US presence or influence • Minimize collateral damage during mission execution	• Obstruction opportunities from secret police &/or regular forces • Security forces are stretched thin and can be diverted by other tasks • Expect pending conference to add many tasks • Informers including family member are source of concern	• Asset cooperation tenuous and subject to outside and family influences • SEAL Team available for action • Airborne Team available with 1 week preparation • Delta Team available for action • CIA has several operatives within 1 day of target city	• Seacoast location includes survailed coast, deserted coast and harbor • Urban terrain is highly built up city, with few locations for helicopter landing • Suburban terrain offers more landing opportunities • Seasonal weather expected to stay mild and constant	• Major government/ science conference scheduled date; will bring political visitors and colleagues of target asset • Conference activities will affect security disposition • Conference activities may affect chance of defection plans leaking

Insert new story elements here

MAJ SMITH'S STORY MATRIX

	Extraction Time Options	Enemy-Time		Mission: Extract human asset and documents	Mission: Avoid detection of US presence or influence	Mission: Minimize collateral damage during mission execution
Story #1 **Participant A**	Extraction during conference	Attention of security forces will be high before but low during the conference		Yes	Yes	Yes
	Insert new option here					

Figure A-1 MAJ Smith's First Story

Insert new story elements here

CAPT JONE'S STORY MATRIX

	Extraction Time Options	**Enemy-Time**		**Mission: Extract human asset and documents**	**Mission: Avoid detection of US presence or influence**	**Mission: Minimize collateral damage during mission execution**
Story #2 Participant B	Extraction after conference	Size of security forces will be increasing before conference, reach a maximum during conference, and go back to normal afterwards.		Yes	Yes	Yes
	Insert new option here					

Figure A-2 CAPT Jones' Independent Story

Insert new story elements here

INTEGRATED STORY MATRIX

	Extraction Time Options	Enemy-Time Attention of security forces	Enemy-Time Size of security forces		Mission: Extract human asset and documents (*Yes*, *No*)	Mission: Avoid detection of US presence or influence (*Yes*, *No*)	Mission: Minimize collateral damage during mission execution (*Yes*, *No*)
Story #1 Participant A	Extraction during conference	Attention to individual surveillance by security forces will be high before conference, low during conference, and intermediate (normal) afterwards.			Yes	Yes	Yes
Story #2 Participant B	Extraction after conference		Size of security forces will be higher before conference, highest during conference, and low (normal) after conference		Yes	Yes	Yes
	Insert new option here						

Figure A-3 Integrated Story Matrix for Collaborative Work

Insert new story elements here

INTEGRATED STORY MATRIX

	Extraction Time Options *(During conference, after conference, before conference)*	Enemy-Time Attention of security forces *(Low, Normal, High)*	Enemy-Time Size of security forces *(Normal, Higher, Highest)*		Mission: Extract human asset and documents *(Yes, No)*	Mission: Avoid detection of US presence or influence *(Yes, No)*	Mission: Minimize collateral damage during mission execution *(Yes, No)*
Story #1 Participant A	Extraction <u>during conference</u>	Attention to individual surveillance by security forces will be <u>high</u> before conference, <u>low</u> during conference, and intermediate <u>(normal)</u> afterwards.	Same as B.		<u>Yes</u> <u>No</u> B	<u>Yes</u> <u>No</u> B CONFLICT	<u>Yes</u> <u>No</u> B
70 Story #2 Participant B	Extraction <u>after conference</u>	Same as A.	Size of security forces will be <u>higher</u> before conference, <u>highest</u> during conference, and low <u>(normal)</u> after conference		<u>Yes</u> <u>No</u> A	<u>Yes</u> <u>No</u> A CONFLICT	<u>Yes</u> <u>No</u> A
	Insert new option here						

Figure A-4 Conflict Recognition

Attachment B
Applications of Tornado Diagram

This section describes how the TGDAS Facilitator uses the tornado diagram as basis for recommending more analysis, information collection, or option revision.

B.1 Access to one-way sensitivity analysis

Figure B-1 shows that by clicking on the corresponding bar in the tornado diagram, team members can zoom in on a particular parameter to view its one-way sensitivity analysis. In this example, they are viewing one-way sensitivity for the most influential parameter, probability of mission element success for best case force effectiveness.

Comparison of the one-way sensitivity analysis with the relevant bar in the tornado diagram shows that the height of the bar is the same as the difference between Aggregated Value when the parameter is at its lowest level and Aggregated Value when the parameter is at its highest level – given that the best option is chosen for each parameter setting.

Because the lines in the one-way sensitivity graph do not cross, this particular parameter (probability for best case) does not affect which option should be chosen. Nevertheless, to the extent that it is uncertain, the overall Aggregated Value of the mission itself is uncertain. The Facilitator may recommend that team members collect more information or perform more analysis relating to this parameter. Alternatively, they can look for new options whose outcomes do not depend as critically on assumptions about its value.

B.2 Comparison of one-way analyses for related parameters

Figure B-2 illustrates why it is useful to compare one-way sensitivity analyses for related parameters.

By clicking on the *Related Parameters* button while probability for best case is already displayed, team members request a display that includes the variables that appear in the same rules with it. These are the parameters that combine with probability for best case to influence conditional probabilities and determine the impact of enemy force effectiveness on the three mission elements.

Team members can see at a glance that the only variable with significant influence, aside from probability of best case, is the impact of enemy force effectiveness on successful extraction. The reason for this is the significantly higher importance weight assigned to successful extractions compared to other mission elements.

B.3 Analysis of parameters that determine Aggregated Value

Figure B-3 shows why importance weights by themselves don't matter much, since achievement of mission elements is highly correlated.

The display shows one-way sensitivity analyses of the variables that combine to determine Aggregated Value, i.e., importance weights on the three mission elements. None of the weights by itself has much impact on Aggregated Value, for two reasons: Accomplishment of mission elements is highly correlated because of their shared dependence on force effectiveness; and to the extent that one weight is reduced, other weights are increased so that they continue to sum to 100.

(Because the weights must sum to 100, this is an exception to the rule that in a tornado diagram, each parameter is varied while keeping others constant. When the weight on extraction was varied, weights on both collateral damage and secrecy were reduced, while keeping their ratio constant. It was impossible, given present software, to do the same adjustment for all the weights. When either secrecy or collateral was varied, the other was reduced, while keeping the importance of collateral constant.)

B.4 Analysis of parameter effects on Best Option

Figure B-4 is a display of one-way sensitivity analyses for the two parameters that jointly determine force effectiveness probabilities. It turns out that either of these parameters can influence on the best course of action. In the one-way analyses, this influence is indicated by crossing of the lines representing the best option. These crossing points are represented by heavy black lines in the tornado diagram.

Team members already knew that the attentiveness versus size parameter influences the choice of extraction time. They now learn that the probability of the most likely effect does so as well. This parameter corresponds to the predictability of force effectiveness. Although MAJ Smith and CPT Jones do not necessarily disagree on the value of this parameter, it is worth a closer look. And since both of these parameters influence choice of action, their interaction is also worth checking. The Facilitator may therefore perform a two-way sensitivity analysis.

NOTE: For both parameters, the Aggregated (expected) Value at the crossing point is outside the range of Aggregated Values corresponding to the lowest and highest level of the parameter. Thus, the heavy black line is located slightly outside the bar representing influence on Aggregated Value.

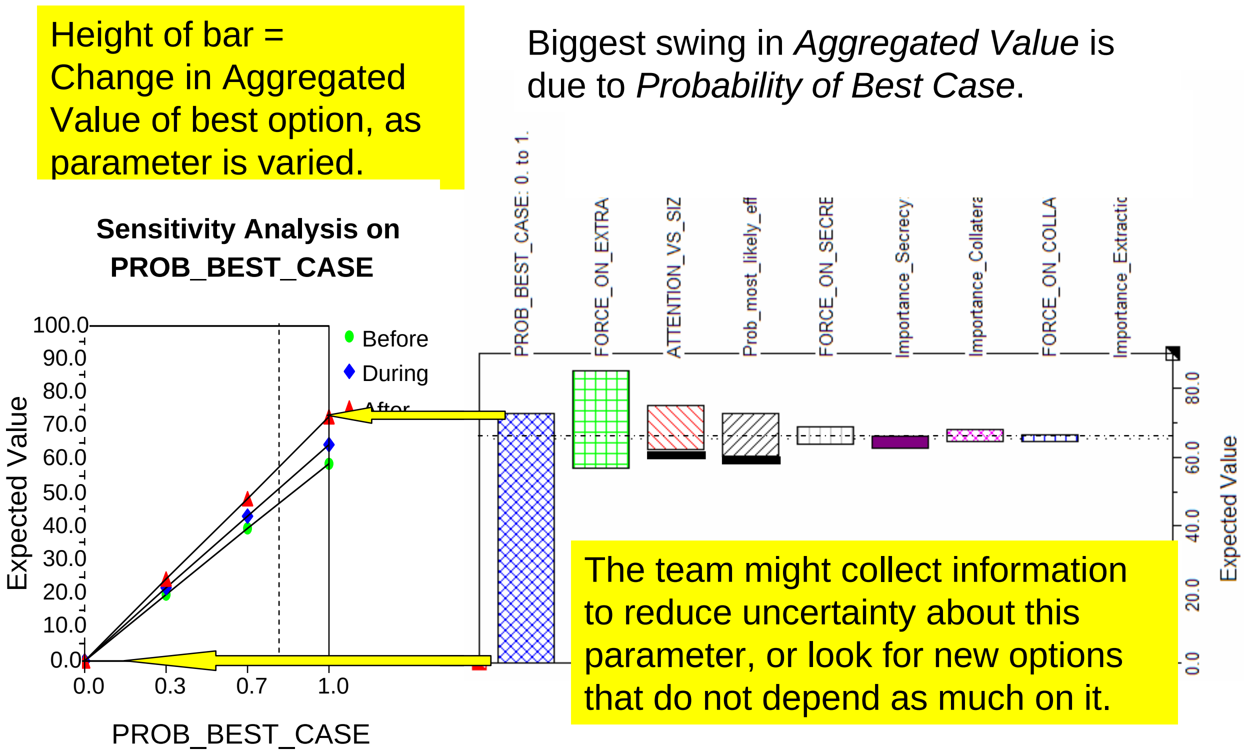

Figure B-1 Tornado Diagram and One-Way Sensitivity Analysis

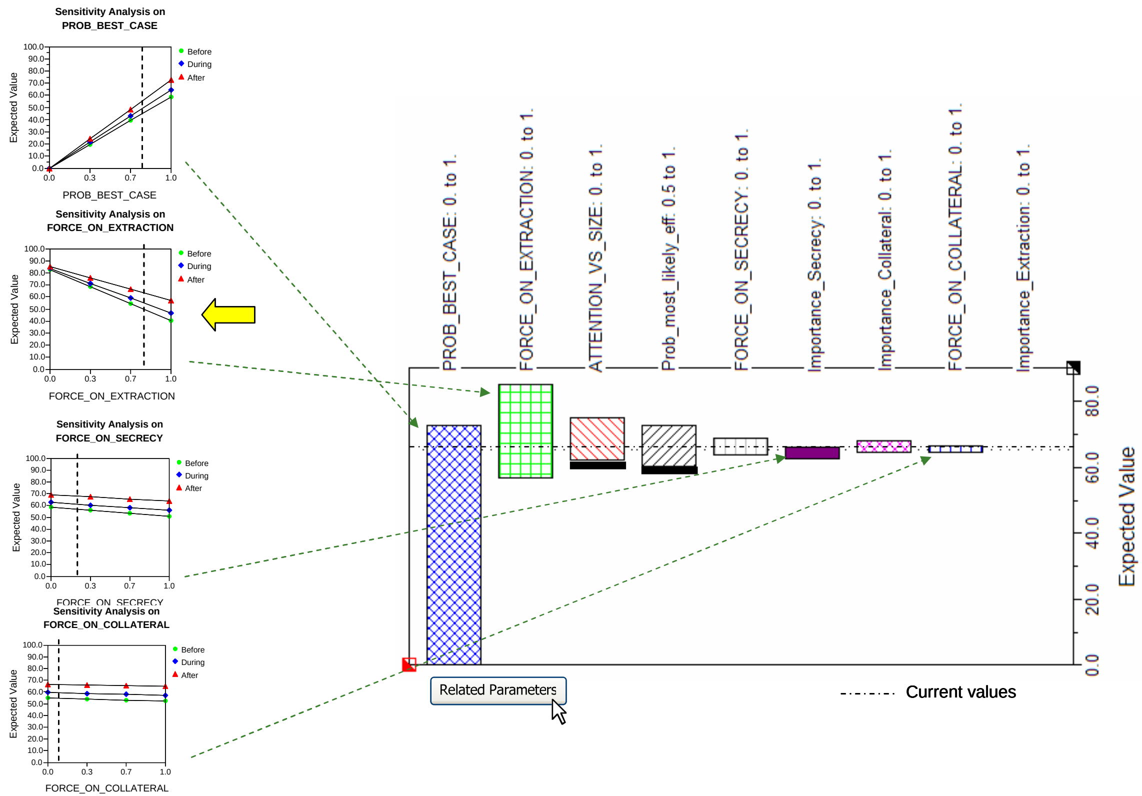

Figure B-2 Tornado Diagram Showing Comparison of One-Way Analyses

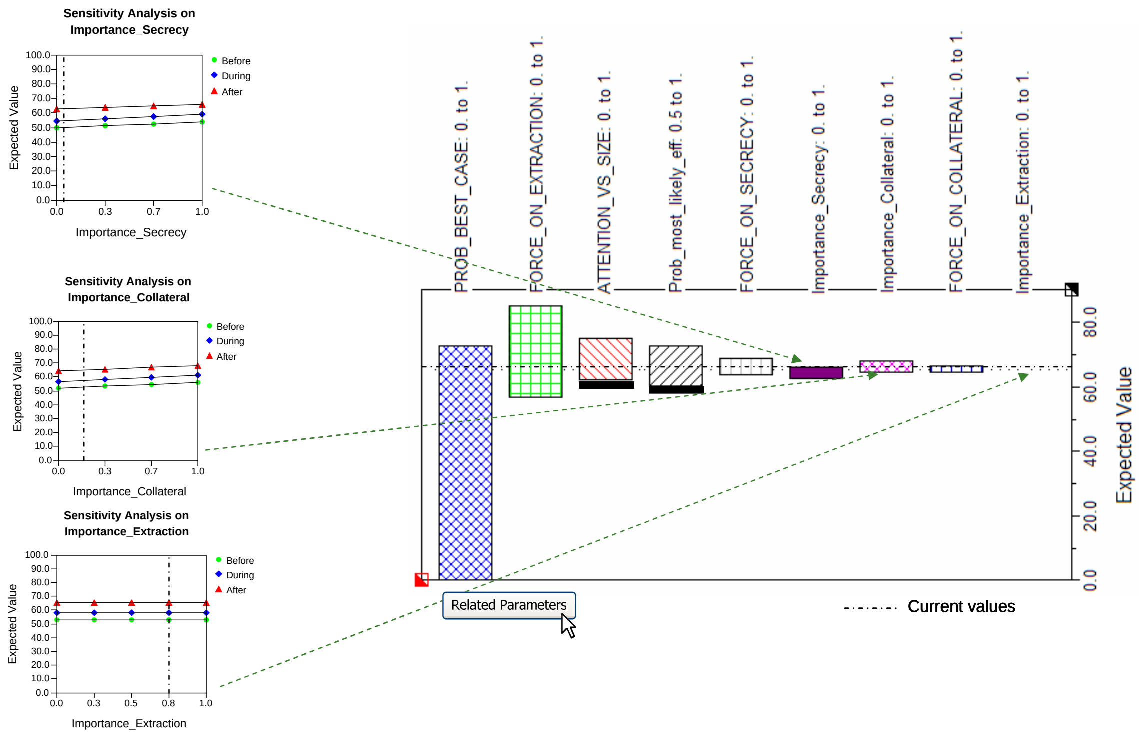

Figure B-3 Tornado Diagram Showing Parameters that Directly Determine Expected Value

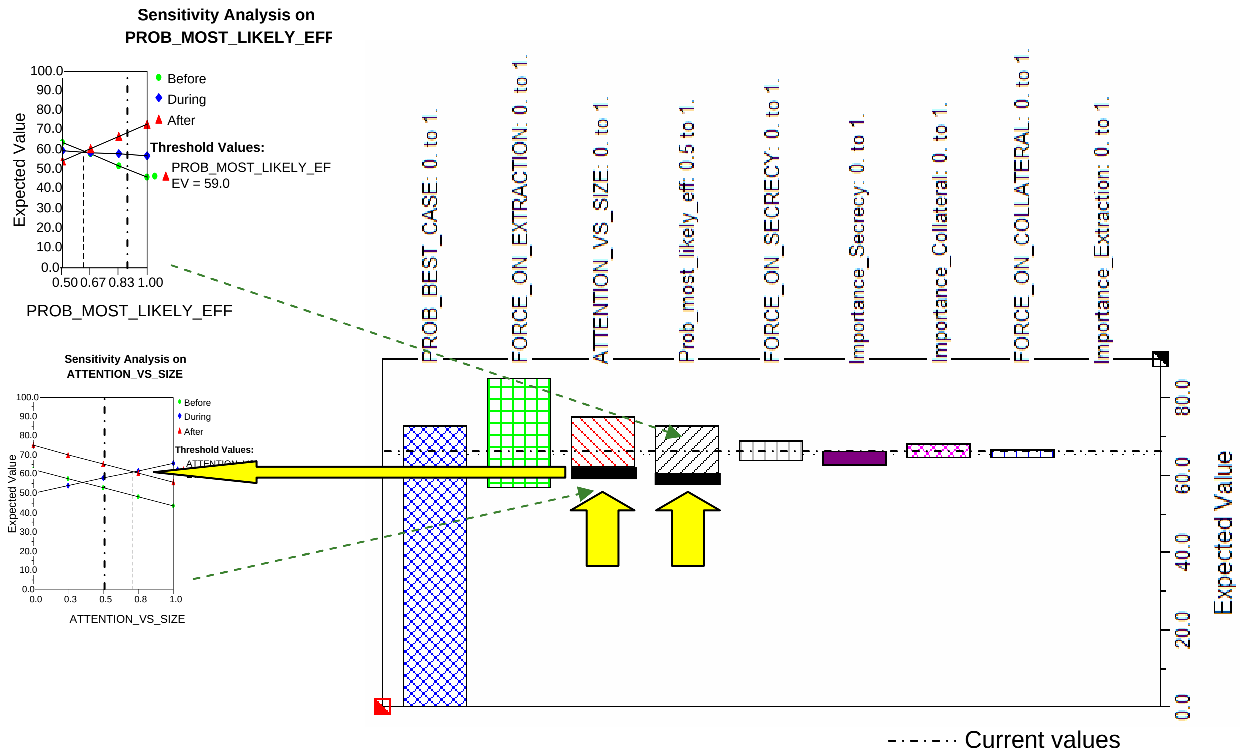

Figure B-4 Tornado Diagram and Parameter Effects on Best Option