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Spill Response System Configuration Study

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16. Abstract

This report describes the development of a prototype decision support system for oil spill response configuration planning that will help U.S. Coast Guard planners to determine the appropriate response equipment and personnel for major spills. The report discusses the application of advanced artificial intelligence planning techniques, as well as other software tools for spill trajectory modeling, plan evaluation and map display. The implementation of the prototype system is discussed in the context of two specific major spill scenarios in the San Francisco Bay.

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METRIC CONVERSION FACTORS

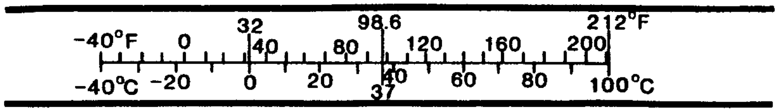
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

SRI International (SRI) is pleased to present this final report on the tasks undertaken during the Spill Response System Configuration Study project, which took place between February 1993 and July 1994. Under this contract, SRI has developed a prototype decision support system that assists U.S. Coast Guard (USCG) planners in determining the appropriate types, quantities, and locations of oil spill response equipment and personnel to minimize the impact of possible spills at a number of locations. This tool also highlights shortfalls in necessary resources and assists the user in exploring the specific spills or spill scenarios.

Under this project we performed a comprehensive literature search for potential systems, tools, and techniques that could be adopted for use within the prototype configuration tool. We reviewed and tested various software prototypes, including the Knowledge Support System (KSS), developed at the University of Michigan. We pursued a rapid prototyping approach that allowed us to design and implement an initial prototype system during the first phase, and to successfully demonstrate several iterations of the initial prototype system to potential users from the USCG at the national and regional level. This approach enabled us to obtain valuable feedback much sooner than originally planned in the original statement of work.

The prototype comprises advanced artificial intelligence (AI) planning technology, together with color map display capabilities, and modules for spill trajectory modeling and response plan evaluation implemented with the aid of commercial software. We were able to leverage advanced technology from Department of Defense (DoD)-funded projects on military operations crisis planning.

The (final) August 1994 demonstration presented the full capabilities identified in the original statement of work for the spill response configuration model. These capabilities include the following:

- Highlighting the consequences of shortfalls in the spill response equipment inventory
- Modeling two major spill scenarios concurrently, using replanning techniques
- Generating multiple response plans for the same scenario
- Displaying response plans on a PERT chart and on a map-based display
- Presenting choices of spill response operations and equipment for spill scenarios
- Highlighting resource conflicts and response-plan inconsistencies
- Simulating the effectiveness of equipment by modeling its interaction with the transport of oil among sectors
- Summarizing and displaying in charts the environmental damages to shores and sea sectors due to the consequence of the oil spreading.

The underlying AI planning techniques provide a powerful representation and automated reasoning mechanisms that permit the user to explore a greater number of spill scenarios than is practical with manual methods. These mechanisms also keep track of all the decisions made and notify the user when they contradict or are inconsistent with each other. The use of a commercial spreadsheet tool for the evaluation module permits the user to access the evaluation model more easily. The spreadsheet tool also provides an excellent array of tabular displays and charts for representing environment damage and equipment shortfalls.

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1 INTRODUCTION

SRI International (SRI) is pleased to present this final report on the tasks undertaken during the Spill Response System Configuration Study project (contract number DTRS-57-89-D-0091, TTD RA 3072). Under this contract, SRI has developed a prototype decision support system that assists U.S. Coast Guard (USCG) planners in determining the appropriate types, quantities, and locations of oil spill response equipment and personnel to minimize the impact of spills that might occur at a number of locations. This tool also highlights any shortfalls in necessary resources and assists the user in exploring the specific spills or spill scenarios.

The project consisted of three phases.* This document reports on the completion of all three phases, which took place between February 1993 and July 1994. We pursued a rapid prototyping approach that allowed us to design and implement an initial prototype system during the first phase, and to successfully demonstrate four iterations of the initial prototype system to potential users from the USCG at the national and regional level. SRI received valuable feedback from potential users from the National Strike Force Coordination Center (NSFCC); from USCG Headquarters (G-MEP and G-MIM-2); from the marine safety offices (MSOs) of San Francisco, Los Angeles/ Long Beach, Boston, Providence, and New Orleans; from marine environmental pollution offices (MEPs) of Los Angeles and New Orleans; and from the USCG Research and Development Center (RDC) and the Volpe National Transportation Systems Center (VNTSC). This approach enabled us to obtain valuable feedback much sooner than originally planned in the original statement of work (SOW).

The prototype comprises advanced artificial intelligence (AI) planning technology, together with color map display capabilities, and modules for spill trajectory modeling and response plan evaluation implemented with the aid of commercial software. We were able to use as leverage advanced technology from Department of Defense (DoD)-funded projects on military operations crisis planning.† The prototype is derived from a military crisis action planning tool developed by SRI under funds from the Advanced Research Projects Agency (ARPA) and the U.S. Air Force's Rome Laboratory. SRI successfully demonstrated this tool, System for Operations Crisis Action Planning (SOCAP), at the Pentagon, on military scenarios derived from classes taught at various military staff colleges. In total, the prototype and its underlying AI planning technology represents over a decade of development.

As a result of our participation in the Response Strategy Working Group of the Area Committee for the development of the San Francisco Area Contingency Plan, we were able to base our San Francisco scenario on data and modeling derived from the 1993 area contingency plan. In addition, we met and interacted with many members of the local spill response community, comprising representatives of MSO San Francisco; the State of California Department of Fish and Game (DFG); the Office of State Parks and Rangers (OSPR); the Offices of Emergency Services (OESs) for Marin and Alameda Counties; the Marine Spill Response Corporation (MSRC); the Clean Bay Cooperative; and several spill response contractors.

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[*] Phases I and II were conducted concurrently, followed by Phase III. The successful completion of both Phase I and Phase II has been previously reported.

[†] We received a letter of support from our DoD client encouraging us to demonstrate the dual-use application of the advanced AI technology developed under their contracts. See Appendix A.

The prototype described in this report has been implemented sufficiently to demonstrate many of the important capabilities required for a fully operational decision support system for spill response configuration planning. We designed the architecture of the system to provide sufficient flexibility for integration with other existing software modules and tools, such as databases, spreadsheets, and display tools. The advanced technology within the current prototype system can be extended to deal with the tactical and operational spill response planning task.

Recently, SRI has been awarded two research grants under the USCG Oil Pollution Research Grants Program. The efforts identified within both grants will enhance the capabilities of the prototype system described in this report. In particular, one of the research grants proposes the transfer of additional AI technology developed under DoD and SRI funding to further improve the replanning and user interface capabilities. The other grant proposes further extensions to decision support technology, to determine which response plan achieves the most desirable results: specifically, the most effective cleanup with the fewest environmental impacts.

1.1 OBJECTIVE OF THE SYSTEM

The basic objective of the spill response configuration system (SRCS) was to assist USCG planners in answering the following questions:

1. If the USCG is "required" to purchase specific types of equipment, where should it be placed and in what quantities?
2. If the USCG has funds for equipment purchase, what are the equipment-type purchase and distribution priorities?
3. With the equipment now available, what shortfalls would there be in the levels of equipment in each region, should a major spill occur?
4. Are the present equipment sites in the correct locations based on analyses of risk for the entire country?
5. Are personnel requirements adequate to respond to a spill, based on the projected spill scenarios?

Above all, the decision support tool should assist the end user in determining the appropriate spill response equipment and personnel, based on specific spill scenarios, exploring the configuration and prepositioning of these resources at various locations, and exploring the trade-offs and costs associated with the alternative configurations.

1.2 TASK OVERVIEW

As previously noted, this project was divided into three phases, which took place between February 1993 and July 1994. Phase I involved the analysis of potential systems, tools, models, and techniques for use within the prototype configuration system; this phase was completed in October 1993. Phase II, completed in September 1993, comprised the analysis of an existing knowledge support system (KSS) for use within the same prototype system or as part of a decision support system for the larger task of planning oil spill responses. Phase III involved the further development of the prototype configuration system, and was completed in July 1994.

1.2.1 Task Overview (Phase I)

The completed tasks within Phase I, listed below, are now briefly discussed.

- Task 1: Literature Review
- Task 2: Familiarization with Models
- Tasks 3 and 4: Model Selection and Development
- Task 5: Model Description.

1.2.1.1 Literature Review (Task 1)

The objective of the literature review was to conduct a comprehensive literature search for potential systems, tools, and techniques that could be adopted for use within the prototype configuration tool. We made use of our in-house computerized literature search facilities to identify titles of reports, papers, and books; their authors and affiliations; information on funding; and abstracts and news articles. We found around 100 articles on decision support systems developed for emergency situations, including oil spills and other disasters. An additional search for decision support systems coupled with Geographic Information Systems (GISs) produced a very long list of articles, of which only about 15 looked promising. In addition to about 100 pages of news articles and abstracts on oil spill cleanup equipment, we found an 87-page online directory of cleanup equipment and services that was recently published in *The Oil Daily*. We also received a copy of the USCG's database of oil pollution R&D projects, which has a small section on decision support tools.We acquired or ordered those papers, reports, and books that seemed most promising, and reviewed these in greater depth for Task 2. This task was completed in accordance with the SOW by the beginning of March 1993. More details about this task are given in the Phase I final report, which was submitted to the USCG under separate cover.

1.2.1.2 Familiarization with Models (Task 2)

The objective of this task was to review in greater depth a subset of the various systems, tools, techniques, and models derived from the literature review, and to determine whether they would be appropriate for inclusion within the prototype configuration tool. We found that many of the techniques and models that have been applied to the oil spill response tasks and other related tasks were very limited and inflexible, particularly those that make use of operations research (OR) techniques and rule-based approaches. However, more advanced AI techniques have recently proven to be powerful and flexible, and ready to be considered for inclusion in an advanced prototype. Two previous projects were of particular interest: the work at MIT performed by Psaraftis, Tharakan, and Cedar,[*] and a subsequent doctoral thesis by Octavio[†] on decision support for oil spill response planning; and a project funded by Environment Canada that is investigating prespill preparation, oil spill containment, and cleanup. The MIT project makes great use of operations research techniques, whereas Environment Canada is exploring the use of rule-based methods. This literature review was completed, in accordance with the SOW, by the beginning of May 1993.

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[*] Psaraftis, H., G. Tharakan, and A. Cedar. 1986. "Optimal Response to Oil Spills: The Strategic Decision Case," in *Operations Research,* Vol. 34, No. 2 (March-April).

[†] Octavio, K. 1987. "Decision Support Framework for Oil Spill Response," Ph.D. thesis, Massachusetts Institute of Technology (June).

1.2.1.3 Model Selection and Development (Tasks 3 and 4)

The objectives of these tasks were to select appropriate systems, tools, techniques, and models for inclusion in the prototype configuration system, and to develop the system. In reviewing papers and books on decision support systems for oil spills and disaster management, we found a variety of software approaches to developing such systems.

Traditional software engineering approaches to decision support problems often involve the use of decision trees. Such representations are easy to encode and manageable for well-defined applications. However, applying this representation to very large problems becomes increasingly complex as the number of decision variables and their potential values increase.

Operations research techniques do provide methods for exploring tradeoffs between factors, but these methods are generally not incremental. Thus, when exploring tradeoffs one must run the computation from the beginning to explore the consequences of changes in parameter values. On the other hand, operations research algorithms are in general computationally very efficient, and have been extensively researched and applied to a variety of problems.

The use of rule-based (knowledge-based) representations for reasoning is becoming widespread, and many software developers have familiarity and experience with this type of representation. A rule-based structure, however, has serious limitations in the types of knowledge that it can represent, particularly uncertain information and complex planning knowledge. Rule-based representations also impose strong restrictions on the types of dependence that can be represented, thereby making knowledge engineering more difficult. In particular, rule-based representations have difficulty representing intercausal relationships, making it much harder for the engineer to capture the effect of such relationships.

Recently, AI planning and scheduling techniques have been shown to be versatile for exploring the tradeoffs between different deployment options in military operations planning. In view of our success in applying these techniques to crisis management problems, we proposed a design that involved the application of AI planning techniques to assist the user in generating responses to user-specified spill scenarios. We felt that these techniques best met the design objectives of flexibility, ease of use, extensibility, and interactiveness, and were better suited to the client's needs.

With agreement from USCG and VNTSC, the SOW (which called for the submission of a design document by the end of Phase I) was modified to allow us to pursue a rapid prototyping approach. This approach enabled us to demonstrate two initial prototypes to potential end users during Phase I and obtain valuable feedback much sooner than originally envisioned. This task was completed, in accordance with the revised SOW, by October 1993.

1.2.1.4 Model Description (Task 5)

The initial prototype system was fully described in the Phase I Final Report, in accordance with the revised SOW.

1.2.2 Task Overview (Phase II)

The completed tasks within Phase II were

- Task 6: KSS Familiarization
- Task 7: KSS Analysis
- Task 8: KSS Demonstration
- Task 9: Evaluate KSS as a Potential Decision Support Tool.

These tasks involved the analysis of a prototype software system, the Knowledge Support System, developed by Professor Kimbrough and his team from the University of Michigan. The main objectives were to determine the suitability of KSS or some of its modules for both the prototype configuration system and an eventual crisis response system. The results of this analysis were fully documented and provided to the USCG under separate cover. The analysis showed that KSS does not offer much capability to the prototype that cannot be more easily obtained from commercially available software. The choice of hardware and software for KSS, the Apple Macintosh computer* and the computer language, Prolog, were severe impediments to including KSS in the prototype design. Although KSS promised a flexible architecture, very few of its planned modules were implemented. However, the idea of employing spreadsheet tools for representing evaluation models was incorporated in the prototype design.

The Phase II tasks were undertaken by our subcontractor, Mei Technology Corporation (Mei) of Lexington, Massachusetts, and completed in accordance with the SOW.

1.2.3 Task Overview (Phase III)

The completed tasks within Phase III were

- Task 10: Development of a Prototype Configuration System
- Task 11: Demonstration of a Prototype Configuration System.

Since we adopted a rapid prototyping approach from the beginning of the project, a more pertinent description of these tasks would be the *further* development and demonstration of the prototype configuration system. During Phase III, there were two further demonstrations of the prototype, each significantly more successful than the two Phase I demonstrations. Major additions to the prototype in Phase III were (1) a commercially available spreadsheet tool, Informix's HyperScript Tools, for evaluating the spill response plan, graphically displaying the environmental damage in various charts, and highlighting the consequences of shortfalls in specific spill response equipments and other resources; and (2) the development of a more sophisticated and more accurate spill scenario model derived from the 1994 San Francisco Area Contingency Plan.

1.3 RESULTS AND DEMONSTRATIONS

We pursued a rapid prototyping approach to achieving the task objective. This approach involves developing an initial design of the prototype, producing a rapid implementation of the prototype, getting feedback as soon as possible from potential users on the capabilities and features of the prototype system and revising the prototype based on the feedback. We felt that such an

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*All product names mentioned in this document are the trademarks of their respective holders.

approach would encourage users to influence more directly the development of the prototype system. As a result, we proposed and gave four demonstrations of the prototype system. The first demonstration took place at the beginning of August 1993, at SRI-Menlo Park, (six months after the beginning of the contract). The second demonstration took place at the VNTSC in Boston, during October 1993 at the end of Phase I. The third demonstration took place at SRI-Menlo Park in March 1994, and the fourth and final demonstration took place at the USCG Headquarters building in Washington D.C. during August 1994.

The August 1993 demonstration presented a single scenario involving a major oil spill off the coast of San Francisco Bay. We demonstrated the feasibility of an AI planning approach that forms a large part of the proposed design, but also identified necessary software modules and databases within the system design. We also developed a sample knowledge base for spill response operation that were further refined in subsequent demonstrations. The initial prototype system incorporated modules that have been developed on previous SRI contracts, including AI planning and color map display technology developed under DoD funds. Although some of the software was not fully implemented, we were able to demonstrate the benefits of the features it would eventually provide.

The October 1993 demonstration emphasized configuration planning capability, rather than just response planning. We extended the existing knowledge base for spill response operations and explored interfaces to existing USCG databases, models, and other relevant software. We demonstrated how an end user of the prototype system would explore questions concerning the siting of spill response equipment, damage assessments, and spill trajectory. We also demonstrated the map display capabilities of the system for highlighting the current state of the spill or the spill response. This demonstration took place in conjunction with the presentation of the Phase I results. In attendance were representatives of the USCG RDC, VNTSC, and other USCG personnel from the National Strike Force Coordination Center and from the MSOs of Boston, Massachusetts, and Providence, Rhode Island.

The February 1994 demonstration introduced the evaluation module that was implemented with the spreadsheet component of Informix's HyperScript Tools. We showed how the evaluation module would highlight the environmental damage that might occur despite the execution of the spill response plan. We modified and enhanced the spill scenario, based on our participation in the Response Strategy Working Group of the San Francisco Area Committee meeting. We incorporated a spill response example derived from the 1994 San Francisco Area Contingency Plan. This example better reflects the strategies and equipments required to cope with a major spill incident. In attendance were USCG personnel from the NSFCC and from the MSOs of San Francisco, Los Angeles/Long Beach, New Orleans, and Providence, Rhode Island, and other personnel from RDC and VNTSC.

The (final) August 1994 demonstration presented the full capabilities identified in the original statement of work for the spill response configuration model. We demonstrated the following capabilities of the system:

- Highlighting the consequences of shortfalls in the spill response equipment inventory
- Modeling two major spill scenarios concurrently, using replanning techniques
- Generating multiple response plans for the same scenario

- Displaying response plans on a PERT chart and on a map-based display
- Presenting choices of spill response operations and equipment for spill scenarios
- Highlighting resource conflicts and response plan inconsistencies
- Simulating the effectiveness of equipment by modeling its interaction with the transport of oil among sectors
- Summarizing and displaying in charts environmental damages, caused by oil spreading, to shores and sea sectors.

The final prototype system permits the user to highlight potential shortfalls in an equipment inventory by exploring a variety of "what-if" spill scenarios, and displaying the consequences of these shortfalls in damage evaluation charts and on a map display. In attendance at the final demonstration were USCG personnel from the NSFCC and from the Commandant's Marine Environmental Pollution division (G-MEP) at the USCG Headquarters building in Washington, D.C., as well as personnel from RDC and VNTSC.

1.4 ORGANIZATION OF THIS REPORT

In the remaining sections of this final report, we describe the design and implementation of the SRCS (Section 2); discuss the final prototype demonstration in greater depth (Section 3); and summarize the main capabilities of SRCS, highlighting potential further development of SRCS.

Appendix A contains a letter of support from Rome Laboratory encouraging us to pursue dual-use applications of the underlying AI planning technology developed under their contract.

2 SPILL RESPONSE CONFIGURATION SYSTEM

This section discusses the overall design and implementation of the SRCS. We describe the design objectives, and the architecture of SRCS, emphasizing the benefits derived from the underlying AI planning technology, the commercial spreadsheet tool, and the color map display. We also briefly discuss the integration of other modules and databases, such as an inventory database.

2.1 DESIGN OBJECTIVE

The main objectives of the spill response configuration system are to assist the USCG planner in determining the appropriate spill response equipment and personnel from specific spill scenarios, exploring the configuration and prepositioning of these resources at various locations, and exploring the trade-offs and costs associated with the configuration alternatives. To achieve these objectives, the configuration system must be

- Flexible
- Easy to use
- Extensible
- Interactive.

The system should be flexible enough to analyze the dynamics of two major oil spills at the same time, whether in proximity to each other or widely separated. It should be able to present the evaluation of its decisions in terms of quantitative measures of increased response effectiveness. It should also keep track of response equipment and resources, project the consequences of resource limitations and conflicts, and provide extensive "what-if" capabilities.

The system should be easy to use, since the model will be operated by personnel having a variety of backgrounds (but few with computer science training), potentially at many sites around the country.

Since the configuration system will never be complete enough to fully answer the questions above for all situations, it should be extensible. For example, new equipment capabilities may radically improve the effectiveness of certain response methods under very adverse weather conditions. Thus, it is important that the consequences of the introduction of this new equipment be easily represented and incorporated into the system.

Finally, the system should be interactive. We do not believe that the previous characteristics of flexibility, ease of use, and extensibility can be achieved without a highly interactive system. The system is required to assist in the exploration of trade-offs among different factors by presenting alternative choices interactively for equipment deployment, use, and mix, and reconnaissance during the spill response.

2.2 DESIGN ARCHITECTURE

The overall design, represented by the dataflow diagram shown in Figure 1, comprises four main modules (shown as oval nodes):

- Equipment and Logistics Planner
- Trajectory and Oil Disposition Model
- Evaluation Module
- Color Map Display.

To explore a configuration planning problem, the end user must first provide relevant information about the spill scenarios to be examined and the equipment available for responding to the spill. This information is denoted in Figure 1 by the data-store nodes SCENARIOS and RESOURCES. This information, together with FACTS, provides the main inputs for the equipment and logistics planner. The user can modify the scenario, the locations of spill response resources, or the choices of response operations within the RESPONSE PLAN that is generated. The response plan provides an input for updating the trajectory and oil disposition model, for evaluating the environmental and cost impacts, and for presenting the plan to the user on a map display.

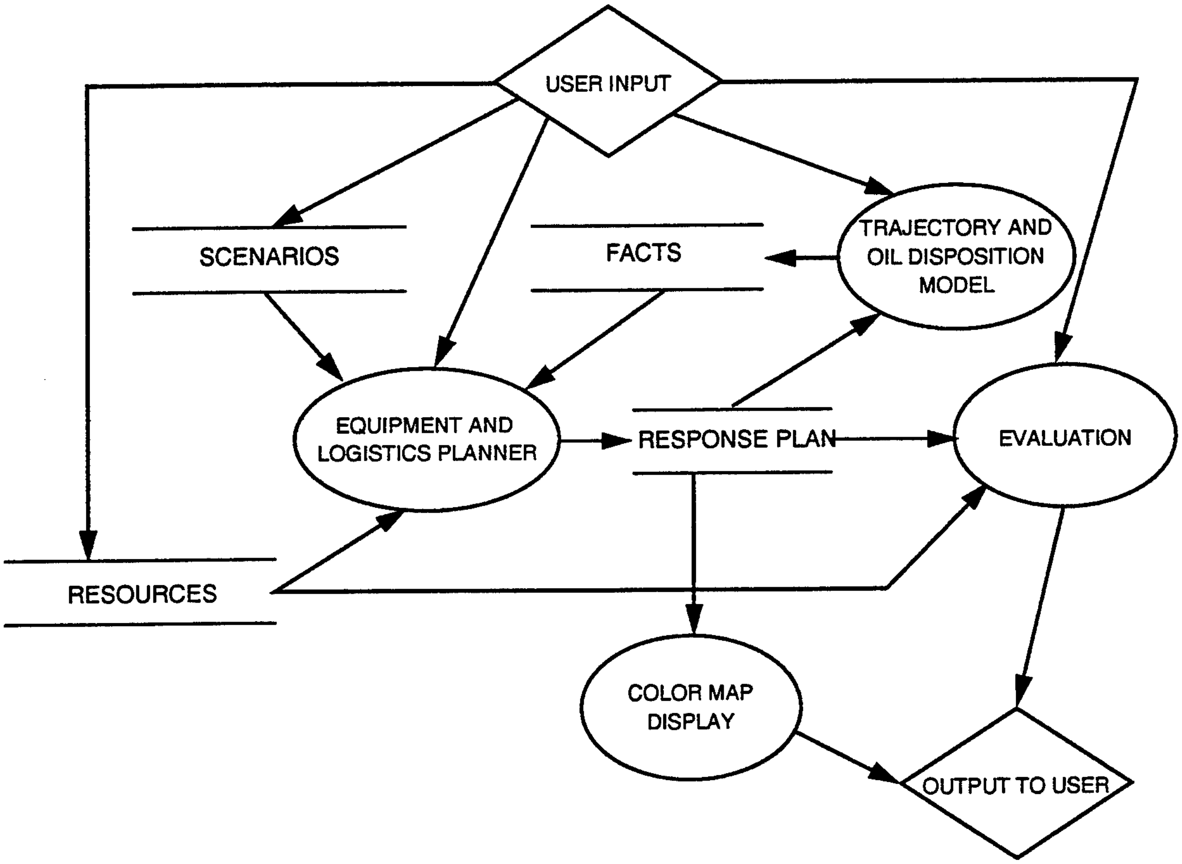

Figure 1. Dataflow Diagram

2.2.1 Equipment and Logistics Planner

The main capabilities of the equipment and logistics planner are provided by state-of-the-art advanced AI planning technology, embodied within the System for Interactive Planning and Execution (SIPE-2*). This technology meets the four main design criteria of flexibility, ease of use, extensibility, and interactiveness. SIPE-2 was developed at SRI during the early 1980s and has been demonstrated on a variety of planning problems. During 1992, it was demonstrated at the U.S. Central Command and at the Pentagon as a potential military operations crisis action planning tool.

The underlying AI planning technology provides good plan representation capabilities, as well as mechanisms for interactive and automated reasoning. SIPE-2 provides traditional PERT and Gantt-chart representations of the plans it produces. PERT charts, or partially ordered graphs shown in Figure 2 provide a standard description of the plan as a set of actions ordered by links showing which action should come before another. Most systems that assist in project planning represent plans as PERT charts. However, this form of representation is insufficient to capture or represent the rationale between the choices for certain actions in a plan. SIPE-2 is able to record the intentions and justification for specific actions, as well as their effects, and utilizes this knowledge to build a more complex dependency network that captures plan rationale. This knowledge is an essential component of the planning system because it helps to model the process of how plans are developed within specific domains such as spill response.†

SIPE-2 is also able to represent spill response procedures and operations at multiple levels of detail. A high-level representation may be useful for identifying that no major parts of the overall response plan are missing, whereas lower-level plans show exactly which resources are being utilized within the plan. The number of planning levels can be increased or decreased as needed. Figure 2 depicts the development of the plan from level 1 to level N. At each level different pieces of information are brought to bear about the current situation, the applicability of specific response operations, or their duration and effectiveness, as shown by the layered operators in Figure 2. Thus, SIPE-2 manages the integration of the relevant information hierarchically without confusion.

During the planning process, SIPE-2 keeps track of a great deal of information, and presents choices to the user concerning the selection of procedures or operations, resources, locations, or times. Where there is a choice for any of these, SIPE-2 will present a list to the user. The list is not prioritized, but all members of the list have been checked for consistency. For instance, in presenting choices of operations, SIPE-2 will have already checked that they achieve the necessary effects, and meet the applicability conditions for the current problem. In choosing appropriate response equipment, SIPE-2 checks whether the equipment can withstand the operating environment. In this way, SIPE-2 guides the selection of planning choices, but requires the user to make the final choice.‡

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*SIPE-2 is proprietary software, developed and licensed by SRI International.

†As a result, one can classify SIPE-2 as an Intelligent PERT-chart builder. Although it does provide many more capabilities than assisting with the process of initially generating the PERT chart.

‡As more knowledge is captured within the planning system, it is possible for SIPE-2 to make more of the decisions, without the need for the user to make the final choice. In this way, one can automate more of the mundane choices, leaving the more complex choices to the user.

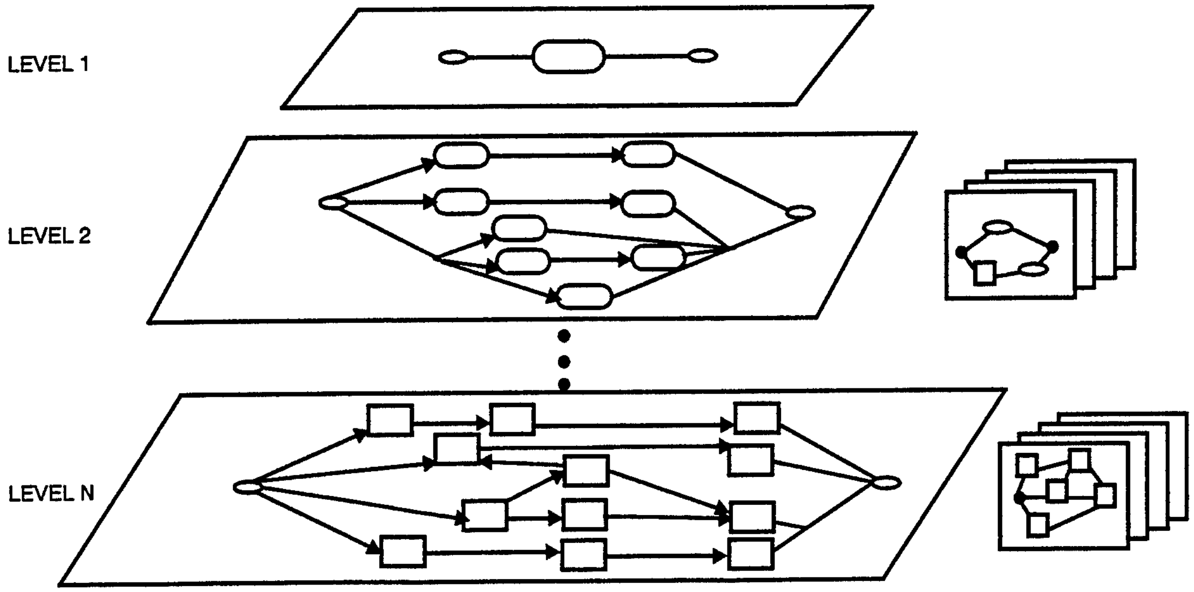

Figure 2. Hierarchical Planning

At the end of each planning level, SIPE-2 checks that the plan is consistent. This involves ensuring that no actions undo the effects of others, and checking that there are no temporal or resource conflicts among concurrent branches of the plan. Examples of these conflicts are the placing of a boom across a harbor to prevent access to the harbor for offloading skimmed oil, the arrival of a specific piece of response equipment too late for it to be effective, or plans for an item of equipment to be used at the same time in different locations. SIPE-2 is able to identify these situations and suggest remedies either by choosing different resources, locations, and times, or by ordering the actions such that the conflict is avoided.

As the situation changes, SIPE-2 checks to see that operations within the plan are still applicable and consistent with each other. If not, then SIPE-2 identifies those parts of the plans that are affected by the changes and presents choices to the user to remedy the situation change. For instance, the severity of the weather conditions might affect the effectiveness of specific booms and, as a result, additional booms may be required. Weather conditions might also affect the spill trajectory, resulting in the possibility of using dispersants off-shore to break up the spill.

The replanning capability within SIPE-2 permits the user to explore how changes in the situations affect existing planned choices. It also allows the user to explore the what-if questions identified at the beginning of this report, which are essential for configuration planning.

The underlying knowledge and database that SIPE-2 utilizes during the planning process comprises information about the following:

- Spill response resources, such as their location, type, quantity, and other more detailed information about their operating conditions and capabilities
- Spill response operations, such as the use of booms, skimmers and vacuum trucks

- Geographic information about the surrounding shores and sea-sectors, such as the location of sensitive areas, equipment storage sites and sea and ground transports, but also water temperature, wind and tidal data
- Spill incident data, such as discharge rates and quantities, location and time of the initial spill.

Details about the knowledge and databases utilized during the San Francisco spill scenario demonstrations were provided to the USCG under separate cover.

The capabilities within SIPE-2 are continually being expanded under DoD contracts, incorporating more sophisticated technology for distributed reasoning, planning in uncertain environments, and machine learning. Above all, the existing AI planning technology has been shown to be feasible and practical in related crisis response domains, such as military operations planning. In the current spill response domain, we have demonstrated the suitability and extensibility of this technology as a decision support tool for spill response configuration planning.

SIPE-2 is implemented in LUCID Common Lisp, running under the Sun Microsystems, Inc. (Sun) operating system, SunOS version 4.1.3. SIPE-2 also utilizes the LUCID Common Lisp Interface Manager, CLIM version 1.0.

2.2.2 Trajectory and Oil Disposition Model

Within the planning system the oil spill trajectory module offers a physical simulation of the spread of oil with which to plan against and test various configurations. The nature of the planning problem is a race against time, so that cleanup actions, to be effective, must be completed within the time predicted for the oil's landfall. This simulation is done by the trajectory model.

The trajectory model begins with the description of an incident that releases oil upon the water, and the wind, tide, and weather conditions during which the oil spreads. From this it generates the possible extent of the spill for each planning stage, and ultimate disposition of the oil.

The requirements of the oil spill trajectory module differ from that of a model used predictively for emergency response. To plan effectively, the oil trajectory must take into account the uncertainty that oil spill cleanup response forces face during an actual spill. This means that at each stage the planner will not know exactly where the oil will go at subsequent stages. It is more of a challenge to plan when the sea and weather conditions are not entirely known and the location of the oil is only known to within an envelope of uncertainty. To simulate this, at each stage the module describes future stages' transport by the envelope in which the oil will be likely to have spread.

In the trajectory model used for configuration, the demand for detailed and numerically intensive predictions are not as great, as compared to the more complex trajectory models needed for emergency response. The configurations that the planner generates by use of the oil spill response system are not sensitive to fine changes in predicted location of the oil, as much as they are to the forecasted level of uncertainty in the oil location.

2.2.2.1 Significant Processes

The physical processes affecting oil that the module considers are waterborne transport, spreading of the oil on the water, and transformation of the oil to determine its "fates." These processes are modeled only to the level of detail necessary to determine an effective response by the planning module of the system.

Once oil is released on the water, it is transported by currents and the wind. Oil on the surface of the water moves with the current; thus, a prediction of the currents where there is oil present is needed to predict the oil transport. In addition, the wind relative to the current generates a shear force on the oil so that a fraction of the wind velocity is imparted to the oil slick, and moves it across the surface of the water. This fraction has been determined experimentally to be typically about 3 percent.

In addition to the gross movement (called *advection*) of the oil in the direction determined by the current and wind, the oil spreads out to form a slick. Within the time scale of response, the speed of spreading is less than the speed of transport; thus, the oil typically forms a widening plume originating at the point of the spill. Spreading processes are less well understood than advection processes. Processes that have been used to explain spreading are flow of the oil due to gravity (or, more accurately, buoyancy), inertia, viscosity and surface tension. Predictions on this basis correspond roughly to observed spreading rates, and there is current research to understand spreading processes in actual sea conditions by modeling the effect of wind and waves on oil surface spreading.

Over the course of days, oil on the water's surface ages and thickens and often forms a solid "mouse." Solidified oil ceases to flow, impeding spreading. The processes that affect solidification are evaporation of lighter oil fractions and emulsification of water by the oil. Both of these processes depend strongly upon the chemical composition of the oil and the ambient temperature. Crude oils vary widely in the percent that will evaporate, but it is not rare that up to half of the oil spilled will eventually evaporate and add to atmospheric hydrocarbons. Further, the rate of mouse formation depends upon the amount of natural emulsificants within the oil's composition.

Depending upon conditions, evidence of oil will disappear from the water's surface within days to weeks. Aged oil may eventually sink, or be dispersed in the "water column" where it is subject to further chemical and biological degradation. In contrast, oil that is washed up on shorelines tends to persist, often for years. This is a major concern compared to oil whose final disposition is at sea, since the social and ecological effects of oiled shoreline are severe, and the remediation of the shoreline is expensive. Further, if left alone, a fouled shoreline will bleed oil back out to sea, to cause further fouling.

2.2.2.2 Relevant Variables

The requirements of the oil spill trajectory module are further determined by identifying which output variables describe effects relevant to planning oil spill cleanup. The trajectory model considers the processes just described at a level of detail sufficient for accurate planning. Any variation of the output variables not sufficient to change plans can be safely left out of the forecasting model. This line of thought simplifies the model significantly.

The significant output variables to describe the oil transport are

1. The location of the oil, as shown by which geographic sectors contain oil
2. The quantity of oil, both fresh and aged, in each sector
3. The extent (enclosing diameter) of the slick within a sector
4. The thickness of the oil slick, by sector; the efficiency of oil skimming depends strongly on the thickness of oil that the skimmer encounters.

The significant effects of the oil determined by the trajectory model are the oil landfall locations, times, and amounts that determine the amount and locations of oil washed up on shore. In general the effects of the oil are determined by a combination of the significant transport variables and the effectiveness of the planned cleanup operations.

The oil transport simulation variables also include an envelope for the extent of the oil spill. The envelope describes the range in which the oil will spread with some probability. Just as the oil spill location progresses over time, the envelope shape evolves, depending upon the known location of the oil at the last surveillance time. The envelope uncertainty in oil location is important because if deployment takes time and equipment must be predeployed, preplanning is necessary in anticipation of the oil's arrival at sensitive reaches of the shore. The range of shoreline that must be protected is determined by where the projected envelope overlaps the coast.

2.2.2.3 The Model and Its Interaction with the Planner

The equipment and logistics planner and the trajectory model interact strongly between all stages in the scenario. Since planning is done in stages, the trajectory module makes an incremental prediction for each stage in the process. Each prediction reports to the planning module the distance the oil has traveled and the degree to which it has spread. From the predictions and the location and effectiveness of the equipment already deployed, the evaluation model can determine the decrease in oil on the water due to removal and natural processes of evaporation and deposition on shorelines. The trajectory model predicts the fraction of oil within each sector transported in each period for each neighboring sector. These fractions are available to the evaluation module, so that the effects of the natural and planned actions on the disposition of oil in subsequent periods can be determined. These predictions, in turn, become the basis for the next planning stage. In this way the degree of spreading and the distance the oil has traveled affect the location and effectiveness of the equipment.

The trajectory model is implemented in LUCID Common Lisp.

2.2.3 Evaluation Module

The evaluation of the plan and of the corresponding situation facts comprises the following three steps, as shown in Figure 3.

1. Damage evaluation combines the predictions of the trajectory model with the plan to determine the final disposition of the oil as a result of control actions.

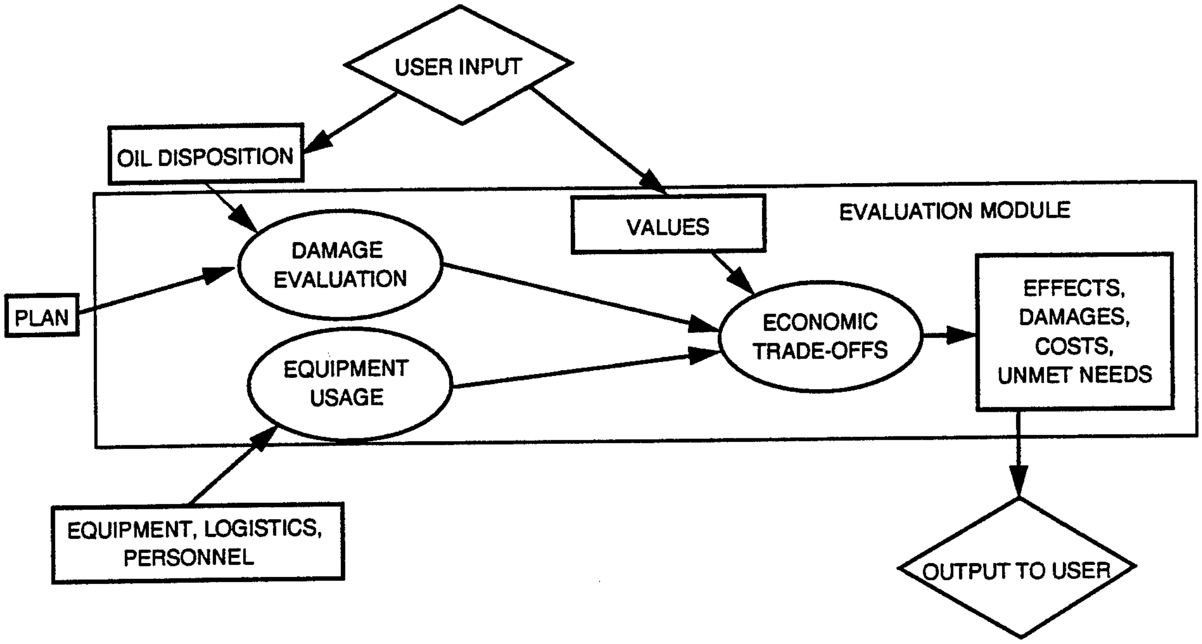

Figure 3. Evaluation Module

2. Equipment usage enables the module to compare the deployment generated in the plan with the quantities of equipment originally at each site. By comparing scenarios with different amounts of equipment, the evaluation module can calculate the effects of the equipment that was not employed or that could have been deployed had it been available.
3. Economic trade-offs complete the evaluation by comparing damage, cost, and unmet needs. By comparing equipment usage among scenarios, the module can relate the effect of different equipment availability to the difference in damage. The details and assumptions that are incorporated in this module are entirely available for modification and extension by USCG personnel as the demands placed upon the system evolve.

The table generated in the evaluation module on the completion of a plan addresses one scenario. Comparisons of plan scenarios are necessary to determine which response strategy is best, and, once the strategy is chosen, to choose the equipment configuration that is most appropriate for a range of scenarios that represent the risk of major spills. Only by comparing the damages for multiple scenarios can unmet needs and trade-offs be shown.

Evaluation requires the combination of all the data and variables that determine the consequences of an oil-spill cleanup operation, from each module in the system. Relevant aspects of the scenario are the facts that describe the incident, and the ambient weather and sea conditions. The planner must provide the effects of actions to deploy and employ equipment and other resources as functions of time and location. For purposes of comparison, the original amounts of resources at the sites where they are stored must also be known. The necessary trajectory model outputs define the amount of oil transported between sectors by the changing wind and tides. The wind and tides are also important, since they affect the effectiveness of cleanup operations.

Evaluation also depends upon functions that describe planned actions, physical processes, and valuation of effects. For planned actions, these functions model the effectiveness of equipment under the conditions of use. Oil on the sea continues to spread during attempts to clean it up, so that effectiveness measures must take into account the size of the area that operations must cover. The thickness of the oil layer, the degree of its transformation, and the speed of its movement must be modeled. Once there is a complete model of the oil's fate, the model must be summarized by evaluating the damages the oil causes, so that a value can be ascribed to the cleanup operations.

2.2.3.1 Display Outputs

The output of the evaluation module is displayed to the user as graphs and tables showing the transport of oil among sectors after operations to prevent oil from reaching the shore. The amount of oil remaining in each sector, in each time period, is presented in a chart that summarizes the combined results of the transport and planning model. Another chart shows the disposition of oil in each time period, in terms of the amounts recovered, physically and chemically transformed, remaining on the water, and deposited on shore. These outputs clarify the effects of changes to a plan, and can used be used to compare the relative success of two scenarios.

The hyperscript features of the modeling tool make it possible to overlay controls on the user's screen, to automate navigation among multiple display by mouse clicks on the controls. These controls can also be served to load new scenario plans and to run comparisons between them.

2.2.3.2 Layout of the Evaluation Model

In the evaluation model, the primary step that evaluates damage is laid out in a table with time periods represented in the columns, and sectors represented in the rows. This table combines the outputs of the trajectory model and the planning operations to determine the disposition of the oil. For each time period and sector unit there is an accounting of the oil. Starting with the amount of oil entering a sector at the beginning of the period, and the amount previously contained, the accounting determines (1) the amount of oil contained and removed by equipment in the sector during the period, (2) the amount transformed by natural processes, and (3) the amount that escapes to adjacent sectors—adjacent sea or land sectors—in the next period. The movement of oil among sectors from period to period derived from the results of the trajectory model run. By the final period, substantially all the oil will have left the water's surface and come to rest, so its final disposition will be known. On this table, any of the quantities may be changed—for instance, the amount of equipment in a sector in a period, or the amount of oil contained in a sector, to see the effects of transformation and transport of the oil in later periods.

2.2.3.3 Implementation

The evaluation module is implemented in a commercial modeling tool, as a spreadsheet that is generated by the planner. Upon completion of a plan, the user can execute a command that generates an evaluation as a spreadsheet macro file. When this file is loaded into the spreadsheet modeling software, the software constructs an evaluation model specific to the scenario and plan.

The evaluation model constructed from the plan explicitly expresses all the assumptions necessary for an evaluation. All plan operations are shown in the tables that make up the module. All constants, expressions, and functions that describe oil transport and removal are also shown in these tables, and are modifiable within the evaluation modeling tool, so that the user can change any part of the evaluation model and any of its assumptions without needing to modify or rerun any of the modules upon which it depends. In this way the evaluation module can be used to perform what-if analysis on the results of a scenario and on the plan generated in response to the scenario. Furthermore, the versatility of the modeling tool, and the explicit display of the entire evaluation model and its assumptions, enable the user to extend and customize the model to answer new concerns that may be addressed to it.

2.2.4 Color Map Display

The color map display module, SITMAP (Situation Map), was originally developed under contract for U.S. Army Europe during the 1980s and has been demonstrated and used for military exercises in Germany, as well as for part of the SOCAP system mentioned earlier. SITMAP provides many of the capabilities required of a graphic information system, but also forms part of a larger distributed tactical database that is very useful where situation information is rapidly changing.

SITMAP takes user-scanned maps of the area of interest and permits a wide variety of user-generated overlays and icons to be placed over the digitized color maps. It is also possible to bring up information in pop-up windows activated by mouse-clicking on icons on the maps and overlays. One can zoom in and out of the view of the map. A panbox shows the amount of the map currently displayed on the screen. The total amount of magnification is 16x. Several maps may be stored and accessed as needed. The only real limitation on the number of maps is the amount of disk space on the computer. It is also possible to represent the situation on the map at various times or dates by clicking on the timeline bar at the base of the map display window.*

SITMAP provides most of the essential features of a GIS. One can generate a variety of overlays to show marine preservation areas, the trajectory of the spill, the locations of current response equipment—its home base or current position during the response operation, the transportation routes for the movement of the response equipment to the area of operations, and the amount and location of the damage that ensued as a result of the oil spill. For each of the icons that depict the above information on the map, it is possible to display more detailed textual information in pop-up windows. In this way, the color map display module provides the necessary capabilities to display information from the equipment and logistics planner, the trajectory and oil spill disposition model, and the evaluation module.

2.2.5 Inventory Database

We explored the integration of the Response Resource Inventory (RRI) system into the prototype configuration system. The RRI is currently being developed by the RDC, and will be maintained by the NSFCC. However, as explained here, we were not able to incorporate the current version of the RRI into our prototype system.

The RRI database has been compiled by gathering information from all USCG contractors. A diskette was sent to each of the contractors who then added response equipment information to the diskette and return it to NSFCC. The current plan is for the database to be updated in a similar manner by diskette on an annual basis. Access to the database by interested personnel is made via a computer bulletin board administered by NSFCC.

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*This time-phased map display facility was not useful at the October demonstration, but was previously demonstrated for the SOCAP project.

The main disadvantages of the RRI system are that there is no direct access to the database, and the access via bulletin board is not very interactive, making it difficult and slow to perform the necessary configuration planning operations. There is also a lot of manual work required to maintain the database. In its current form, the RRI could not be used in a tactical manner to record the changing locations of the response equipment. As a result of these limitations, we did not incorporate the RRI into our system. Instead, we relied entirely upon the information derived from our participation in the Response Strategy Working Group of the San Francisco Area Committee. A report of the RRI detailed analysis was provided to the USCG under separate cover.

3 FINAL PROTOTYPE DEMONSTRATION

Prototype demonstrations are the most straightforward way to present the results of this project. The demonstrations we have presented are benchmarks from which to evaluate progress and an excellent source of useful feedback from potential users. These demonstrations show how the decision support tool assists the user (a USCG planner) to identify the appropriate spill response equipment and resources to deal with specific spills. In particular, the decision support tool assists the user to explore decisions as to the choice and prepositioning of equipment so as to be readily available for use in combating spills. The decision support tool also highlights equipment shortfalls by showing subsequent damage to the environment.

Two oil-spill scenarios involving the San Francisco Bay Area were developed to test the capabilities of the prototype configuration system. The first scenario was shown during the August and October 1993 demonstrations. The second scenario was demonstrated in February and August 1994. In addition, both scenarios were used to demonstrate the ability to model two spills concurrently. In this report we will discuss the final demonstration given at USCG Headquarters in August 1994, highlighting the main features of the prototype, and, in particular, user interactions with the three of four main modules: the equipment and logistics planner, the color map display, and the evaluation module.*

3.1 SAN FRANCISCO SCENARIO DESCRIPTION

The San Francisco spill scenario presented in the final demonstration involves the collision of the oil tanker *Catastrophe* with Harding Rock in the middle of the San Francisco Bay, at 0600 hours on the morning of 3 February 1992. The oil tanker is carrying a cargo of 12,000 barrels of Alaska crude oil when the collision occurs. The crude oil is spilling from the tanker at a rate of 2,000 barrels per hour. Many sensitive marine preservation areas within the bay must be protected, as well as important commercial areas for shipping and recreation. The weather conditions are not severe at the time of the spill, but weather predictions show that the weather will deteriorate within the next 8 hours, so time is of the essence. The overall goal is to make use of resources within the San Francisco Bay region to combat the spill. However, because of the severity of the spill, resources will be required from neighboring regions to the north and south, and may be required from national agencies. Figures 4 and 5 show the trajectory of the spill after 5 and 15 hours.

3.2 SRCS DEMONSTRATION

The spill trajectory displays depicted in Figures 4 and 5 highlight the areas where the spill is predicted to spread and the parts of the shoreline that will be affected if no attempt is made to contain it. This information is encoded in the equipment and logistics planner, such that it can define specific objectives for the response plan. In these figures, the spill trajectory is displayed as an overlay on the color map display. In particular, the grid represents the area covered by the

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*The remaining module, the trajectory and oil disposition module, has been partially implemented. The user interface for this module has not been implemented.

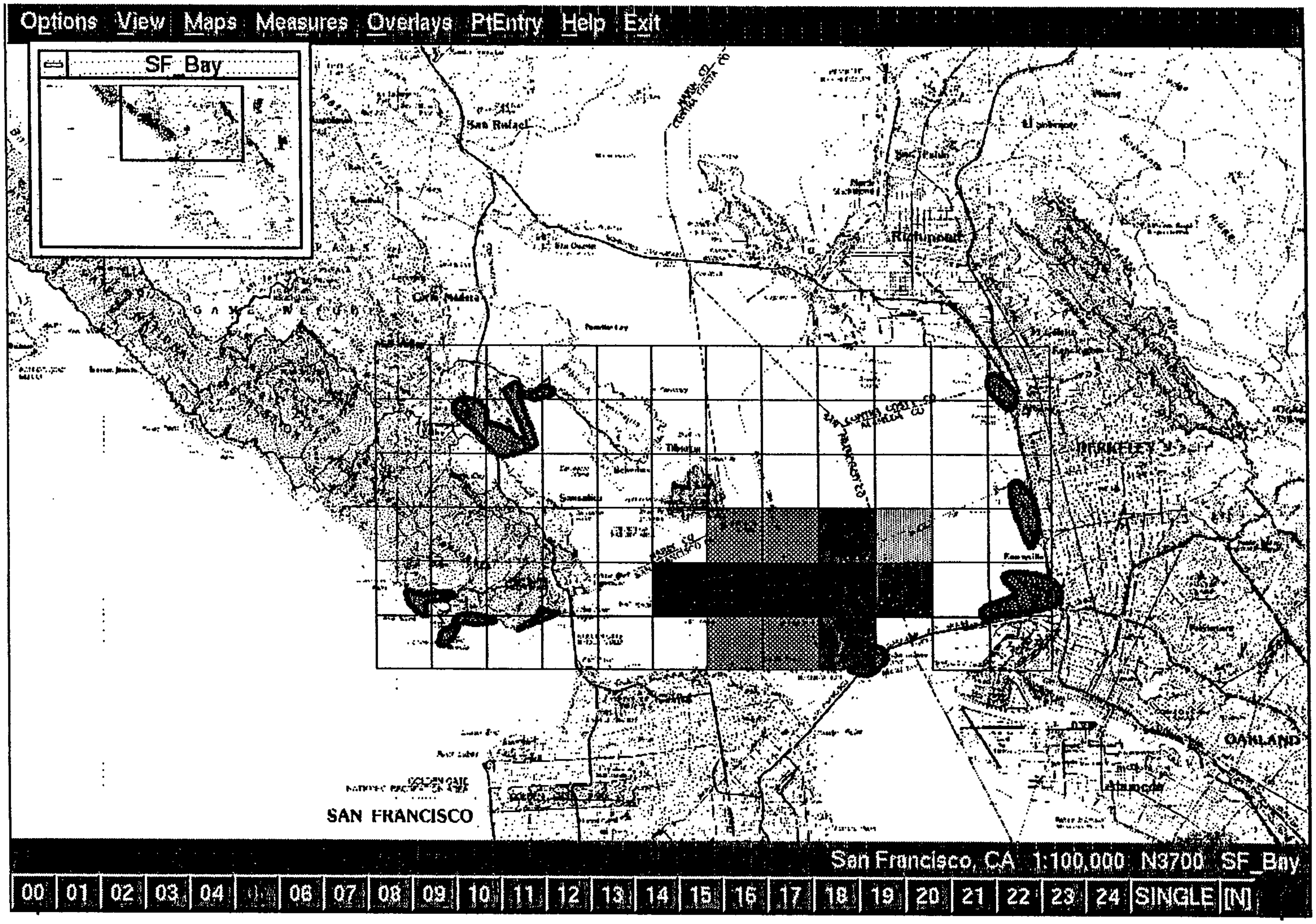

Figure 4. Spill Trajectory after 5 Hours

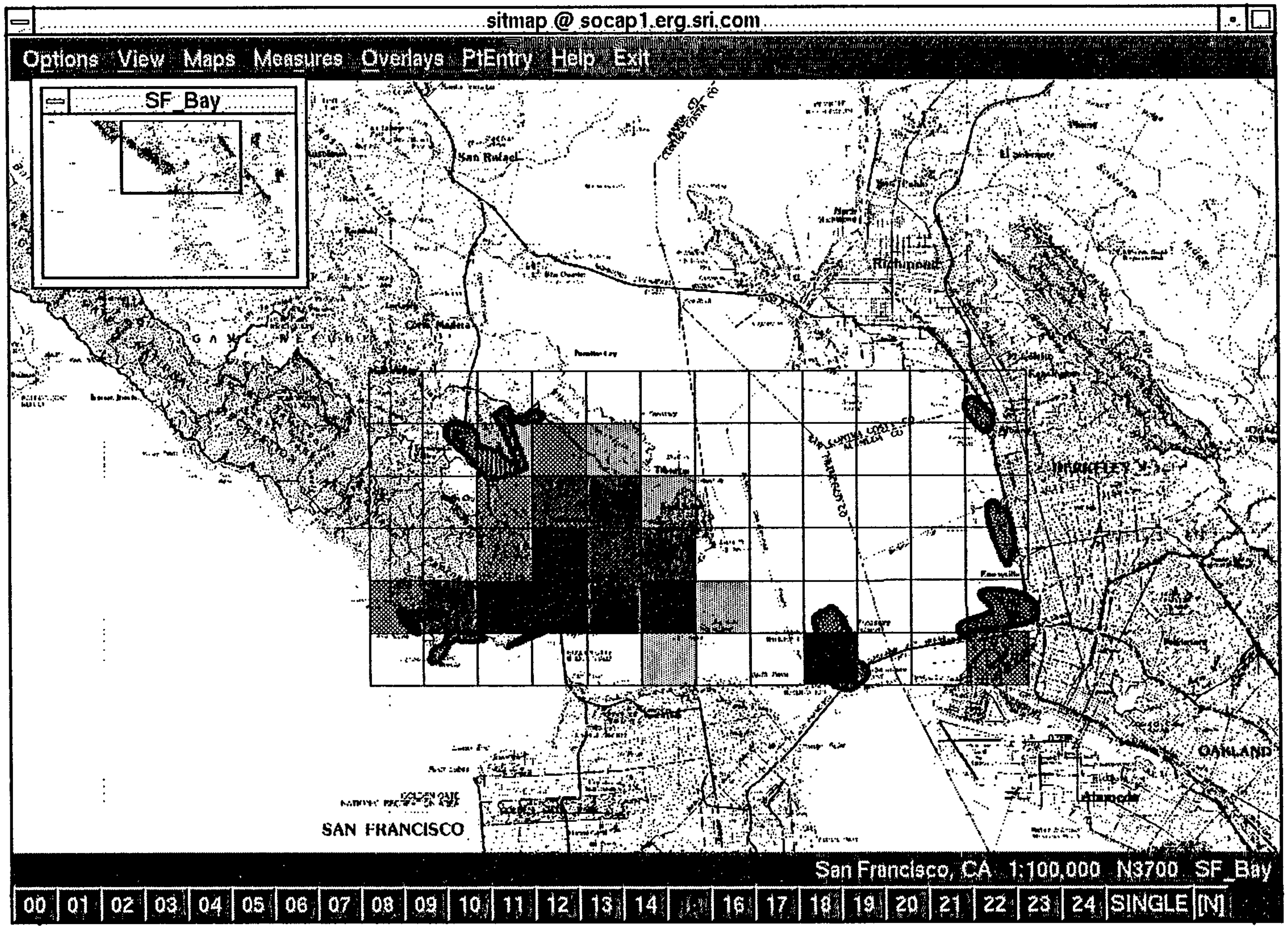

Figure 5. Spill Trajectory after 15 Hours

trajectory model, with the gray squares denoting sectors covered by oil. The darker the square, the greater the amount of oil within that sector. The other irregular polygons within the grid represent sensitive areas.

Figure 4 shows that one of the sensitive areas is severely impacted 5 hours after the initial spill, as the tide pushes the oil further into the bay. Figure 5 shows several more sensitive areas impacted 15 hours after the initial spill as the tide pulls the oil out of the bay through the Golden Gate. Users can call up a display of the spill trajectory a given number of hours after the spill, by selecting the number from the timeline below the map.

The information about the scenario, including the spill trajectory, is entered into the equipment and logistic planner as follows. First, the planning process is invoked. On ascertaining that the incident is a major spill, the planning module selects a major spill operation. Figure 6 shows a set of five objectives as nodes arranged in parallel clusters; these nodes constitute a major spill response. One objective is to stabilize the discharge of oil from the tanker; another is to remove the oil from the water. The other three objectives are to protect three sensitive parts of the shoreline.* The highlighted node represents the objective of stabilizing the discharge from the oil tanker. In the top right-hand corner of the screen is a list of four response operations. The system is requesting the user to choose one of these operations, each of which is deemed suitable for satisfying the objective. Before making a choice, the user may view details of each of these operations.

Figure 7 shows details about an operation that might satisfy one objective: specifically, the choice of booms that are available to protect the sensitive shoreline area, Berkeley Eelgrass. Detailed information about one of the booms is displayed in an information window. Note that none of the available booms is long enough to meet the requirement of 6,000 feet of boom; and that the planning module will not remove the objective until it is fully satisfied. The planning module continues to present choices of response operations and equipment until all the necessary choices have been made. In addition, for each item of response equipment, deployment plans are determined such that travel times can be computed.

At each level of the plan, the equipment and logistics planner checks for logical consistency and for resource conflicts. Whenever an inconsistency or conflict is encountered, it is presented to the user, along with a set of suggestions for dealing with it, as shown in Figures 8 and 9. In this case, the planner has found a resource conflict. The birds-eye view in Figure 8 shows two parallel branches of the plan in which nodes are highlighted. These nodes employ the same resource, `Vac-truck1-richmond-1000`. In the top right-hand corner is a list of suggestions for remedying this resource conflict: by ordering these branches of the plan with respect to each other, by delaying the decision until later on in the planning process, by permitting the same resource to be used in two different parts of the plan, or by changing one of the resources. Figure 9 shows the last of these alternatives, as presented in the `Resource Conflict Analysis` window. The user may select one of the other available resources to replace the resource in one branch of the plan.

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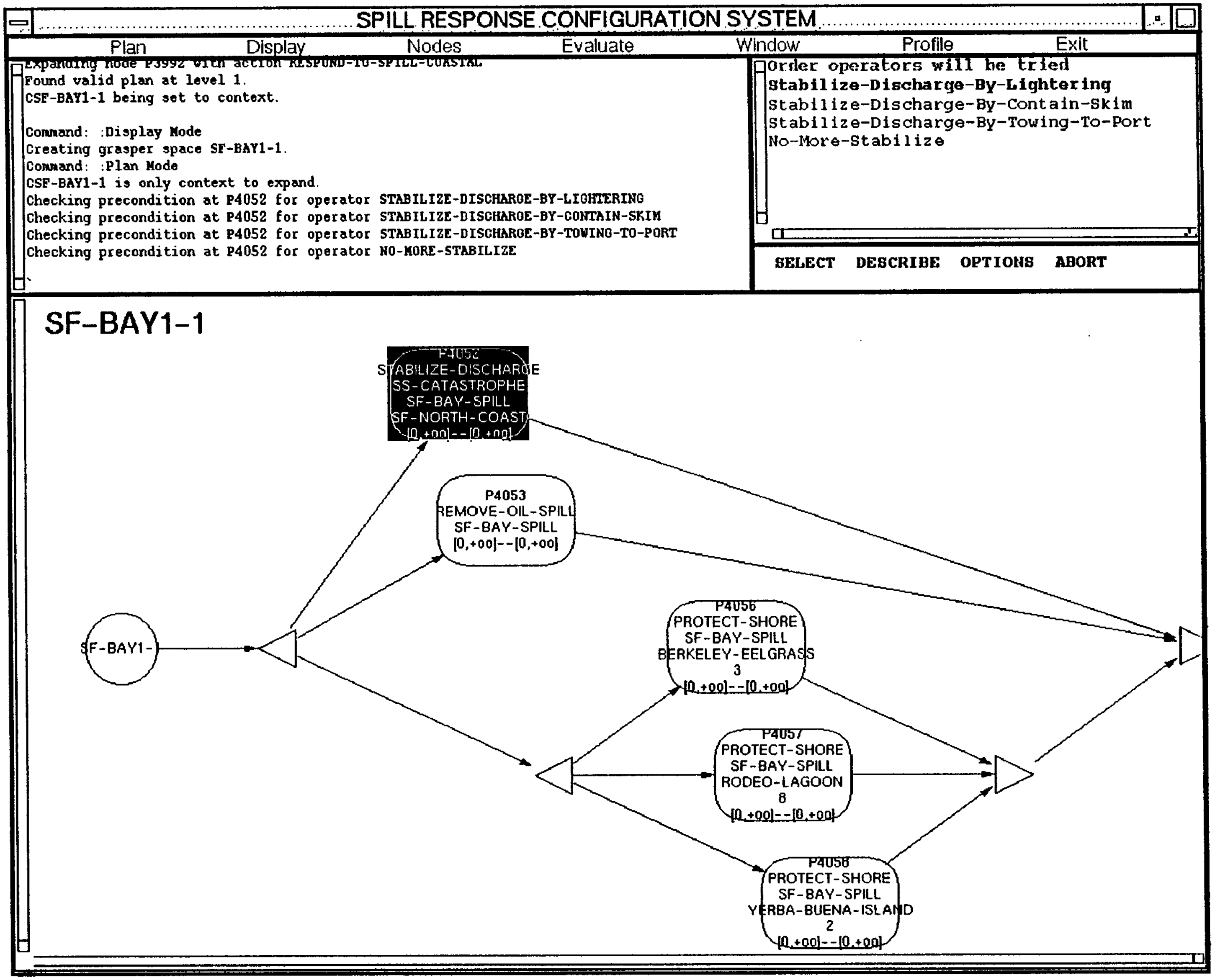
*These three objectives represent sensitive shoreline areas that need to be protected. The number of sensitive areas impacted was reduced such that the full prototype demonstration would last no more than one hour.

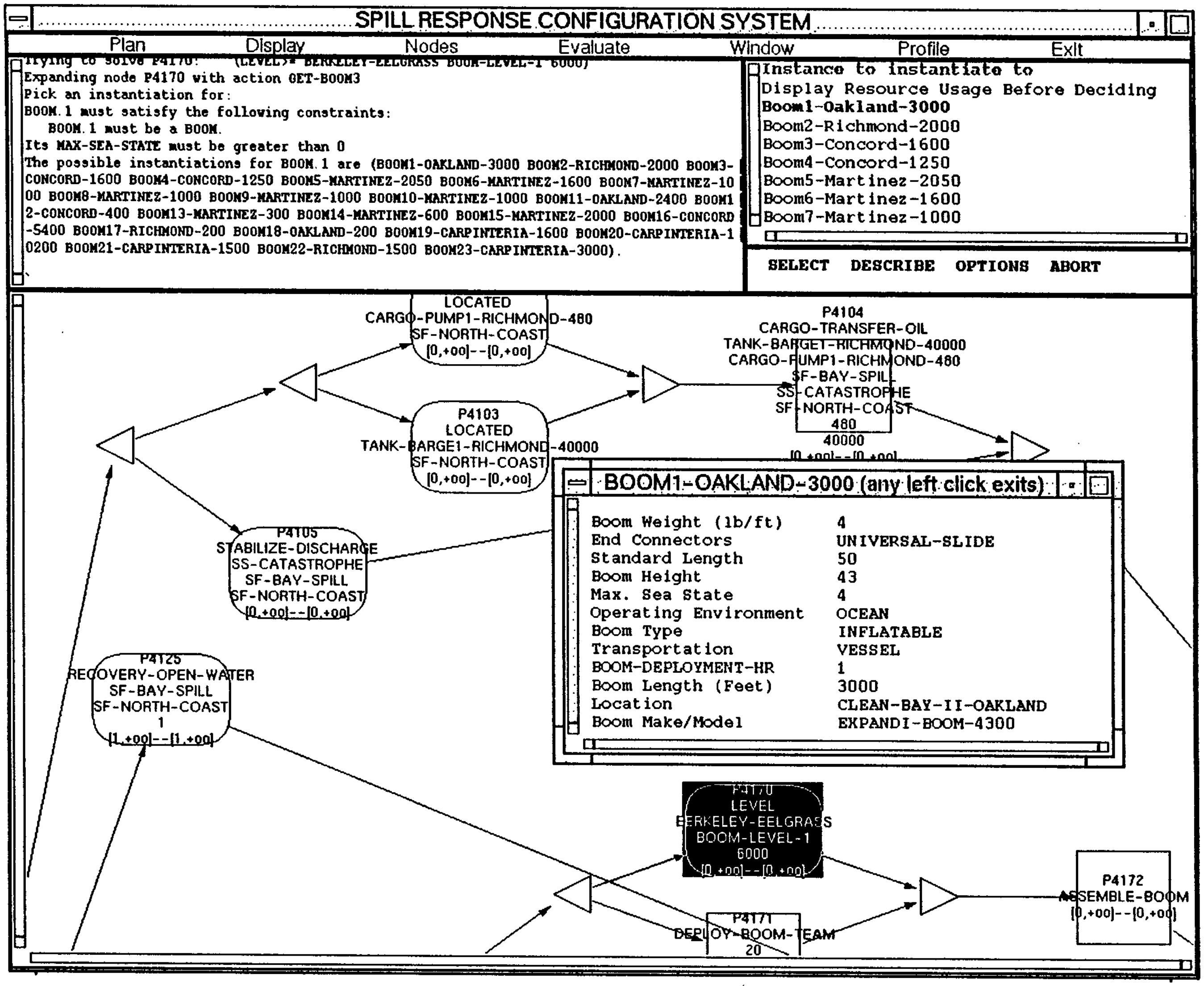


```
Expanding node P3992 with action RESPOND-TO-SPILL-COASTAL
Found valid plan at level 1.
CSF-BAY1-1 being set to context.

Command: :Display Mode
Creating grasper space SF-BAY1-1.
Command: :Plan Mode
CSF-BAY1-1 is only context to expand.
Checking precondition at P4052 for operator STABILIZE-DISCHARGE-BY-LIGHTERING
Checking precondition at P4052 for operator STABILIZE-DISCHARGE-BY-CONTAIN-SKIM
Checking precondition at P4052 for operator STABILIZE-DISCHARGE-BY-TOWING-TO-PORT
Checking precondition at P4052 for operator NO-MORE-STABILIZE
```

```
Order operators will be tried
Stabilize-Discharge-By-Lightering
Stabilize-Discharge-By-Contain-Skim
Stabilize-Discharge-By-Towing-To-Port
No-More-Stabilize
```

Figure 6. Response to a Major Spill: Five Objectives

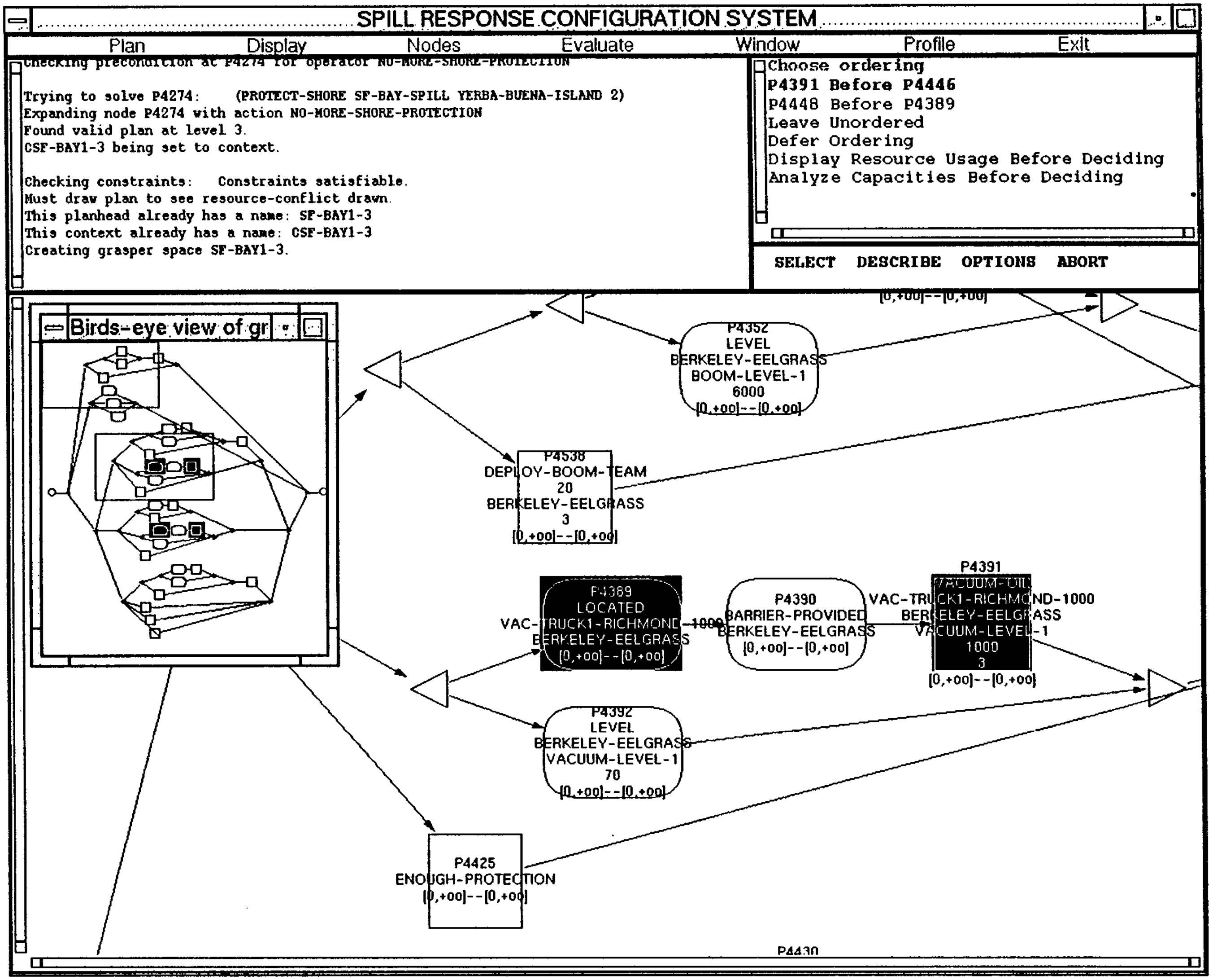


```
Trying to solve P4170:     (LEVEL>= BERKELEY-EELGRASS BOOM-LEVEL-1 6000)
Expanding node P4170 with action GET-BOOM3
Pick an instantiation for:
BOOM.1 must satisfy the following constraints:
   BOOM.1 must be a BOOM.
Its MAX-SEA-STATE must be greater than 0
The possible instantiations for BOOM.1 are (BOOM1-OAKLAND-3000 BOOM2-RICHMOND-2000 BOOM3-
CONCORD-1600 BOOM4-CONCORD-1250 BOOM5-MARTINEZ-2050 BOOM6-MARTINEZ-1600 BOOM7-MARTINEZ-10
00 BOOM8-MARTINEZ-1000 BOOM9-MARTINEZ-1000 BOOM10-MARTINEZ-1000 BOOM11-OAKLAND-2400 BOOM1
2-CONCORD-400 BOOM13-MARTINEZ-300 BOOM14-MARTINEZ-600 BOOM15-MARTINEZ-2000 BOOM16-CONCORD
-5400 BOOM17-RICHMOND-200 BOOM18-OAKLAND-200 BOOM19-CARPINTERIA-1600 BOOM20-CARPINTERIA-1
0200 BOOM21-CARPINTERIA-1500 BOOM22-RICHMOND-1500 BOOM23-CARPINTERIA-3000).
```

```
Instance to instantiate to
Display Resource Usage Before Deciding
Boom1-Oakland-3000
Boom2-Richmond-2000
Boom3-Concord-1600
Boom4-Concord-1250
Boom5-Martinez-2050
Boom6-Martinez-1600
Boom7-Martinez-1000
```

```
Boom Weight (lb/ft)      4
End Connectors           UNIVERSAL-SLIDE
Standard Length          50
Boom Height              43
Max. Sea State           4
Operating Environment    OCEAN
Boom Type                INFLATABLE
Transportation           VESSEL
BOOM-DEPLOYMENT-HR       1
Boom Length (Feet)       3000
Location                 CLEAN-BAY-II-OAKLAND
Boom Make/Model          EXPANDI-BOOM-4300
```

Figure 7. Booms Available to Protect Berkeley Eelgrass



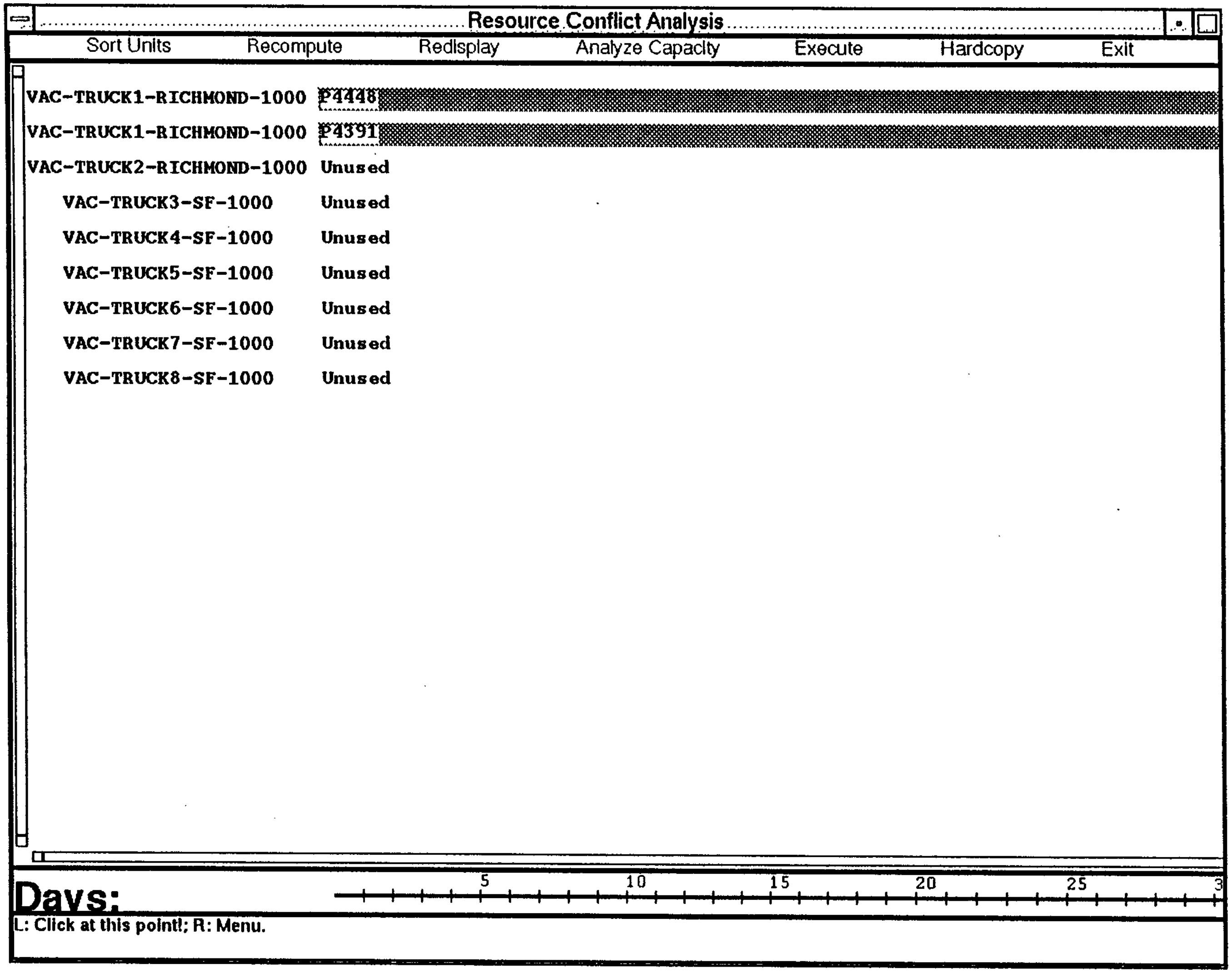
```
Checking precondition at P4274 for operator NO-MORE-SHORE-PROTECTION

Trying to solve P4274:    (PROTECT-SHORE SF-BAY-SPILL YERBA-BUENA-ISLAND 2)
Expanding node P4274 with action NO-MORE-SHORE-PROTECTION
Found valid plan at level 3.
CSF-BAY1-3 being set to context.

Checking constraints:   Constraints satisfiable.
Must draw plan to see resource-conflict drawn.
This planhead already has a name: SF-BAY1-3
This context already has a name: CSF-BAY1-3
Creating grasper space SF-BAY1-3.
```

```
Choose ordering
P4391 Before P4446
P4448 Before P4389
Leave Unordered
Defer Ordering
Display Resource Usage Before Deciding
Analyze Capacities Before Deciding
```

Figure 8. Presentation of a Resource Conflict



```
VAC-TRUCK1-RICHMOND-1000 P4448
VAC-TRUCK1-RICHMOND-1000 P4391
VAC-TRUCK2-RICHMOND-1000 Unused
  VAC-TRUCK3-SF-1000     Unused
  VAC-TRUCK4-SF-1000     Unused
  VAC-TRUCK5-SF-1000     Unused
  VAC-TRUCK6-SF-1000     Unused
  VAC-TRUCK7-SF-1000     Unused
  VAC-TRUCK8-SF-1000     Unused
```

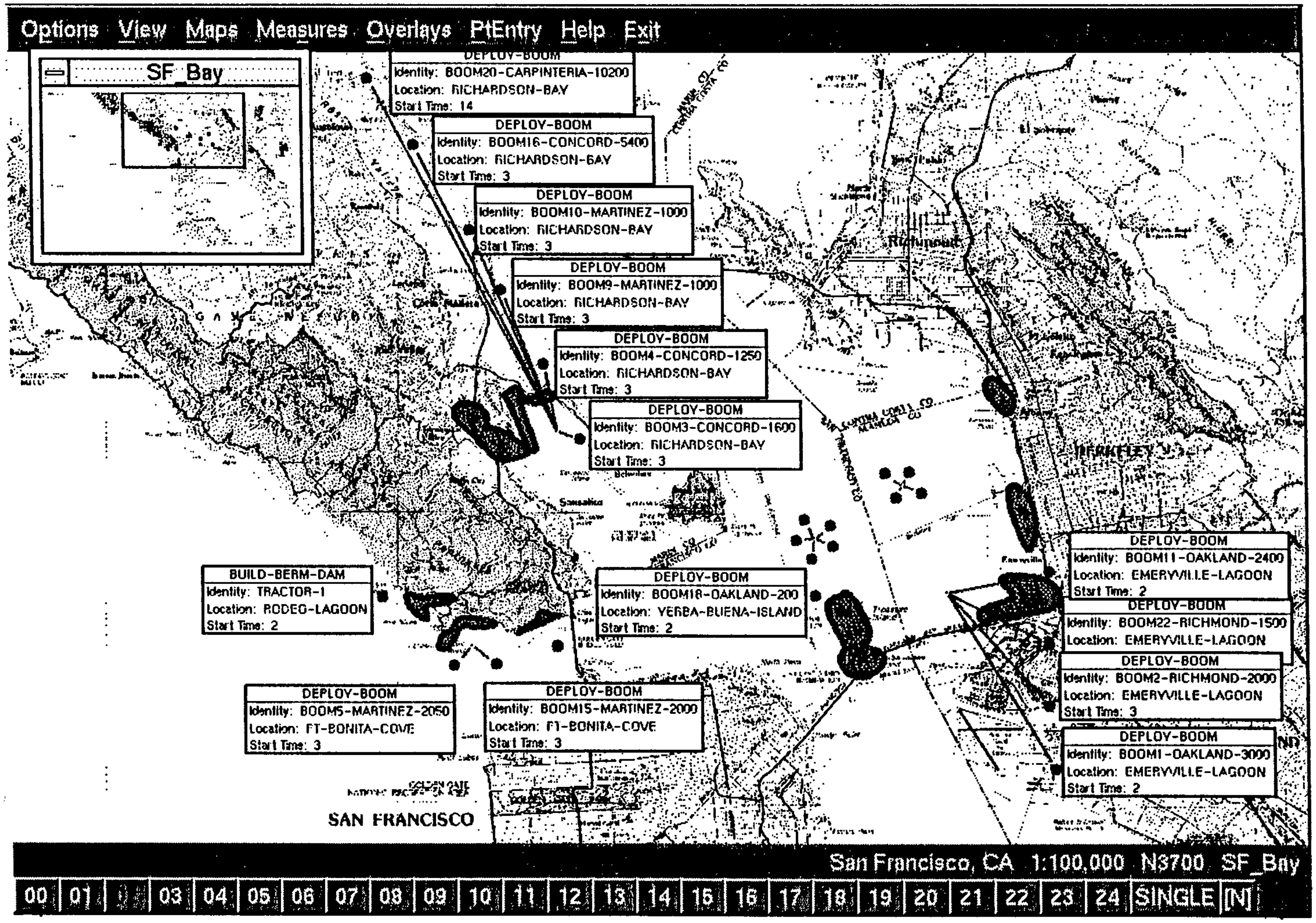
L: Click at this point!; R: Menu.

Figure 9. Resource Conflict Analysis Window

Having completed the development of the response plan, the user may then view the employment and deployment actions on the color map display, as shown in Figures 10 and 11. For the employment actions, the information windows show the name of the response operation, the type of response equipment, the location of the operation, the latest start time, and the location in which the equipment was based. For the deployment actions, the travel time duration is included in the information window. In addition, the route of the movement is shown, as well as the form of transport, which in the case of the equipment in Figure 11 is both sealift and ground movement.

The user then evaluates the response plan by feeding the output of the planning module, together with other information about the scenario, into HSTools. A spreadsheet is generated from which a variety of charts may be displayed. Figure 12 shows the oil that will reach the sensitive areas and the corresponding sea sectors along the route of the spill. One of the sensitive areas will be severely fouled since insufficient boom has been allocated to it. By modifying values in the spreadsheet the user can identify the amount of additional protection this are will need. Figure 13 shows the consequences of adding 8,000 feet of boom to this area, and ensuring its arrival 5 hours after the spill. To complete the loop, the user must now add this boom to the inventory database and determine, with the aid of the planning module, where this equipment should be physically located, and whether any additional resources are required to transport the boom to the endangered shoreline.

To summarize, the final prototype demonstration showed how the user could explore the consequences of spill response equipment shortfalls by evaluating the environmental damage in a spreadsheet model. By adding more equipment into the database or repositioning existing equipment, it is possible to replan the spill scenario and determine whether these equipment decisions are feasible and consistent with the rest of the plan.



DEPLOY-BOOM
Identity: BOOM20-CARPINTERIA-10200
Location: RICHARDSON-BAY
Start Time: 14

DEPLOY-BOOM
Identity: BOOM16-CONCORD-5400
Location: RICHARDSON-BAY
Start Time: 3

DEPLOY-BOOM
Identity: BOOM10-MARTINEZ-1000
Location: RICHARDSON-BAY
Start Time: 3

DEPLOY-BOOM
Identity: BOOM9-MARTINEZ-1000
Location: RICHARDSON-BAY
Start Time: 3

DEPLOY-BOOM
Identity: BOOM4-CONCORD-1250
Location: RICHARDSON-BAY
Start Time: 3

DEPLOY-BOOM
Identity: BOOM3-CONCORD-1600
Location: RICHARDSON-BAY
Start Time: 3

BUILD-BERM-DAM
Identity: TRACTOR-1
Location: RODEO-LAGOON
Start Time: 2

DEPLOY-BOOM
Identity: BOOM18-OAKLAND-200
Location: YERBA-BUENA-ISLAND
Start Time: 2

DEPLOY-BOOM
Identity: BOOM5-MARTINEZ-2050
Location: FT-BONITA-COVE
Start Time: 3

DEPLOY-BOOM
Identity: BOOM15-MARTINEZ-2000
Location: FT-BONITA-COVE
Start Time: 3

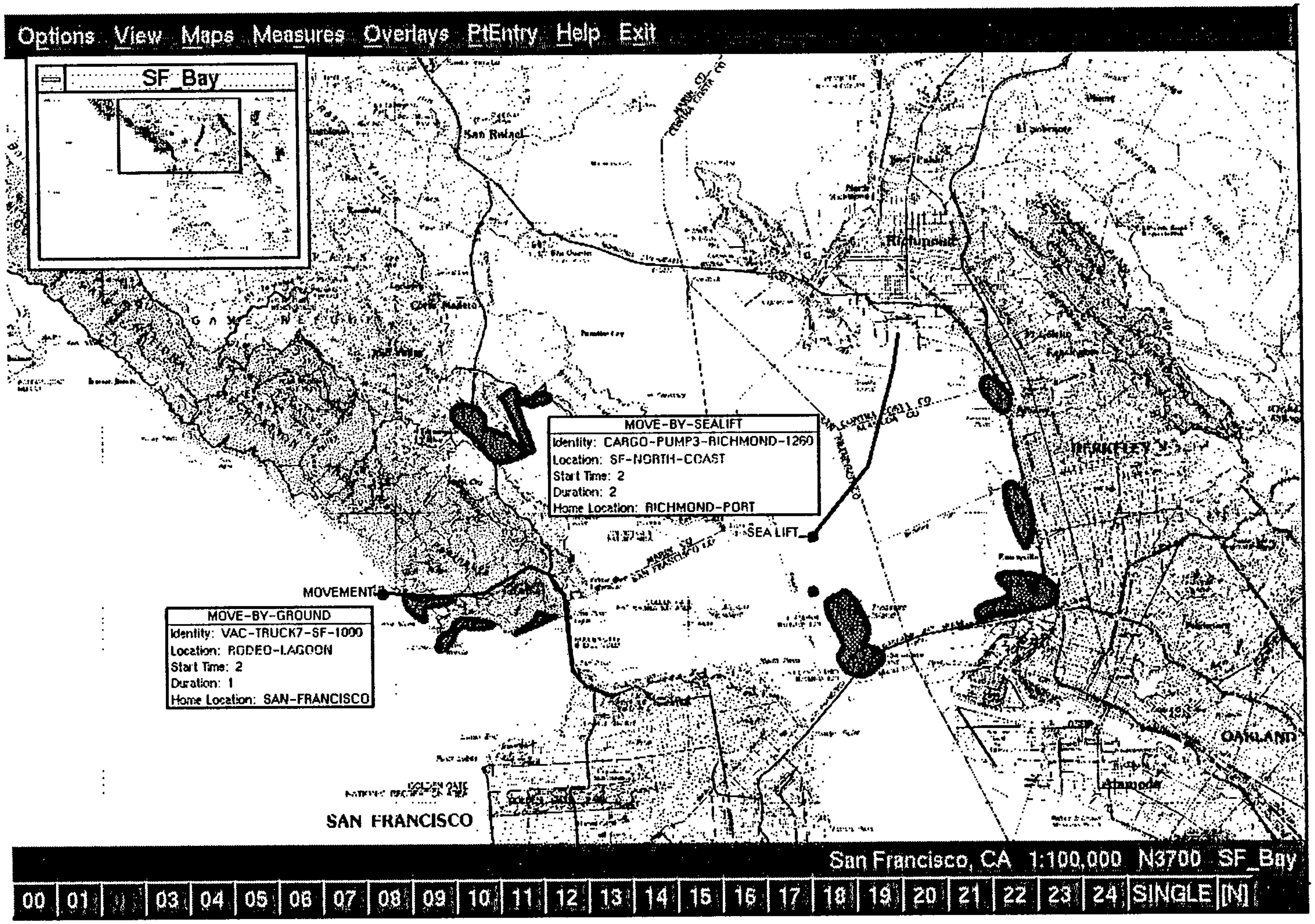
DEPLOY-BOOM
Identity: BOOM11-OAKLAND-2400
Location: EMERYVILLE-LAGOON
Start Time: 2

DEPLOY-BOOM
Identity: BOOM22-RICHMOND-1500
Location: EMERYVILLE-LAGOON

DEPLOY-BOOM
Identity: BOOM2-RICHMOND-2000
Location: EMERYVILLE-LAGOON
Start Time: 3

DEPLOY-BOOM
Identity: BOOM1-OAKLAND-3000
Location: EMERYVILLE-LAGOON
Start Time: 2

Figure 10. Deployment Actions



MOVE-BY-SEALIFT
Identity: CARGO-PUMP3-RICHMOND-1260
Location: SF-NORTH-COAST
Start Time: 2
Duration: 2
Home Location: RICHMOND-PORT

MOVE-BY-GROUND
Identity: VAC-TRUCK7-SF-1000
Location: RODEO-LAGOON
Start Time: 2
Duration: 1
Home Location: SAN-FRANCISCO

Figure 11. Employment Actions

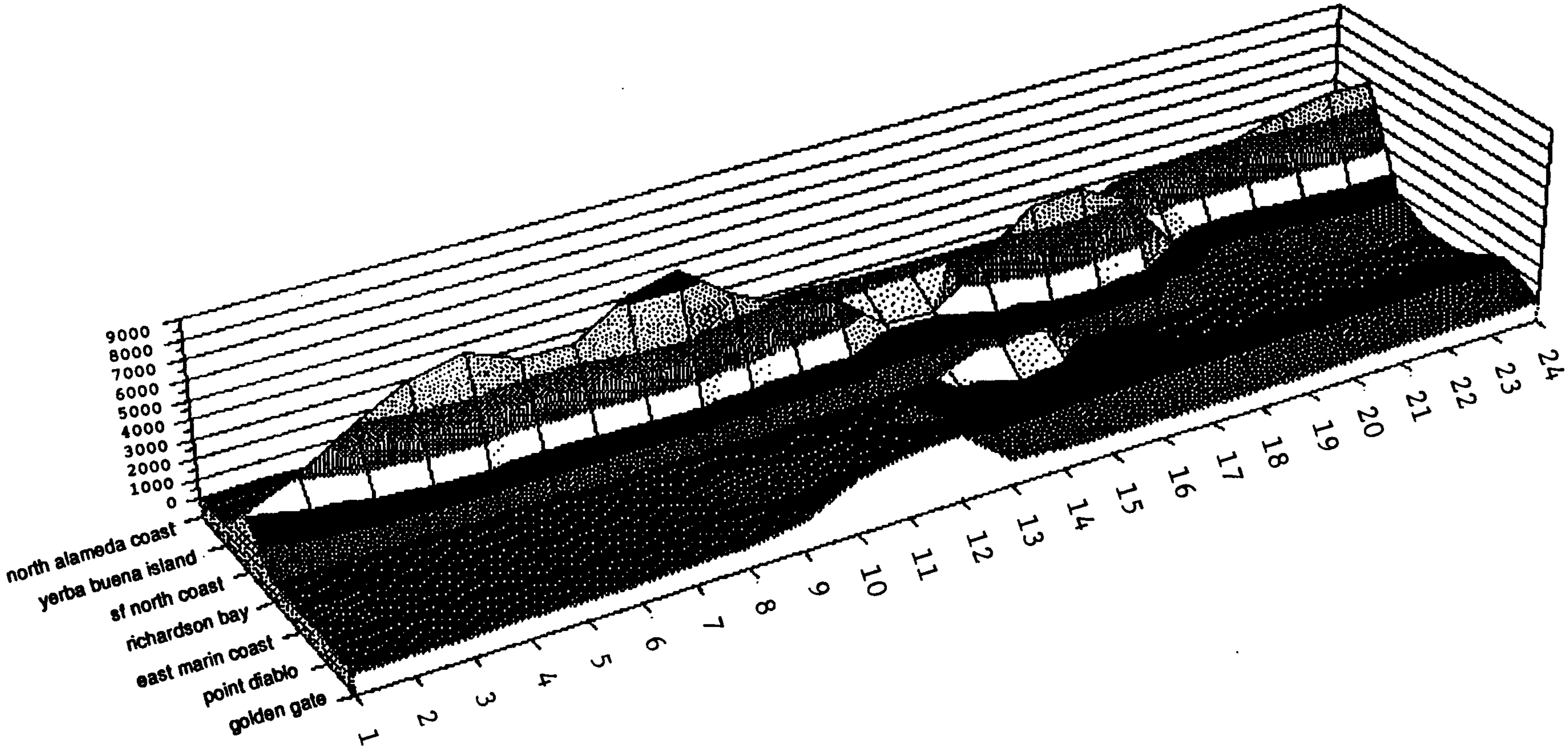


Figure 12. Extent of Oil Spread (Initial Response Plan)

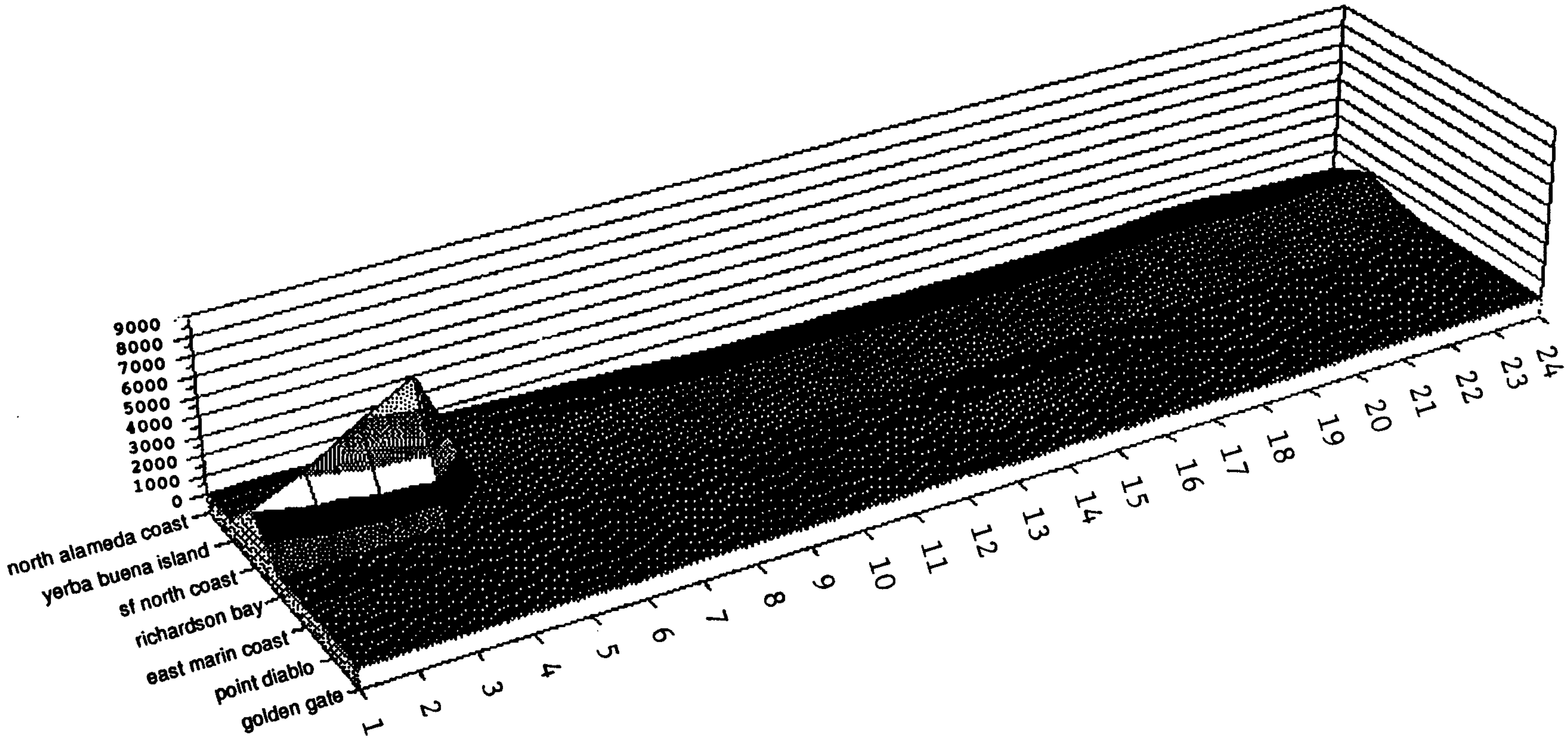


Figure 13. Extent of Oil Spread
(Additional Boom Added to Protect One of the Unprotected Sensitive Shoreline Areas)

4 SUMMARY AND FUTURE WORK

In this report, we have described the development of a decision support tool for oil spill response configuration planning. SRCS assists the user to explore equipment configuration decisions by simulating spill response scenarios, and highlights the shortfalls and trade-offs for various configuration alternatives. During this project, we have demonstrated how the integration of advanced AI planning techniques, together with a commercial spreadsheet tool and color map display, can provide a decision support tool for spill response configuration planning. Indeed, SRCS has been demonstrated on several occasions to various USCG personnel at the national and regional levels.

The underlying AI planning techniques provide a powerful representation and automated reasoning mechanisms that permit the user to explore a greater number of spill scenarios than is practical with manual methods. These mechanisms also keep track of all the decisions made and notify the user when the decisions contradict or are inconsistent with each other. The use of a commercial spreadsheet tool for the evaluation module facilitates the user's access to the evaluation model. The spreadsheet tool also provides an excellent array of tabular displays and charts for representing environmental damage and equipment shortfalls.

The knowledge gained in the initial tasks in Phase I—the literature review and familiarization with models—permitted us to adopt a rapid prototyping approach. Our previous experience in developing decision support tools for crisis management operations was transferred to this domain, resulting in a flexible, extensible, interactive, and eventually easy-to-use decision support tool for spill response configuration management.

The next stage would involve the further development of the existing prototype, both to make the system more robust and to enhance it with additional technology. Under two research grants from the USCG Oil Pollution Research Grants Program, we will transfer additional AI technology developed under DoD and SRI funding to further improve the prototype's replanning and user interface capabilities, and add further extensions to determine which response plan achieves the most desirable results: specifically, the most effective cleanup with the fewest environmental impacts.

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Appendix A

LETTER OF SUPPORT FROM THE U.S. DEPARTMENT OF THE AIR FORCE

DEPARTMENT OF THE AIR FORCE
ROME LABORATORY (AFMC)
GRIFFISS AIR FORCE BASE, NEW YORK

3 Mar 94

MEMORANDUM FOR Anthony Flaherty, DTS 853
Grant Administrator
Volpe National Transportation Systems Center
US Department of Transportation
Research & Special Programs Administration
55 Broadway
Cambridge MA 02142-1093

FROM: RL/C3CA
525 Brooks Rd
Griffiss AFB NY 13441-4505

SUBJECT: Dual Use Application of Planning Technology

Rome Laboratory and the Advanced Research Projects Agency are jointly funding contract (91-C-0039 and 93-C-0071) with SRI International to expand the technology base in the area of planning. We agree with, and fully support the dual use of this technology of applications of interest to the US Coast Guard. Generic technology development in the specific areas of replanning, course of action planning, and machine learning will continue pending any unforeseen budget cuts. We support this dual use technology transfer program with the understanding that these contracts will continue with no change in scope, cost or schedule and that the dual use application will be funded by the US Coast Guard.

DONALD SPECTOR
Tech Transfer Officer
Directorate of Command, Control & Communications

cc: Mr Ivan Lissauer
US Coast Guard Research and Development Center
1082 Shennecossett Road
Groton CT 06340-6096

"Where Visions Become Reality"