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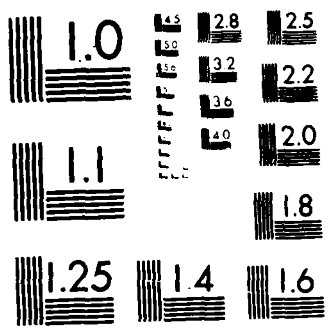

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A PROTOTYPE KNOWLEDGE-BASED SYSTEM TO AID SPACE SYSTEM RESTORATION MANAGEMENT

THESIS

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Abstract

This research effort investigates the application of Artificial Intelligence knowledge-based techniques to the problem of space system restoration management. A prototype decision aid was developed to demonstrate the feasibility of a knowledge-based decision aid capable of assisting the Commander of the US Space Command in maximizing the use of remaining space resources following wartime losses and degradation of space systems. Programmed with the Automated Reasoning Tool (ART), the prototype decision aid generates alternative restoration plans based on the mission priorities specified by the user. To rank the alternative plans by their effectiveness, the prototype uses an objective function which encompasses the multiple objectives of restoring communications, navigation and weather mission capabilities. The prototype decision aid also contains provisions to handle uncertain data and uses a branch and bound pruning algorithm to eliminate inferior partial plans and thereby hasten the solution process.

A PROTOTYPE KNOWLEDGE-BASED SYSTEM TO AID SPACE SYSTEM RESTORATION MANAGEMENT

I. Introduction

General Issue

The Department of Defense (DOD) is becoming increasingly reliant on satellite systems that perform the force enhancement missions of communications, tactical warning, meteorology, reconnaissance, navigation and mapping. These space systems have become so capable, and in some cases, so vital to the conduct of military operations, that their unimpeded use in future conflicts could prove decisive (12:15-12). To ensure that these systems will be available when the DOD requires, the United States Space Policy calls for the increased survivability of all elements of space systems (12:15-18). Satellite system designers are also looking into interoperability between satellite systems to enhance survivability and provide a means to reconstitute critical satellite networks when system losses and degradation occur during wartime.

Space system restoration management, maximizing the use of remaining space assets in a post-attack environment, is a high priority in the DOD (14:308). As the decision maker responsible for the restoration process, the Commander of the United States Space Command (CINCSPACE) must be prepared to quickly develop and implement a plan to restore critical mission capabilities. Depending on the stage of the conflict and the extent of damage to the satellite systems, the restoration decision can become extremely complex. To determine the optimal plan for restoring mission capabilities, the decision maker must consider numerous factors. These include: (1) the compatibility of the available satellite systems, (2) the accuracy and completeness of the system status updates and intelligence reports, (3) the mission requirements of the various battle commanders, (4) the tactics of the enemy, and (5) the amount of time and resources necessary to implement the proposed changes. Space system restoration management is not a one-time reallocation of resources; every time the mission priorities and/or the status of available space systems change, a new plan must be developed and implemented.

Problem Statement

Because of the importance of space system restoration management, an automated decision aid is required to assist CINCSPACE in quickly generating effective restoration plans to ensure the best use of available space resources.

Background

Although much has been written on the need for a space system management system, only one research effort has proposed a methodology for managing the restoration process.

In a Master's thesis at the Air Force Institute of Technology, Captain Calvin Hedgeman addressed the feasibility of optimally reconfiguring a satellite fleet using goal programming and integer programming techniques. Under the sponsorship of HQ AF SPACE CMD, Captain Hedgeman developed a prototype decision aid to enable CINCSPACE to carry out the restoration process according to his mission priorities. Although Captain Hedgeman's prototype generated optimal allocations, it could not handle situations where satellites shared earth station resources or satellite subsystems were in a degraded status. Captain Hedgeman's prototype system also came close to exceeding the limits of a mainframe computer system when applied to only a small fraction of the systems a real restoration system would have to consider.

Algorithmic tools, like Captain Hedgeman's, have enjoyed limited success in battle management applications like space system restoration management. Battle management involves making the best use of defense resources, including situation monitoring, resource accounting and resource allocation (20:3-6). These mathematical models are often unwieldy, and do not respond well to real life complications such as incomplete information, the desire to minimize equipment changes, and time constraints.

Artificial Intelligence (AI) knowledge-based systems, however, have demonstrated promising results in solving complex battle management problems. According to Professor Edward Feigenbaum, a leading researcher in AI, an expert system, or knowledge-based system is "an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution" (17). Knowledge-based systems are especially applicable to battle management problems like space system restoration management because they can cope with incomplete or uncertain information, generate several alternative solutions, and explain the line of reasoning used to generate the solutions. Recognizing the capabilites of knowledge-based systems, the DOD has initiated many research efforts in applying knowledge-based systems to battle management problems. Several of these projects are reviewed in Chapter IV.

Research Objective

The purpose of this research effort was to demonstrate the feasibility of using an AI knowledge-based system to aid space system restoration management. To accomplish this, the requirements for a space system restoration management decision aid were investigated, a prototype knowledge-based system was developed, and the prototype was tested with hypothetical wartime scenarios.

Scope of Research

Because most military satellite programs are classified, the prototype knowledge-based system does not involve actual military satellite systems. Rather, generic satellite systems that are representative of current and proposed military satellite systems in terms of function and configuration were developed. In order to demonstrate the full potential of a space system restoration management decision aid, the generic space systems were designed with a larger degree of interoperability than what is actually possible today. Some simplifying assumptions about the operation of the satellite systems were made in this research effort, but these assumptions do not diminish the prototype's capability to demonstrate the feasibility of a space system restoration management decision aid. The force enhancement missions of communications, navigation and meteorology are the only satellite missions used in the research. Although commercial satellites would be used in a national emergency, their use in the restoration of military satellites is not addressed in this research effort.

Overview

The next chapter discusses the current level of interoperability between space systems and the relationship of space system restoration management to space battle management. Following an outline of the general requirements for an operational space system restoration management decision aid, Chapter III describes the requirements for the prototype knowledge-based system developed in this research effort. Next, artificial intelligence and knowledge-based systems are discussed, and several knowledge-based systems that perform various battle management functions are examined. Chapter V then describes the methodology that was used in this thesis effort, and Chapter VI presents the prototype system design. The results from the testing of the prototype with hypothetical scenarios are discussed in Chapter VII, along with an analysis of the prototype's performance. Finally, Chapter VIII addresses the feasibility of a knowledge-based system to aid space system restoration management, and provides recommendations for future research.

II. Space System Restoration Management

Space system restoration management, maximizing the use of remaining space assets in a wartime environment, is essentially a two-fold problem: (1) how does the United States achieve space system interoperability and survivability to make the reallocation of assets feasible and effective during a conflict, and (2) how will CINCSPACE manage the reallocation process to ensure the timely and best use of available space assets? The problem of managing the reallocation process falls under the larger domain of space battle management, which will be defined and discussed in the latter part of this chapter. First, the current and proposed efforts to achieve space system interoperability and survivability are addressed.

Interoperability and Survivability

The interoperability and survivability of military and commercial satellite systems is of growing concern to the DOD. The increasing reliance of the military on satellite systems to perform vital wartime missions and the increasing use of commercial communications satellite assets has led the military to investigate ways to ensure the interoperability and survivability of space assets. Currently, 95% of all government communication services are provided by the commercial sector, and future plans indicate that the commercial sector will have ten times as many communications satellites as the military in the 1990's (32:209, 6:420).

In the past, interoperability between satellite systems was not a design requirement for new satellite system programs; interoperability was only instituted when convenient or cost-effective (3:885). However, with the increasing dependence of the military on both civilian and military satellite systems, interoperability has become a necessity. Largely a straight-forward engineering problem of compatible frequencies, polarizations, access techniques, earth station signal levels, and look angles, interoperability is an achievable goal (34:206). The more difficult problem is developing the policy, procedures and funding responsibilities required to implement an interoperable system capability (32:211).

A small degree of interoperability exists today, and a real start has been made through a combination of industry-government cooperative efforts to investigate commercial communications satellite interoperability (34:211). In addition, a Presidential advisory commitee is studying how the government could fund commercial satellite companies to improve the surivability of their systems (32:209). The military is also looking into a new frequency plan for their communications satellites to include the commercial Ku band (15.35 to 17.25 Hz). This use of commercial frequencies will enhance the physical survivability of military satellites because it diminishes the attractiveness of military satellites as targets. If the military satellites are destroyed, earth terminals will still be able to communicate through any surviving Ku band commercial satellite (6:419).

Many researchers have proposed highly survivable satellite networks that rely heavily on interoperability, internetting, alternate routing, and adaptive protocols (14:308). Others have proposed centralized "restoration centers" that would service a number of government and commercial satellites, and be able to switch data between the different systems (34:207).

In the article "Commercial SATCOM Interoperability Issues," Lt. Gen Lee Paschall and Dr. John McLucas present the actions necessary to form a basic foundation to establish an initial restoral capability through satellite communications interoperability. They are:

1) Catalog earth stations and determine those that can now interoperate at radio frequency (RF).

2) Identify those earth stations at key nodes which should be modified to provide a level of interoperability.

3) Determine the desired level(s) of interoperability standardization.

4) Define an acceptable standard for minimum essential communications interoperability.

5) Determine what regulatory issues must be addressed in order to ensure that pre-established authorizations exist in the event of a crisis (32:211).

Paschall and McLucas further state that in addition to defining the technical means of achieving interoperability, the government must:

1) Define responsibilities and assignments.

2) Establish a government program office for implementation.

3) Define minimum essential requirements in terms of capacity and connectivity.

4) Define critical system nodes.

5) Establish priority assignments for various classes of users.

6) Develop protocols and procedures for implementation.

7) Define the level and method for achieving interoperabilty.

8) Define a time phased architecture.

9) Establish necessary funding levels consistent with the architecture.

10) Provide a mechanism for exercising any proposed emergency system during peacetime (32:211).

The actions listed above show how far the US is from an effective satellite system interoperability scheme and the tremendous amount of work that needs to be done to establish it. As the foundation of a restoral capability, these are the requirements that must be met before any meaningful space system restoration management system can be implemented. Although this research effort presses ahead into the development of such a management system, it is with the caveat that interoperability between satellite systems must be also be established to make such a space sytem restoration management system worthwhile.

Space Battle Management

Space battle management is "the judicious use of assigned space forces in a military conflict to accomplish assigned missions" (30:1). The forces involved in space battle management include satellite systems, command and control systems, ground-based support systems, communications links, surveillance systems, and combat systems (30:2). CINCSPACE is responsible for the accomplishment of six primary missions: (1) monitoring the space environment and disseminating information on threats, attacks, and the status of all space systems, (2) protecting US and allied space systems against threats, (3) negating enemy space systems through offensive combat operations, (4) providing attack warning and attack assessment, (5) commanding and controlling the operation of assigned satellite systems and support facilities, and (6) planning and testing the Strategic Defense Initiative (SDI) (30:2).

Space battle management, like other battle management problems, involves the interoperation of numerous complex command, control, and communication (C^3) systems. In order for space battle management to be conducted effectively, an extraordinary level of interoperability, exchange of information, and coordination must be achieved between the participating centers, networks, and nodes (30:14). The following is a list of just a few of the organizations and networks that would have to be "in the loop" for space battle management: the Consolidated Space Operations Center

(CSOC); the Space Defense Operations Center (SPADOC); the Missile Warning Center; the Space Operations Intelligence Center; the Space Surveillance Center; the Air Launched ASAT Mission Control Complex; the Air Force Satellite Control Network (AFSCN); dedicated tracking, telemetry, and command (TT&C) networks; missile and space surveillance networks; the NORAD Command Post; other CINC command posts; and the National Command Authorities (NCA) (30:14).

Space System Restoration Management

Space system restoration management is a small part of space battle management which falls under two of CINCSPACE's missions: command and control, and monitoring and informing. Since the purpose of the command and control mission, to ensure the continued flow of support from satellite systems to users, encompasses the goal of space system restoration management, a space system restoration management decision aid could be effectively integrated into a larger system designed to aid the whole command and control mission.

The status reports obtained from the systems performing the mission of monitoring and informing would be required as inputs to such a space system restoration management decision aid. Ideally, the decision aid would receive these updates automatically from a system processing intelligence reports and sensor reports. When the change of status for a space system (or systems) warrants a restoration decision, the restoration decision aid would have all current information required to generate a restoration plan.

III. Requirements for a Decision Aid

Crisis situations in the military require the prompt and secure planning of complex actions. However, plans generated in time critical situations are subject to error for a number of reasons. First, not all viable alternatives are considered when time is critical, and those alternatives that are considered cannot be investigated thoroughly. Second, errors can result when security restrictions prevent crisis planners from having access to specialized experts and the data required to complete the plan (2-ix). Third, planning is often performed by staff officers who lack sufficient experience to do the job. These and many other reasons have led to the popularity of automated decision aids to help in crisis planning. These decision aids have typically been developed with problem-solving techniques drawn from the fields of Operations Research, Decision Analysis, and Artificial Intelligence.

This chapter explains the basic requirements for an operational space system restoration management decision aid and the requirements for the prototype system developed in this thesis effort. The requirements are summarized in Table 3.1, and are listed under five categories: scope of system, resident knowledge, system functions, user interface, and system performance.

Table 3.1 System Requirements

Requirement	Actual System	Prototype
SCOPE OF SYSTEM:		
Military Systems	all	representative
Civilian Systems	all under CINCSPACE command during wartime	none
Missions	all military	comm, nav, weather
# Space Systems	40	6
# Satellites	150	39
# Earth Terminals	250	58
Orbit Types	all types	geosynchronous
RESIDENT KNOWLEDGE:		
Knowledge Base	satellites, earth terminals, AFSCN, orbital parameters, equipment reconfiguration times, operating parameters, default priorities	satellites, earth terminals, AFSCN, frequencies, default priorities
Rule Base	restoration process, handle uncertainty, orbital calculations, analysis of plans, calculate objective function value, presentation of plans	restoration process, handle uncertainty, calculate objective fcn, presention of plans
SYSTEM FUNCTIONS:		
Use mission priorities	user-specified and default priorities	user-specified and default priorities
Reason with uncertain info	Bayesian Prob or Evidential Reasoning	handled via rules

Table 3.1 System Requirements (continued)

Requirement	Actual System	Prototype
Incorporate time into problem	time to restore, actual time for orbital calculations	not implemented
Incorporate enemy tactics into planning problem	interface with other data bases	not implemented
Share resources	maximum use of remaining assets	limited cases
Develop restoration plans	partial and complete plans	complete plans
Let user specify his own plan	give analysis and impact	not implemented
USER INTERFACE:		
DATA INPUT:		
Update knowledge base	automatically from sensors and adopting plans, manually via menus	scenario files and automatically from adopting plans
OUTPUTS:		
Present restoration plan to user	graphics, text	text
Provide alternate restoration plans	user-specified #	user-specified #
Give reasoning for plan(s)	natural language	reasoning trail for facts generated
Give evaluation of plan(s)	missions weights and percentages, overall numeric value	mission percentages, overall numeric value
Give Sensitivity Analysis	changes in priorities and weights	through repeated runs of system
Give Network Vunerabilites	most important links, nodes, earth terminals, satellites	not implemented

Table 3.1 System Requirements (continued)

Requirement	Actual System	Prototype
SYSTEM PERFORMANCE		
Time to Solve	give all plans and analysis in a few hours, and give partial plans in user-specified time limit	less than 2 hrs

Scope of System

This section of Table 3.1 shows how the prototype system compares in size and problem-solving difficulty with an actual space system restoration management system. As shown, the prototype contains only six military space systems. A space system is defined as the collection of satellites and ground support resources that work together to perform a specific mission. For example, all of the resources of the Global Positioning System (GPS) including 21 satellites and the numerous earth stations supporting GPS would be considered one space system. Civilian space systems are not included in the prototype system, although they would have to be incorporated into an actual decision aid system. To scale down the problem further, the prototype only involves space systems performing the missions of communications, navigation and meteorology. An actual system would of course involve all missions performed by space systems under CINCSPACE control in wartime.

The prototype therefore handles only a fraction of the space systems, satellites and earth terminals an operational system would be responsible for. Also, the amount of data stored on each of the space systems components is significantly smaller in the prototype than would be in an actual system. Many simplifications and assumptions were made for the prototype including the fact that all satellites in the prototype have geosynchronous orbits. This assumption was made to preclude the representation of time and the requirement for orbital calculations in the prototype decision aid. Obviously, an actual system would require such orbital calculations, and this segment would probably comprise a significant portion of the decision aid.

Resident Knowledge

The "Resident Knowledge" section of Table 3.1 summarizes the kinds of knowledge a space system restoration management decision aid requires. Both the prototype and an operational system require knowledge about the configuration and operating parameters of the space systems under CINCSPACE control. Also, both systems require sets of default mission priorities to be used when time constraints prevent the new derivation of mission priorites. Because the prototype uses the geosynchronous orbit simplification, only the actual space system restoration management system requires knowledge about the orbital parameters of the satellites. The operational system also requires knowledge about the time required to reconfigure the various space assets to handle new and added responsibilities.

Both the prototype and an operational decision aid require procedural information to interact with the knowledge base in order to generate the restoration plans. Because this procedural information is often stored in "if xx, then yy" rules, the body of rules is called the "rule base" in a knowledge-based system. Both the prototype and an operational system require rules to carry out the restoration process, decide on the course of action in the presence of incomplete or uncertain information, calculate the overall "value" of the plans, and present the plans to the decision maker. In addition, the operational system must contain rules to perform the orbital calculations and analyze the plans for potential vulnerabilities.

System Functions

The "System Functions" section of Table 3.1 summarizes the major operations the prototype system and an operational decision aid must perform to generate restoration plans.

Mission Priorities. First, both systems must use the mission priorities specified by CINCSPACE to drive the reallocation of resources. These priorities will be based on the stage of conflict, the operations of the military forces, and the needs of the battle commanders CINCSPACE supports. The mission priorities and numerical weights attached to the missions are used to determine the merits of the restoration plans. The development of the numerical weights is detailed in Chapter V. In an actual decision aid, sets of these priorities and weights would be developed beforehand for different possible scenarios, and stored in the decision aid as "default priorities." Therefore, if time limitations precluded CINCSPACE from developing his numerical priorities and weights at the time of the crisis, he could select the default priority set most applicable to the situation. This feature is also used in the prototype system.

Incomplete Information. The handling of incomplete and uncertain information in a decision system is vitally important to the system's value and acceptance. According to Cohen, Thompson, and Chinnis, the authors of Design Principles for Personalized Decision Aiding: An Application to Tactical Air Force Route Planning, "the representation, manipulation, and display of uncertainty is central for a decision-maker's understanding of his own problem and for the consistent exchange of information among diverse decision makers and among different automated systems" (13:1). Much has been written on the representation of uncertainty in decision systems, and methods range from Bayesian probability techniques to evidential reasoning to fuzzy set theory. An actual space system restoration management decision aid must include the feature of dealing with uncertainty, and the method used must be acceptable to the decision maker. The prototype system must also handle uncertainty, and the method that was used is discussed in Chapter VI.

Representation of Time. As mentioned earlier, the prototype does not involve the representation of time. However, an actual sytem must incorporate time for a number of reasons. First, the representation of time is required to perform the orbital calculations to determine such information as the times a satellite will be in view of a particular earth terminal. Second, the restoration plans will require a certain period of time to be implemented, and this timing may affect combat operations. A decision aid that does not handle the impact of the timing required to implement the recommended plans may produce plans that do not meet the needs of the battle commanders.

Enemy Tactics. Incorporating enemy tactics and expectations into the restoration problem is necessary for space system restoration management to be effective, but this feature need not be built directly into a space system restoration decision aid. Rather, an operational space system restoration decision aid could interface with a system that performs situation assessment and forecasting. Situation assessment is another application area for automated decision aids, and the DOD is currently sponsoring several situation assessment research projects. Without some consideration of enemy tactics, a space system restoration management system is likely to produce seemingly good plans that are in fact extremely vulnerable. Therefore, an actual system would have to assess the vulnerabilites of the plans generated, and use this information to determine the merits of the plans. This feature is well beyond the scope of the prototype decision aid.

Sharing of Resources. As satellites and earth terminals are destroyed during a crisis, support resources previously dedicated to particular systems will have to be shared among remaining space assets, if technologically feasible. Some space subsystems, like earth terminals that perform TT&C functions, may be able to handle additional tasking, but some subsystems may have been designed for use with only one space system. The sharing of resources is related to the vulnerability aspect just mentioned. The greater the load on any one resource, the greater the likelihood that resource will be attacked. Therefore, an operational restoration decision aid would have to provide for the sharing of resources, and integrate this function with vulnerability assessment. The prototype demonstrates the sharing of resources on a small scale, with predetermined load capacities placed on certain resources.

User-Specified Plans. For a restoration aid to be fully responsive to CINCSPACE's needs, it must have the capability to accept and evaluate restoration plans generated outside the decision aid. Similarly, the decision aid must have the capability to accept certain restrictions, caveats, and even partial plans, and then generate complete restoration plans with these considerations. With these features in the decision aid, CINCSPACE's judgement, experience and knowledge can enhance the automated restoration process. Also, the plans generated are likely to be more acceptable to CINCSPACE. This requirement is beyond the scope of the prototype.

User Interface

The "user interface" section in Table 3.1 summarizes the inputs and outputs required for a space system restoration management decision aid. Before these requirements are examined in detail, it is necessary to address the issue of user acceptance of a decision aid.

User Acceptance Issues. Decision aids, regardless of the type of decision-making strategy used, must be used to be useful, and that requires acceptance on the part of the user. Therefore, those aspects of a decision aid which lead to greater user acceptance should be integrated into the decision aid to ensure that the system is used. The Naval Air Development Center sponsored a research project to determine the critical user acceptance issues in AI decision aids (48). This study gave several recommendations for the user interface portion of a decision aid.

The first design guideline suggested by the study is user control over the number of decision alternatives displayed by the decision aid. Depending on the time available for the decision to be made, the user can specify the number of alternatives he wishes to review and consider (48:4).

The study also suggested user control over system functions to explain the steps taken to derive the recommendations. When the user has a great deal of time to make his decision, he might want to examine every detail of how the decision aid arrived at a plan. When time is critical, the user may wish to suspend any explanation of the results.

The third design guideline proposed by the study is the effective display of probability or confidence estimates for each alternative. Since most real-world planning situations involve incomplete and imprecise information, these factors must be addressed and incorporated in the decision process. According to the study, the more quantitative facts a user has at his disposal to facilitate the comparison of the alternative plans, the more likely the user is to believe and rely on the decision aid.

Finally, the study suggested that decision aids be designed so that persons with limited computer knowledge could operate them. This "user-friendly" guideline does not mean that the user is inundated with instructions and endless menus every time he operates the system. Rather, tutorials and help menus should be available when the user needs them, but they should not hinder an experienced user who knows exactly what he wants to do.

The above guidelines give some insight into the ways a decision aid developer can improve his product and serve as a foundation for the user interface requirements of an operational space system restoration management decision aid.

Inputs. As mentioned earlier, an actual restoration decision aid would have to be tied to other automated sytems to access status information on the space assets under CINCSPACE control. In case the interface between the systems failed, the restoration management decision aid would require provisions for manual entry of status information. This manual entry would probably be accomplished through a series of menus. The prototype uses scenario files for the updating of status information and also contains a provision for the automatic update of the knowledge base when the user selects a particular restoration plan. An operational system would also require the automatic update feature.

For simplification, the prototype uses three categories of status: red, yellow, and green. A space system component with red status means that the component has been destroyed, or is unusable because there are no resources to support its operation. Yellow status means that the component's operation is partially degraded, and green status means that the component is fully operational.

Outputs. As discussed earlier, the format and information included in the outputs and displays of the decision aid are vital to the user's acceptance of the decision aid.

Restoration Plan. The most important output of the system, the "best" restoration plan (as determined by the decision aid), must be presented in a coherent and easily understood manner. Pictorial and graphical displays present the most information with the least confusion, and are therefore requirements for an operational decision aid. Graphics were not implemented with the prototype system.

Alternative Plans. An operational space system restoration management decision aid should allow the user to specify the number of alternative plans he wants displayed. Because the time required for a computer to generate the restoration plans is a function of the number of plans the user wants displayed, this requirement ensures that the decision aid will not waste time generating alternative plans in a time-critical crisis situation if they are not desired. The prototype also allows the user to specify how many plans he wishes to review.

Rationale for Plans. The operational restoration decision aid must be able to "explain" the merits and derivation of the best and alternative plans. The degree to which the decision aid can adequately explain its conclusions is partly based on the type of problem-solving technology used, and a decision aid emloying sophisticated mathematical models might not be able explain itself at the user's level. Regardless of the problem-solving technique used in the decision aid, the user should be able to specify how much of an explanation he desires. Ideally, the explanations should be presented in English, devoid of computer language symbols and statements. The prototype decision aid handles this requirement by giving the reasoning trail used in generating the individual restoration plan facts.

Evaluation of Plans. The degree to which each plan provides critical mission capabilities should be presented to the user to enable him to effectively select the best plan. Examples of the measures of merit used in the prototype include the percentage of critical data nodes that can receive and transmit data, the percentage of users in the conflict area that can receive weather information, and the percentage of ground forces that can use a certain navigational system. These kinds of merits should be incorporated into an overall objective function for each plan generated by the decision aid. The prototype uses the evaluation of this objective function to select the best and alternative plans.

Sensitivity Analysis. Before CINCSPACE selects a particular restoration plan, he might need to know how changes in his priorities and weights affect the plans produced. A suboptimal, but very good, plan might be more "robust" over a wide range of priorities and weights than the decision aid's best plan produced under the original set of weights. Since the priorities and weights are based on CINCSPACE's subjective judgements, and they must hold for a certain length of time, the restoration plan recommended must not be very sensitive to small changes in priorites and weights. The prototype does not have this sensitivity analysis feature imbedded in the system, but a sensitivity analysis of the mission priorities on the restoration plans could be performed through repeated runs of the prototype system.

Vulnerability Assessment. As previously described, the vulnerability of the space system networks resulting from the restoration process must be considered by the decision aid. As part of its outputs, the decision aid must alert CINCSPACE of the most important links, nodes, earth terminals, and satellites so that he can take actions to protect these resources. This feature will not be incorporated into the prototype.

System Performance

Because the time critical nature of space system restoration management forces CINCSPACE to depend on an automated decision aid, it is imperative that the decision aid generate good restoration plans quickly. The time required to "solve" the restoration problem is a function of the number of space systems and resources involved, the number of status changes made, the speed of the computer, and the degree of complexity of the output products requested. While there are additional measures of performance that would be analyzed in an operational space system restoration management decision aid, this research only examines the time required to generate the best possible plan. The time required for the prototype to solve the restoration problems is presented and analyzed in Chapter VII.

Conclusion

This chapter presented a long list of requirements for an operational space system restoration management aid. This list is by no means exhaustive, but should serve to highlight many of the features desirable for such a decision aid. Whether such features are feasible is the subject of the next chapter. After introducing the field of Artificial Intelligence and knowledge-based systems, Chapter IV examines several applications of knowledge-based systems to military battle management problems. Many of these battle management problems have requirements similar to those outlined above for a space system restoration management system.

IV. Artificial Intelligence Knowledge-based Systems

Artificial Intelligence

In simple terms, "artificial intelligence is the study of how to make computers do things at which, at the moment, people are better" (35:1). A relatively new field of computer science with its origins in the early 1960's, AI combines symbolic processing and human problem solving (22:2). AI techniques have been developed for use in the areas of game playing, theorem proving, general problem solving, perception (speech and vision), natural language understanding and expert problem solving (35:3).

In the early days of AI, researchers tried to simulate the complicated process of human thinking by finding general methods for solving broad classes of problems (47:3). Experiencing little success with general purpose programs, researchers turned their attention to specialized programs with narrower problem domains. During the 1970's, AI scientists laid the groundwork for a breakthrough by investigating ways to formulate problems so they would be easy to solve and finding ways to reduce the computer time and memory required by cleverly controlling the search for a solution (47:4). The real breakthrough in AI came in the late 1970's when researchers realized that the problem solving power of an AI program comes from the knowledge it possesses. Donald Waterman explains this breakthrough as follows: "To make a program intelligent, provide it with lots of high-quality, specific knowledge about some problem area" (47:4).

Knowledge-based Systems

The realization that AI programs derived their power from knowledge led to the emergence of "knowledge-based" or "expert" systems. A knowledge-based system is "a computer program that is able to draw conclusions and/or recommend actions in a narrowly defined field of expertise, based upon evidence that the system has at its disposal" (29:6). The use of AI techniques in knowledge-based systems enables computers to assist people in analyzing problems and making decisions.

Knowledge-based systems have been developed to solve many different kinds of problems, but their basic activities can be grouped into the categories of interpretation, prediction, diagnosis, design, planning, monitoring, degugging, repair, instruction and control (47:33). Knowledge systems tend to perform better in narrow problem domains because all of the knowledge and inferencing strategies must be programmed into the knowledge system, and the "common-sense" reasoning required for large problem domains is difficult, arduous, and often impossible to imbed in a knowledge system. Knowledge systems are well suited to higher-level skills, such as problem-solving and logic, because unlike common-sense reasoning, these processes can be mechanized fairly easily (21:45).

In order to generate solutions to problems, knowledge systems employ rules and various search techniques to extrapolate new facts based on the facts in the data base. Conventional problem-solving techniques, such as those used in the field of Operations Research, emphasize the procedural, algorithmic way of solving problems, and ignore domain-specific knowledge that might hasten the solution process (21:44). Knowledge systems employ heuristics, "rules of thumb" about how to proceed, in order to limit the size of the space that must be searched for a solution (47:17). Because of this feature, knowledge systems can cope, in a timely fashion, with large problems that would take a considerable amount of time to solve algorithmically (21:45). The field of knowledge engineering in AI involves the process of extracting from human experts their procedures, strategies, and rules of thumb for problem solving, and builds that knowledge into a knowledge system (47:5).

Military Interest in AI

The Department of Defense is highly interested in the potential military applications of AI, and has funded the majority of AI research over the past ten to fifteen years (1:479). Such DOD organizations as the Defense Advanced Research Projects Agency (DARPA), the Army Research Institute (ARI), the Air Force Office of Scientific Research (AFOSR), the Naval Research Laboratory (NRL), and the Rome Air Development Center (RADC) have sponsored AI projects in the areas of planning, decision-aiding, computer-aided instruction, data base management, image understanding, navigation, guidance, computer-aided design and manufacturing, automated programming, and command and control (1:480,481). In 1983, DARPA launched the largest program in computing technology in the US, a ten year AI research effort called the Strategic Computing Initiative (44:696).

The Strategic Computing Initiative, designed to develop machine intelligence technology, incorporates developments in both the hardware and software aspects of computer science. Three major projects comprise the initiative: an autonomous land vehicle for the Army, a pilot's associate system for the Air Force, and an aircraft carrier battle management system for the Navy (44:691). The autonomous land vehicle project was designed to develop sophisticated robotic devices that would sense and interpret the environment, accept commands, and plan their way around obstacles to carry out their missions (44:691). The pilot's associate will be an intelligent aid to a pilot, and will be trained by the individual pilot user to respond to different situations.

The aircraft carrier battle management system is the most applicable of the three projects to this thesis effort. Designed to operate in a large military engagement, the aircraft carrier battle management system features decision making under uncertainty and the resolution of multiple conflicting goals (44:692). The battle management system assesses the battle situation, hypothesizes about enemy intent, and generates alternative plans of action. In order to tackle this large problem, DARPA divided the program into phases which will be addressed separately and then integrated into the overall battle management system. The first phase of DARPA's battle management program is the development of the Force Requirements Expert System (FRESH). Designed to aid the command and control functions of the Navy's Pacific Fleet, FRESH will monitor fleet readiness and provide advice when readiness problems develop (46:3). DARPA expects that the system will provide a rank ordered list of alternatives when a problem is identified, and will assess the impact of each of the alternatives (46:4).

Battle Management Knowledge Systems

Aside from the DARPA naval battle management system, the DOD has initiated many other battle management projects. Most of these projects are currently under development, and some have already produced working prototype knowledge systems. The knowledge system projects in battle management fall into four of the categories listed earlier as general areas of application for knowledge systems: diagnosis, interpretation, planning and prediction. Of interest to this thesis research are the knowledge systems that perform planning.

Research into AI planners began much later than research in the diagnosis and interpretation areas. T.J. Grant, of the Knowledge-based Planning Group at Brunel

University, describes planning research as the next "hot success" area in AI (21:43). A typical AI planner generates a plan as a sequence of actions (15:191). Planning the sequential operations of the available forces will be the crux of any large battle management knowledge system; the planner will require inputs from those portions of the system performing identification, classification, situation assessment, and prediction of enemy intent.

The remainder of this chapter is devoted to describing several military planning systems that utilize AI techniques applicable to a space system restoration management decision aid. Table 4.1 presents the major planning system requirements for the prototype, and shows how the five knowledge-based systems that were researched are similar to the prototype system.

Table 4.1
Comparison of Current Systems to Prototype System

	Planning System Capabilities				
System	Allocate Resources	Involve Time Constraints	Produce Ranked Alternatives	Use Heuristics	Handle Uncertainty
KBS	yes	yes	yes	yes	no
TEMPLAR (KNOBS)	yes	yes	yes	yes	no
Sleuth	no	no	no	no	yes
TATR	no	yes	yes	no	yes
BATTLE	yes	yes	yes	yes	yes

KBS. Under the sponsorship of RADC, the MITRE Corporation developed a knowledge-based planning system called KBS as a demonstration interactive system to assist the staff officer in developing a set of alternative plans in response to a crisis situation (2:x). The scope of the effort was limited to one scenario, an Air Force Show of Force. To keep KBS unclassified, MITRE used data from military assets in the southwestern US. The states in this region were treated as hypothetical, friendly and unfriendly countries (2:4). Given the basic parameters of the scenario (location of threat, site for Show of Force, the forward operating base, and the number of aircraft required), KBS plans the Show of Force deployment of aircraft from a supporting "country" to a main operating base in a threatened "country."

KBS is interesting because many of its requirements are similar to the requirements outlined in Chapter III for a space system restoration management decision aid. Also, many of the features MITRE has identified as desirable for an operational system, but have not included in the prototype KBS system, match those that this thesis effort also leaves to further research. MITRE accomplished all of the major goals set for the KBS system, and these goals, as stated in "KBS: An Expert Planning System for Crisis Response" were as follows:

"-- Develop crisis action plan alternatives

-- Develop partial plans

-- Check existing crisis action plans

-- Provide an interactive user-controlled system

-- Explain plan choices as required

-- Allow for user supplied additional constraints

-- Allow for user override of any decision

-- Use limited data base, limited scenarios" (2:3).

To perform crisis action planning, KBS uses concepts originally demonstrated in the NOAH planning system developed by Sacerdoti. These concepts include: (1) the use of a plan hierarchy: a step-by-step development of plans from a high level of abstraction down to the finer details, (2) deferred time ordering: the development of the major components of the plan first so that their properties can be used in the timing and ordering of successive plan actions, and (3) introspection and modification of plans: the correction of the plans that had originally been developed without details (2:9). With the hierarchical planning process, KBS seeks to model the human planning process. People typically plan by first developing an overall plan with a set of possible alternatives, and then filling in the details.

To find the best plan, KBS used a heuristic search technique based on the expected rating of the various alternatives. KBS develops alternative plans simultaneously, and allocates its computational resources according to the perceived difficulty of making each plan feasible (2:16).

This search technique also guarantees that the optimal plan will be found, even if the optimal plan was not initially promising.

KBS is implemented on the Interlisp System and uses the Frame Represention Language (FRL) to represent knowledge about the various resources (aircraft, airbases, etc.) in the problem (2:20). The representation of facts in frames is common in knowledge-based systems, and the use of frames is further described in Chapter VI. KBS also contains a geographic data base, a library of rules, and a data structure to represent the plans generated by the system.

The rules in KBS contain knowledge about the selection of steps in the planning process. A rule in a knowledge-based system contains a template and a body, and can be thought of as "if xx, then yy." If the template matches a given set of facts (xx), then the body of the rule is carried out (yy). KBS uses rules to generate successive planning steps and determine if plans are feasible.

KBS uses a tree structure to represent the various plans generated. The levels of the "plan tree" represent different levels of abstraction of the plan (2:25). Alternative plans are contained in the tree as additional branches from each plan step.

The user interface in KBS uses several of the features suggested in Chapter III as desirable for a decision aid. KBS allows the user to control the display of alternative plans, selectively display the explanations about the alternatives, and directly query the data base. KBS was not developed with a graphics capability, although MITRE deemed this a requirement for an operational crisis action planning aid.

MITRE maintains that the KBS system has a general architecture that can be modified to fit many military crisis planning problems. Though KBS met all of MITRE's initial goals, MITRE has suggested more research to fully demonstrate the feasibility of a KBS system in the operational environment. MITRE states that "for users of military planning systems to be convinced that any new system is valuable, actual involvement of the system in realistic situations must be demonstrated" (2:xii). MITRE also recommends that the system be developed on a dedicated computer with strong graphics support, and that the development system interface with military data networks so that it can directly access the required data (2:xii).

KNOBS. A knowledge-based system called KNOBS was developed by the MITRE Corporation prior to the development of KBS. Intended as an experimental aid for Air Force tactical mission planning at the Tactical Air Control Centers, KNOBS uses information about targets, resources, and mission plans to develop an "Air Tasking Order" (ATO) for each of the units involved (16:451). This ATO tells how many and what kind of aircraft to use, what ordnance each plane should deliver, and at what time each sortie should be flown (16:451). In addition to planning the missions, KNOBS checks that each plan generated is consistent with other mission plans.

TEMPLAR. The Air Force instituted a follow-on project to KNOBS, called TEMPLAR. TEMPLAR is significant because it is the first AF project in expert systems to move from research and exploratory development into advanced development (38:1-1). KNOBS was used as the foundation of the TEMPLAR architecture, but the scope of TEMPLAR far exceeds that of KNOBS.

TEMPLAR's goal is to help AF personnel "achieve the most effective employment of tactical air power within a joint theater of operations" (38:2-17). Basically a large scale resource allocation planner, TEMPLAR has many similar requirements to the proposed space system restoration management decision aid.

First, TEMPLAR's focus is on reducing the overall planning time required to produce the ATO's. Great emphasis is being placed on the speed of the computer selected for implementation, the time the computer spends performing the various tasks, and the time the computer spends searching. Advanced Information and Decision Systems, the organization RADC has contracted with to design and develop TEMPLAR, has determined that TEMPLAR requires a dedicated computer for the above reasons.

TEMPLAR generates alternative resource allocation plans, and must employ a search strategy to limit the number of plans tested. The mechanism used in TEMPLAR to reduce the search space is based on the properties of TEMPLAR's template-based instantiation approach (38:6-68). Since TEMPLAR seeks to fill in those slots of a template required to complete an ATO plan, many of the plans that need to be tested are incomplete. TEMPLAR goes about the filling in of these slots in an intelligent way in order to avoid investigating bad solutions (38:6-69). For example, if only one value needs to be filled in for a constraint (rule) to be instantiated, TEMPLAR will "invert the constraint" to determine the list of values for the remaining slot which would not violate the constraint (38:6-70). By eliminating numerous values in this way, several bad candidate plans are not even generated. This heuristic search technique was used in KNOBS with great success (38:3-14).

Probably the most significant contribution of TEMPLAR's design to this research effort is TEMPLAR's use of heuristics within the rules and constraints to ensure that "effective" plans are produced. TEMPLAR seeks to do more than just satisficing, and tries to find solutions which meet the collection of heuristics for good resource use embedded in the rules (38:6-68). Such rules are called "soft constraints" since they indicate preferences for the use of certain resources over others. "Hard rules" are pure productions, and the right hand side of these rules are carried out explicitly.

Sleuth. One of the basic requirements of a space system restoration management decision aid is the capability to reason with incomplete and imprecise information. Knowledge-based systems can deal with incomplete information through a variety of mechanisms, and a significant amount of research is currently underway to refine these techniques and develop new ones. The method of rule simplification has been proposed by Steven Rosenberg of the Artificial Intelligence Laboratory at the Massachusetts Institute of Technology, and Rosenberg has implemented his method in a program called Sleuth. Rule simplification is the process of creating goals that require only a subset of assertions that the original rule required when insufficient data is available (36:2).

Rosenberg designed Sleuth as an extension of Planner, a traditional reasoning program. He maintains that special mechanisms are required to insure that inferencing proceeds correctly when the real-world problems of data incompleteness and instability make the traditional reasoning process break down (36:2). The Sleuth system is "an approach to the interpretation and construction of reasoning rules which allows them to be used sucessfully in certain types of real-world domains" (36:3).

The Planner system Rosenberg based his Sleuth system on has a simple strategy when faced with incomplete information: if a rule cannot "fire" (become instantiated) because a particular fact in the "if" portion of the rule is not in the data base, Planner will try and prove the missing fact. If Planner cannot prove the fact by using other rules, the inference attempt fails (36:9). It is important to note that the rule fails because of insufficient information, not because the inference is wrong for the situation.

Recognizing the inadequacy of this inferencing strategy in a real-world problem domain, Rosenberg created his "rule simplification" and implemented it in Sleuth. Simply, if a rule cannot fire because of incomplete information, Sleuth first tries to deduce the missing fact(s) just as Planner does. But, if this method fails, then Sleuth uses other "last-resort" rules that can operate on the limited information that is available. Rosenberg emphasizes that one must be willing to make assumptions to use these simpler rules, and they are not equivalent to the original rules. Further, the simplified rules are not to be used as sub-goals in the original rule; they replace the original rule when insufficient data precludes the use of the original rule (36:9). In order to implement rule simplification, rules about rules (usually called metaknowledge) must be invoked to determine when the simpler rules can and should be applied.

TATR. Another knowledge system planner currently under development is the Tactical Air Targeting Recommender (TATR). Developed by RAND Corporation, TATR is an aid to help tactical air targeteers plan strikes on enemy airfields. TATR rank orders enemy airfields on the basis of expected damage to the enemy's capability, determines which airfield and specific targets at the airfields to attack, and recommends which weapon systems will be most effective against the targets (7:v). Designed to be a decision aid to the targeteer, this system has a powerful "look ahead" capability to determine the potential effects of one plan or a series of plans.

TATR uses a dynamic updating capability to ensure that the system recognizes and allows for the changing battle environment. As the program runs, the status of the various elements are dynamically updated. Then, after the airstrike has been carried out and intelligence reports on the damage are available, the user can input the actual changes in the status of the enemy's assets. However, if no intelligence information is available after a strike, and TATR is called on to plan the next airfield strike, the system will project the effects of the attack, and reflect these estimated changes in the data base. This feature demonstrates how TATR accomodates the possibility of incomplete information, and uses surrogate information to temporarily replace actual information.

<u>BATTLE</u>. Designed to improve the US Marine Corp's Marine Integrated Fire and Air Support System (MIFASS), the BATTLE knowledge system recommends target allocation plans. Given information on the weapons, targets, and battlefield situation, BATTLE starts off the allocation process by computing the effectiveness of each weapon-target pair. These calculations are performed by a "computation network" that involves 55 factors relating to the scenario. Using

the results of the effectiveness calculations, BATTLE generates and evaluates complete allocation plans.

The method by which BATTLE searches and prunes (i.e. eliminates certain unprofitable paths) the search tree is significant to this thesis effort; BATTLE's developers call the method a "pruned traversal of an allocation tree" (40:2). The following explanation of BATTLE's search and pruning process is taken from Decision Support System for Fire Support Command and Control by J. R. Slagle, M. W. Gaynor, and H. Hamburger of the Navy Center for Applied Research in Artificial Intelligence (40).

To explore all the possible allocation plans in the attempt to determine the optimal plan for a battlefield, a weapon allocation tree is used (40:10). This weapon allocation tree is broken into levels, with each level, corresponding to the use of a different weapon. Therefore, the number of levels equals the number of weapons available for deployment. Figure 4.1 shows the weapon allocation tree for a situation with two weapons (weapon 1 and weapon 2), and three targets (T1, T2, and T3).

As shown in figure 4.1, four branches emanate from the root node. The first three of these brances correspond to the allocation of weapon 1 to T1, T2, and T3. The fourth branch represents the case where weapon 1 is not allocated to any target. Four branches then emanate from each node in level one to represent the allocations of weapon 2. Again, there are four possibilities for target allocation

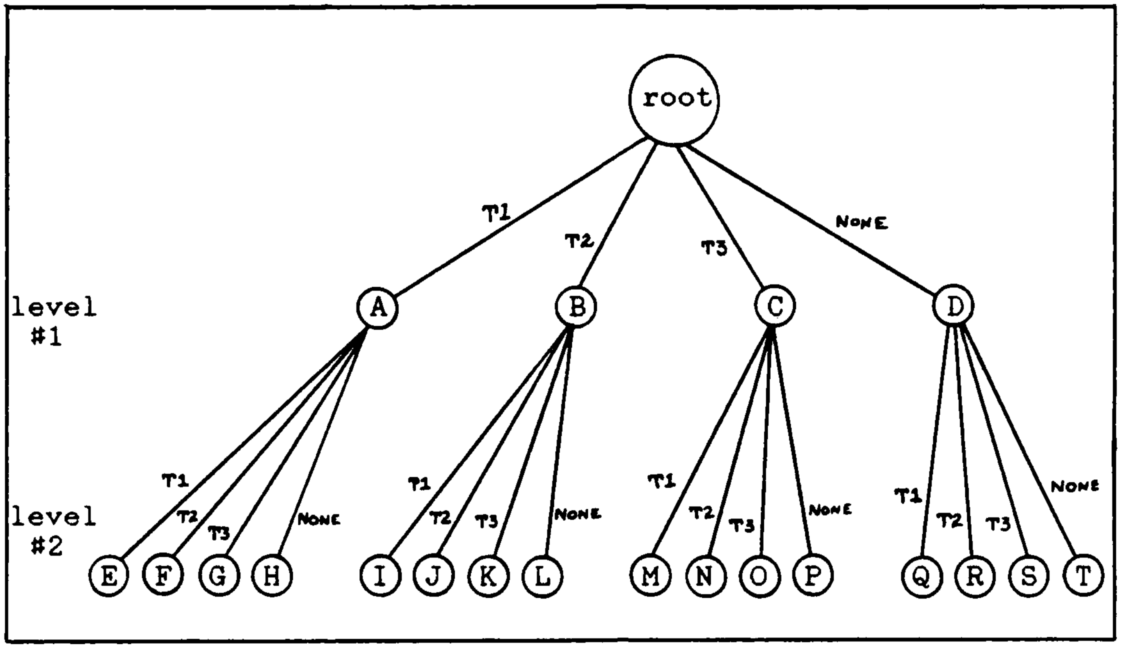

Figure 4.1 Weapon Allocation Tree

for weapon 2. A complete allocation plan is represented by a path from the root node to one of the nodes in level two, which are called "leaves" (there are no descendant nodes from leaves). The massing of several weapons on a single target is represented by a path that for some i, includes the i^{th} branch at each of several nodes on the path (40:11). For example, the path from the root node to leaf E represents the massing of both weapons 1 and 2 on target 1.

The number of leaves on the tree is $(t + 1)^w$, with t the number of targets, and w the number of weapons. The number of leaves corresponds to the number of different allocation plans that would have to be searched to determine the optimal plan. To limit the search space, but still find the optimal solution, BATTLE uses the following pruning algorithm during the tree traversal.

Since BATTLE will produce the k best allocation plans, with the user specifying k, the system must first find k different allocation plans (40:11). Then, BATTLE will evaluate other partial plans to determine if they can be completed to outrank one of the k best plans so far. In Operations Research, this technique is called branch and bound. When a complete plan is found that outranks a plan on the list of the k best plans, the list is altered to include this new plan.

> The pruning algorithm requires, for each type of weapon, the specification of a fighting capacity: the maximum destruction by that weapon type against any target in any circumstance. To see if a partial allocation plan should be pruned, its expected destruction is added to the combined fighting capacities of the weapons remaining to be used in completing the partial plan. If this sum does not exceed the expected destruction from the least destructive of the k complete plans currently on the tentative solution list, no attempt is make to complete the partial plan (40:11).

To further maximize the expected amount of pruning, the weapons and targets are each ordered in decreasing value (40:11).

BATTLE also incorporates special features for cutting off the reasoning process and still obtaining a near-optimal solution if time constraints force the user to stop the program prematurely, and allowing the user to state his own target-weapon preferences to be considered in the planning.

V. Methodology

Overview

The methodology used in this research effort consisted of seven major tasks: (1) developing the generic space systems to serve as the knowledge base, (2) selecting an appropriate programming environment for the decision aid, (3) determining the objective function that would be used to evaluate the restoration plans generated by the decision aid, (4) developing the system design and the restoration rules, (5) programming the knowledge and rules in the programming language selected, (6) testing the system with different scenarios, and (7) analyzing the outputs to determine if artificial intelligence techniques can be effectively applied to the space system restoration mangagement problem.

Design of Generic Space Systems

The first major task of this research effort was to develop simplified, generic space systems as inputs to the prototype decision aid. As noted previously, these simplified systems were used in lieu of operational military systems for two reasons: (1) to keep the research unclassified, and (2) to simplify the technical considerations not bearing directly on the resource allocation problem. The following section outlines the assumptions made about the configuration and operation of the navigation, weather, and communications systems developed for use with the decision aid.

General Framework and Assumptions.

Orbits. Every satellite in this research effort, regardless of mission, is assumed to be in an equatorial geosynchronous orbit. A geosynchronous orbit is a circular orbit with an altitude of 37,700 kilometers (equivalent to six earth radii) and a period of 24 hours (8:50). If a satellite is placed in a geosynchronous orbit near the equator, the satellite essentially remains over the same place on the earth. Because of its altitude, a geosynchronous satellite has a field of view covering more than 80% of the hemisphere beneath it (8:50). Therefore, several satellites spaced evenly around the equator can provide coverage of the entire world, except for the polar regions (8:50). Figure 5.1 shows how four geosynchronous satellites provide worldwide coverage of latitudes between 80°N and 80°S. Because of this large field of view and the absence of tracking problems with geosynchronous satellites, most US communications satellites use geosynchronous orbits.

While some US military satellites occupy orbits other than geosynchronous (e.g. low earth orbit, Molniya orbit, semi-synchronous orbit, and super-synchronous orbit), the geosynchronous satellite's stable location with respect to the earth makes orbital calculations easy. Since satellites in other orbits require detailed orbital calculations to determine their location and field of view at a given time and such calculations are beyond the scope of this project, geosynchronous orbits were chosen for all satellites.

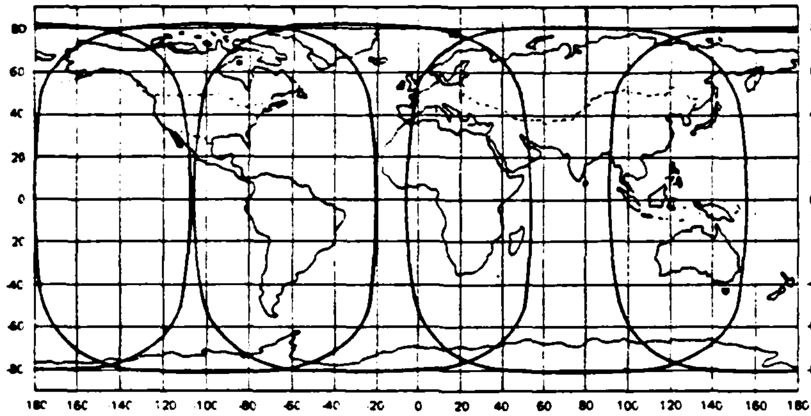

Figure 5.1

Earth Coverage with Geosynchronous Satellites (8:62)

Locational Representation. For the purpose of this research, the earth is divided into 36 areas, each spanning 10° in longitude, and extending from pole to pole. The locations of satellites and earth terminals are then referenced by their area number, with area 1 beginning at 180°W and extending to 170°W. Area 2 lies between 170°W and 160°W, and so on. A satellite that spans areas 1 through 13 is located over the equator at the center of area 6, and has a field of view to all points in areas 1 through 13. Figure 5.2 gives a summary of the locations of all satellites and earth terminals used in this effort, and demonstrates the area reference scheme.

Since it is assumed that a satellite can see all terminals in a particular area, only the area number of the earth

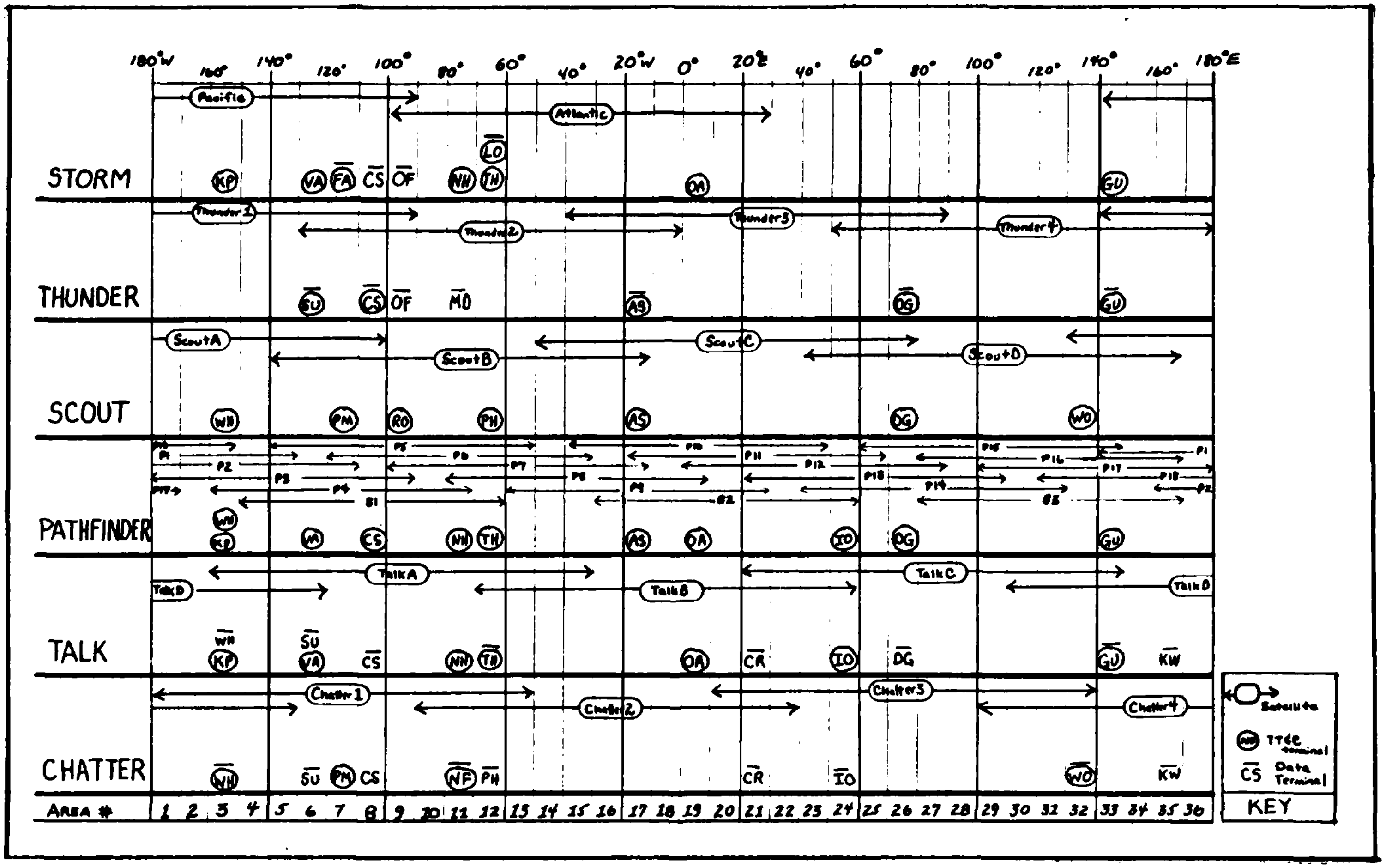

Figure 5.2 Space System Configurations

terminal need be referenced. The area number of a terminal is determined by the longitudinal coordinate of the terminal; the latitudinal coordinate is of no consequence. Appendix A contains information on the coordinates and locations of all earth terminals referenced in this thesis. Hereafter, the location of satellites and earth terminals will be referenced by area number.

Earth Terminals. Satellite system earth terminals are ground facilities that perform one or both of the following functions: (1) tracking, telemetry and command (TT&C), and (2) satellite payload data receipt, processing, and (in the case of communications system terminals) data transmission. The majority of terminals that perform TT&C functions are dedicated to that task, although some terminals also perform data functions.

TT&C functions refer to actions applicable to controlling the orbit and altitude of a satellite, monitoring the status of all sensors and subsystems on the satellite, and tracking the satellite (33:63). All satellites, regardless of their mission, require TT&C (12:5-21).

During normal operation, the telemetry system collects data from the various sensors aboard the satellite that monitor such things as the pressure in the fuel tanks and the amount of current drawn by each subsystem (33:63). Then, this "state-of-health" data is transmitted down to the controlling earth station on a frequency used strictly for this purpose. To control the satellite, the TT&C terminal transmits commands to a satellite at another dedicated frequency. Although the command and telemetry links are usually separate from the mission (payload) frequencies, they may operate in the same frequency band (33:65).

Since all satellites in this research effort are assumed to have geosynchronous orbits, and the earth terminals that each satellite can "see" remain constant, it is assumed that each satellite requires only one TT&C terminal to provide the required TT&C service. It is also assumed that one TT&C terminal can service up to three different satellites for each TT&C antenna it has, provided the satellites do not need constant TT&C monitoring. Different satellites require different amounts of TT&C servicing, but usually not enough to preclude one terminal from servicing three separate satellites during one day.

The data function of an earth terminal depends on the mission of the space system it services. In a communications system, data signals are transmitted between earth terminals and satellites. In a weather system, the satellites collect meteorological information and downlink the data to a receiving earth terminal; no uplink of information is required, except for TT&C information. Similarly, navigation satellites only transmit signal data down to earth-based receivers. Navigation systems do not even require fixed location data terminals, as weather systems do.

This research effort assumes that a "data" terminal can receive data for only one system at a time. For example, if an earth terminal is dedicated to receiving meteorological data from weather system A, then it cannot simultaneously receive weather data from satellites in system B. However, if the earth terminal is capable of receiving the weather information from the satellites in system B because the frequencies and other parameters are compatible, then it may give up receiving data from system A and transform itself into a system B receiver. This assumption also applies to communications data terminals.

Interoperability. As discussed in Chapter II, currently only a small degree of interoperability exists between space systems. To demonstrate the full potential of a space system restoration management decision aid, this research effort assumes interoperability between systems to a larger degree than what is actually possible today. For this research effort, satellites and earth terminals are considered compatible if they share at least one frequency. This assumption grossly underestimates what is required for actual systems to be interoperable. In reality, polarizations, data rates, access techniques, modulation techniques, and a host of other factors must be compared to determine if resources from different systems are compatible. However, the purpose of this research is to demonstrate a methodology for space system restoration management, and the number of parameters the systems checks is not important. Whether the prototype checks one or sixteen parameters to determine interoperability, the restoration methodology is the same.

Because satellites are designed for specific missions, they cannot assume the functions of satellites that perform missions different from their own. A satellite will not even be able to take over for a satellite with a similar mission if the operating parameters are not compatible. This research assumes that there are only two ways to restore capabilities if a satellite is inoperable: (1) activate a spare satellite already in orbit for that space system, or (2) attempt to use the resources of another satellite system, provided it has the same mission.

Air Force Satellite Control Network. Most of the TT&C functions for US military satellites are perfomed by the seven remote tracking stations (RTS) of the Air Force Satellite Control Network (AFSCN). The heart of the AFSCN is the Satellite Test Center (STC) located at Onizuka AFS, CA (formerly Sunnyvale AFS). The seven remote tracking stations are modeled in this research effort as dedicated TT&C earth terminals, and the operational parameters attributed to each earth terminal are as close to the actual parameters as possible, within the confines of the assumptions stated in the last section.

The remote tracking stations all employ standard Space-Ground Link Subsystem (SGLS) equipment, and support downlink telemetry in the 2200 to 2300 Mhz frequency band (41:3-4). All stations can provide uplink support in the

1750 to 1850 Mhz band (41:1.7-1) All stations have two high performance TT&C antennas, except for the Indian Ocean and Oakhanger stations which each have only one antenna.

In this thesis, it is assumed that all of the RTS antennas are identical, and are capable of operating at the frequencies listed above. For details on the locations and parameters of the remote tracking stations as they are modeled, see Appendix A.

Space Systems. Six generic space systems were developed for use with the prototype decision aid: two communications systems, two weather systems, and two navigation systems. The configurations and operational parameters of these systems were patterned after five currently operating space systems and one system under development. Table 5.1 presents the orbital and configuration data on the six space systems that serve as the basis for the simplified systems: the Defense Satellite Communications System (DSCS), the Fleet Satellite Communications System (FLTSATCOM), the Defense Meteorological Satellite Program (DMSP), the civilian GOES meteorological system, Transit, and the Navstar Global Positioning System (GPS).

TALK Communications System. The TALK communications system was patterned after the DSCS system. The DSCS II system consists of four active satellites and two spares in geosynchronous orbits (12:12-2). The TALK system was designed with only four active satellites, spaced evenly around the world, and no spares. Each TALK satellite was

Table 5.1

Systems Used as Basis for Generic Systems (8:59,66,67)

System	Mission	Orbit	# Sat's*	Thesis System
DSCS	comm	geosynchronous	4-6	TALK
FLTSATCOM	comm	geosynchronous	4-6	CHATTER
DMSP	weather	low earth orbit	2	STORM
GOES	weather	geosynchronous	4	THUNDER
Transit	nav	low earth orbit	5	SCOUT
GPS	nav	semi-synchronous	18	PATHFINDER

* denotes nominal constellation size (actual or planned) or average active population

given a 130° coverage area width, which is equivalent to 13 areas. As shown in Figure 5.1, a geosynchronous satellite has a field of view of approximately 150°, so the width of the coverage area used in this effort is a conservative estimate. Unless otherwise noted, all generic satellites used in this thesis have a coverage width of 13 areas.

Since the AFSCN performs all TT&C functions for the DSCS satellites, the RTS's in this research effort were given the same responsibility for the TALK satellites. The frequencies assigned to the TALK system match those used by DSCS. Finally, TALK was designed with six data terminals, placed worldwide in strategic locations to act as data relay stations. Appendix A contains the details on the TALK communications system.

CHATTER Communications System. The CHATTER communications system was modeled after the FLTSATCOM system which performs worldwide communications for DOD strategic and tactical users. There are currently four operational FLTSATCOM satellites, located in geosynchronus orbits in close proximity to the four DSCS satellites.

CHATTER's frequencies were derived from FLTSATCOM's general operating frequency ranges (SHF, UHF). Since FLTSATCOM is operated by the Naval Electronics Systems Command, the FLTSATCOM satellites do not rely on the AFSCN for TT&C service. FLTSATCOM has its own dedicted TT&C terminals. To reflect this, CHATTER uses four dedicated earth terminals to perform TT&C functions. However, the CHATTER TT&C frequencies are compatible with those used at the AFSCN remote tracking stations, so the remote tracking stations may be used for TT&C backup. See Appendix A for the details on CHATTER's satellites, earth terminals, and operating parameters.

STORM Weather System. The STORM weather system was modeled after DMSP, which was designed to meet the unique military requirements for weather information. Two DMSP satellites orbit in 850 km near-polar sun-synchronous orbits. Because these satellites orbit nearer the earth than geosynchronous satellites, they provide much more detail than weather satellites in geosynchronous orbits. DMSP's two main earth terminals are located at Loring AFB, Maine and Fairchild AFB, Washington. These terminals perform all TT&C operations for the DMSP satellites, and also function as the downlink data terminals for weather data. Air Force Global Weather Central, located at Offutt AFB, Nebraska, is the primary user for DMSP information, although the data is also available to the National Oceanic and Atmospheric Administration (NOAA) (28:141).

STORM was not patterned after DMSP as closely as TALK and CHATTER were patterned after the operational communication systems because of the geosynchronous orbit assumption. First, STORM was designed with only two satellites in geosynchronous orbits, one located over the Pacific Ocean, and one located over the Atlantic Ocean. Second, with only two satellites, STORM does not provide the worldwide coverage that DMSP does. However, STORM's frequencies match those used for DMSP and STORM can use the AFSCN remote tracking stations for backup TT&C, as DMSP can. Under normal conditions, earth terminals at Loring AFB and Fairchild AFB provide TT&C service for the two STORM satellites. For more details on STORM's satellites, terminals, and operating parameters, see Appendix A.

THUNDER Weather System. The THUNDER weather system was patterned after GOES, a civilian weather satellite system. There are four GOES satellites in equatorial geosynchronous orbits spaced around the earth to provide worldwide weather coverage. The THUNDER system was designed with its own dedicated TT&C terminals, and the TT&C frequencies preclude the use of AFSCN resources for backup. The weather information obtained by THUNDER is transmitted at the same frequency that STORM uses to transmit its weather information.

SCOUT Navigation System . The SCOUT navigation system was patterned after the Navy's Transit system, an all-weather passive navigation system that has been in use since 1964 (12:12-7). With the Transit system, the user listens to how the received frequency of the signal changes as the transmitting satellite passes from horizon to horizon to determine his location (8:65). There are four Transit satellites in low earth orbits, and each satellite continually broadcasts signals at both 150 Mhz and 400 Mhz. Transit's ground segment consists of four dedicated TT&C stations, located at Prospect Harbor, Maine; Rosemount, Minnesota; Point Mugu, California; and Wahiawi, Hawaii.

The SCOUT system was designed with the same frequencies and number of satellites as Transit, but the SCOUT satellites were given geosynchronous orbits. In reality, Transit could not function as a navigation system if its satellites were in geosynchronous orbits; the doppler shift would not be sufficient to be observed by the earth platforms. Since earth-based platforms need to see only one Transit satellite to obtain navigation information, this research effort assumes that earth-based platforms can obtain navigation information if they can see at least one SCOUT satellite. For more details on SCOUT, see Appendix A.

PATHFINDER Navigation System. The PATHFINDER navigation system was modeled after the Navstar Global

Positioning System. When GPS is fully operational, it will consist of 18 active satellites and 3 on-orbit spares, all in semi-synchronous orbits. Each satellite will continually transmit two L band signals, L_1 at 1575.42 Mhz, and L_2 at 1227.6 Mhz (18:E9.5.1). To determine his location and heading, a user must normally receive signals from four different GPS satellites. However, two or three satellites are sufficient for location determination if the user will accept less accuracy or has a system to aid GPS. Five widely separated monitor stations will track the GPS satellites to determine if they are operating correctly, and three of these stations will perform TT&C functions for all satellites (28:135). The AFSCN remote tracking stations will serve as backups for these TT&C stations (18:E9.5.1).

Even though the PATHFINDER system contains the same number of active and spare satellites as GPS, the configuration was significantly modified to accomodate the geosynchronous orbit assumption. An active PATHFINDER satellite is located over every other area, and the field of view for each satellite is limited to 90° in width from pole to pole. As shown in Figure 5.2, this configuration makes it possible for earth terminals in each area to see 4 or 5 active PATHFINDER satellites.

The PATHFINDER system uses the same frequencies and has monitor stations at the same locations as GPS. However, PATHFINDER must use all five terminals for TT&C servicing because the satellites are in geosynchronous orbits. The

AFSCN remote tracking stations will serve as backup TT&C facilities. For more details on PATHFINDER, see Appendix A.

Landline Network. This research effort assumes that data traffic (communications and weather information) can be transmitted via landlines if necessary. To model this assumption, a network of landlines between the earth terminals was developed. Each of the landlines is capable of two-way traffic, and there are no restrictions on the type, form, or volume of data that can be transmitted. This landline network is included in Appendix A.

Like the space system resources, the landlines are susceptible to enemy attack, and the prototype system allows for the destruction of these landlines. Additionally, when two earth terminals share the same location (e.g. at Wahiawi, Hawaii, there is a CHATTER earth terminal and a TALK earth terminal), it is assumed that communications data can be transmitted between the terminals, provided that the data capabilities at the terminals are still intact. This "cross-town" link is not assumed to be vulnerable to attack in this research effort.

Objective Function

The problem of space system restoration management involves multiple objectives; ideally, CINCSPACE would like to fully restore all mission capabilities. When space resources become unavailable during wartime, however, trade-offs must be made between the various missions. Questions like "Is it more important to restore communications capabilities than navigation capabilities" must be answered in order to properly allocate the remaining space assets.

To determine the impact of the various restoration actions and compare the different restoration architectures, a single quantitative measure is required. The quantitative measure, henceforth called the objective function value, must incorporate the multiple objectives of the space system restoration management problem.

Many techniques for multiple objective decision making use weights to combine attributes into a single indicator of value (25:725). This research effort uses the same approach, with the overall objective function a weighted summation of the different measures of effectiveness (MOEs) for the weather, navigation and communications missions.

Weather Measure of Effectiveness. The measure of effectiveness used for the weather mission is based on the number of areas the operating weather satellites cover with their fields-of-view. This weather MOE is composed of two parts: the percentage of weather coverage of the whole earth, and the percentage of weather coverage of the conflict area. All three mission MOEs are broken down into the global and conflict area components so that the decision aid can more precisely capture CINCSPACE's assessment of the resources that are critical to the current war objectives.

Thus, the weather portion of the overall objective function is:

global weather weight * (% global weather coverage)

+ conflict area weather weight *
(% conflict area weather coverage) (1)

Navigation Measure of Effectiveness. The navigation MOE in this research effort is based on the capability of airborne and earth-borne platforms to use the SCOUT and PATHFINDER navigation systems. As previously stated, airborne platforms that are unaided by other navigation systems require navigation data from at least four satellites in the PATHFINDER system to determine their position and velocity. Unaided earth-borne platforms require navigation data from at least three PATHFINDER satellites. Because of the doppler shift technique used in the SCOUT system, users of this navigation system require the data from only one SCOUT satellite to calculate position and velocity. Therefore, six separate MOE's and their respective weights will combine to form the total navigation MOE, as shown in the following formula:

global navigation weight *
[sub-wt$_1$ (% earth that can see 3 PATHFINDER satellites)
+ sub-wt$_2$ (% earth that can see 4 PATHFINDER satellites)
+ sub-wt$_3$ (% earth that can see 1 SCOUT satellite)]

+ conflict area navigation weight *
[sub-wt$_4$ (% conflict area that can see 3 PATHFINDER sats)
+ sub-wt$_5$ (% conflict area that can see 4 PATHFINDER sats)
+ sub-wt$_6$ (% conflict area that can see 1 SCOUT sat)]
(2)

The subweights in the formula (2) reflect the degree to which the user is depending on airborne, seaborne, and land-based platforms that use the PATHFINDER and SCOUT systems.

Communications Measure of Effectiveness. The communications MOE is based on the percent of pairs of critical nodes that are connected via the satellite communications and landline networks. In order to calculate this MOE within the confines of the knowledge in the prototype system, the world was divided into five theaters: America, Europe, Asia, Far East, and Pacific. Each of these theaters contains one or more major communication "ports." For example, the six ports in the American theater are located at Sunnyvale, Point Mugu, Colorado Springs, Prospect Harbor, and Thule. All ports have either a CHATTER or TALK data terminal (or one of each), and are connected to other ports with landlines. This research effort further assumes that each port serves as the central receipt and dispatch terminal for inter-theater communications for a certain service area. The size of the service area depends on the size of the theater and the number of ports within the theater. For example, if a person in Washington D.C. wishes to communicate with a node in England, the Norfolk port would handle the overseas transmission for the Washington D.C. user and the Crete port would handle the overseas transmission for the node in England. Table A.8 in Appendix

A lists the ports that provide communications service for each theater.

In the communications network developed for the prototype, there are 59 different pairs of inter-theater ports. Therefore, 118 paths are required for full communications capability (one forward, and one backward for each pair of ports). The global component of the communications MOE is the percentage of the 118 inter-theater port pairs that have a connecting communications path.

The conflict area component of the communications MOE is similar to the global component, but uses only those port pairs linking the American theater to the theater(s) corresponding to the conflict area. Therefore, the conflict area component is the percent of the critical pairs that actually have some communications path between the nodes.

Thus, the total communications MOE is as follows:

```
  global communications weight *
        (linked pairs / possible pairs of ports)

+ conflict area communications weight *
        (linked critical pairs / total critical pairs)  (3)
```

<u>Determination of Weights</u>. The weights assigned to the objective function are used to determine the overall measure of merit for each restoration architecture, and these weights must accurately reflect the priorites of CINCSPACE and the battle commanders he supports. While there are many weighting methods available, this research effort uses the Analytic Hierarchy Process (AHP) developed by Thomas Saaty.

Saaty describes AHP as "a flexible model that allows individuals or groups to identify, understand and assess the interactions of a system as a whole" (37:22). Through a simple mathematical procedure using matrices, AHP synthesizes judgements into an overall estimate of the relative priori- ties of alternative courses of action (37:24). AHP is especially suited to problems involving planning and resource allocation.

AHP contains the following four basic steps (49:96):

1) decomposing a problem and setting up a decision hierarchy of interrelated decision elements

2) collecting input data by making pairwise comparisons of the decision elements

3) using the "eigenvalue" method to estimate the relative weights of the decision elements

4) aggregating the relative weights of decision elements to arrive at a set of ratings for the decision alternatives.

The first step in applying the Analytic Hierarchy Process to space system restoration management consisted of breaking the problem down into separate elements to construct the hierarchical representation. Shown in Figure 5.3, the hierarchy for this problem contains four levels: focus, contributing missions, location emphasis, and navigation resource requirements. The fourth level applies only to the navigation mission.

The focus of the space system restoration management problem is wartime capability, and maximizing this measure is the overall objective of the planning process. Level 2

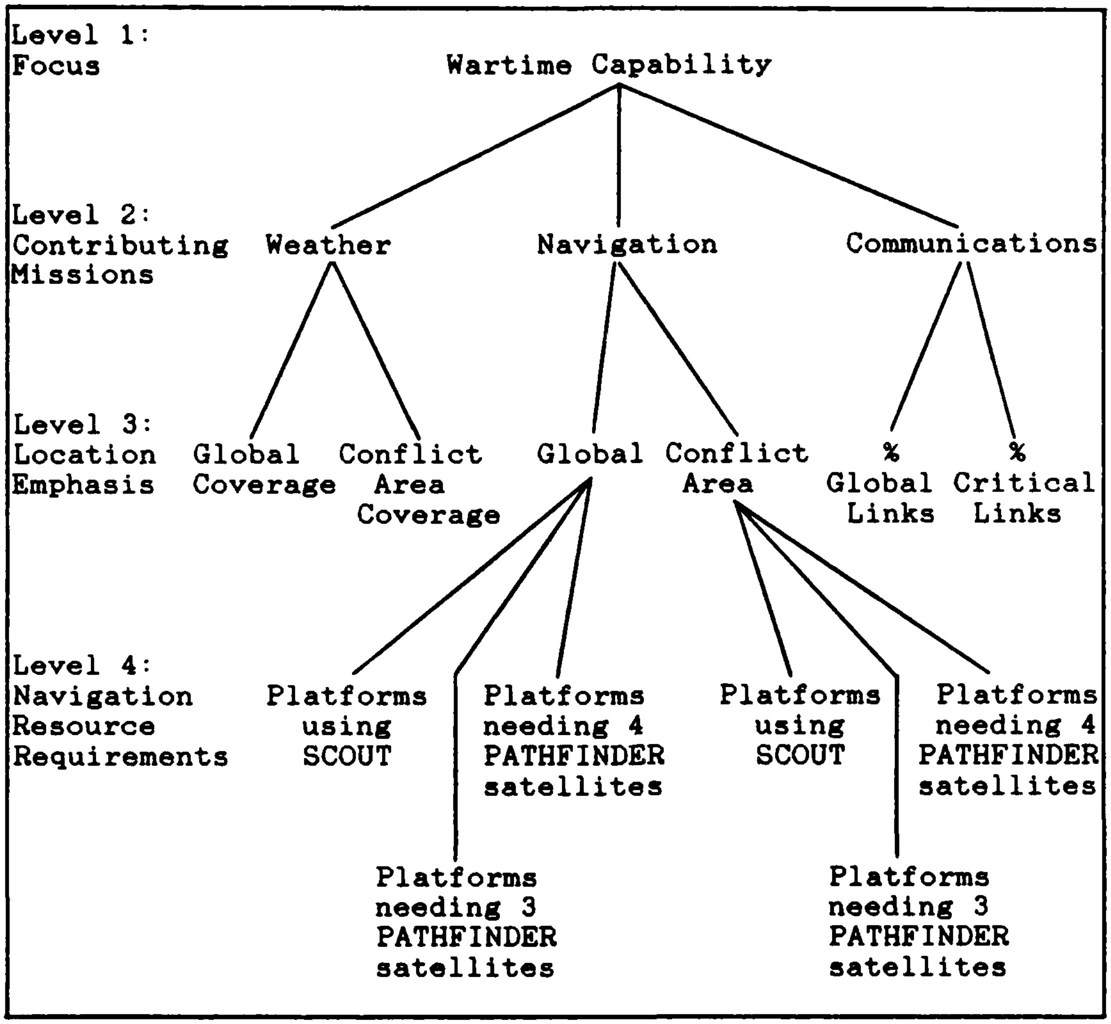

Figure 5.3 AHP Hierarchy

contains the missions performed by the space systems in this research effort; the accomplishment of these missions contributes to the overall wartime capability. Level 3 contains the global and conflict area components to the individual mission areas. Finally, level 4 contains the breakdown of the requirements for navigation satellite resources. Note that the bottom level of each branch of the hierarchy tree corresponds to one of the individual measures of effectiveness discussed in the last section.

Appendix B shows how the AHP can be used to compute the weights for use with the space system restoration management decision aid. The numbers used for the pairwise comparisons are hypothetical, and this research does not attempt to determine the actual priorities CINCSPACE would use in any one scenario. Figure 5.4 summarizes the results of the AHP weighting process by showing the AHP hierarchy and the weights assigned to each element, as derived in Appendix B.

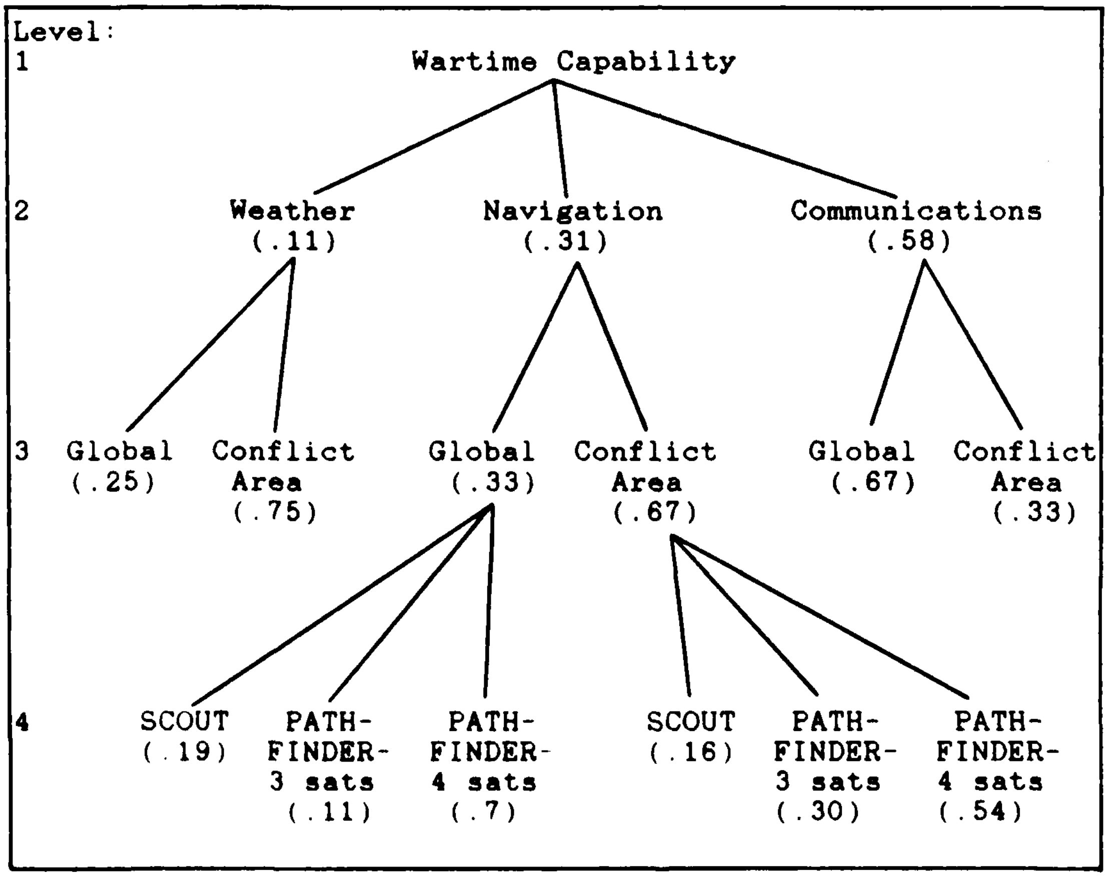

Figure 5.4 AHP Hierarchy with Weights

In this example, communications was determined to be the highest priority mission, navigation the second highest, and weather the lowest priority mission.

Using the weights from Figure 5.4, and combining equations (1), (2), and (3) yields the following total objective function:

```
  .11  [  .25 (% global weather coverage)
        + .75 (% conflict area weather coverage) ]

+ .31 {   .33 [  .19(% earth that can see 1 SCOUT sat)
               + .11(% earth that can see 3 PATHFINDER sat's)
               + .7(% earth that can see 4 PATHFINDER sat)]
        + .67 [  .16(% con area that can see 1 SCOUT sat)
               + .30(% con area that can see 3 PATHFINDER's)
               + .54(% con area that can see 4 PATHFINDER's)}

+ .58 [  .67(% global links) + .33(% critical links) ]
                                                          (4)
```

Several different sets of weights were used during the testing of the prototype. For more information on the Analytic Hierarchy Process, see (37).

Selection of Programming Environment

Choosing an Appropriate Tool. According to Hayes-Roth, Waterman and Lenat, the authors of Building Expert Systems, the following five characteristics must be considered when selecting an appropriate programming environment: (1) generality, (2) testing, (3) accessibility, (4) development speed, and (5) tool features (23:210). The generality of a tool is important because it provides more design flexibility. On the other hand, the more general a tool is, the harder the programmer must work. Testing usually consists of building a small prototype system very early in the development process to test the capabilities of a tool under consider- ation. The accessibility of a tool and supporting documen- tation are important becasuse old tools may no longer be supported by the developer. The authors also caution that tools which are still under development may be even worse than old tools because they lack documentation and may contain numerous system bugs (23:210). Because AI programs typically undergo an evolutionary process where each program version is more powerful and capable than the previous one, expert system tools must facilitate fast system development. Finally, understanding the features of a tool is critical to determining if the tool is appropriate to the application (23:211).

Programming Environment Tradeoff Study. Table 5.2 summarizes the results of the tradeoff study performed to determine the most suitable AI programming environment for the space system restoration management decision aid. The criteria used for selecting the programming tool were based on the general guidelines outlined in the previous section and the system requirements described in Chapter III. Although there are numerous expert system design tools currently on the market, only those programming environments available at the Air Force Institute of Technology (AFIT) were evaluated.

The criteria shown in Table 5.2 reflect the character- istics of the problem domain (planning), the characteristics

Table 5.2

Programming Environment Tradeoff Study

Criteria	ART	M.1	OPS5	ROSIE	ROSS	HrsyIII	FRL
Supports planning	X		X				
Forward chaining	X		X	X		X	
Frames	X	X			X		X
Multiple data bases (contexts)	X						
Inference engine embedded	X	X	X	X	X	X	
Graphics	X	X	X				
Explanation capability	X	X	X				

of the proposed approach to solving the problem (forward chaining, frames, contexts, and embedded inference engine), and the desired characteristics of the final knowledge-based system (graphics and explanation capability). It should be noted that the criteria are based on the requirements for both the prototype and an operational space system restoration management decision aid, and although some of the features (e.g. graphics and explanation) are not necessarily required for the prototype, they are still valid criteria for the tool selected. Possible follow-on research to this thesis effort would include exploring the graphics and explanation capability of the tool selected.

ART. As shown in Table 5.2, the Automated Reasoning Tool (ART) was the only programming tool that met all of the criteria. Consequently, ART was chosen as the programming environment for the prototype knowledge-based system.

ART (Version 2.0) was developed by Inference Corporation, and runs on a dedicated Lisp machine (Symbolics 3600 or LMI Lambda), or a VAX-type system. ART is a rule-based knowledge engineering language that also supports frame-based and procedure-oriented representation methods (47:357). ART's principle characteristics include forward and backward chaining control schemes, a very powerful context mechanism with the use of "viewpoints," an inference engine that is well integrated with the knowledge base, and the capability to use all Zetalisp functions (46:37). ART also contains packages which allow the user to develop sophisticated graphics and menus for use with a knowledge-based system. Many of these features were used in the prototype system, and they are explained in more detail in Chapter VI.

Because ART Version 2.0 was released only recently (in 1985), there are only a few expert systems that have been developed with ART. One system is Navigation Expert (NAVEX), an expert system developed by the Inference Corporation in conjunction with NASA and the Johnson Space Center. NAVEX was designed to monitor the radar data that is collected in real-time during a space shuttle lift-off, and warn the mission control center of any errors (47:299). NAVEX is a rule-based, frame-oriented program, and has reached the stage of a research prototype.

Prototype Design and Programming

The discussion of the steps involved in designing the prototype knowledge-based system and programming the knowledge and restoration rules is deferred to Chapter VI.

Testing the Prototype

The prototype system was tested with three hypothetical wartime scenarios: Limited War, Major War, and Central War. Additional tests were also performed to ensure that the prototype responded appropriately to all possible situations. The testing procedure and results are described in Chapter VII.

Analysis of Results

Finally, the restoration plans generated by the prototype decision aid were analyzed. This analysis and subsequent conclusions are presented in Chapter VIII.

VI. Prototype System Design

Chapter V described the preliminary steps in designing and implementing a prototype space system restoration management knowledge-based system: developing generic space systems to serve as the data for the prototype, determining an objective function to quantitatively assess the overall mission capability of a restoration plan, and selecting an appropriate programming environment for the prototype. This chapter initially provides an explanation of ART's knowledge representation scheme and an overview of the steps in the restoration process. Next, each of the major components of the restoration process is explained, and the major features of ART required to fully explain the system design are discussed.

ART Knowledge Representation

Facts. ART uses two basic forms for knowledge representation: facts and schemata. In ART, a fact is a piece of knowledge consisting of two parts: a proposition and an extent (9:11). The first part of a fact, the proposition, is a fundamental piece of information like "The conflict theater is Europe," which could be represented in ART as (theater Europe). In this example, "theater" is the relation name, and "Europe" is the argument. ART supports relations with an unlimited number of arguments. The second part of a fact, the extent, describes the circumstances under which the fact is true and becomes important when

ART's viewpoint mechanism is used. For example, the fact "(theater Europe) in Plan-1 ¦ Plan-2" has an extent of Plan-1 ¦ Plan-2 which means that the fact is true in Plan-1 and no longer true in Plan-2.

Schemata in ART are the same as frames used in other AI languages. In short, schemata are data structures which represent objects or classes of objects that share certain properties (9:16). In Figure 6.1, the TALK communications system "is-a" space system and "has-parts" earth terminals and satellites. Similarly, the other space systems in the prototype have an "is-a" relationship to the general space system class, and they are connected to their constituent parts with a "has-parts" relationship. Facts that are true about the general class of objects (e.g. space system) are inherited by specific instances of that class of objects (e.g. TALK, CHATTER, etc).

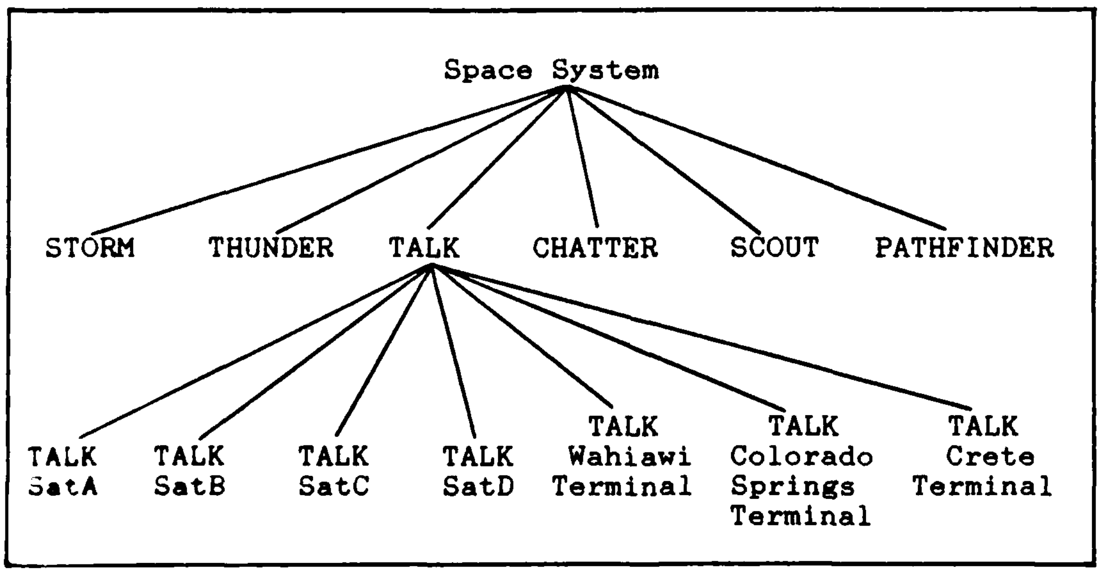

Figure 6.1 TALK Schema Structure

```
(defschema talksatC
   (viewpoint ?root)
   (part-of talk)
   (orbit geosynch)
   (is-a satellite)
   (data-tx-freq-lower 7250)
   (data-rx-freq-lower 7900)
   (data-tx-freq-upper 7750)
   (data-rx-freq-upper 8400)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (sat-coverage 21 22 23 24 25 26 27 28 29 30 31 32 33)
   (sat-cov-list (21 22 23 24 25 26 27 28 29 30 31 32 33))
   (over 27)
   (can-use-rts yes)
   (primary-ttc rts-IndianOcean)
   (backup-ttc rts-Guam)
   (sat-status green))
```

Figure 6.2

ART Code for TALK Satellite C Schema

The schema definition for TALK Satellite C (talksatC), one of the TALK satellites, is shown in Figure 6.2. The first line of this segment of ART code creates the talksatC schema. The second line, (viewpoint ?root) indicates that this schema should be placed in root viewpoint, the initial body of knowledge (Plan-1). The remainder of the schema consists of slot names and slot values. In this example, the slot names "part-of" and "is-a" are inheritance relations, and talksatC will inherit information from the TALK schema and the satellite schema.

While most frame languages allow for the inheritance of facts only through the "is-a" relation, ART provides for additional inheritance relations defined by the user. For example, in Figure 6.3, which displays a segment of the prototype's schema hierarchy, Pathsat9 (PATHFINDER satellite #9) is related to the PATHFINDER system by a "has-parts" relation. Pathsat9 is also related to the general satellite class through a "kinds" relation. This means that Pathsat9 is "part-of" PATHFINDER, and inherits all of the information stored in the PATHFINDER schema. Pathsat9 is also a "kind-of" satellite, and therefore inherits all of the information stored in the satellite schema. In addition, ART allows the user to disable the inheritance of specific relations between classes, if desired.

ART Rules. ART uses two basic kinds of rules to represent procedural information: forward chaining rules, and backward chaining rules. Forward chaining rules are of the "if a, then b" type, and direct the program to take some form of action when the conditions of the "if" portion are satisfied. Backward chaining rules react to the presence of "goals" in the program, and try to achieve these goals through the use of special forward chaining rules.

ART also uses special forward chaining rules that work with the viewpoint mechanism. Hypothetical rules generate new viewpoints when certain conditions are satisfied, and constraint rules prevent certain viewpoint situations from

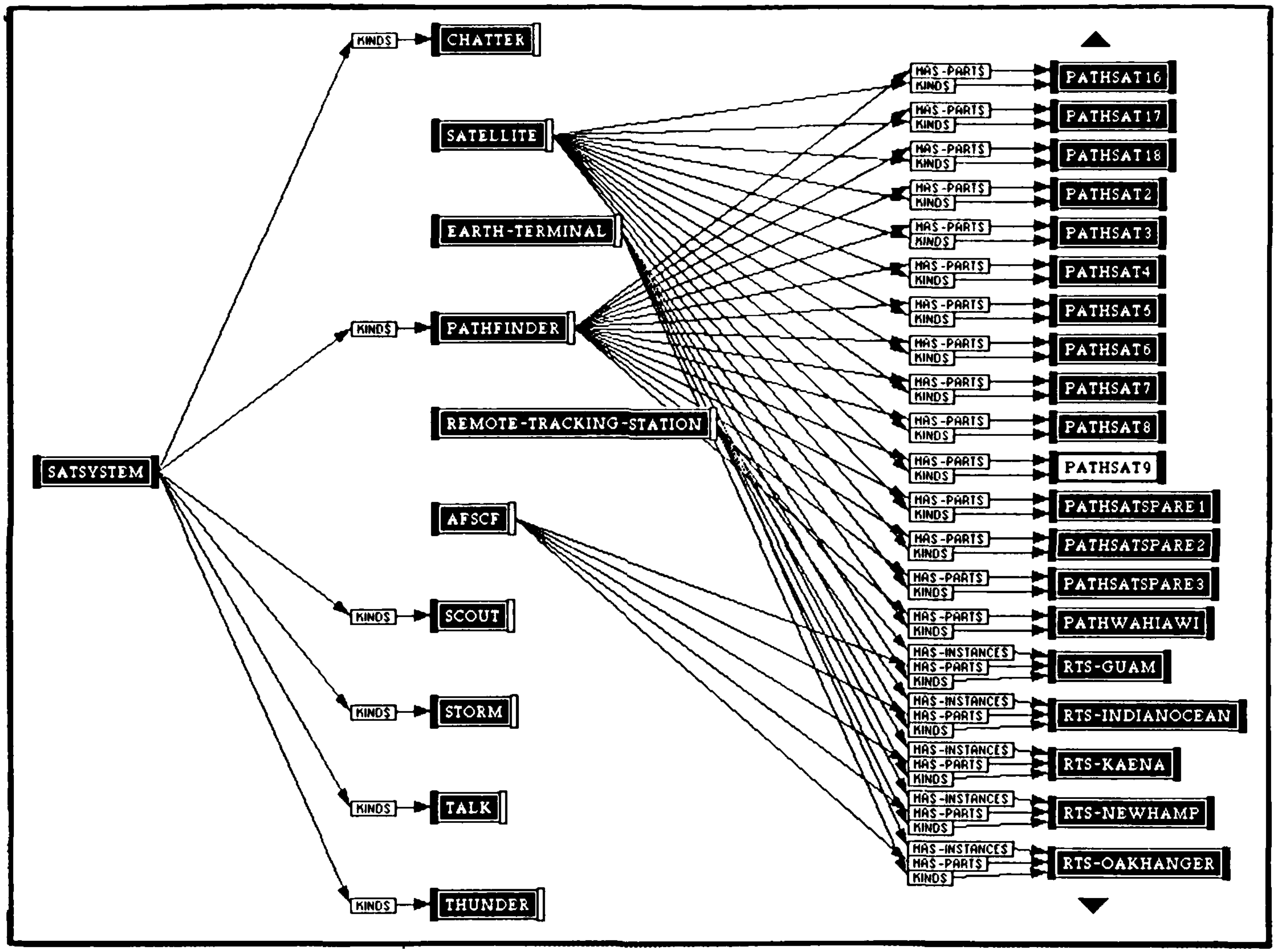

Figure 6.3 Prototype Schema Hierarchy

```
;;; CENTRAL WAR SCENARIO

(defrule start-scenario-central-war-test
   (declare (salience *maximum-salience*))
   (testcase central-test)
=>
   (assert
    (get-priorities central)
    (give-plans 3)
    (conflict-areas (3 4 5 6 7 8 9 10 11 12 13))
    (theater USA)
    (change-ttc-status chatterMugu  red destroyed)
    (change-data-status chatterMugu  red destroyed)
    (change-data-status chatterWahiawi red destroyed)
    (change-ttc-status chatterWahiawi red destroyed)
    (change-ttc-status thunderAscension unknown no-data-avail)
    (change-data-status thunderAscension unknown no-data-avail)
    (change-satellite-status chatter1 red destroyed)
    (change-satellite-status pathsat10 unknown no-data-avail)
    (change-satellite-status pathsat3 red destroyed)
    (change-satellite-status thunder2 red destroyed)
    (change-satellite-status ScoutsatC red destroyed)
    (groundlink-destroyed Kaena-Pt-Hawaii Guam)))
```

Figure 6.4 Sample Rule in ART

happening. The use of these special rules is explained later in this chapter.

Figure 6.4 gives an example of a typical ART forward chaining rule. This particular rule starts the Central War scenario by asserting facts (e.g. (theater USA) and (change-satellite-status chatter1 red destroyed)) into the knowledge base when the fact (testcase central-test) is already present in the knowledge base. The information preceding the arrow in Figure 6.4 is the "if" portion of the rule, and the information following the arrow is the "then" portion of the rule. The second line of the rule, (declare (salience *maximum-salience*)) gives the rule the highest priority of all rules, which means that this rule should "fire" ahead of all other rules that are also able to "fire." See Appendix C for the ART code for the prototype.

Restoration Process

Overview. Figure 6.5 presents a simplified overview of the prototype restoration process. As shown at the top of Figure 6.5, the restoration process is initiated when the user inputs the space system status changes, the mission priorities, and the limits of the conflict area. Control is then passed to the prototype which generates alternative restoration plans without any further intervention from the user.

The restoration process is composed of three distinct phases, one for each mission area. During the first phase, only the space systems performing the highest priority mission are restored. Similarly, only mission #2 systems are restored in phase 2, and only mission #3 systems are restored in phase 3. In each phase, TT&C capabilities are restored before any "data" capabilities because a TT&C link with the ground is essential for the operation of the satellite. During all phases, the space systems are restored with resources from systems of equal or lower priority. However, a higher priority system may provide TT&C restoration to a lower priority system if it has excess TT&C capability.

After all possible alternative restoration plans have been generated for the first priority systems, the prototype calculates the objective function value for each partial

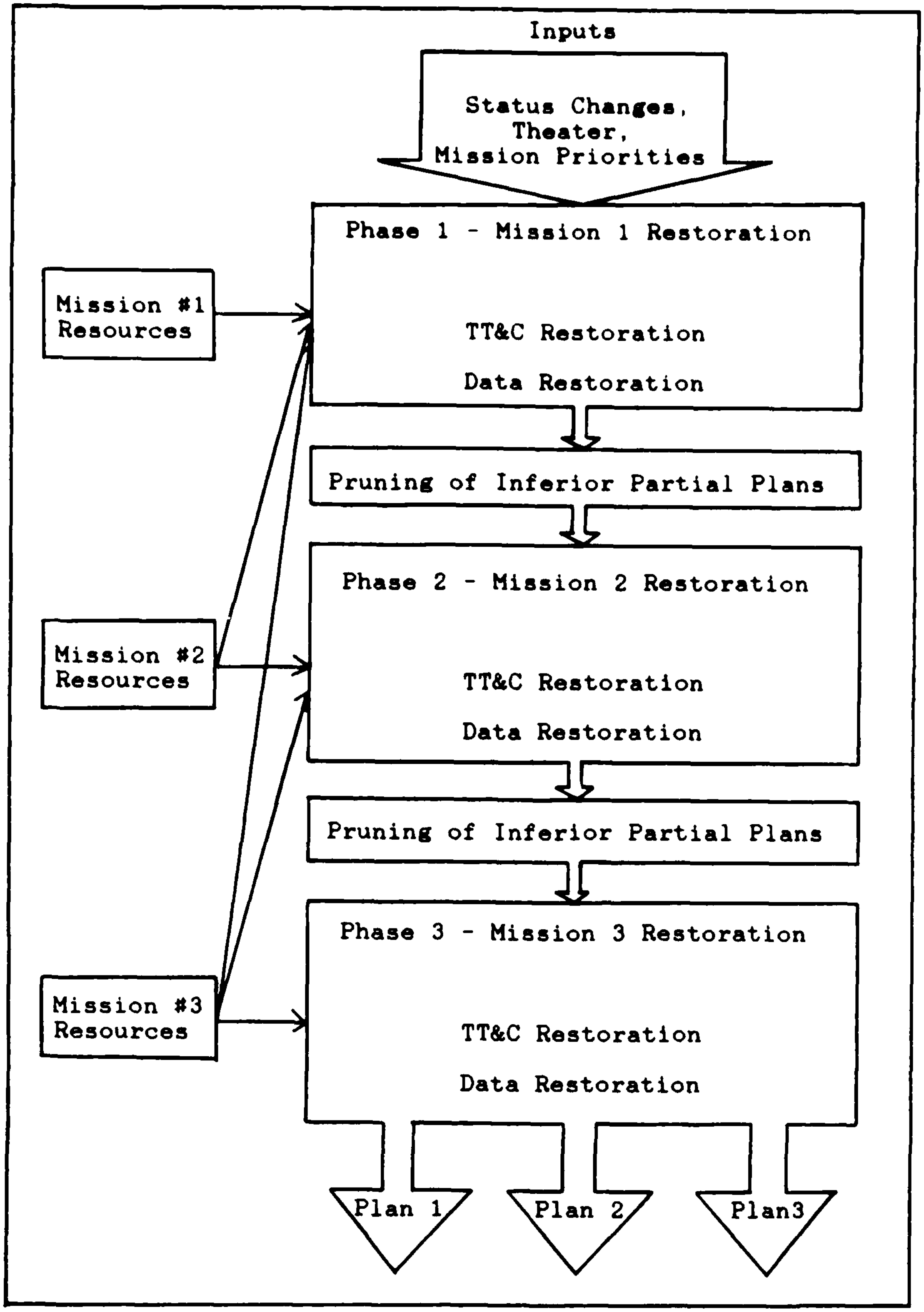

Figure 6.5 Prototype System Design

plan. This objective function value represents the measure of total mission capability if the restoration process were halted after the first phase. Next, a pruning algorithm is applied to the set of partial plans to determine if any of the plans are inferior and can be discarded. The remaining partial plans then enter the second phase of the restoration process, which proceeds in the same manner as the first phase.

After the third phase is complete, the final composite restoration plans are ranked by their objective function values. The best plans are then presented to the user who decides which plan he wishes to implement. After selecting a plan, the user notifies the prototype of his choice. The system then updates the knowledge base to reflect the restoration changes, thereby keeping the system current and ready to solve future restoration problems.

Inputs. To start the restoration process, the user must first input the changes in status of the satellites and earth terminals which caused the need for restoration. If the status of a particular resource is not known, the prototype will accept "unknown" as the status, and it will use other information to infer the status of the resource.

The user must also input the appropriate weights and priorities for the current conflict situation, by either selecting a set of default priorities or developing a new set with the AHP method described in Chapter V. Finally, the user must input the area numbers associated with the conflict theater, the name of the theater, and the number of alternative plans he wishes to see.

Initialization of Restoration Process. After the user inputs the necessary restoration information, the prototype performs some "housekeeping" to set up the restoration process. This housekeeping consists of translating the status changes into restoration requirements, freeing the resources that were supporting satellites which have been destroyed, determining the critical communication node pairs between the conflict theater and the US, and retrieving the default priorities if the user elected to use the defaults. After these initialization steps, the restoration system is ready to generate the possible restoration plans and the "moves" comprising each plan.

Viewpoints. Before the various restoration moves are discussed, it is necessary to describe ART's "viewpoint" mechanism which creates the structure for the restoration process. A feature unique to ART, viewpoints keep track of the various alternative plans that are generated by the knowledge-based system. Simply, a viewpoint is a structure that represents a possible "state of the world." Viewpoints are linked together in a branching tree so that information common to several viewpoints is inherited through the tree structure. Nodes in the branching tree represent the different individual restoration moves that are possible. The following discussion explains how viewpoints were implemented in the prototype.

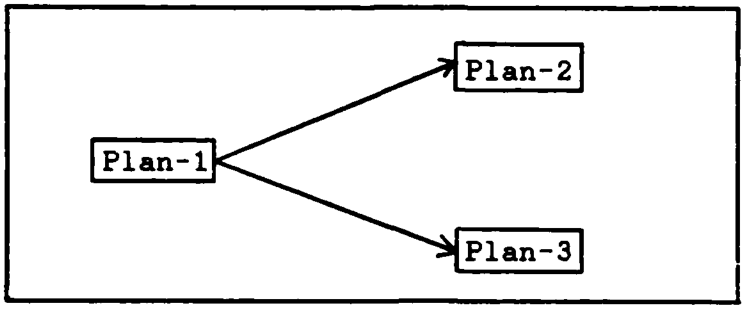

Figure 6.6 Branching of Viewpoints

The initial "state of the world," shown in Figure 6.6 as Plan-1, contains all of the prototype's knowledge, including the new information added during input and initialization. If none of the first priority space systems require TT&C or data restoration, the system enters phase 2. However, if some restoration is required for the first priority systems, the program will "sprout" new viewpoints from Plan-1, one for each separate restoration move that is possible. For example, suppose that the weather mission is declared as the top priority mission, and the earth terminal that was performing TT&C functions for weather satellite A has been destroyed. Therefore, satellite A requires TT&C restoration in phase 1, and this information resides in the current "state of the world," the Plan-1 viewpoint. If another earth terminal is able to perform the TT&C functions for satellite A, a plan to use this terminal to restore satellite A is hypothesized, or sprouted from Plan-1. The information associated with this hypothesis is then located in the new viewpoint, Plan-2. Similarly, if another earth terminal is also able to provide the TT&C functions to satellite A, another viewpoint (Plan-3) will by hypothesized from Plan-1. In addition to inheriting all of Plan-1's information, Plan-2 and Plan-3 will contain information about the earth terminals that were used to restore TT&C service. To understand ART's viewpoint structure, one may visualize that each viewpoint contains an entire data base separate from all other viewpoints. In reality, the knowledge base is not copied into each viewpoint; ART keeps track of the places (viewpoints) where certain facts are true through the use of contexts and extents. Only one copy of the knowledge base actually exists.

After the program sprouts all possible viewpoints to restore the TT&C functions to mission #1 satellites, the prototype then collects all possible combinations of the TT&C restorations through the "merging" of viewpoints.

ART provides the capability to create new hypothetical viewpoints by merging two or more existing viewpoints (10:38). This merging mechanism is controlled through the use of contradiction rules which forbid ("poison") the merging of certain viewpoints.

In the example used above, suppose the requirement for TT&C restoration for weather satellite B is added. Furthermore, assume that there are two possible TT&C restorations for satellite A, and only one possible TT&C restoration for satellite B. In Figure 6.7, Plan-2 and Plan-3 represent the two possible restorations for satellite A, and Plan-4

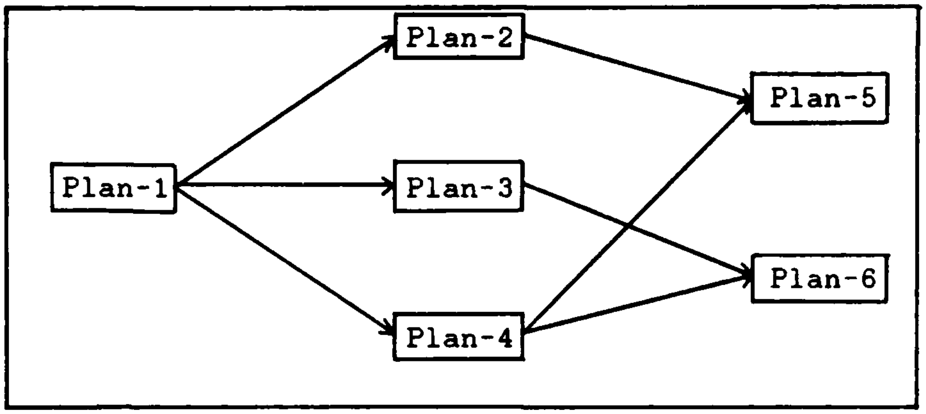

Figure 6.7 Merging of Viewpoints

represents the restoration for satellite B. In this example, the prototype would merge Plan-2 and Plan-4 to form Plan-5, and merge Plan-3 and Plan-4 to form Plan-6. Thus, Plan-5 and Plan-6 represent the two possible combinations of plans to restore both satellites A and B. The contradiction (poisoning) rule designed for the prototype does not permit the merging of viewpoints that restore the TT&C capability to the same satellite (e.g. Plan-2 and Plan-3). The merging of viewpoints is used throughout the prototype program to generate the alternative restoration plans.

Use of Spare Satellites. Only one of the generic space systems, PATHFINDER, has on-orbit spare satellites. When one of the regular PATHFINDER satellites is destroyed, the prototype determines if one (or two) of the spares should be put into use to restore navigation capabilities. To accomplish this, the prototype checks for spare satellites with coverage areas that overlap with the coverage areas of the destroyed satellite. Once a spare satellite is declared operational, it cannot revert back to being a spare.

<u>TT&C Restoration</u>. The prototype uses the same TT&C restoration process for all satellites. When a satellite requires a new TT&C earth terminal, and the restoration process is in the proper phase for the restoration of that satellite, the prototype uses four rules to find alternate TT&C earth terminals. First, the prototype checks whether the satellite has a designated backup TT&C terminal that is still operating. Second, it checks whether the satellite's TT&C frequencies are compatible with those of another system, and if that other system has a "green" earth terminal within the field of view of the satellite. This other earth terminal must have the capability to take on the responsibility of TT&C service to the satellite without affecting the satellites it is already servicing.

In the case where the satellite that requires TT&C service can only obtain that service at the expense of some lower priority satellite, the prototype will "takeover" one of the TT&C slots of that earth terminal. The lower priority satellite will be designated as requiring TT&C restoration in a later phase.

Finally, if none of the above rules yield a restoration of TT&C service to the satellite, the prototype asserts that there is no possible TT&C restoration, the satellite's status is changed to "red," and "No-TT&C-availiable" is recorded as the reason for the satellite's red status.

The prototype was also designed to handle the case of a remote tracking station in a degraded mode of operation (i.e. one of the two TT&C antennas is not operational). Such a remote tracking station would have a TT&C status of yellow. When the status is changed to yellow, the prototype determines if the remaining TT&C antenna can handle all of the TT&C responsibilities for that station. If it cannot, the prototype selects the lowest priority satellites to undergo TT&C restoration.

Weather Data Restoration. When a weather satellite requires a data terminal to receive the downlink weather information, the prototype tries three different restoration methods. First, the prototype attempts to find a compatible data terminal that is "open," one that is not currently receiving or transmitting data for any satellites. If a compatible open terminal is not found, the prototype then looks for compatible earth terminals that are supporting lower priority systems. If such an earth terminal is found, then the weather satellite takes over the terminal and the satellites that originally had a data link to the terminal are flagged for future data restoration. If no compatible lower priority data terminals are found, the prototype looks to the other weather system's data terminals for restoration. Again, the frequencies must match for restoration. If the data link between the weather satellite and an earth terminal cannot be restored, the prototype changes the

AD-A179 336 A PROTOTYPE KNOWLEDGE-BASED SYSTEM TO AID SPACE SYSTEM RESTORATION MANAGEMENT(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. B A PHILLIPS 2/4

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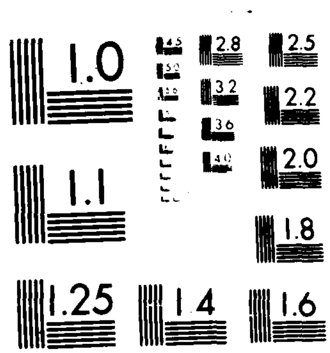

MICROCOPY RESOLUTION TEST CHART

satellite's status to "red" and records the circumstances of the change in status.

Navigation Data Restoration. Because of the operational procedures of the navigation space systems, no navigation data restoration is ever required. Each navigation satellite continuously transmits the same navigation signal, and those platforms that are within range of the satellite receive the signal and use it to calculate their position, velocity and heading. Because the prototype's navigation satellite systems do not require data restoration (they do not need to locate particular earth terminals to receive the navigation information), the navigation data process is by-passed in the prototype.

Communications Data Restoration. As described in Chapter V, the communications measure of effectiveness is based on the number of pairs of inter-theater nodes that have an operating communications path. Therefore, the communications data restoration process consists of finding alternate communications paths for those pairs of nodes that have been disconnected.

The initial knowledge base contains at least one communications path between all inter-theater communication "ports." When a communications satellite, communications data terminal, or landline is destroyed, the prototype removes all of the communications paths which used the resources which were destroyed. The prototype then flags the ports which are no longer connected to each other, and a requirement to reconnect these ports serves as the basis for the communications data restoration.

The prototype uses a breadth-first search algorithm to find the communications path with the fewest number of nodes between the two ports. Because this research does not place any restriction on the amount of communications traffic that can use the various communications links, there is no reason to generate or store all of the possible communications paths between every pair of ports. When a pair of nodes is flagged for communications path restoration, only one new path is generated.

CHATTER and TALK, the two communications space systems in the prototype, were designed with limited interoperability. Specifically, any CHATTER or TALK earth terminal can transmit data to any communications satellite, but, because of frequency incompatibility, CHATTER and TALK satellites can only transmit data down to their own earth terminals. Therefore, communications paths which involve the transmission of data from an earth terminal of one communications system to a satellite of the other communications system are not reversible. To account for this, the prototype first tries to find communications path restorations that do not involve this kind of "mixed" system. If no "pure" path can be found, the prototype will then allow the use of a mixed system configuration.

Outputs. After the prototype generates the alternative restoration plans, a summary of each of the plans is output for the user's review. As described earlier, the user has the option of reviewing as many plans as he wishes. If two or more plans have the same objective function value, then they are all output for the user's review. Appendix D contains the outputs for several of the test scenarios.

Adopting a Plan. After the prototype presents the restoration plans to the user, the decision maker selects one of the plans, and the prototype is notified of the selection, the knowledge base is automatically updated to reflect the components of the plan. In effect, the prototype "believes" the plan that was chosen, and collapses the viewpoint structure into that plan. This plan then becomes the root viewpoint for the next restoration process.

Pruning Algorithm

The branching and opportunistic merging of viewpoints has the potential of producing a large number of possible plans (viewpoints) early in the restoration process. The more branches in the search tree, the longer the prototype will take to determine the best restoration plan. In an attempt to limit the search space, a "pruning" algorithm was developed. Applied to all plans at the end of the first and second restoration phases, the pruning algorithm discards those plans that cannot, at best, yield an objective function value equal or greater than the objective function of the third-best partial plan generated so far.

During the restoration process, the prototype keeps track of the objective function values of all partial (and eventually complete) plans that are generated. Each time the prototype calculates a particular plan's objective function value (at the end of each phase), the list of objective function values is updated, and the top three values are flagged. The third-best value is used for comparison when the system attempts to prune an unproductive partial plan.

To illustrate the pruning algorithm, suppose that the weather mission is the top priority mission, and the first phase of the restoration process has been completed. As a result of the first phase, the prototype generated six partial restoration plans, plans 2 through 7 (recall that Plan-1 contains the initial body of knowledge). Further suppose that the partial plans have the following objective function values:

Plan-2: 16

Plan-3: 20

Plan-4: 10

Plan-5: 5

Plan-6: 15

Plan-7: 8

As the restoration process proceeds, the objective function values must increase (or remain the same), so the objective function values shown for Plans 2-7 represent the absolute minimum value for any later plan that "branches off" Plans 2-7.

Because plans 2, 3, and 6 have the highest objective function values obtained so far, they are not considered for pruning. The other three plans, however, are each considered separately for elimination from the search space. When each plan is considered, the prototype calculates the absolute maximum the objective function could achieve if the second and third priority missions were fully restored. This calculation is summarized in the following formula:

$$\begin{array}{l} \text{Actual MOE} \\ \text{for 1st} \\ \text{priority} \end{array} + \begin{array}{l} \text{weights} \\ \text{on 2nd} \\ \text{priority} \end{array} (100\%) + \begin{array}{l} \text{weights} \\ \text{on 3rd} \\ \text{priority} \end{array} (100\%) \qquad (5)$$

If the value obtained from this calculation is less than the third objective function value (15), then the plan will be pruned. The above formula serves to place an upper bound on the value of the plan's objective function. If this upper bound is less than the objective function of an attainable plan, the plan will never yield an objective function value among the top three, and the plan should be eliminated from consideration.

After phase 2, pruning is attempted in the same manner as above, except that only the third priority mission is given 100% attainment in the upper bound calculations. Obviously, no pruning is performed after phase 3; all plans are complete after phase 3, and the three best plans can be easily determined from the final objective function values.

Uncertainty

As mentioned earlier, the user of the prototype decision aid has the option of inputting "unknown" as the status of a particular resource. The way the prototype handles the presence of unknown values is similar to the method used in the Sleuth system, which was described in Chapter IV. Although the prototype's handling of uncertainty is simple, it demonstrates that the system's wealth of knowledge can be used to infer the status of a resource.

If the status of the TT&C equipment at an earth terminal is unknown, the prototype uses four rules to assign the terminal a status of red or green. First, the prototype checks the last known status of the terminal. If the terminal already had a red status, the prototype disregards the uncertainty, and assumes that the status is still red. If the last known status was green, however, the prototype checks whether the terminal was responsible for providing TT&C service to any satellites. If the terminal was only a backup TT&C terminal, its status is set to red. If the terminal provides TT&C servicing to one or more satellites, the prototype checks the status of the satellites. If the status of these satellites are red or unknown, then the prototype assumes that the TT&C terminal is not operational, and changes its status to red. But if there exists at least one satellite that is still fully operational, and this satellite relies on that earth terminal for TT&C servicing, then the terminal's TT&C status is assumed to be green.

Finally, if all of the above rules fail to infer the TT&C terminal's status, the prototype assumes the terminal has been destroyed.

If the status of a data terminal is unknown, the prototype assumes the terminal in not operational, and performs the necessary data restoration.

If the status of a satellite is unknown, the prototype treats the satellite as not operational, but does not release the supporting resources (data, TT&C) for that satellite until a positive determination of the satellite's status is made.

VII. Tests and Analysis

Test Plan

The prototype space system restoration management decision aid was tested with 15 different test scenarios. The first three tests were based on the scenarios of Limited War, Major War, and Central War. The remainder of the test scenarios were designed to test special features of the prototype decision aid and to insure that the prototype was performing correctly.

Table 7.1 summarizes the 15 test scenarios, in terms of the number of resources involved in the restoration process, the prototype features that were tested, and the prototype's performance. The performance of the prototype is expressesd as the number of inferences required for the restoration process and the number of alternate "best" plans generated. The number of inferences made in a test is provided by ART following a program run, and represents the number of rules that were fired during the course of a run. However, since all rules do not take the same amount of time to execute, this measure is not perfectly correlated with run time. As with the number of inferences, the number of alternate plans generated is not a perfect measure of the prototype's performance. If only one plan is possible, the prototype cannot make up additional plans to improve performance. Therefore, these measures of performance only serve as general statistics about the test scenarios.

Table 7.1 Test Matrix

	Test Scenario		
	Limited War	Major War	Central War
RESOURCES INVOLVED:			
a) Satellites Destroyed			
Communications	0	1	1
Navigation	2	2	2
Weather	1	1	1
b) TT&C Terminals Down	3	3	2
c) RTS's Degraded	0	0	0
d) Data Terminals Down			
Communications	0	1	1
Weather	1	0	1
e) Landlines Destroyed	0	2	1
UNKNOWN STATUS:			
a) Satellites			
Communications	0	0	0
Navigation	1	1	1
Weather	0	0	0
b) TT&C Terminals	0	0	1
c) Data Terminals			
Communications	0	0	0
Weather	0	0	1
SYSTEM FUNCTIONS TESTED:			
TT&C rest w/ own system	X	X	X
TT&C rest w/ other sys			X
No TT&C rest possible			X
RTS yellow TT&C status			
Weather data rest			
Comm data restoration		X	X
Spare satellites used	X	X	X
Pruning alg. activated			
Select plan, update kb			
SYSTEM PERFORMANCE:			
# Inferences	244	4506	4448
# Plans Generated	1	1	3

Table 7.1 Test Matrix (continued)

	Test Scenario					
	1	2a	2b	2c	3	4
RESOURCES INVOLVED:						
a) Satellites Destroyed						
Communications	0	0	0	0	0	0
Navigation	0	1	1	1	0	3
Weather	0	0	0	0	0	1
b) TT&C Terminals Down	0	2	2	2	3	2
c) RTS's Degraded	0	0	0	0	0	0
d) Data Terminals Down						
Communications	0	0	0	0	0	0
Weather	0	2	2	2	0	0
e) Landlines Destroyed	2	0	0	0	0	2
STATUS UNKNOWN:						
a) Satellites						
Communications	0	0	0	0	0	0
Navigation	0	0	0	0	0	0
Weather	1	0	0	0	0	0
b) TT&C Terminals	1	0	0	0	0	1
c) Data Terminals						
Communications	0	0	0	0	0	0
Weather	0	0	0	0	0	0
SYSTEM FUNCTIONS TESTED:						
TT&C rest w/ own system		X	X	X	X	X
TT&C rest w/ other sys		X	X	X		
No TT&C rest possible		X	X	X	X	
RTS yellow TT&C status	X					
Weather data rest		X	X	X		
Comm data restoration	X					X
Spare satellites used		X	X	X		X
Pruning alg. activated			X	X		
Select plan, update kb		X				
SYSTEM PERFORMANCE:						
# Inferences	537	974	973	521	177	1111
# Plans Generated	1	3	3	3	1	6

Table 7.1 Test Matrix (continued)

	Test Scenario					
	5	6	7	8	9	10
RESOURCES INVOLVED:						
a) Satellites Destroyed						
Communications	0	2	0	0	0	0
Navigation	2	1	1	2	3	4
Weather	0	0	0	0	0	1
b) TT&C Terminals Down	3	0	3	3	1	2
c) RTS's Degraded	0	1	0	0	0	0
d) Data Terminals Down						
Communications	1	0	1	1	0	0
Weather	1	0	2	1	0	0
e) Landlines Destroyed	1	2	0	1	0	1
STATUS UNKNOWN:						
a) Satellites						
Communications	0	0	0	0	0	0
Navigation	0	0	0	0	0	0
Weather	0	0	0	0	0	0
b) TT&C Terminals	0	0	0	0	1	0
c) Data Terminals						
Communications	0	0	0	0	1	0
Weather	0	0	0	0	0	0
SYSTEM FUNCTIONS TESTED:						
TT&C rest w/ own system	X		X	X		X
TT&C rest w/ other sys	X		X	X		X
No TT&C rest possible		X	X			X
RTS yellow TT&C status		X				
Weather data rest			X			
Comm data restoration	X	X	X	X	X	
Spare satellites used	X	X	X	X	X	X
Pruning alg. activated						
Select plan, update kb				X		
SYSTEM PERFORMANCE:						
# Inferences	1693	3807	8370	3236	931	2786
# Plans Generated	8	1	6	8	1	22

Scenarios

The test scenarios for the prototype were derived from Capt. Calvin Hedgeman's thesis on space system restoration management. In his research effort, Hedgeman developed three scenarios for the 1995 time period: Limited War, Major War, and Central War. He selected these three scenarios from a larger group of scenarios that are currently used in space operations studies. This larger group includes: peacetime, local crises, theater war/non-nuclear, theater war/nuclear, central conflict/initial phase and central war/reconstitution phase (30:23-2). Based on the estimates of Soviet objectives and capabilities for the 1995 time frame, Hedgeman determined which space resources were likely to be attacked in each of the three scenarios. Although it was not possible to use the identical scenarios Hedgeman used in his thesis (because of the basic differences between

Table 7.2 Test Scenarios (24:26)

Characteristic	Limited War	Major War	Central War
Number of Phases	1	2	3
Targets:			
Low Altitude	yes	yes	yes
High Altitude	no	no	yes
CONUS Systems Attacked	no	no	yes
Overseas Systems Attacked	yes	yes	yes
Ordering of Missions Affected	navigation weather	navigation weather comm	comm navigation weather

the assumptions and structure required by Hedgeman's algorithmic approach and those required by the knowledge-based approach), this research effort uses Hedgeman's general scenario guidelines to formulate the test cases for the prototype decision aid. Table 7.2 summarizes the major features of these three scenarios.

Limited War. Hedgeman defined a limited war as a non-nuclear conventional war where US forces are deployed in the conflict area (24:24). He maintained that the Soviet emphasis on surprise suggests that they will attack only the navigation and meteorological systems supporting the US forces deployed in the Limited War. No US-based space resources would be targets in such a scenario.

Table 7.3 Limited War Scenario

Theater: Far East (areas 29-34)

Satellite	Mission	New Status	Coverage Area
Pathsat16	nav	red	27-35
Pathsat17	nav	red	29-36, 1
Pathsat18	nav	unknown	31-36, 1-3
Thunder4	weather	red	24-36

Earth Terminal	Mission	New Status	Use	Area #
RTS-Guam	AFSCF RTS	red	TT&C	33
ScoutWoomera	navigation	red	TT&C	32
ThunderGuam	weather	red	TT&C, data	33

Mission Priority	Global Weight	Conflict Area Weight
1 - communications	50.1	25.1
2 - navigation	10.2	6.0
3 - weather	4.0	4.6

These general guidelines for the Limited War scenario were used to construct a Limited War scenario in the Far Eastern theater. Table 7.3 details the resources that are destroyed in this scenario prior to the use of the restoration decision aid. It is assumed that all space system resources were operational before the start of the Limited War. As stated earlier, the mission weights used in the test scenarios are hypothetical, and used solely to demonstrate that the restoration priorities and weights can be rearranged according to each specific scenario.

Major War. According to Hedgeman, the Soviet objectives in a Major War include limiting US force employment and deterring the escalation of the conflict to a Central War (24:24). Therefore, the US space resources likely to be attacked in a Major War are the same as those likely to be attacked in a Limited War. In addition, early warning and communications space systems supporting the US forces in the conflict area will probably be targeted for attack. Assuming that space systems would be attacked according to the level of conflict, the first systems to be attacked in a Major War would probably be the weather and navigation systems (24:25). As the level of the conflict increases, strategic systems, including communication systems and tactical warning systems, would probably be attacked to forestall the employment of US strategic nuclear forces (24:25). As in the Limited War scenario, CONUS-based systems are not likely to be attacked in a Major War.

Table 7.4 Major War Scenario

Theater: Europe (areas 17-24)

Satellite	Mission	New Status	Coverage Area
TalksatB	comm	red	12-24
Pathsat10	nav	red	15-23
Pathsat11	nav	unknown	17-25
ScoutsatC	nav	red	14-26
Thunder3	weather	red	15-27

Earth Terminal	Mission	New Status	Use	Area #
RTS-Oakhanger	AFSCF RTS	red	TT&C	19
Thunder-Diego Garcia	weather	red	TT&C	26
Thunder-Ascension Island	weather	red	TT&C	17
Chatter-Crete	comm	red	data	21

Groundlinks Destroyed

Crete-Greece to Ascension-Island
Thule-Greenland to Oakhanger-UK

Priority	Global Weight	Conflict Area Weight
1 - navigation	10.0	40.0
2 - communications	15.0	25.0
3 - weather	2.0	8.0

The Major War scenario developed as a test case for the prototype decision aid uses the European theater for the conflict area. Table 7.4 details the resources that are affected in the Major War test scenario.

Central War. The Central War scenario involves the Soviet attack of CONUS-based strategic weapons systems and the worldwide disruption of US command and control systems

(24:25). In this scenario, the Soviets would initially attack communications and early warning space systems. In later phases, navigation and meteorological systems would be attacked (24:25). In order to degrade the overall capabilities of the US space systems, the Soviet Union is also likely to attack both CONUS and overseas earth terminals (24:25).

Of the three scenarios, the Central War scenario developed to test the prototype involves the most damage to US space systems, especially the communications systems.

Table 7.5 Central War Scenario

Theater: USA (areas 3-13)

Satellite	Mission	New Status	Coverage Area
Chatter1	comm	red	1-13
Pathsat10	nav	unknown	15-23
Pathsat3	nav	red	1-9
Thunder2	weather	red	6-18
ScoutsatC	nav	red	14-26

Earth Terminal	Mission	New Status	Use	Area #
Chatter-Mugu	comm	red	TT&C, data	7
Chatter-Wahiawi	comm	red	TT&C, data	3
Thunder-Ascension	weather	red	TT&C, data	17

Groundlinks Destroyed

Kaena Point, Hawaii to Guam

Priority	Global Weight	Conflict Area Weight
1 - communications	35.0	25.0
2 - navigation	10.0	20.0
3 - weather	2.0	8.0

Table 7.5 shows the resources that are affected in the Central War scenario.

Scenario Results

Limited War. The Limited War scenario tested two major functions of the prototype: restoring TT&C service to satellites and activating spare satellites to restore capabilities when satellites are destroyed.

The prototype generated only one restoration plan for this scenario. This plan is summarized in Figure 7.6, which is the output from the decision aid for the Limited War scenario. As shown in Figure 7.6, the restoration plan has a total objective function value of 88.041 (out of a possible 100), and the navigation and weather missions have only limited capabilities even after the restoration.

Figure 7.6 also shows the resources that were not operational and why they were not functioning. In this scenario, the prototype tried to regain some of the navigation capability that was lost when Pathsat16 and Pathsat17 were destroyed by putting a spare satellite (PathsatSpare3) into use. However, no TT&C terminal was able to provide TT&C service for the spare satellite, so the spare could not be used. In addition, ScoutsatD required TT&C restoration in this scenario because the TT&C terminal at Woomera, the terminal responsible for ScoutsatD's TT&C, was destroyed. The prototype determined that the SCOUT TT&C terminal at

```
BEST RESTORATION PLAN:

PLAN-4 Restoration plan has value 88.0411111

Communications Value: 75.2
Navigation Value:     8.04333334
Weather Value:        4.797777776

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.2999999998
                            Global:        0.830555556

Weather Percentages:        Conflict Area: 0.3333333333
                            Global:        0.861111111

Resources not operational and reason for red status:

Satellite THUNDER4   Reason: DESTROYED
Satellite PATHSAT18   Reason: POSSIBLE
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
Satellite PATHSATSPARE3   Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal RTS-GUAM   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-4 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Use SCOUTDIEGOGARCIA terminal for satellite SCOUTSATD TT&C servicing.
- - - - - - - - - - - - - - - - - - - -
```

Figure 7.6 Limited War Scenario Output

Diego Garcia could handle the extra TT&C responsibility for ScoutsatD.

Major War. The Major War scenario tested the communications data restoration process resulting from the destruction of landlines and a communciations satellite, the handling of an unknown status value for a navigation satellite, the TT&C restoration of a weather satellite, and the use of spare satellites.

Only one restoration plan was generated for the Major

War scenario (see Appendix D). In this scenario, the destruction of TalksatB and two landlines caused the disconnection of sixteen pairs of inter-theater communications ports. The prototype found all 32 alternate communications paths required for complete communications restoration. In this scenario, the only satellite that lost its TT&C service was Thunder4, and the prototype restored its TT&C service with the THUNDER TT&C terminal at Guam. Also, the prototype recommended using PathsatSpare2 to offset the loss of navigation capability caused by the destruction of Pathsat10 and the possible destruction of Pathsat11.

Central War. The Central War Scenario tested the prototype's handling of unknown status values for a TT&C terminal, a weather data terminal, and a navigation satellite. This scenario also tested TT&C restoration for a communications satellite, communications data restoration, and the use of a spare satellite. Because two communications data terminals and one communications satellite were destroyed, the prototype had to find a large number of alternate communications paths.

The prototype generated three alternate restoration plans for this scenario (see Appendix D). All three of these plans have the same objective function value.

Additional Tests

The purpose of each of the additional twelve tests is explained in the following section. The outputs for some of the more interesting tests, namely tests 2a, 4, 7 and 8, are included in Appendix D. The ART viewpoint branching diagrams for tests 2a, 4, 7 and 8 are also included in Appendix D. The ART code in Appendix C shows the scenarios and priority schemes used in all the following scenarios.

Test 1. The first additional test was designed to test the case of degraded TT&C capability (yellow status) at a remote tracking station with two TT&C antennas. The prototype was programmed to handle the case where only one of the TT&C antennas was functioning. Test 1 also tested the communications data restoration process required because of the destruction of two landlines. In this test case, the prototype generated only one restoration plan, but restored all systems to 100% capability.

Test 2a. Test 2a was designed to test the TT&C restoration of navigation and weather satellites, and weather data restoration. In this test case, six final plans were generated, three with an objective function value of 99.5838, and the three with an objective function value of 99.9833. The plans with the lower objective function value could not restore TT&C service to one satellite because the only TT&C terminal that could service that satellite was already operating at full capacity.

Test 2b. Test 2b used the same system losses as Test 2a, but the mission priorities were changed from weather-communications-navigation to weather-navigation-communications. In this test, the prototype generated the same three plans as in Test 2a, but pruned away three unprofitable plans after the navigation restoration phase (phase 2).

Test 2c. Like Test 2b, Test 2c was designed to test the pruning algorithm. Test 2c used the same system losses as Test 2a, but the priority scheme was changed to navigation-weather-communications. After the first phase, the prototype pruned off one unprofitable plan. As with Tests 2a and 2b, Test 2c generated three "best" restoration plans of equal value.

Test 3. Test 3 was designed to test TT&C restoration for navigation and weather satellites, the case where no TT&C restoration was possible for a satellite, and the "freeing" of a weather data terminal that was no longer receiving weather information.

Test 4. Test 4 was designed to test the case where the status of a TT&C terminal was unknown, but the satellite the terminal was servicing was still operational. Test 4 also tested the communications data restoration required after the destruction of landlines.

Test 5. Test 5 was designed to test the TT&C restoration of communications and navigation satellites, communications data restoration, and the implementation of spare satellites. Eight final restoration plans were generated in Test 5, each having the same objective function value.

Test 6. Test 6 was designed to test how the prototype would handle a case of degraded capabilities at a remote tracking station, and a case of no possible TT&C restoration for a satellite. In this scenario, the prototype attempted to put both PathsatSpare1 and PLathsatSpare2 in service because Pathsat2 was destroyed. No TT&C capability was available for either spare satellite, so the status of each was changed to red.

Test 7. One of the more interesting (and computer memory-extensive) test cases, Test 7 was designed to test whether the failure to find an available TT&C terminal for a communications satellite mid-way through the restoration process would trigger subsequent communications data restoration. Therefore, communications data restoration was performed prior to phase 1 (as in the normal case), and after Chatter1's status was changed to red.

Test 8. Test 8 was designed to test the prototype's ability to adopt one of the final restoration plans generated, and update the knowledge base to reflect the new restoration information. Test 8 consisted of running Test 4, selecting one of the six final restoration plans, and running the Test 5 scenario with the updated knowledge base.

Test 9. Test 9 was a variation of the Major War scenario, but used the Far Eastern theater for the conflict area. This test was designed to test the handling of unknown values for the status of a TT&C terminal and a communications data terminal.

Test 10. Perhaps the most arduous restoration test case for the prototype was Test 10. In this test, five navigation satellites required TT&C restoration in the same phase. While the prototype had no trouble finding several alternative TT&C restorations for each satellite, the prototype labored for over two hours in determining all the possible combinations of the TT&C restorations. In the end, 22 different restoration plans were generated, all with the same objective function value. This scenario came close to exceeding the 8 megabyte memory capacity of the LMI Lambda computer on which the prototype is implemented.

Analysis of Results

Since the prototype was developed to determine if a knowledge-based approach could provide a good, workable solution to the problem of space system restoration management, the testcases were analyzed with this goal in mind. The prototype test results were analyzed in four primary areas: satisfaction of requirements, time to solve, generation of alternative plans, and performance of the pruning algorithm.

Overall Assessment of Prototype. The prototype demonstrated several of the key requirements for a space system restoration management decision aid. First, the prototype demonstrated the use of priorities specified by the user to govern the restoration process and assess the numeric "value" of each of the final plans. Second, it demonstrated a method to reason with incomplete information. Third, it demonstrated a convenient knowledge representation scheme through the use of schemata, and showed how the sharing of resources could be modeled. Fourth, it generated alternative restoration plans that attempted to maximize mission capabilites and minimize the number of equipment reconfigurations required. Fifth, the prototype presented the alternative plans to the user, gave the option to select one of the final plans, and automatically updated the knowledge base to reflect the restoration actions from the plan selected.

It is important to note that the prototype does not guarantee an optimal solution as Hedgeman's OR approach did. Rather, the prototype was designed to show that good plans could be generated in a short amount of time, with consideration to mission priorities, incomplete information, and the number of equipment changes that would result.

To give an example of an optimal plan that the prototype would not find, assume that satellite A has the highest mission priority and satellite B has the lowest mission priority. Further assume that satellite B requires TT&C restoration, satellite A is currently receiving TT&C service from terminal 1, and satellite B's TT&C could be restored by terminal 1. If terminal 1 is already servicing all of the satellites it is capable of handling, then the protoype would not permit satellite B to takeover any of the TT&C slots at terminal 1 (because satellite B has the lowest priority). The prototype would not consider assigning satellite A to another TT&C terminal and then assigning satellite B to the open TT&C slot at terminal 1, even if this resulted in a higher objective function value. The protoype was designed to keep the number of equipment changes low, and does not reshuffle higher priority resources to meet the needs of lower priority resources.

Time to Solve. All of the test cases, except for Test 10, were completed in less than 20 minutes. The run time for each scenario was highly correlated with the number of inferences, but not so dependent on the number of plans that were generated. The run time was more dependent on when most of the branching took place; the earlier the branching, the longer the run time. This result was due to the fact that the prototype treated each partial plan separately in the restoration process. If three partial plans were generated in phase one, then the prototype had to perform phase two restoration on each of those partial plans, and subsequently perform phase three restoration on all of the partial plans generated from the phase two branchings. This behavior of the prototype led to the decision to perform as many of the "common" restoration actions (such as activating spare satellites) in the root node as possible.

In order to analyze the run time of the prototype with respect to the requirements of an operational decision aid, several factors must be considered. First, most of the scenarios were run as the first restoration attempt following the outbreak of a conflict. At the beginning of a conflict, there will probably be more possible restoration combinations than at the later stages of a conflict when only a few space assets remain. Therefore, when time is critical, an operational decision aid will have to employ heuristics to cut down the search space, even if all of the possible plans the system could generate would be excellent.

The second factor that must be considered is the scope of the prototype in relation to the scope of an operational system. Because the restoration problem gets harder as the number of resources increases, it is reasonable to assume that an operational system would require more time to solve some restoration problems. In addition, an operational system would have to perform many more complex tasks than the prototype, including orbital calculations and vulnerability analysis. The prototype involves approximately 1/5 of the resources an operational system would have to handle, and the simplifying assumptions of this research effort also widen the gap between what the prototype does and what an operational system would actually require.

The third factor that impacts on the time to solve the restoration problem is the difficulty of the scenario. Because the decision aid would contain the latest information, and be available for consultation at all times, it is doubtful that the decision maker would wait until half of his resources were destroyed before he would use the space system restoration management decision aid. Even if there were significant losses, the status changes could be input to the decision aid in increments and the restoration program would be run several times to produce the overall restoration plan.

The hardware and software of the operational decision aid would also significantly impact on the time required to generate restoration plans. It was clear early in the coding phase of this research effort that the environment used for the prototype would not be adequate for an operational space system restoration management system. The prototype program took over 45 minutes to load, and the 8 megabyte memory capacity of the LMI Lambda computer supporting the ART language could not handle more than three runs of the simpler scenarios (due to the absence of "garbage collection" in the Lambda's operating system). If an operational system were implemented on a faster and more powerful computer, perhaps it would produce plans in a reasonable amount of time, even if all of the additional features outlined in the requirements section were added. While a more detailed evaluation of ART is provided in Chapter VIII, here it is sufficient to say that ART Version 2.0 would be inadequate for an operational system. If future versions of ART, such as the version Inference Corporation is currently developing in "C," live up to the expectations of running 4-5 times faster on a micro-Vax computer, then ART may be an adequate programming environment for an operational system (43).

Alternative Restoration Plans. In most of the test cases, the prototype generated more than one final plan.

One of the more significant results of the test cases was the fact that many tests yielded alternative plans with the same objective function value. The following four factors contributed to this result: (1) most of the TT&C earth terminals had excess capacity in all of the test cases, and this resulted in the restoration of the majority of the resources that required restoration, (2) the prototype discarded all infeasible plans, (3) the pruning algorithm discarded recognizably inferior plans, and (4) the rules that combined the individual restorations to develop the composite restoration plans in each phase sought to restore as many resources as possible. Only when there was insufficient capacity for total restoration did the prototype consider restoring higher priority systems at the expense of lower priority systems.

The cases where the prototype generated several plans with the same objective function value demonstrate the need for a space system restoration management decision aid to provide additional analysis besides a numeric value. When the decision maker is presented with several different plans that all have the same numeric value, he needs such information as the vulnerabilities of each plan and estimates of the time required to implement each plan before he makes his decision.

Pruning Algorithm. The pruning algorithm developed for the prototype was only activated in two of the test cases. Since the pruning algorithm can only be activated in cases where complete restoration is not possible for all systems, it is likely that it would be activated more often in scenarios with significant losses. Also, since the pruning algorithm was designed to catch those cases where the heuristics in the rules allowed an unprofitable plan to slip through, a restoration process that is completed without the use of the pruning algorithm is perfectly acceptable.

VIII. Conclusions and Recommendations

Operational System Feasibility

Based on the results of this research, an effective operational space system restoration management decision aid could definitely be developed with the knowledge-based approach. The prototype knowledge-based system demonstrated that several of the key requirements for such a decision aid could be fulfilled with an AI system. The prototype was able to generate feasible restoration plans in a short period of time, reason with incomplete information, and display the set of alternative plans to the decision maker. In addition, the prototype acted as a data base for the space system configurations, and contained provisions for keeping the knowledge base current and compatible with the restoration plans which were adopted.

While the AI methodology is sound for the space system restoration management problem, the practicality of using a programming environment based on the LISP language, such as ART, is questionable. Since expert system building tools in more conventional programming languages (e.g. Fortran and C) are starting to appear on the commercial software market, and these languages are faster and can be implemented on larger computer systems, it would probably be more reasonable for an operational system to be developed with one of them.

Future Research

There exist many opportunities for follow-on research to this thesis effort. Many of the prototype's features need to be expanded and refined to better match the real space system restoration problem. Probably the most important step toward achieving an operational space system restoration management decision aid is the development of an orbital calculation package to be used with the decision aid. Because the geosynchronous orbit assumption greatly simplified the problem of locating satellites and determining which earth terminals could transmit and receive data from which satellites, the development of an orbital calculation package would significantly enhance the findings of this research.

Potential follow-on research also includes using Bayesian probability theory for the handling of uncertain and incomplete information, developing a graphical user interface, and developing the capability to explain the rationale used by the prototype to generate the various restoration plans. Developments in these three areas would clearly benefit the user acceptance of the decision aid. A mathematical approach to uncertainty would also facilitate the comparison between the alternative plans. Future research into the graphics interface could include provisions for adding new space system resources, querying the knowledge base, graphically displaying the status and locations of space resources, and graphically presenting the alternative restoration plans. Research into the explanation capability area could include the development of a module that converts the system's reasoning trail into a natural language explanation.

The use of more Operations Research techniques in conjunction with the AI techniques could improve the performance of the decision aid in terms of the time required to generate the restoration plans and the quality of the plans themselves. Specific OR techniques, such as the shortest path algorithm, could be programmed as modules withing the AI program. A "second-pass" algorithm to reshuffle resources in the final restoration plans could also be developed to improve the quality of the restoration plans.

Further research also includes using actual space system information with the decision aid. When this has been accomplished, the system could be used to perform cost-benefit analyses on the value of interoperability and the use of on-orbit spare satellites.

Evaluation of ART

ART Version 2.0 is a powerful AI programming tool, but contains several inherent weaknesses that significantly detract from its appeal. The most significant problems encountered with ART Version 2.0 were the massive amount of memory capacity required to load and run the prototype, the inability to save compiled versions of the code, and the substandard quality of the documentation. Several of ART's major features, including viewpoints, schema, and a sophisticated debugging system, were found to be quite good. By the time the Inference Corporation releases a version of ART in C, many of the frustrating weaknesses described above should be remedied.

Conclusion

This thesis effort demonstrated that the knowledge-based approach offers significant advantages over the mathematical programming approach that was previously applied to the space system restoration management problem. However, because artificial intelligence is such a new field, it will undoubtedly take some time before the hardware and software will be adequate to permit the development of an operational space system restoration management decision aid. It will also take some time before the US achieves the degree of space system interoperability necessary to make a space system restoration management tool worthwhile. Perhaps with more research into both of these areas, the hammer and the nail will arrive on the scene at the same time.

Appendix A: Generic Space Systems

Table A.1

AFSCN Remote Tracking Stations

RTS (Location)	Longitude	Area	# Antennas
Kaena Point (Hawaii)	158° 15'W	3	2
Vandenberg (California)	120° 31'W	6	2
New Hampshire (Manchester, NH)	71° 38'W	11	2
Thule (Greenland)	68° 36'W	12	2
Oakhanger (United Kingdom)	0° 54'E	19	1
Indian Ocean (Seychelles Islands)	55° 28'E	24	1
Guam (South Pacific)	144° 15'E	33	2

Table A.2

TALK Communications System

TALK Satellites:

Satellite	Longitude	Coverage Areas
TalksatA	95° W	3 - 15
TalksatB	5° W	12 - 24
TalksatC	85° E	21 - 33
TalksatD	175° E	30 - 36, 1 - 6

TALK Data Terminals:

Terminal	Longitude	Area
Wahiawi	158° 3'W	3
Sunnyvale	122° 1'W	6
Colorado Springs	104° 49'W	8
Thule	68° 36'W	12
Crete	24° 42'E	21
Diego Garcia	72° 25'E	26
Guam	144° 15'E	33
Kwajelein	167° 20'E	35

AFSCN RTS for TT&C:

RTS	Area	Primary for TT&C	Backup for TT&C
Kaena Pt	3	TalksatD	TalksatA
Vandenberg	6	TalksatA	TalksatD
New Hampshire	11		TalksatA
Thule	12		TalksatA, TalksatB
Oakhanger	19		TalksatB
Indian Ocean	24	TalksatB, TalksatC	
Guam	33		TalksatC, TalksatD

Frequencies:

Data: uplink freq: 7900 - 8400 Mhz
downlink freq: 7250 - 7750 Mhz

TT&C: uplink freq: 1800 Mhz
downlink freq: 2250 Mhz

Table A.3

CHATTER Communications System

CHATTER Satellites:

Satellite	Longitude	Coverage Areas
Chatter1	115° W	1 - 13
Chatter2	25° W	10 - 22
Chatter3	75° E	20 - 32
Chatter4	165° E	29 - 36, 1 - 5

CHATTER Data Terminals:

Terminal	Longitude	Area
Wahiawi	158° 3'W	3
Sunnyvale	122° 1'W	6
Point Mugu		7
Colorado Springs	104° 49'W	8
Norfolk	76° 15'W	11
Prospect Harbor		12
Crete	24° 42'E	21
Indian Ocean	55° 28'E	24
Woomera	136° 43'E	32
Kwajelein	167° 20'E	35

CHATTER TT&C Terminals

Terminal	Area	Primary for TT&C	Backup for TT&C
Wahiawi	3	Chatter4	Chatter1
Point Mugu	7	Chatter1	
Norfolk	11	Chatter2	Chatter1
Woomera	32	Chatter3	Chatter4

Frequencies:

Data: uplink freq: 225 - 400 Mhz, 7900 - 8400 Mhz
downlink freq: 225 - 400 Mhz

TT&C: uplink freq: 1800 Mhz
downlink freq: 2252 Mhz, 2262 Mhz

Table A.4

STORM Meteorological System

STORM Satellites:

Satellite	Longitude	Coverage Areas
Storm Atlantic	35° W	9 - 21
Storm Pacific	155° W	1 - 9, 33 - 36

STORM Data Terminals:

Terminal	Longitude	Area
Fairchild AFB	117° 25'W	6
Colorado Springs	104° 49'W	8
Offutt AFB	95° 57'W	9
Loring AFB	67° 54'W	12

STORM TT&C Terminals:

Terminal	Area	Primary for TT&C	Backup for TT&C
Fairchild AFB	6	Storm Pacific	
Loring AFB	12	Storm Atlantic	
AFSCN RTS's as backups:			
Kaena Point	3		Storm Pacific
Vandenberg	6		Storm Pacific
New Hampshire	11		Storm Atlantic
Thule	12		Storm Atlantic
Oakhanger	19		Storm Atlantic
Guam	33		Storm Pacific

Frequencies:

Data: downlink freq: 2500 Mhz

TT&C: uplink freq: 1800 Mhz
downlink freq: 2250 Mhz

Table A.5

THUNDER Meteorological System

THUNDER Satellites:

Satellite	Longitude	Coverage Areas
Thunder1	155° W	1 - 9, 33 - 36
Thunder2	65° W	6 - 18
Thunder3	25° E	15 - 27
Thunder4	115° E	24 - 36

THUNDER Data Terminals:

Terminal	Longitude	Area
Sunnyvale	122° 1'W	6
Colorado Springs	104° 49'W	8
Offutt AFB	95° 57'W	9
Maryland		11
Ascension Island		17
Diego Garcia	72° 25'E	26
Guam	144° 15'E	33

THUNDER TT&C Terminals:

Terminal	Area	Primary for TT&C	Backup for TT&C
Sunnyvale	6		Thunder1, Thunder2
Colorado Springs	8	Thunder1, Thunder2	
Ascension Is.	17		Thunder3
Diego Garcia	26	Thunder3, Thunder4	
Guam	33		Thunder4

Frequencies:

Data: downlink freq: 2500 Mhz

TT&C: uplink freq: 9000 Mhz
downlink freq: 8000 Mhz

Table A.6

SCOUT Navigation System

SCOUT Satellites:

Satellite	Longitude	Coverage Areas
Scout A	165° W	1 - 8, 32 - 36
Scout B	75° W	5 - 17
Scout C	15° E	14 - 26
Scout D	105° E	23 - 35

SCOUT TT&C Terminals:

Terminal	Area	Primary for TT&C	Backup for TT&C
Wahiawi	3		Scout A
Point Mugu	7	Scout A, Scout B	
Rosemount, MN	9		Scout B
Prospect Harbor	12		Scout B
Ascension Id.	17	Scout C	
Diego Garcia	26		Scout C, Scout D
Woomera	32	Scout D	Scout A

Frequencies:

Data: downlink freq: 150 Mhz, 400 Mhz

TT&C: uplink freq: 143.5 Mhz
downlink freq: 150 Mhz

Table A.7

PATHFINDER Navigation System

PATHFINDER Satellites:

Satellite	Longitude	Coverage Areas
Pathsat1	175° W	1 - 5, 33 - 36
Pathsat2	155° W	1 - 7, 35 - 36
Pathsat3	135° W	1 - 9
Pathsat4	115° W	3 - 11
Pathsat5	95° W	5 - 13
Pathsat6	75° W	7 - 15
Pathsat7	55° W	9 - 17
Pathsat8	35° W	11 - 19
Pathsat9	15° W	13 - 21
Pathsat10	5° E	15 - 23
Pathsat11	25° E	17 - 25
Pathsat12	45° E	19 - 27
Pathsat13	65° E	21 - 29
Pathsat14	85° E	23 - 31
Pathsat15	105° E	25 - 33
Pathsat16	125° E	27 - 35
Pathsat17	145° E	29 - 36, 1
Pathsat18	165° E	31 - 36, 1 - 3
Spares:		
PathSpare 1	95° W	5 - 13
PathSpare 2	15° E	16 - 24
PathSpare 3	125° E	27 - 35

PATHFINDER TT&C Terminals:

Terminal	Area	Primary for TT&C	Backup for TT&C
Wahiawi	3	P1, P2, P3	P18, P4
Colorado Springs	8	P4, P5, P6, S1	P3
Ascension Is.	17	P7, P8, P9, P10, P11, S2	
Diego Garcia	26	P12, P13, P14, P15	
Guam	33	P16, P17, P18, S3	P15, P1

Table A. 7 PATHFINDER Navigation System (continued)

AFSCN RTS for TT&C:

RTS	Area	Primary for TT&C	Backup for TT&C
Kaena Pt	3		P1, P2, P3, P4, P18
Vandenberg	6		P2, P3, P4, P5, S1
New Hampshire	11		P4, P5, P6, P7, P8, S1
Thule	12		P5, P6, P7, P8, S1
Oakhanger	19		P8, P9, P10, P11, S2
Indian Ocean	24		P11, P12, P13, P14, S2

Frequencies:

Data: downlink freq: 1575.4 Mhz, 1227.6 Mhz

TT&C: uplink freq: 1800 Mhz
downlink freq: 2250 Mhz

Table A.8

Theater Communications Ports

Pacific Theater:

Wahiawi

American Theater:

Sunnyvale
Point Mugu
Colorado Springs
Norfolk
Prospect Harbor
Thule

European Theater:

Crete

Asian Theater:

Indian Ocean
Diego Garcia

Far Eastern Theater:

Woomera
Guam
Kwajelein

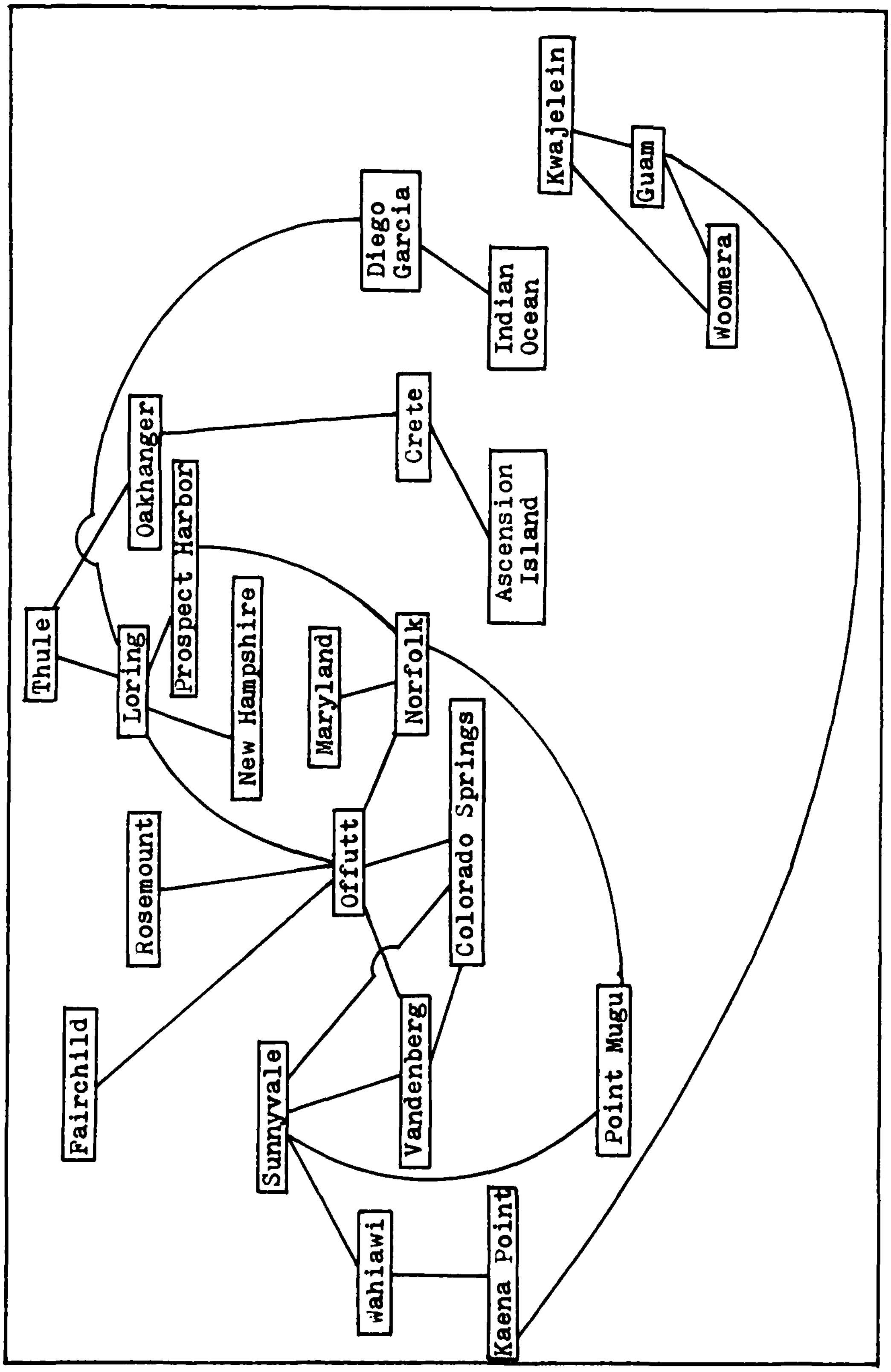

Figure A.1 Landline Network

Appendix B: Computation of Weights with AHP

This appendix demonstrates how the Analytic Hierarchy Process can be used to compute the weights associated with the various measures of effectiveness which comprise the objective function. The numbers used for the comparisons are hypothetical, and do not reflect the Air Force's or CINCSPACE's assessments. Because the determination of the weights is dependent on the scenario, the Analytic Hierarchy Process described in this appendix would have to be repeated for each different scenario.

Pairwise Comparison Matrices

The top element of the hierarchy in Figure 5.3, wartime capability, was used as the criterion for the first set of pairwise comparisons. Table B.1 shows the first set of pairwise comparisons; the elements of the second level (weather, navigation, and communications) were compared with each other, with respect to their relative contribution to wartime capability.

Table B.1
Comparison Matrix for Missions

Criterion: Wartime Capability	Weather	Navigation	Communications
Weather	1	1/3	1/5
Navigation	3	1	1/2
Communications	5	2	1

To determine the matrix entries, each element in the column at the left of the matrix was compared with each element in the row across the top of the matrix with respect to the criterion. To make such a comparison, the decision maker should ask himself, "How much more strongly does this element contribute to the wartime capability (at the current stage of the conflict) than the element with which it is being compared?" Saaty recommends using numbers 1 through 9 to represent the relative importance of one element over another with respect to the criterion (37:77).

When comparing an element in the matrix with itself, the comparison must yield unity (1), so the diagonal of the matrix can be filled in with one's, as shown in Table B.1 (37:78). Also, the reciprocal of the number used for the comparison of A with B is assigned to the comparison of B with A. For example, in Table B.1, the navigation mission was determined to be three times more important than the weather mission. Therefore, using the reciprocal rule, the weather mission was assigned one-third the importance of the navigation mission. The remainder of the matrix was completed in this manner. When filling in the matrix, Saaty cautions that care must be taken to insure that the judgements are fairly consistent. In a case where communications is judged six times as important as weather and twice as important as navigation, navigation would have to be judged three times as important as weather to achieve perfect

Three matricies were required, and they are shown in Tables B.3, B.4, and B.5. The comparison matrix in Table B.3 demonstrates the relative comparison of the value of global weather information to the value of weather information about the conflict area. Table B.4 shows the relative importance of worldwide navigation capability to navigation capability in only the conflict area. Table B.5 demonstrates the relative importance of global communications capability to communications capability between just the CONUS and the conflict theater. The normalized matricies are shown to the right of each of the pairwise comparison matrices.

Table B.3
Location Emphasis Comparison (Weather Mission)

Comparision Matrix			Normalized Matrix			Weight
Weather	Global	Conflict	Weather	Global	Conflict	Avg
Global	1	1/3	Global	.25	.25	.25
Conflict	3	1	Conflict	.75	.75	.75

Table B.4
Location Emphasis Comparison (Navigation Mission)

Comparision Matrix			Normalized Matrix			Weight
Nav	Global	Conflict	Nav	Global	Conflict	Avg
Global	1	1/2	Global	.33	.33	.33
Conflict	2	1	Conflict	.67	.67	.67

Table B.5
Location Emphasis Comparison (Communications Mission)

Comparision Matrix			Normalized Matrix			Weight
Comm	Global	Conflict	Comm	Global	Conflict	Avg
Global	1	2	Global	.67	.67	.67
Conflict	1/2	1	Conflict	.33	.33	.33

Only the navigation mission has a fourth level, and two 3x3 matrices were required for the pairwise comparisons for the fourth level, one for the global navigation situation, and one for the conflict area navigation situation. As described in Chapter V, six measures of merit were required to describe the total navigation capability: the percent of the earth (or conflict area) that can see one SCOUT satellite, the percent of the earth (or conflict area) that can see three PATHFINDER satellites, and the percent of the earth (or conflict area) that can see four PATHFINDER satellites. The pairwise comparisons in the fourth level reflect the degree to which the decision maker is depending on resources that use the PATHFINDER and SCOUT satellite navigation systems. The numbers, types, and locations of platforms which use the PATHFINDER and SCOUT systems will influence the pairwise comparisons judgements. For example, if support to airborne platforms that use the PATHFINDER system for navigation is the top priority for the battle commanders, the "Platforms needing 4 PATHFINDER satellites" element in the fourth level would be assigned a high number relative to the other elements. Tables B.6 and B.7 show the pairwise comparison matrices, normalized matrices, and resulting weights for the global and the conflict area situations.

Table B.6
Navigation Resources Comparison (Global)

Global Nav	SCOUT	PATH-3	PATH-4		SCOUT	PATH3	PATH4	Avg
	Comparision Matrix			Normalized Matrix				Weight
SCOUT	1	2	1/4	SCOUT	.18	.22	.18	.19
PATH-3	1/2	1	1/6	PATH3	.09	.11	.12	.11
PATH-4	4	6	1	PATH4	.73	.67	.70	.7

Table B.7
Navigation Resources Comparison (Conflict Area)

Theater Nav	SCOUT	PATH-3	PATH-4		SCOUT	PATH3	PATH4	Avg
	Comparision Matrix			Normalized Matrix				Weight
SCOUT	1	1/2	1/3	SCOUT	.17	.14	.18	.16
PATH-3	2	1	1/2	PATH3	.33	.29	.27	.30
PATH-4	3	2	1	PATH4	.50	.57	.55	.54

After all of the comparison matrices are developed and the synthesis process yields the relative weights for each level, these weight can be combined to form the objective function weights. Figure 5.4 shows the AHP hierarchy with the weights just calculated. Chapter V describes how these weights were incorporated into the objective function.

Appendix C: ART Code

```
;;; -*- Mode:Art; Package:au; Base:10. -*-

;;; FILE:  D:BAP;LOADER.ART

(art-load "d:bap;weather.art")
(art-load "d:bap;successors.art")
(art-load "d:bap;trails.art")
(art-load "d:bap;trails2.art")
(art-load "d:bap;commplans.art")
(art-load "d:bap;commplans2.art")
(art-load "d:bap;navigation.art")
(art-load "d:bap;communication.art")
(art-load "d:bap;scenarios.art")
(art-load "d:bap;mainprogram.art")
(art-load "d:bap;tryother.art")
(art-load "d:bap;forlink.art")
(art-load "d:bap;startup.art")
(art-load "d:bap;reports.art")
(art-load "d:bap;forbreadth.art")
(art-load "d:bap;chooseplan.art")
```

```
;;; -*- Mode:Art; Package:ART-USER; Base:10. -*-

;;; FILE D:BAP;WEATHER.ART

;;; DEFINITION OF GLOBALS, RELATIONS, AND SCHEMA

(def-viewpoint-levels
   plan)

(defglobal ?*weather* = #l '())
(defglobal ?*scoutareas* = #l '())
(defglobal ?*allPathareas* = #l '())
(defglobal ?*stormcov* = #l '())
(defglobal ?*thundercov* = #l '())


;;; Inheritance Relations

(defschema part-of
   (instance-of inh-relation)
   (inverse has-parts))

(defschema has-parts
   (instance-of relation)
   (inverse part-of))

;;; No Inheritance to Children

(defschema system-satellites
   (instance-of slot)
   (slot-what nothing)
   (slot-how-many multiple-values))

(defschema coverage-areas
   (instance-of slot)
   (slot-what nothing))

;;; Multiple Value Slots


(defschema can-get-data-down
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema system-coverage
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema data-transmit-freq
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema data-receive-freq
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema receive-data-from
```

```
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema design-receive-data-from
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema ttc-transmit-freq
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema ttc-receive-freq
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema sat-coverage
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema backup-ttc
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema primary-ttc-for
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema design-primary-ttc-for
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema use
   (instance-of slot)
   (slot-how-many multiple-values))

(defschema backup-ttc-for
   (instance-of slot)
   (slot-how-many multiple-values))

;;; Poison if Two Values in Slot

(defschema primary-ttc
   (instance-of slot)
   (slot-multiple poison))

;;; Define Relations

(defrelation link (?term1 ?term2) symmetric)

(defrelation column (?whereat))
(defrelation priority (?rank ?mission))
(defrelation weight-global (?mission ?weight))
(defrelation weight-conflict (?mission ?weight))
(defrelation conflict-areas (?areas))
(defrelation ttc-restoration-required (?satellite ?phasenumber))
(defrelation needs-data-restoration (?satellite ?phasenumber))
(defrelation data-restoration (?satellite ?terminal))
(defrelation data-restoration-process (?mission ?status))
(defrelation weather-coverage-areas (?areas))
```

```
(defrelation send-over-data (?terminal))
(defrelation ttc-restoration-process (?mission ?status))
(defrelation ttc-restoration (?satellite ?terminal))
(defrelation calculator (?next))
(defrelation weather-percentages (?status))
(defrelation empty-list (?stat))
(defrelation global-weather-percent (?val))
(defrelation conflict-weather-percent (?number))
(defrelation check-to-free-data-terminal (?sat))
(defrelation path3areas (?sequence))
(defrelation path4areas (?sequence))
(defrelation global-scout-percent (?val))
(defrelation conflict-scout-percent (?val))
(defrelation global-path3-percent (?val))
(defrelation global-path4-percent (?val))
(defrelation conflict-path3-percent (?val))
(defrelation conflict-path4-percent (?val))
(defrelation sub-global (?system ?cansee ?value))
(defrelation sub-conflict (?system ?cansee ?value))
(defrelation objective-function-value (?value ?phase))
(defrelation value-added (?mission ?value))
(defrelation put-spare-in-use (?sat))
(defrelation prune (?mission))
(defrelation change-ttc-status (?terminal ?color ?reason))
(defrelation change-data-status (?terminal ?color ?reason))
(defrelation change-satellite-status (?sat ?color ?reason))
(defrelation change-rts-status-yellow (?rts ?color ?reason))
(defrelation ttc-capability-down (?terminal ?reason))
(defrelation data-capability-down (?terminal ?reason))
(defrelation satellite-down (?satellite ?reason))
(defrelation unload-responsibilities (?satellite))
(defrelation gave-away-data-slot (?terminal ?system))
(defrelation best (?value))
(defrelation second-best (?value))
(defrelation third-best (?value))
(defrelation restoration (?status))
(defrelation check-for-other-data-dn (?satellite))
(defrelation phase (?number))
(defrelation one-antenna-down (?rts ?reason))
(defrelation successor (?list ?this ?next))
(defrelation path (?how ?begin ?finish ?trail))
(defrelation accumulate-path (?how ?start ?fin))
(defrelation expand-on (?lst))
(defrelation partials (?lst))
(defrelation collect-hold (?lst))
(defrelation used-link (?from ?to))
(defrelation critical-paths-out (?number))
(defrelation all-paths-out (?number))
(defrelation port (?where ?who))
(defrelation critical-pair (?location ?otherplace) symmetric)
(defrelation critical-pair-count (?num))
(defrelation update-ttc-service (?who))
(defrelation ttc-bypass-tested (?yes))
(defrelation comm-path-restoration-required (?a ?b ?c))
(defrelation comm-path-restoration-done (?a ?b ?c))
(defrelation conflict-comm-percent (?a))
(defrelation global-comm-percent (?a))
(defrelation take-out-links (?a))
(defrelation check-stranded (?a))
```

```
(defrelation groundlink-destroyed (?from ?to))
(defrelation testcase (?scenario))
(defrelation bypass-calculation (?mission))
(defrelation give-plans (?number))
(defrelation give-all-plans (?yes))
(defrelation output-viewpoint (?plan))
(defrelation restoration-finished (?plan))
(defrelation print-path-list (?trail))
(defrelation get-priorities (?scenarios))
(defrelation objective-values (?lst))
(defrelation ttc-bypass-mission1 (?x))
(defrelation found-one-critical (?x ?y))
(defrelation found-one-global (?a ?b))
(defrelation global-navigation-percent (?value))
(defrelation conflict-navigation-percent (?value))
(defrelation get-ranked-values (?yes))
(defrelation find-the-best (?yes))
(defrelation data-dn-checked (?yes))
(defrelation gave-away-slot (?a ?b))
(defrelation retrieve-path (?a ?b ?c))
(defrelation theater (?cont))
(defrelation path-was-printed (?x ?y))
(defrelation clean-up (?yes))
(defrelation clear-out (?junk))

;;; Dummy Schema

(defschema dummy-system
   (needs-system-coverage)
   (system-satellites-operating)
   (system-coverage))

 (defschema dummy-satellite
    (can-get-data-down)
    (spare-in-use)
    (ttc-slot-given-away))

(defschema dummy-terminal
   (data-rx-freq-lower)
   (data-rx-freq-upper)
   (data-rx-freq-lower2)
   (data-rx-freq-upper2))

;;; Initial Facts


(deffacts initial-situation
     (column 0)
     (port USA Sunnyvale)
     (port USA Point-Mugu)
     (port USA Colorado-Springs)
     (port USA Norfolk-Virginia)
     (port USA Thule-Greenland)
     (port Europe Crete-Greece)
     (port Asia Indian-Ocean)
     (port Asia Diego-Garcia)
     (port FarEast Woomera-Australia)
     (port FarEast Kwajelein-Island)
     (port Pacific Wahiawi-Hawaii)
```

```
    (objective-values ())
    (critical-pair-count 0)
    (critical-paths-out 0)
    (all-paths-out 0)
    (best 0)
    (second-best 0)
    (third-best 0))


;;;  Weather Satellite System STORM

(defschema storm
   (viewpoint ?root)
   (system-name storm)
   (system-status green)
   (mission weather)
   (coverage-areas (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
                    33 34 35 36))
   (system-coverage-list (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
                           20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-satellites stormAtlantic stormPacific)
   (is-a satsystem))

;;;  STORM Satellites

(defschema stormAtlantic
   (viewpoint ?root)
   (data-transmit-freq 2500)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (orbit geosynch)
   (sat-coverage 9 10 11 12 13 14 15 16 17 18 19 20 21)
   (sat-cov-list (9 10 11 12 13 14 15 16 17 18 19 20 21))
   (over 15)
   (sat-status green)
   (primary-ttc stormLoring)
   (can-use-RTS yes)
   (backup-ttc RTS-NewHamp RTS-Thule RTS-Oakhanger)
   (is-a satellite)
   (part-of storm))

(defschema stormPacific
   (viewpoint ?root)
   (is-a satellite)
   (part-of storm)
   (data-transmit-freq 2500)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (orbit geosynch)
   (sat-coverage 33 34 35 36 1 2 3 4 5 6 7 8 9)
   (sat-cov-list (33 34 35 36 1 2 3 4 5 6 7 8 9))
   (over 3)
   (sat-status green)
   (primary-ttc stormFairchild)
   (can-use-RTS yes)
   (backup-ttc RTS-Guam RTS-Kaena RTS-Vandenberg))


;;; STORM Earth Terminals
```

```
(defschema stormFairchild
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of storm)
   (location Fairchild-Washington)
   (area 7)
   (use data ttc)
   (receive-data-for storm)
   (primary-ttc-for stormPacific)
   (design-receive-data-for storm)
   (design-primary-ttc-for stormPacific)
   (receive-data-from stormPacific)
   (design-receive-data-from stormPacific)
   (design-can-ttc-service 3)
   (data-receive-freq 2500)
   (ttc-transmit-freq 1800)
   (ttc-receive-freq 2250)
   (can-ttc-service 3)
   (is-ttc-servicing 1)
   (ttc-status green)
   (data-status green))

(defschema stormColoSprings
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of storm)
   (location Colorado-Springs)
   (area 8)
   (data-status green)
   (receive-data-for storm)
   (design-receive-data-for storm)
   (receive-data-from stormPacific)
   (design-receive-data-from stormPacific)
   (use data)
   (data-receive-freq 2500))

(defschema stormLoring
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of storm)
   (location Loring-Maine)
   (area 12)
   (use data ttc)
   (primary-ttc-for stormAtlantic)
   (design-primary-ttc-for stormAtlantic)
   (design-receive-data-for storm)
   (design-can-ttc-service 3)
   (receive-data-from stormAtlantic)
   (design-receive-data-from stormAtlantic)
   (data-receive-freq 2500)
   (ttc-transmit-freq 1800)
   (ttc-receive-freq 2250)
   (can-ttc-service 3)
   (is-ttc-servicing 1)
   (ttc-status green)
   (receive-data-for storm)
   (data-status green))
```

```
(defschema stormOffutt
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of storm)
   (location Offutt-Nebraska)
   (area 9)
   (use data)
   (receive-data-for storm)
   (design-receive-data-for storm)
   (receive-data-from stormAtlantic stormPacific)
   (design-receive-data-from stormAtlantic stormPacific)
   (data-receive-freq 2500)
   (data-status green))

;;;  AFSCF Remote Tracking Stations

(defschema AFSCF
   (system-name AFSCF))

(defschema remote-tracking-station
   (viewpoint ?root)
   (ttc-rx-freq-lower 2200)
   (ttc-rx-freq-upper 2300)
   (ttc-tx-freq-lower 1750)
   (ttc-tx-freq-upper 1850)
   (use ttc))

(defschema RTS-Kaena
   (viewpoint ?root)
   (part-of AFSCF)
   (can-ttc-service 6)
   (is-ttc-servicing 1)
   (location Kaena-Pt-Hawaii)
   (area 3)
   (number-of-antennas 2)
   (primary-ttc-for talksatD)
   (design-primary-ttc-for talksatD)
   (design-can-ttc-service 6)
   (backup-ttc-for talksatA stormPacific pathsat18 pathsat2 pathsat3 pathsat4)
   (ttc-status green)
   (instance-of remote-tracking-station)
   (is-a earth-terminal))

(defschema RTS-Vandenberg
   (viewpoint ?root)
   (part-of AFSCF)
   (location Vandenberg)
   (area 6)
   (number-of-antennas 2)
   (can-ttc-service 6)
   (is-ttc-servicing 1)
   (primary-ttc-for talksatA)
   (design-primary-ttc-for talksatA)
   (design-can-ttc-service 6)
   (backup-ttc-for talksatD stormPacific pathsat2 pathsat3 pathsat4
                pathsat5 pathsatSpare1)
   (ttc-status green)
   (instance-of remote-tracking-station)
   (is-a earth-terminal))
```

```
(defschema RTS-NewHamp
   (viewpoint ?root)
   (part-of AFSCF)
   (location New-Hampshire)
   (area 11)
   (number-of-antennas 2)
   (can-ttc-service 6)
   (design-can-ttc-service 6)
   (is-ttc-servicing 0)
   (backup-ttc-for stormAtlantic pathsat4 talksatA pathsat5 pathsatSpare1
                   pathsat6 pathsat7 pathsat8)
   (instance-of remote-tracking-station)
   (is-a earth-terminal)
   (ttc-status green))

(defschema RTS-Thule
   (viewpoint ?root)
   (part-of AFSCF)
   (location Thule-Greenland)
   (area 12)
   (number-of-antennas 1)
   (can-ttc-service 3)
   (is-ttc-servicing 0)
   (backup-ttc-for stormAtlantic pathsatSpare1 pathsat5 pathsat6 pathsat7
                   pathsat8 talksatA talksatB)
   (instance-of remote-tracking-station)
   (is-a earth-terminal)
   (ttc-status green))

(defschema RTS-Oakhanger
   (viewpoint ?root)
   (part-of AFSCF)
   (location Oakhanger-UK)
   (area 19)
   (number-of-antennas 1)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 0)
   (backup-ttc-for stormAtlantic pathsat8 talksatB pathsat9 pathsat10
                   pathsatSpare2 pathsat11)
   (instance-of remote-tracking-station)
   (is-a earth-terminal)
   (ttc-status green))

(defschema RTS-IndianOcean
   (viewpoint ?root)
   (part-of AFSCF)
   (location Indian-Ocean)
   (area 24)
   (number-of-antennas 1)
   (can-ttc-service 3)
   (is-ttc-servicing 2)
   (design-can-ttc-service 3)
   (design-primary-ttc-for talksatB talksatC)
   (primary-ttc-for talksatB talksatC)
   (backup-ttc-for pathsatSpare2 pathsat11 pathsat12 pathsat13 pathsat14)
   (instance-of remote-tracking-station)
   (is-a earth-terminal)
```

```
   (ttc-status green))

(defschema RTS-Guam
   (viewpoint ?root)
   (part-of AFSCF)
   (location Guam)
   (area 33)
   (number-of-antennas 2)
   (can-ttc-service 6)
   (is-ttc-servicing 3)
   (design-can-ttc-service 6)
   (design-primary-ttc-for pathsat16 pathsat17 pathsat18 pathsatSpare3)
   (primary-ttc-for pathsat16 pathsat17 pathsat18 pathsatSpare3)
   (backup-ttc-for pathsat15 pathsat1)
   (instance-of remote-tracking-station)
   (is-a earth-terminal)
   (ttc-status green))


;;; Weather Satellite System THUNDER


(defschema thunder
   (viewpoint ?root)
   (system-name thunder)
   (system-status green)
   (mission weather)
   (coverage-areas (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
          19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-coverage-list (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
               18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-satellites thunder1 thunder2 thunder3 thunder4)
   (is-a satsystem))


;;; THUNDER Satellites

(defschema thunder1
   (viewpoint ?root)
   (part-of thunder)
   (is-a satellite)
   (data-transmit-freq 2500)
   (ttc-transmit-freq 8000)
   (ttc-receive-freq 9000)
   (orbit geosynch)
   (sat-coverage 1 2 3 4 5 6 7 8 9 33 34 35 36)
   (sat-cov-list (1 2 3 4 5 6 7 8 9 33 34 35 36))
   (over 3)
   (sat-status green)
   (can-use-RTS no)
   (primary-ttc thunderColoSprings)
   (backup-ttc thunderSunnyvale))

(defschema thunder2
   (viewpoint ?root)
   (part-of thunder)
   (is-a satellite)
   (data-transmit-freq 2500)
   (ttc-transmit-freq 8000)
```

```
   (ttc-receive-freq 9000)
   (orbit geosynch)
   (sat-coverage 6 7 8 9 10 11 12 13 14 15 16 17 18)
   (sat-cov-list (6 7 8 9 10 11 12 13 14 15 16 17 18))
   (over 12)
   (sat-status green)
   (can-use-RTS no)
   (primary-ttc thunderColoSprings)
   (backup-ttc thunderSunnyvale))

(defschema thunder3
   (viewpoint ?root)
   (part-of thunder)
   (is-a satellite)
   (data-transmit-freq 2500)
   (ttc-transmit-freq 8000)
   (ttc-receive-freq 9000)
   (orbit geosynch)
   (sat-coverage 15 16 17 18 19 20 21 22 23 24 25 26 27)
   (sat-cov-list (15 16 17 18 19 20 21 22 23 24 25 26 27))
   (over 21)
   (can-use-RTS no)
   (primary-ttc thunderDiegoGarcia)
   (backup-ttc thunderAscension)
   (sat-status green))

(defschema thunder4
   (viewpoint ?root)
   (part-of thunder)
   (is-a satellite)
   (data-transmit-freq 2500)
   (ttc-transmit-freq 8000)
   (ttc-receive-freq 9000)
   (orbit geosynch)
   (sat-coverage 24 25 26 27 28 29 30 31 32 33 34 35 36)
   (sat-cov-list (24 25 26 27 28 29 30 31 32 33 34 35 36))
   (over 30)
   (can-use-RTS no)
   (primary-ttc thunderDiegoGarcia)
   (backup-ttc thunderGuam)
   (sat-status green))

;;; THUNDER Earth Terminals

(defschema thunderSunnyvale
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of thunder)
   (location Sunnyvale)
   (area 6)
   (use data ttc)
   (backup-ttc-for thunder1 thunder2)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 0)
   (data-recieve-freq 2500)
   (ttc-receive-freq 8000)
   (ttc-transmit-freq 9000)
   (receive-data-for thunder)
```

```
   (design-receive-data-for thunder)
   (receive-data-from thunder1 thunder2)
   (design-receive-data-from thunder1 thunder2)
   (ttc-status green)
   (data-status green))

(defschema thunderColoSprings
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of thunder)
   (location Colorado-Springs)
   (area 8)
   (use data ttc)
   (primary-ttc-for thunder1 thunder2)
   (design-primary-ttc-for thunder1 thunder2)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 2)
   (data-receive-freq 2500)
   (ttc-receive-freq 8000)
   (ttc-transmit-freq 9000)
   (receive-data-for thunder)
   (design-receive-data-for thunder)
   (receive-data-from thunder1 thunder2)
   (design-receive-data-from thunder1 thunder2)
   (ttc-status green)
   (data-status green))

(defschema thunderOffutt
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of thunder)
   (location Offutt-Nebraska)
   (area 9)
   (use data)
   (data-receive-freq 2500)
   (receive-data-for thunder)
   (design-receive-data-for thunder)
   (receive-data-from thunder1 thunder2)
   (design-receive-data-from thunder1 thunder2)
   (data-status green))

(defschema thunderMaryland
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of thunder)
   (location Maryland)
   (area 11)
   (use data)
   (data-receive-freq 2500)
   (receive-data-for thunder)
   (receive-data-from thunder2)
   (design-receive-data-from thunder2)
   (design-receive-data-for thunder)
   (data-status green))

(defschema thunderAscension
   (viewpoint ?root)
   (is-a earth-terminal)
```

```
   (part-of thunder)
   (location Ascension-Island)
   (area 17)
   (use data ttc)
   (data-receive-freq 2500)
   (ttc-receive-freq 8000)
   (ttc-transmit-freq 9000)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 0)
   (backup-ttc-for thunder3)
   (receive-data-for thunder)
   (design-receive-data-for thunder)
   (receive-data-from thunder2 thunder3)
   (design-receive-data-from thunder2 thunder3)
   (ttc-status green)
   (data-status green))

(defschema thunderDiegoGarcia
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of thunder)
   (location Diego-Garcia)
   (area 26)
   (use data ttc)
   (data-receive-freq 2500)
   (ttc-receive-freq 8000)
   (ttc-transmit-freq 9000)
   (primary-ttc-for thunder3 thunder4)
   (design-primary-ttc-for thunder3 thunder4)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 2)
   (receive-data-for thunder)
   (design-receive-data-for thunder)
   (receive-data-from thunder3 thunder4)
   (design-receive-data-from thunder3 thunder4)
   (ttc-status green)
   (data-status green))

(defschema thunderGuam
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of thunder)
   (location Guam)
   (area 33)
   (use data ttc)
   (data-receive-freq 2500)
   (ttc-receive-freq 8000)
   (ttc-transmit-freq 9000)
   (backup-ttc-for thunder4)
   (receive-data-for thunder)
   (design-receive-data-for thunder)
   (receive-data-from thunder1 thunder4)
   (design-receive-data-from thunder1 thunder4)
   (design-can-ttc-service 3)
   (can-ttc-service 3)
   (is-ttc-servicing 0)
   (ttc-status green)
```

```
(data-status green))
```

```
;;;-*- mode:Art; Package:au; Base:10.-*-

;;; FILE:  D:BAP;SUCCESSORS.ART

(deffacts links-and-successors
 (SUCCESSOR TALK TALKSATD TALKWAHIAWI)
 (SUCCESSOR TALK TALKSATA TALKWAHIAWI)
 (SUCCESSOR TALK TALKSATA TALKSUNNYVALE)
 (SUCCESSOR TALK TALKSATD TALKSUNNYVALE)
 (SUCCESSOR TALK TALKSATA TALKCOLOSPRINGS)
 (SUCCESSOR TALK TALKSATB TALKTHULE)
 (SUCCESSOR TALK TALKSATA TALKTHULE)
 (SUCCESSOR TALK TALKSATB TALKCRETE)
 (SUCCESSOR TALK TALKSATC TALKCRETE)
 (SUCCESSOR TALK TALKSATC TALKDIEGOGARCIA)
 (SUCCESSOR TALK TALKSATC TALKGUAM)
 (SUCCESSOR TALK TALKSATD TALKGUAM)
 (SUCCESSOR TALK TALKSATD TALKKWAJELEIN)
 (SUCCESSOR TALK TALKWAHIAWI WAHIAWI-HAWAII)
 (SUCCESSOR TALK TALKSUNNYVALE SUNNYVALE)
 (SUCCESSOR TALK TALKCOLOSPRINGS COLORADO-SPRINGS)
 (SUCCESSOR TALK TALKTHULE THULE-GREENLAND)
 (SUCCESSOR TALK TALKCRETE CRETE-GREECE)
 (SUCCESSOR TALK TALKDIEGOGARCIA DIEGO-GARCIA)
 (SUCCESSOR TALK TALKGUAM GUAM)
 (SUCCESSOR TALK TALKKWAJELEIN KWAJELEIN-ISLAND)
 (SUCCESSOR CHATTER CHATTER1 CHATTERWAHIAWI)
 (SUCCESSOR CHATTER CHATTERMUGU CHATTER1)
 (SUCCESSOR CHATTER CHATTERSUNNYVALE CHATTER1)
 (SUCCESSOR CHATTER CHATTERCOLOSPRINGS CHATTER1)
 (SUCCESSOR CHATTER CHATTERNORFOLK CHATTER1)
 (SUCCESSOR CHATTER CHATTERPROSPECTHARBOR CHATTER1)
 (SUCCESSOR CHATTER CHATTER2 CHATTERNORFOLK)
 (SUCCESSOR CHATTER CHATTERPROSPECTHARBOR CHATTER2)
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 (SUCCESSOR CHATTER CHATTERINDIANOCEAN CHATTER3)
 (SUCCESSOR CHATTER CHATTERWOOMERA CHATTER3)
 (SUCCESSOR CHATTER CHATTER4 CHATTERWOOMERA)
 (SUCCESSOR CHATTER CHATTERKWAJELEIN CHATTER4)
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 (SUCCESSOR CHATTER CHATTERSUNNYVALE SUNNYVALE)
 (SUCCESSOR CHATTER CHATTERMUGU POINT-MUGU)
 (SUCCESSOR CHATTER CHATTERCOLOSPRINGS COLORADO-SPRINGS)
 (SUCCESSOR CHATTER CHATTERNORFOLK NORFOLK-VIRGINIA)
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 (SUCCESSOR CHATTER CHATTERCRETE CRETE-GREECE)
 (SUCCESSOR CHATTER CHATTERINDIANOCEAN INDIAN-OCEAN)
 (SUCCESSOR CHATTER CHATTERWOOMERA WOOMERA-AUSTRALIA)
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(LINK GUAM KAENA-PT-HAWAII)
(SUCCESSOR LANDLINE KAENA-PT-HAWAII GUAM)
(SUCCESSOR LANDLINE OFFUTT-NEBRASKA VANDENBERG)
(LINK OFFUTT-NEBRASKA VANDENBERG)
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(SUCCESSOR LANDLINE COLORADO-SPRINGS VANDENBERG)
(LINK COLORADO-SPRINGS VANDENBERG)
(SUCCESSOR LANDLINE VANDENBERG COLORADO-SPRINGS)
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(LINK OFFUTT-NEBRASKA FAIRCHILD-WASHINGTON)
(SUCCESSOR LANDLINE FAIRCHILD-WASHINGTON OFFUTT-NEBRASKA)
(SUCCESSOR LANDLINE OAKHANGER-UK THULE-GREENLAND)
(LINK OAKHANGER-UK THULE-GREENLAND)
(SUCCESSOR LANDLINE THULE-GREENLAND OAKHANGER-UK)
(SUCCESSOR LANDLINE LORING-MAINE NEW-HAMPSHIRE)
(LINK LORING-MAINE NEW-HAMPSHIRE)
(SUCCESSOR LANDLINE NEW-HAMPSHIRE LORING-MAINE)
(SUCCESSOR LANDLINE LORING-MAINE OFFUTT-NEBRASKA)
(LINK LORING-MAINE OFFUTT-NEBRASKA)
(SUCCESSOR LANDLINE OFFUTT-NEBRASKA LORING-MAINE)
(SUCCESSOR LANDLINE ROSEMOUNT-MINN OFFUTT-NEBRASKA)
(LINK ROSEMOUNT-MINN OFFUTT-NEBRASKA)
(SUCCESSOR LANDLINE OFFUTT-NEBRASKA ROSEMOUNT-MINN)
(SUCCESSOR LANDLINE COLORADO-SPRINGS OFFUTT-NEBRASKA)
(LINK COLORADO-SPRINGS OFFUTT-NEBRASKA)
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(LINK GUAM WOOMERA-AUSTRALIA)
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(LINK SUNNYVALE COLORADO-SPRINGS)
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(LINK WHITE-SANDS COLORADO-SPRINGS)
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(LINK WAHIAWI-HAWAII SUNNYVALE)
(SUCCESSOR LANDLINE SUNNYVALE WAHIAWI-HAWAII)
(SUCCESSOR LANDLINE POINT-MUGU SUNNYVALE)
(LINK POINT-MUGU SUNNYVALE)
(SUCCESSOR LANDLINE SUNNYVALE POINT-MUGU)
(SUCCESSOR LANDLINE POINT-MUGU NORFOLK-VIRGINIA)
(LINK POINT-MUGU NORFOLK-VIRGINIA)
(SUCCESSOR LANDLINE NORFOLK-VIRGINIA POINT-MUGU)
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(LINK KWAJELEIN-ISLAND WOOMERA-AUSTRALIA)
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(SUCCESSOR LANDLINE KWAJELEIN-ISLAND GUAM)
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(SUCCESSOR LANDLINE CRETE-GREECE OAKHANGER-UK)
(SUCCESSOR LANDLINE DIEGO-GARCIA LORING-MAINE)
(LINK DIEGO-GARCIA LORING-MAINE)
(SUCCESSOR LANDLINE LORING-MAINE DIEGO-GARCIA)
(SUCCESSOR LANDLINE THULE-GREENLAND LORING-MAINE)
(LINK THULE-GREENLAND LORING-MAINE)
(SUCCESSOR LANDLINE LORING-MAINE THULE-GREENLAND)
(LINK LORING-MAINE THULE-GREENLAND)
(LINK LORING-MAINE DIEGO-GARCIA)
(LINK CRETE-GREECE OAKHANGER-UK)
(LINK OFFUTT-NEBRASKA NORFOLK-VIRGINIA)
(LINK GUAM KWAJELEIN-ISLAND)
(LINK WOOMERA-AUSTRALIA KWAJELEIN-ISLAND)
(LINK LORING-MAINE PROSPECT-HARBOR-MAINE)
(LINK NORFOLK-VIRGINIA PROSPECT-HARBOR-MAINE)
(LINK NORFOLK-VIRGINIA POINT-MUGU)
(LINK SUNNYVALE POINT-MUGU)
(LINK SUNNYVALE WAHIAWI-HAWAII)
(LINK COLORADO-SPRINGS SUNNYVALE)
(LINK WOOMERA-AUSTRALIA GUAM)
(LINK INDIAN-OCEAN DIEGO-GARCIA)
(LINK ASCENSION-ISLAND CRETE-GREECE)
(LINK OFFUTT-NEBRASKA COLORADO-SPRINGS)
(LINK OFFUTT-NEBRASKA ROSEMOUNT-MINN)
(LINK OFFUTT-NEBRASKA LORING-MAINE)
(LINK NEW-HAMPSHIRE LORING-MAINE)
(LINK THULE-GREENLAND OAKHANGER-UK)
(LINK FAIRCHILD-WASHINGTON OFFUTT-NEBRASKA)
(LINK VANDENBERG COLORADO-SPRINGS)
(LINK VANDENBERG SUNNYVALE)
(LINK VANDENBERG OFFUTT-NEBRASKA)
(LINK KAENA-PT-HAWAII GUAM)
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(SUCCESSOR CHATTER WOOMERA-AUSTRALIA CHATTERWOOMERA)
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(SUCCESSOR CHATTER CRETE-GREECE CHATTERCRETE)
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(SUCCESSOR CHATTER SUNNYVALE CHATTERSUNNYVALE)
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(SUCCESSOR CHATTER CHATTER1 CHATTERCOLOSPRINGS)
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(SUCCESSOR CHATTER CHATTER1 CHATTERMUGU)
(SUCCESSOR CHATTER CHATTERWAHIAWI CHATTER1)
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(SUCCESSOR TALK GUAM TALKGUAM)
(SUCCESSOR TALK DIEGO-GARCIA TALKDIEGOGARCIA)
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(SUCCESSOR TALK THULE-GREENLAND TALKTHULE)
(SUCCESSOR TALK COLORADO-SPRINGS TALKCOLOSPRINGS)
(SUCCESSOR TALK SUNNYVALE TALKSUNNYVALE)
 (SUCCESSOR TALK WAHIAWI-HAWAII TALKWAHIAWI)
 (SUCCESSOR TALK TALKKWAJELEIN TALKSATD)
 (SUCCESSOR TALK TALKGUAM TALKSATD)
 (SUCCESSOR TALK TALKGUAM TALKSATC)
 (SUCCESSOR TALK TALKDIEGOGARCIA TALKSATC)
 (SUCCESSOR TALK TALKCRETE TALKSATC)
 (SUCCESSOR TALK TALKCRETE TALKSATB)
 (SUCCESSOR TALK TALKTHULE TALKSATA)
 (SUCCESSOR TALK TALKTHULE TALKSATB)
 (SUCCESSOR TALK TALKCOLOSPRINGS TALKSATA)
 (SUCCESSOR TALK TALKSUNNYVALE TALKSATD)
 (SUCCESSOR TALK TALKSUNNYVALE TALKSATA)
 (SUCCESSOR TALK TALKWAHIAWI TALKSATA)
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 (SUCCESSOR MIXED TALKGUAM CHATTER4)
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 (SUCCESSOR MIXED TALKCRETE CHATTER3)
 (SUCCESSOR MIXED TALKTHULE CHATTER2)
 (SUCCESSOR MIXED TALKTHULE CHATTER1)
 (SUCCESSOR MIXED TALKCOLOSPRINGS CHATTER1)
 (SUCCESSOR MIXED TALKSUNNYVALE CHATTER1)
 (SUCCESSOR MIXED TALKWAHIAWI CHATTER4)
 (SUCCESSOR MIXED TALKWAHIAWI CHATTER1)
 (SUCCESSOR MIXED CHATTERKWAJELEIN TALKSATD)
 (SUCCESSOR MIXED CHATTERWOOMERA TALKSATD)
 (SUCCESSOR MIXED CHATTERWOOMERA TALKSATC)
 (SUCCESSOR MIXED CHATTERINDIANOCEAN TALKSATC)
 (SUCCESSOR MIXED CHATTERINDIANOCEAN TALKSATB)
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 (SUCCESSOR MIXED CHATTERCRETE TALKSATB)
 (SUCCESSOR MIXED CHATTERPROSPECTHARBOR TALKSATB)
 (SUCCESSOR MIXED CHATTERPROSPECTHARBOR TALKSATA)
 (SUCCESSOR MIXED CHATTERNORFOLK TALKSATA)
 (SUCCESSOR MIXED CHATTERCOLOSPRINGS TALKSATA)
 (SUCCESSOR MIXED CHATTERMUGU TALKSATA)
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 (SUCCESSOR MIXED CHATTERWAHIAWI TALKSATA))
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;;; FILE:  D:BAP;TRAILS.ART


(deffacts chatterpaths

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 (PATH CHATTER POINT-MUGU WAHIAWI-HAWAII
     (POINT-MUGU CHATTERMUGU CHATTER1 CHATTERWAHIAWI WAHIAWI-HAWAII))

 (PATH CHATTER COLORADO-SPRINGS WAHIAWI-HAWAII
     (COLORADO-SPRINGS CHATTERCOLOSPRINGS CHATTER1
      CHATTERWAHIAWI WAHIAWI-HAWAII))

 (PATH CHATTER NORFOLK-VIRGINIA WAHIAWI-HAWAII
     (NORFOLK-VIRGINIA CHATTERNORFOLK CHATTER1
      CHATTERWAHIAWI WAHIAWI-HAWAII))

 (PATH CHATTER PROSPECT-HARBOR-MAINE WAHIAWI-HAWAII
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 (PATH CHATTER CRETE-GREECE WAHIAWI-HAWAII
     (CRETE-GREECE CHATTERCRETE CHATTER2 CHATTERPROSPECTHARBOR
      CHATTER1 CHATTERWAHIAWI WAHIAWI-HAWAII))

 (PATH CHATTER INDIAN-OCEAN WAHIAWI-HAWAII
     (INDIAN-OCEAN CHATTERINDIANOCEAN CHATTER3 CHATTERCRETE CHATTER2
      CHATTERNORFOLK CHATTER1 CHATTERWAHIAWI WAHIAWI-HAWAII))

 (PATH CHATTER WOOMERA-AUSTRALIA WAHIAWI-HAWAII
     (WOOMERA-AUSTRALIA CHATTERWOOMERA CHATTER4
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     (KWAJELEIN-ISLAND CHATTERKWAJELEIN CHATTER4
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     (POINT-MUGU CHATTERMUGU CHATTER1 CHATTERSUNNYVALE SUNNYVALE))

 (PATH CHATTER COLORADO-SPRINGS SUNNYVALE
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     CHATTERSUNNYVALE SUNNYVALE))

 (PATH CHATTER NORFOLK-VIRGINIA SUNNYVALE
    (NORFOLK-VIRGINIA CHATTERNORFOLK CHATTER1
     CHATTERSUNNYVALE SUNNYVALE))

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 (PATH CHATTER CRETE-GREECE SUNNYVALE
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   (INDIAN-OCEAN CHATTERINDIANOCEAN CHATTER3 CHATTERWOOMERA
    CHATTER4 CHATTERWAHIAWI CHATTER1 CHATTERSUNNYVALE SUNNYVALE))

(PATH CHATTER WOOMERA-AUSTRALIA SUNNYVALE
    (WOOMERA-AUSTRALIA CHATTERWOOMERA CHATTER4 CHATTERWAHIAWI
     CHATTER1 CHATTERSUNNYVALE SUNNYVALE))

(PATH CHATTER KWAJELEIN-ISLAND SUNNYVALE
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(PATH CHATTER NORFOLK-VIRGINIA POINT-MUGU
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(PATH CHATTER WOOMERA-AUSTRALIA POINT-MUGU
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(PATH CHATTER PROSPECT-HARBOR-MAINE COLORADO-SPRINGS
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(PATH CHATTER CRETE-GREECE COLORADO-SPRINGS
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(PATH CHATTER INDIAN-OCEAN COLORADO-SPRINGS
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(PATH CHATTER KWAJELEIN-ISLAND COLORADO-SPRINGS
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(PATH CHATTER CRETE-GREECE NORFOLK-VIRGINIA
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(PATH CHATTER INDIAN-OCEAN NORFOLK-VIRGINIA
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(PATH CHATTER WOOMERA-AUSTRALIA NORFOLK-VIRGINIA
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      CHATTER1 CHATTERNORFOLK NORFOLK-VIRGINIA))

(PATH CHATTER KWAJELEIN-ISLAND NORFOLK-VIRGINIA
      (KWAJELEIN-ISLAND CHATTERKWAJELEIN CHATTER4 CHATTERWAHIAWI
       CHATTER1 CHATTERNORFOLK NORFOLK-VIRGINIA))

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(PATH CHATTER WOOMERA-AUSTRALIA PROSPECT-HARBOR-MAINE
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(PATH CHATTER KWAJELEIN-ISLAND PROSPECT-HARBOR-MAINE
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      (INDIAN-OCEAN CHATTERINDIANOCEAN CHATTER3
       CHATTERCRETE CRETE-GREECE))

(PATH CHATTER WOOMERA-AUSTRALIA CRETE-GREECE
      (WOOMERA-AUSTRALIA CHATTERWOOMERA CHATTER3
       CHATTERCRETE CRETE-GREECE))

(PATH CHATTER KWAJELEIN-ISLAND CRETE-GREECE
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      CHATTER3 CHATTERCRETE CRETE-GREECE))

(PATH CHATTER WOOMERA-AUSTRALIA INDIAN-OCEAN
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(PATH CHATTER KWAJELEIN-ISLAND INDIAN-OCEAN
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(PATH CHATTER KWAJELEIN-ISLAND WOOMERA-AUSTRALIA
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(path chatter Wahiawi-Hawaii Point-Mugu
       (Wahiawi-Hawaii chatterWahiawi chatter1
        chatterMugu Point-Mugu ))

(path chatter Wahiawi-Hawaii Colorado-Springs
       (Wahiawi-Hawaii chatterWahiawi chatter1
        chatterColoSprings Colorado-Springs ))

(path chatter Wahiawi-Hawaii Norfolk-Virginia
      (Wahiawi-Hawaii chatterWahiawi chatter1
       chatterNorfolk Norfolk-Virginia ))

(path chatter Wahiawi-Hawaii Prospect-Harbor-Maine
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       chatterProspectHarbor Prospect-Harbor-Maine ))

(path chatter Wahiawi-Hawaii Crete-Greece
      (Wahiawi-Hawaii chatterWahiawi chatter1
       chatterProspectHarbor chatter2 chatterCrete Crete-Greece ))

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      (Wahiawi-Hawaii chatterWahiawi chatter1 chatterNorfolk
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       chatterIndianOcean Indian-Ocean ))

(path chatter Wahiawi-Hawaii Woomera-AUSTRALIA
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       chatterWoomera Woomera-AUSTRALIA ))

(path chatter Wahiawi-Hawaii Kwajelein-Island
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(path chatter Sunnyvale Colorado-Springs
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(path chatter Sunnyvale Norfolk-Virginia
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       chatterNorfolk Norfolk-Virginia))

(path chatter Sunnyvale Prospect-Harbor-Maine
      (Sunnyvale chatterSunnyvale chatter1
       chatterProspectHarbor Prospect-Harbor-Maine))
```

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(path chatter Sunnyvale Crete-Greece
      (Sunnyvale chatterSunnyvale chatter1
       chatterNorfolk chatter2 chatterCrete Crete-Greece))

(path chatter Sunnyvale Indian-Ocean
      (Sunnyvale chatterSunnyvale chatter1 chatterWahiawi chatter4
       chatterWoomera chatter3 chatterIndianOcean Indian-Ocean))

(path chatter Sunnyvale Woomera-AUSTRALIA
      (Sunnyvale chatterSunnyvale chatter1 chatterWahiawi chatter4
       chatterWoomera Woomera-AUSTRALIA))

(path chatter Sunnyvale Kwajelein-Island
      (Sunnyvale chatterSunnyvale chatter1 chatterWahiawi
      chatter4 chatterKwajelein Kwajelein-Island ))


(path chatter Point-Mugu Colorado-Springs
      (Point-Mugu chatterMugu chatter1
       chatterColoSprings  Colorado-Springs ))

(path chatter Point-Mugu Norfolk-Virginia
      (Point-Mugu chatterMugu chatter1
       chatterNorfolk Norfolk-Virginia))

(path chatter Point-Mugu Prospect-Harbor-Maine
      (Point-Mugu chatterMugu chatter1
       chatterProspectHarbor Prospect-Harbor-Maine ))

(path chatter Point-Mugu Crete-Greece
      (Point-Mugu chatterMugu chatter1 chatterNorfolk
       chatter2 chatterCrete Crete-Greece  ))

(path chatter Point-Mugu Indian-Ocean
      (Point-Mugu chatterMugu chatter1 chatterNorfolk chatter2
       chatterCrete chatter3 chatterIndianOcean  Indian-Ocean ))

(path chatter Point-Mugu Woomera-AUSTRALIA
      (Point-Mugu chatterMugu chatter1 chatterWahiawi
       chatter4 chatterWoomera Woomera-AUSTRALIA  ))

(path chatter Point-Mugu Kwajelein-Island
      (Point-Mugu chatterMugu chatter1 chatterWahiawi chatter4
       chatterKwajelein Kwajelein-Island  ))


(path chatter Colorado-Springs Norfolk-Virginia
      (Colorado-Springs chatterColoSprings chatter1
       chatterNorfolk  Norfolk-Virginia))

(path chatter Colorado-Springs Prospect-Harbor-Maine
      (Colorado-Springs chatterColoSprings chatter1
       chatterProspectHarbor Prospect-Harbor-Maine ))

(path chatter Colorado-Springs Crete-Greece
      (Colorado-Springs chatterColoSprings chatter1 chatterNorfolk
       chatter2 chatterCrete  Crete-Greece))

(path chatter Colorado-Springs  Indian-Ocean
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      (Colorado-Springs chatterColoSprings chatter1 chatterNorfolk
      chatter2 chatterCrete chatter3 chatterIndianOcean Indian-Ocean))

(path chatter Colorado-Springs Woomera-AUSTRALIA
      (Colorado-Springs chatterColoSprings chatter1 chatterWahiawi
      chatter4 chatterWoomera  Woomera-AUSTRALIA))

(path chatter Colorado-Springs Kwajelein-Island
      (Colorado-Springs chatterColoSprings chatter1 chatterWahiawi
       chatter4 chatterKwajelein  Kwajelein-Island))


(path chatter Norfolk-Virginia Prospect-Harbor-Maine
      (Norfolk-Virginia chatterNorfolk chatter2
       chatterProspectHarbor Prospect-Harbor-Maine))

(path chatter Norfolk-Virginia Crete-Greece
      (Norfolk-Virginia chatterNorfolk chatter2
       chatterCrete Crete-Greece))

(path chatter Norfolk-Virginia Indian-Ocean
      (Norfolk-Virginia chatterNorfolk chatter2 chatterCrete chatter3
      chatterIndianOcean  Indian-Ocean))

(path chatter Norfolk-Virginia Woomera-AUSTRALIA
      (Norfolk-Virginia chatterNorfolk chatter1 chatterWahiawi
      chatter4 chatterWoomera Woomera-Australia))

(path chatter Norfolk-Virginia Kwajelein-Island
      (Norfolk-Virginia chatterNorfolk chatter1 chatterWahiawi chatter4
       chatterKwajelein Kwajelein-Island))


(path chatter Prospect-Harbor-Maine Crete-Greece
      (Prospect-Harbor-Maine chatterProspectHarbor chatter2
       chatterCrete Crete-Greece ))

(path chatter Prospect-Harbor-Maine Indian-Ocean
      (Prospect-Harbor-Maine chatterProspectHarbor chatter2 chatterCrete
       chatter3 chatterIndianOcean Indian-Ocean ))

(path chatter Prospect-Harbor-Maine Woomera-AUSTRALIA
      (Prospect-Harbor-Maine chatterProspectHarbor chatter1 chatterWahiawi
       chatter4 chatterWoomera Woomera-AUSTRALIA ))

(path chatter Prospect-Harbor-Maine Kwajelein-Island
      (Prospect-Harbor-Maine chatterProspectHarbor chatter1
       chatterWahiawi chatter4 chatterKwajelein Kwajelein-Island ))


(path chatter Crete-Greece Indian-Ocean
      (Crete-Greece chatterCrete chatter3
       chatterIndianOcean Indian-Ocean ))

(path chatter Crete-Greece Woomera-AUSTRALIA
      (Crete-Greece chatterCrete chatter3
       chatterWoomera Woomera-AUSTRALIA ))

(path chatter Crete-Greece Kwajelein-Island
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      (Crete-Greece chatterCrete chatter3 chatterWoomera
       chatter4 chatterKwajelein Kwajelein-Island))


(path chatter Indian-Ocean Woomera-AUSTRALIA
      (Indian-Ocean chatterIndianOcean chatter3
       chatterWoomera Woomera-AUSTRALIA))

(path chatter Indian-Ocean Kwajelein-Island
      (Indian-Ocean chatterIndianOcean chatter3 chatterWoomera
                    chatter4 chatterKwajelein Kwajelein-Island))


(path chatter Woomera-AUSTRALIA Kwajelein-Island
      (Woomera-AUSTRALIA chatterWoomera chatter4
       chatterKwajelein Kwajelein-Island))

(path chatter Point-Mugu Diego-Garcia
      (Point-Mugu chatterMugu chatter1 chatterWahiawi
       chatter4 chatterWoomera chatter3 chatterIndianOcean
       Indian-Ocean Diego-Garcia))

(path chatter Point-Mugu Guam
      (Point-Mugu chatter1 chatterWahiawi chatter4 chatterKwajelein
       Kwajelein-Island Guam))

(path chatter Norfolk-Virginia Diego-Garcia
      (Norfolk-Virginia chatterNorfolk chatter2 chatterCrete chatter3
       chatterIndianOcean Indian-Ocean Diego-Garcia))

(path chatter Prospect-Harbor-Maine Diego-Garcia
      (Prospect-Harbor-Maine chatterProspectHarbor chatter2
       chatterCrete chatter3 chatterIndianOcean
       Indian-Ocean Diego-Garcia))

(path chatter Norfolk-Virginia Guam
      (Norfolk-Virginia chatterNorfolk chatter1 chatterWahiawi
       chatter4 chatterWoomera Woomera-AUSTRALIA Guam))

(path chatter Prospect-Harbor-Maine Guam
      (Prospect-Harbor-Maine chatterProspectHarbor chatter1
       chatterWahiawi chatter4 chatterWoomera Woomera-AUSTRALIA Guam))

(path talk Thule-Greenland Indian-Ocean
      (Thule-Greenland talkThule talksatB talkCrete talksatC
       talkDiegoGarcia Diego-Garcia Indian-Ocean))

(path talk Thule-Greenland Woomera-AUSTRALIA
      (Thule-Greenland talkThule talksatB talkCrete talksatC talkGuam
       Guam Woomera-AUSTRALIA))

(path chatter Indian-Ocean Guam
      (Indian-Ocean chatterIndianOcean chatter3 chatterWoomera
       Woomera-AUSTRALIA Guam))

(path talk Diego-Garcia Woomera-AUSTRALIA
      (Diego-Garcia talkDiego-Garcia talksatC talkGuam
       Guam Woomera-AUSTRALIA))
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(path chatter Diego-Garcia Point-Mugu
      (Diego-Garcia Indian-Ocean chatterIndian-Ocean
       chatter3 chatterWoomera chatter4 chatterWahiawi chatter1
       chatterMugu Point-Mugu))

(path chatter Guam Point-Mugu
      (Guam Kwajelein-Island chatterKwajelein chatter4 chatterWahiawi
       chatter1 chatterMugu Point-Mugu))

(path chatter Diego-Garcia Norfolk-Virginia
      (Diego-Garcia Indian-Ocean chatterIndianOcean chatter3
       chatterCrete chatter2 chatterNorfolk Norfolk-Virginia))

(path chatter Diego-Garcia Prospect-Harbor-Maine
     (Diego-Garcia Indian-Ocean chatterIndian-Ocean
      chatter3 chatterCrete chatter2 chatterProspectHarbor
      Prospect-Harbor-Maine))

(path chatter Guam Norfolk-Virginia
     (Guam Woomera-AUSTRALIA chatterWoomera chatter4 chatterWahiawi
      chatter1 chatterNorfolk Norfolk-Virginia))

(path chatter Guam Prospect-Harbor-Maine
     (Guam Woomera-AUSTRALIA chatterWoomera chatter4 chatterWahiawi
      chatter1 chatterProspectHarbor Prospect-Harbor-Maine))

(path talk Indian-Ocean Thule-Greenland
     (Indian-Ocean Diego-Garcia talkDiegoGarcia talksatC
      talkCrete talksatB talkThule Thule-Greenland))

(path talk Woomera-AUSTRALIA Thule-Greenland
     (Woomera-AUSTRALIA Guam talkGuam talksatC talkCrete
      talksatB talkThule Thule-Greenland))

(path chatter Guam Indian-Ocean
     (Guam Woomera-AUSTRALIA chatterWoomera chatter3
      chatterIndianOcean Indian-Ocean))

(path talk Woomera-AUSTRALIA Diego-Garcia
     (Woomera-AUSTRALIA Guam talkGuam talksastC
      talkDiegoGarcia DiegoGarcia)))
```

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;;; -*-Mode:Art; Package:ART-USER; Base:10. -*-

;;; FILE: D:BAP;COMMPLANS2.ART


(deffacts talk-paths
(path talk Wahiawi-Hawaii Sunnyvale
     (Wahiawi-Hawaii talkWahiawi talksatA talkSunnyvale Sunnyvale ))

(path talk Wahiawi-Hawaii Colorado-Springs
     (Wahiawi-Hawaii talkWahiawi talksatA
      talkColoSprings Colorado-Springs ))

(path talk Wahiawi-Hawaii Thule-Greenland
     (Wahiawi-Hawaii talkWahiawi talksatA talkThule Thule-Greenland))

(path talk Wahiawi-Hawaii Crete-Greece
     (Wahiawi-Hawaii talkWahiawi talksatA talkThule
      talksatB talkCrete  Crete-Greece))

(path talk Wahiawi-Hawaii Diego-Garcia
     (Wahiawi-Hawaii talkWahiawi talksatD talkGuam
      talksatC talkDiegoGarcia Diego-Garcia ))

(path talk Wahiawi-Hawaii Guam
     (Wahiawi-Hawaii talkWahiawi talksatD talkGuam Guam ))

(path talk Wahiawi-Hawaii Kwajelein-Island
     (Wahiawi-Hawaii talkWahiawi talksatD
      talkKwajelein Kwajelein-Island ))

(path talk Sunnyvale Colorado-Springs
     (Sunnyvale talkSunnyvale talksatA
      talkColoSprings  Colorado-Springs))

(path talk Sunnyvale Thule-Greenland
     (Sunnyvale talkSunnyvale talksatA talkThule Thule-Greenland))

(path talk Sunnyvale Crete-Greece
     (Sunnyvale talkSunnyvale talksatA talkThule talksatB
      talkCrete  Crete-Greece))

(path talk Sunnyvale Diego-Garcia
     (Sunnyvale talkSunnyvale talksatA talkWahiawi talksatC
      talkDiegoGarcia  Diego-Garcia ))

(path talk Sunnyvale Guam
     (Sunnyvale talkSunnyvale talksatA talkWahiawi
      talksatD talkGuam Guam ))

(path talk Sunnyvale Kwajelein-Island
     (Sunnyvale talkSunnyvale talksatA talkWahiawi
      talksatD talkKwajelein  Kwajelein-Island ))

(path talk Colorado-Springs Thule-Greenland
     (Colorado-Springs talkColoSprings talksatA
      talkThule Thule-Greenland))
```

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(path talk Colorado-Springs Crete-Greece
     (Colorado-Springs talkColoSprings talksatA talkThule talksatB
      talkCrete Crete-Greece))

(path talk Colorado-Springs Diego-Garcia
     (Colorado-Springs talkColoSprings talksatA talkThule talksatB
      talkCrete talksatC talkDiegoGarcia Diego-Garcia ))

(path talk Colorado-Springs Guam
     (Colorado-Springs talkColoSprings talksatA talkWahiawi
      talksatD talkGuam Guam ))

(path talk Colorado-Springs Kwajelein-Island
     (Colorado-Springs talkColoSprings talksatA talkWahiawi
      talksatD talkKwajelein Kwajelein-Island ))

(path talk Thule-Greenland Crete-Greece
     (Thule-Greenland talkThule talksatB talkCrete Crete-Greece ))

(path talk Thule-Greenland Guam
     (Thule-Greenland talkThule talksatB talkCrete
      talksatC talkGuam Guam  ))

(path talk Thule-Greenland Kwajelein-Island
     (Thule-Greenland talkThule talksatA talkWahiawi talksatD
      talkKwajelein  Kwajelein-Island ))

(path talk Thule-Greenland Diego-Garcia
     (Thule-Greenland talkThule talksatB talkCrete talksatC
      talkDiegoGarcia Diego-Garcia ))

(path talk Crete-Greece Diego-Garcia
     (Crete-Greece talkCrete talksatC talkDiegoGarcia Diego-Garcia ))

(path talk Crete-Greece Guam
     (Crete-Greece talkCrete talksatC talkGuam Guam ))

(path talk Crete-Greece Kwajelein-Island
     (Crete-Greece talkCrete talksatC talkGuam talksatD
      talkKwajelein  Kwajelein-Island ))

(path talk Diego-Garcia  Guam
     (Diego-Garcia  talkDiegoGarcia talksatC talkGuam Guam))

(path talk Diego-Garcia  Kwajelein-Island
     (Diego-Garcia  talkDiegoGarcia talksatD
      talkKwajelein Kwajelein-Island ))


(path talk Guam Kwajelein-Island
     (Guam talkGuam talksatD talkKwajelein Kwajelein-Island )) )
```

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;;; -*- Mode:Art; Package:ART-USER; Base:10. -*-

;;; FILE: D:BAP;NAVIGATION.ART


;;; Navigation Space System PATHFINDER

(defschema pathfinder
   (viewpoint ?root)
   (system-name pathfinder)
   (system-status green)
   (mission navigation)
   (coverage-areas (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
                    21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-satellites pathsat1 pathsat2 pathsat3 pathsat4 pathsat5
                      pathsat6 pathsat7 pathsat8 pathsat9 pathsat10
                      pathsat11 pathsat12 pathsat13 pathsat14 pathsat15
                      pathsat16 pathsat17 pathsat18 pathsatSpare1
                      pathsatSpare2 pathsatSpare3)
   (is-a satsystem))


;;; PATHFINDER Satellites

(defschema pathsat1
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 1 2 3 4 5 33 34 35 36)
   (sat-cov-list (1 2 3 4 5 33 34 35 36))
   (over 1)
   (primary-ttc pathWahiawi)
   (backup-ttc RTS-Guam RTS-Kaena))

(defschema pathsat2
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 1 2 3 4 5 6 7 35 36)
   (sat-cov-list (1 2 3 4 5 6 7 35 36))
   (over 3)
   (primary-ttc pathWahiawi)
   (backup-ttc RTS-Kaena RTS-Vandenberg))
```

```
(defschema pathsat3
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 1 2 3 4 5 6 7 8 9)
   (sat-cov-list (1 2 3 4 5 6 7 8 9))
   (over 5)
   (primary-ttc pathWahiawi)
   (backup-ttc pathColoSprings RTS-Kaena RTS-Vandenberg))

(defschema pathsat4
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 3 4 5 6 7 8 9 10 11)
   (sat-cov-list (3 4 5 6 7 8 9 10 11))
   (over 7)
   (primary-ttc pathColoSprings)
   (backup-ttc pathWahiawi RTS-Kaena RTS-Vandenberg RTS-NewHamp))

(defschema pathsat5
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 5 6 7 8 9 10 11 12 13)
   (sat-cov-list (5 6 7 8 9 10 11 12 13))
   (over 9)
   (primary-ttc pathColoSprings)
   (backup-ttc RTS-Vandenberg RTS-NewHamp RTS-Thule))

(defschema pathsat6
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 7 8 9 10 11 12 13 14 15)
```

```
   (sat-cov-list (7 8 9 10 11 12 13 14 15))
   (over 11)
   (primary-ttc pathColoSprings)
   (backup-ttc RTS-NewHamp RTS-Thule))

(defschema pathsat7
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 9 10 11 12 13 14 15 16 17)
   (sat-cov-list (9 10 11 12 13 14 15 16 17))
   (over 13)
   (primary-ttc pathAscension)
   (backup-ttc RTS-NewHamp RTS-Thule))

(defschema pathsat8
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 11 12 13 14 15 16 17 18 19)
   (sat-cov-list (11 12 13 14 15 16 17 18 19))
   (over 15)
   (primary-ttc pathAscension)
   (backup-ttc RTS-NewHamp RTS-Thule RTS-Oakhanger))

(defschema pathsat9
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 13 14 15 16 17 18 19 20 21)
   (sat-cov-list (13 14 15 16 17 18 19 20 21))
   (over 17)
   (primary-ttc pathAscension)
   (backup-ttc RTS-Oakhanger))

(defschema pathsat10
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
```

```
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 15 16 17 18 19 20 21 22 23)
   (sat-cov-list (15 16 17 18 19 20 21 22 23))
   (over 19)
   (primary-ttc pathAscension)
   (backup-ttc RTS-Oakhanger))

(defschema pathsat11
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 17 18 19 20 21 22 23 24 25)
   (sat-cov-list (17 18 19 20 21 22 23 24 25))
   (over 21)
   (primary-ttc pathAscension)
   (backup-ttc RTS-IndianOcean RTS-Oakhanger))

(defschema pathsat12
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 19 20 21 22 23 24 25 26 27)
   (sat-cov-list (19 20 21 22 23 24 25 26 27))
   (over 23)
   (primary-ttc pathDiegoGarcia)
   (backup-ttc RTS-IndianOcean))

(defschema pathsat13
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 21 22 23 24 25 26 27 28 29
   (sat-cov-list (21 22 23 24 25 26 27 28 29
   (over 25)
   (primary-ttc pathDiegoGarcia
   (backup-ttc RTS-IndianOcean

 defschema pathsat14
```

```
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 23 24 25 26 27 28 29 30 31)
   (sat-cov-list (23 24 25 26 27 28 29 30 31))
   (over 27)
   (primary-ttc pathDiegoGarcia)
   (backup-ttc RTS-IndianOcean))

(defschema pathsat15
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 25 26 27 28 29 30 31 32 33)
   (sat-cov-list (25 26 27 28 29 30 31 32 33))
   (over 29)
   (primary-ttc pathDiegoGarcia)
   (backup-ttc RTS-Guam))

(defschema pathsat16
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 27 28 29 30 31 32 33 34 35)
   (sat-cov-list (27 28 29 30 31 32 33 34 35))
   (over 31)
   (primary-ttc RTS-Guam)
   (backup-ttc))

(defschema pathsat17
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 29 30 31 32 33 34 35 36 1)
   (sat-cov-list (29 30 31 32 33 34 35 36 1))
```

```
   (over 33)
   (primary-ttc RTS-Guam)
   (backup-ttc))

(defschema pathsat18
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 31 32 33 34 35 36 1 2 3)
   (sat-cov-list (31 32 33 34 35 36 1 2 3))
   (over 35)
   (primary-ttc RTS-Guam)
   (backup-ttc pathWahiawi))

(defschema pathsatSpare1
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 5 6 7 8 9 10 11 12 13)
   (sat-cov-list (5 6 7 8 9 10 11 12 13))
   (over 9)
   (primary-ttc pathColoSprings)
   (backup-ttc RTS-Vandenberg RTS-NewHamp RTS-Thule)
   (spare-in-use no))

(defschema pathsatSpare2
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
   (data-transmit-freq 1575 1228)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (can-use-rts yes)
   (sat-status green)
   (sat-coverage 16 17 18 19 20 21 22 23 24)
   (sat-cov-list (16 17 18 19 20 21 22 23 24))
   (over 20)
   (primary-ttc pathAscension)
   (backup-ttc RTS-Oakhanger RTS-IndianOcean)
   (spare-in-use no))

(defschema pathsatSpare3
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of pathfinder)
```

```
(data-transmit-freq 15[illegible] 1228
(ttc-transmit-freq 2250
(ttc-receive-freq 1800
(can-use-rts yes)
(sat-status green
(sat-coverage 27 28 29 3[illegible] 3[illegible] 3[illegible] 3[illegible] 34 [illegible]
(sat-cov-list (27 28 29 3[illegible] 3[illegible] 3[illegible] 3[illegible] 34 [illegible]
(over 31)
(primary-ttc RTS-Guam
(backup-ttc)
(spare-in-use no)

;;; PATHFINDER EARTH TERMINALS

(defschema pathWahiawi
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of pathfinder)
   (use ttc)
   (ttc-status green)
   (location Wahiawi-Hawaii)
   (area 3)
   (ttc-receive-freq 2250)
   (ttc-transmit-freq 1800)
   (can-ttc-service 3)
   (is-ttc-servicing 3)
   (primary-ttc-for pathsat1 pathsat2 pathsat3)
   (backup-ttc-for pathsat18 pathsat4)
   (design-can-ttc-service 3)
   (design-primary-ttc-for pathsat1 pathsat2 pathsat3)

(defschema pathColoSprings
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of pathfinder)
   (use ttc)
   (ttc-status green)
   (location Colorado-Springs)
   (area 8)
   (ttc-receive-freq 2250)
   (ttc-transmit-freq 1800)
   (can-ttc-service 3)
   (is-ttc-servicing 3)
   (primary-ttc-for pathsat4 pathsat5 pathsat6 pathsatSpare1)
   (backup-ttc-for pathsat3)
   (design-primary-ttc-for pathsat4 pathsat5 pathsat6 pathsatSpare1)
   (design-can-ttc-service 3))

(defschema pathAscension
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of pathfinder)
   (use ttc)
   (ttc-status green)
   (location Ascension-Island)
   (area 17)
   (ttc-receive-freq 2250)
   (ttc-transmit-freq 1800)
   (can-ttc-service 6)
```

```
   (is-ttc-servicing 5)
   (primary-ttc-for pathsatSpare2 pathsat7 pathsat8 pathsat9
                    pathsat10 pathsat11)
   (backup-ttc-for)
   (design-primary-ttc-for pathsatSpare2 pathsat7 pathsat8 pathsat9
                    pathsat10 pathsat11)
   (design-can-ttc-service 6))

(defschema pathDiegoGarcia
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of pathfinder)
   (use ttc)
   (ttc-status green)
   (location Diego-Garcia)
   (area 26)
   (ttc-receive-freq 2250)
   (ttc-transmit-freq 1800)
   (can-ttc-service 6)
   (is-ttc-servicing 4)
   (primary-ttc-for pathsat12 pathsat13 pathsat14 pathsat15)
   (backup-ttc-for)
   (design-primary-ttc-for pathsat12 pathsat13 pathsat14 pathsat15)
   (design-can-ttc-service 6))

;;; Navigation Space System SCOUT

(defschema scout
   (viewpoint ?root)
   (system-name scout)
   (system-status green)
   (mission navigation)
   (coverage-areas (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
                    21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-satellites scoutsatA scoutsatB scoutsatC scoutsatD)
   (is-a satsystem))


;;; SCOUT Satellites


(defschema scoutsatA
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of scout)
   (data-transmit-freq 150 400)
   (ttc-transmit-freq 150)
   (ttc-receive-freq 143.5)
   (can-use-rts no)
   (sat-status green)
   (sat-coverage 1 2 3 4 5 6 7 8 32 33 34 35 36)
   (sat-cov-list (1 2 3 4 5 6 7 8 32 33 34 35 36))
   (over 2)
   (primary-ttc scoutMugu)
   (backup-ttc scoutWahiawi scoutWoomera))

(defschema scoutsatB
   (viewpoint ?root)
```

```
   (orbit geosynch)
   (is-a satellite)
   (part-of scout)
   (data-transmit-freq 150 400)
   (ttc-transmit-freq 150)
   (ttc-receive-freq 143.5)
   (can-use-rts no)
   (sat-status green)
   (sat-coverage 5 6 7 8 9 10 11 12 13 1 4 15 16 17)
   (sat-cov-list (5 6 7 8 9 10 11 12 13 1 4 15 16 17))
   (over 11)
   (primary-ttc scoutMugu)
   (backup-ttc scoutRosemount scoutAscension scoutProspectHarbor))

(defschema scoutsatC
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of scout)
   (data-transmit-freq 150 400)
   (ttc-transmit-freq 150)
   (ttc-receive-freq 143.5)
   (can-use-rts no)
   (sat-status green)
   (sat-coverage 14 15 16 17 18 19 20 21 22 23 24 25 26)
   (sat-cov-list (14 15 16 17 18 19 20 21 22 23 24 25 26))
   (over 20)
   (primary-ttc scoutAscension)
   (backup-ttc scoutDiegoGarcia))

(defschema scoutsatD
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of scout)
   (data-transmit-freq 150 400)
   (ttc-transmit-freq 150)
   (ttc-receive-freq 143.5)
   (can-use-rts no)
   (sat-status green)
   (sat-coverage 23 24 25 26 27 28 29 30 31 32 33 34 35)
   (sat-cov-list (23 24 25 26 27 28 29 30 31 32 33 34 35))
   (over 29)
   (primary-ttc scoutWoomera)
   (backup-ttc scoutDiegoGarcia))


;;;  SCOUT Earth Terminals

(defschema scoutWahiawi
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Wahiawi-Hawaii)
   (area 3)
```

```
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 0)
   (primary-ttc-for)
   (backup-ttc-for scoutsatA))

(defschema scoutMugu
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Point-Mugu)
   (area 7)
   (can-ttc-service 3)
   (is-ttc-servicing 2)
   (primary-ttc-for scoutsatA scoutsatB)
   (design-can-ttc-service 3)
   (design-primary-ttc-for scoutsatA scoutsatB)
   (backup-ttc-for))

(defschema scoutRosemount
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Rosemount-Minn)
   (area 9)
   (can-ttc-service 3)
   (is-ttc-servicing 0)
   (design-can-ttc-service 3)
   (primary-ttc-for)
   (backup-ttc-for scoutsatB))

(defschema scoutProspectHarbor
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Prospect-Harbor-Maine)
   (area 12)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 0)
   (primary-ttc-for)
   (backup-ttc-for scoutsatB))

(defschema scoutAscension
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
```

```
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Ascension-Island)
   (area 17)
   (can-ttc-service 3)
   (is-ttc-servicing 1)
   (design-can-ttc-service 3)
   (design-primary-ttc-for scoutsatC)
   (primary-ttc-for scoutsatC)
   (backup-ttc-for scoutsatB))

(defschema scoutDiegoGarcia
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Diego-Garcia)
   (area 26)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 0)
   (primary-ttc-for)
   (backup-ttc-for scoutsatC scoutsatD))

(defschema scoutWoomera
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of scout)
   (use ttc)
   (ttc-status green)
   (ttc-receive-freq 150)
   (ttc-transmit-freq 143.5)
   (location Woomera-Australia)
   (area 32)
   (can-ttc-service 3)
   (design-can-ttc-service 3)
   (is-ttc-servicing 1)
   (primary-ttc-for scoutsatD)
   (design-primary-ttc-for scoutsatD)
   (backup-ttc-for scoutsatA))
```

```
;;; -*- Mode:Art; Package:ART-USER; Base:10. -*-

;;; FILE: O:BAP;COMMUNICATION.ART

;;; Communications Space System TALK

(defschema talk
   (viewpoint ?root)
   (system-name talk)
   (system-status green)
   (mission communications)
   (coverage-areas (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
                    22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-coverage-list  (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
                    22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-satellites talksatA talksatB talksatC talksatD)
   (is-a satsystem))

;;; TALK Satellites

(defschema talksatA
   (viewpoint ?root)
   (part-of talk)
   (orbit geosynch)
   (is-a satellite)
   (data-tx-freq-lower 7250)
   (data-rx-freq-lower 7900)
   (data-tx-freq-upper 7750)
   (data-rx-freq-upper 8400)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (sat-coverage 3 4 5 6 7 8 9 10 11 12 13 14 15)
   (sat-cov-list (3 4 5 6 7 8 9 10 11 12 13 14 15))
   (over 9)
   (can-use-rts yes)
   (primary-ttc rts-Vandenberg)
   (backup-ttc rts-Kaena rts-NewHamp rts-Thule)
   (sat-status green))

(defschema talksatB
   (viewpoint ?root)
   (part-of talk)
   (orbit geosynch)
   (is-a satellite)
   (data-tx-freq-lower 7250)
   (data-rx-freq-lower 7900)
   (data-tx-freq-upper 7750)
   (data-rx-freq-upper 8400)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (sat-coverage 12 13 14 15 16 17 18 19 20 21 22 23 24)
   (sat-cov-list (12 13 14 15 16 17 18 19 20 21 22 23 24))
   (over 18)
   (can-use-rts yes)
```

```
   (primary-ttc rts-IndianOcean)
   (backup-ttc rts-Thule rts-Oakhanger)
   (sat-status green))

(defschema talksatC
   (viewpoint ?root)
   (part-of talk)
   (orbit geosynch)
   (is-a satellite)
   (data-tx-freq-lower 7250)
   (data-rx-freq-lower 7900)
   (data-tx-freq-upper 7750)
   (data-rx-freq-upper 8400)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (sat-coverage 21 22 23 24 25 26 27 28 29 30 31 32 33)
   (sat-cov-list (21 22 23 24 25 26 27 28 29 30 31 32 33))
   (over 27)
   (can-use-rts yes)
   (primary-ttc rts-IndianOcean)
   (backup-ttc rts-Guam)
   (sat-status green))

(defschema talksatD
   (viewpoint ?root)
   (part-of talk)
   (orbit geosynch)
   (is-a satellite)
   (data-tx-freq-lower 7250)
   (data-rx-freq-lower 7900)
   (data-tx-freq-upper 7750)
   (data-rx-freq-upper 8400)
   (ttc-transmit-freq 2250)
   (ttc-receive-freq 1800)
   (sat-coverage 1 2 3 4 5 6 30 31 32 33 34 35 36)
   (sat-cov-list (1 2 3 4 5 6 30 31 32 33 34 35 36))
   (over 35)
   (can-use-rts yes)
   (primary-ttc rts-Kaena)
   (backup-ttc rts-Vandenberg rts-Guam)
   (sat-status green))


;;; TALK Earth Terminals


(defschema talkWahiawi
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Wahiawi-Hawaii)
   (area 3)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
```

```
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatA talksatD)
   (design-receive-data-from talksatA talksatD))

(defschema talkSunnyvale
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Sunnyvale)
   (area 6)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatA talksatD)
   (design-receive-data-from talksatA talksatD))

(defschema talkColoSprings
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Colorado-Springs)
   (area 8)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from  talksatA)
   (design-receive-data-from talksatA))

(defschema talkCrete
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Crete-Greece)
   (area 21)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatB talksatC)
   (design-receive-data-from talksatB talksatC))
```

```
(defschema talkDiegoGarcia
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Diego-Garcia)
   (area 26)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatC)
   (design-receive-data-from talksatC))

(defschema talkKwajelein
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Kwajelein-Island)
   (area 35)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatD)
   (design-receive-data-from talksatD))

(defschema talkThule
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
   (location Thule-Greenland)
   (area 12)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatA talksatB)
   (design-receive-data-from talksatA talksatB))

(defschema talkGuam
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of talk)
```

```
   (location Guam)
   (area 33)
   (use data)
   (data-status green)
   (receive-data-for talk)
   (design-receive-data-for talk)
   (data-rx-freq-lower 7250)
   (data-tx-freq-lower 7900)
   (data-rx-freq-upper 7750)
   (data-tx-freq-upper 8400)
   (receive-data-from talksatC talksatD)
   (design-receive-data-from talksatC talksatD))



;;; Communications Space System CHATTER

(defschema chatter
   (viewpoint ?root)
   (system-name chatter)
   (mission communications)
   (coverage-areas (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
                   22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-coverage-list (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
                   20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36))
   (system-satellites chatter1 chatter2 chatter3 chatter4)
   (is-a satsystem))


;;; CHATTER Satellites


(defschema chatter1
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of chatter)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-rx-freq-lower2 7900)
   (data-rx-freq-upper2 8400)
   (ttc-transmit-freq 2252.5 2262.5)
   (ttc-receive-freq 1800)
   (sat-coverage  1 2 3 4 5 6 7 8 9 10 11 12 13)
   (sat-cov-list (1 2 3 4 5 6 7 8 9 10 11 12 13))
   (over 7)
   (can-use-rts yes)
   (primary-ttc chatterMugu)
   (backup-ttc chatterNorfolk chatterWahiawi)
   (sat-status green))


(defschema chatter2
   (viewpoint ?root)
   (orbit geosynch)
```

```
   (is-a satellite)
   (part-of chatter)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-rx-freq-lower2 7900)
   (data-rx-freq-upper2 8400)
   (ttc-transmit-freq 2252.5 2262.5)
   (ttc-receive-freq 1800)
   (sat-coverage 10 11 12 13 14 15 16 17 18 19 20 21 22)
   (sat-cov-list (10 11 12 13 14 15 16 17 18 19 20 21 22))
   (over 16)
   (can-use-rts yes)
   (primary-ttc chatterNorfolk)
   (sat-status green))

(defschema chatter3
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of chatter)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-rx-freq-lower2 7900)
   (data-rx-freq-upper2 8400)
   (ttc-transmit-freq 2252.5 2262.5)
   (ttc-receive-freq 1800)
   (sat-coverage 20 21 22 23 24 25 26 27 28 29 30 31 32)
   (sat-cov-list (20 21 22 23 24 25 26 27 28 29 30 31 32))
   (over 26)
   (can-use-rts yes)
   (primary-ttc chatterWoomera)
   (sat-status green))

(defschema chatter4
   (viewpoint ?root)
   (orbit geosynch)
   (is-a satellite)
   (part-of chatter)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-rx-freq-lower2 7900)
   (data-rx-freq-upper2 8400)
   (ttc-transmit-freq 2252.5 2262.5)
   (ttc-receive-freq 1800)
   (sat-coverage 1 2 3 4 5 29 30 31 32 33 34 35 36)
   (sat-cov-list (1 2 3 4 5 29 30 31 32 33 34 35 36))
   (over 35)
   (can-use-rts yes)
   (primary-ttc chatterWahiawi)
   (backup-ttc chatterWoomera)
   (sat-status green))
```

;;; CHATTER Earth Terminals

```
(defschema chatterWahiawi
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Wahiawi-Hawaii)
   (area 3)
   (use data ttc)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter1 chatter4)
   (design-receive-data-from chatter1 chatter4)
   (ttc-receive-freq 2252.5 2262.5)
   (ttc-transmit-freq 1800)
   (can-ttc-service 3)
   (design-ttc-service 3)
   (is-ttc-servicing 1)
   (primary-ttc-for chatter4)
   (design-primary-ttc-for chatter4)
   (backup-ttc-for chatter1)
   (ttc-status green))

(defschema chatterSunnyvale
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Sunnyvale)
   (area 6)
   (use data)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter1)
   (design-receive-data-from chatter1))

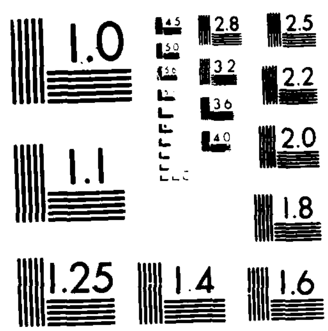

(defschema chatterMugu
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Point-Mugu)
   (area 7)
   (use data ttc)
   (data-status green)
   (receive-data-for chatter)
```

```
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter1)
   (design-receive-data-from chatter1)
   (ttc-receive-freq 2252.5 2262.5)
   (ttc-transmit-freq 1800)
   (can-ttc-service 3)
   (design-ttc-service 3)
   (is-ttc-servicing 1)
   (primary-ttc-for chatter1)
   (design-primary-ttc-for chatter1)
   (ttc-status green))

(defschema chatterColoSprings
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Colorado-Springs)
   (area 8)
   (use data)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter1)
   (design-receive-data-from chatter1))

(defschema chatterNorfolk
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Norfolk-Virginia)
   (area 11)
   (use data ttc)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900
   (data-tx-freq-upper2 84[illegible]
   (receive-data-from chatter[illegible]
   (design-receive-data-from [illegible]
   (ttc-receive-freq 2252 [illegible]
   (ttc-transmit-freq 18[illegible]
   (can-ttc-service [illegible]
   (design-ttc-service [illegible]
```

AD-A179 336 A PROTOTYPE KNOWLEDGE-BASED SYSTEM TO AID SPACE SYSTEM 3/4
RESTORATION MANAGEMENT(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. B A PHILLIPS
UNCLASSIFIED DEC 86 AFIT/GOR/OS/86-12 F/G 22/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

```
   (is-ttc-servicing 1)
   (primary-ttc-for chatter2)
   (design-primary-ttc-for chatter2)
   (backup-ttc-for chatter1)
   (ttc-status green))

(defschema chatterProspectHarbor
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Prospect-Harbor-Maine)
   (area 12)
   (use data)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter1 chatter2)
   (design-receive-data-from chatter1 chatter2))

(defschema chatterCrete
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Crete-Greece)
   (area 21)
   (use data)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter2 chatter3)
   (design-receive-data-from chatter2 chatter3))

(defschema chatterIndianOcean
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Indian-Ocean)
   (area 24)
   (use data)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
```

```
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter3)
   (design-receive-data-from chatter3))

(defschema chatterWoomera
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Woomera-Austrailia)
   (area 32)
   (use data ttc)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter3 chatter4)
   (design-receive-data-from chatter3 chatter4)
   (ttc-receive-freq 2252.5 2262.5)
   (ttc-transmit-freq 1800)
   (can-ttc-service 3)
   (design-ttc-service 3)
   (is-ttc-servicing 1)
   (primary-ttc-for chatter3)
   (design-primary-ttc-for chatter3)
   (backup-ttc-for chatter4)
   (ttc-status green))

(defschema chatterKwajelein
   (viewpoint ?root)
   (is-a earth-terminal)
   (part-of chatter)
   (location Kwajelein-Island)
   (area 35)
   (use data)
   (data-status green)
   (receive-data-for chatter)
   (design-receive-data-for chatter)
   (data-rx-freq-lower 225)
   (data-rx-freq-upper 400)
   (data-tx-freq-lower 225)
   (data-tx-freq-upper 400)
   (data-tx-freq-lower2 7900)
   (data-tx-freq-upper2 8400)
   (receive-data-from chatter4)
   (design-receive-data-from chatter4))
```

```
;;; -*- Mode:Art; Package:au; Base:10. -*-


;;; FILE D:BAP;SCENARIOS.ART


;;; --------- DEFAULT PRIORITIES----------


;;; DEFAULT PRIORITIES FOR LIMITED WAR  (COMM-NAV-WEA)

(defrule default-priorities-limited
   (declare (salience *maximum-salience*))
   (get-priorities limited)
=>
   (assert
    (priority 1 communications)
    (priority 2 navigation)
    (priority 3 weather)
    (weight-global weather 4.0)
    (weight-conflict weather 4.6)
    (weight-global navigation 6.0)
    (weight-conflict navigation 10.2)
    (weight-global communications 50.1)
    (weight-conflict communications 25.1)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.6)
    (sub-conflict path 4 0.2)))

;;; DEFAULT PRIORITIES FOR MAJOR WAR  (NAV-COMM-WEA)

(defrule default-priorities-major
   (declare (salience *maximum-salience*))
   (get-priorities major)
=>
   (assert
    (priority 1 navigation)
    (priority 2 communications)
    (priority 3 weather)
    (weight-global weather 2.0)
    (weight-conflict weather 8.0)
    (weight-global navigation 10.0)
    (weight-conflict navigation 40.0)
    (weight-global communications 15.0)
    (weight-conflict communications 25.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))
```

```
;;; DEFAULT PRIORITIES FOR CENTRAL WAR  (COMM-NAV-WEA)

(defrule default-priorities-central
   (declare (salience *maximum-salience*))
   (get-priorities central)
=>
   (assert
    (priority 1 communications)
    (priority 2 navigation)
    (priority 3 weather)
    (weight-global weather 2.0)
    (weight-conflict weather 8.0)
    (weight-global navigation 10.0)
    (weight-conflict navigation 20.0)
    (weight-global communications 35.0)
    (weight-conflict communications 25.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))

;;; DEFAULT PRIORITIES (WEA-COMM-NAV)

(defrule default-priorities-weather-first
   (declare (salience *maximum-salience*))
   (get-priorities hurricane)
=>
   (assert
    (priority 1 weather)
    (priority 2 communications)
    (priority 3 navigation)
    (weight-global weather 10.0)
    (weight-conflict weather 60.0)
    (weight-global navigation 2.0)
    (weight-conflict navigation 12.0)
    (weight-global communications 11.0)
    (weight-conflict communications 5.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))


;;; DEFAULT PRIORITIES (WEA-NAV-COMM)

(defrule default-priorities-weather-nav-comm
   (declare (salience *maximum-salience*))
   (get-priorities wea-nav-comm)
=>
   (assert
    (priority 1 weather)
    (priority 2 navigation)
```

```
      (priority 3 communications)
      (weight-global weather 20.0)
      (weight-conflict weather 30.0)
      (weight-global navigation 15.0)
      (weight-conflict navigation 15.0)
      (weight-global communications 15.0)
      (weight-conflict communications 5.0)
      (sub-global scout 1 0.3)
      (sub-global path 3 0.4)
      (sub-global path 4 0.3)
      (sub-conflict scout 1 0.2)
      (sub-conflict path 3 0.5)
      (sub-conflict path 4 0.3)))

;;; DEFAULT PRIORITIES (COMM-WEA-NAV)

(defrule default-priorities-comm-weather-nav
   (declare (salience *maximum-salience*))
   (get-priorities comm-wea-nav)
=>
   (assert
      (priority 2 weather)
      (priority 3 navigation)
      (priority 1 communications)
      (weight-global weather 20.0)
      (weight-conflict weather 10.0)
      (weight-global navigation 5.0)
      (weight-conflict navigation 10.0)
      (weight-global communications 30.0)
      (weight-conflict communications 25.0)
      (sub-global scout 1 0.3)
      (sub-global path 3 0.4)
      (sub-global path 4 0.3)
      (sub-conflict scout 1 0.2)
      (sub-conflict path 3 0.5)
      (sub-conflict path 4 0.3)))

;;; DEFAULT PRIORITIES (NAV-WEA-COMM)

(defrule default-priorities-special-three
   (declare (salience *maximum-salience*))
   (get-priorities special-three)
=>
   (assert
      (priority 1 navigation)
      (priority 2 weather)
      (priority 3 communications)
      (weight-global weather 10.0)
      (weight-conflict weather 20.0)
      (weight-global navigation 30.0)
      (weight-conflict navigation 20.0)
      (weight-global communications 15.0)
      (weight-conflict communications 5.0)
      (sub-global scout 1 0.3)
      (sub-global path 3 0.4)
      (sub-global path 4 0.3)
      (sub-conflict scout 1 0.2)
```

```
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))

;;; ------ TEST SCENARIOS ------

;;; LIMITED WAR SCENARIO

(defrule limited-FarEast
   (declare (salience *maximum-salience*))
   (testcase limitedFarEast)
=>
 (assert
   (get-priorities limited)
   (theater FarEast)
   (conflict-areas (29 30 31 32 33 34))
   (give-plans 3)
   (change-ttc-status rts-Guam red destroyed)
   (change-ttc-status scoutWoomera red destroyed)
   (change-ttc-status thunderGuam red destroyed)
   (change-data-status thunderGuam red destroyed)
   (change-satellite-status pathsat16 red destroyed)
   (change-satellite-status pathsat17 red destroyed)
   (change-satellite-status pathsat18 unknown no-data-avail)
   (change-satellite-status thunder4 red destroyed)))


;;; MAJOR WAR SCENARIO

(defrule major-Europe
  (declare (salience *maximum-salience*))
  (testcase majorEurope)
=>
  (assert
    (get-priorities major)
    (theater Europe)
    (conflict-areas (17 18 19 20 21 22 23 24))
    (give-plans 3)
    (change-ttc-status rts-Oakhanger red destroyed)
    (change-ttc-status thunderDiegoGarcia red destroyed)
    (change-ttc-status thunderAscension red destroyed)
    (change-data-status chatterCrete red destroyed)
    (change-satellite-status thunder3 red destroyed)
    (change-satellite-status pathsat10 red destroyed)
    (change-satellite-status pathsat11 unknown no-data-avail)
    (change-satellite-status scoutsatC red destroyed)
    (change-satellite-status talksatB red destroyed)
    (groundlink-destroyed Crete-Greece Ascension-Island)
    (groundlink-destroyed Thule-Greenland Oakhanger-UK)))

;;; CENTRAL WAR SCENARIO

(defrule start-scenario-central-war-test
   (declare (salience *maximum-salience*))
   (testcase central-test)
=>
```

```
   (assert
    (get-priorities central)
    (give-plans 3)
    (conflict-areas (3 4 5 6 7 8 9 10 11 12 13))
    (theater USA)
    (change-ttc-status chatterMugu  red destroyed)
    (change-data-status chatterMugu  red destroyed)
    (change-data-status chatterWahiawi red destroyed)
    (change-ttc-status chatterWahiawi red destroyed)
    (change-ttc-status thunderAscension unknown no-data-avail)
    (change-data-status thunderAscension unknown no-data-avail)
    (change-satellite-status chatter1 red destroyed)
    (change-satellite-status pathsat10 unknown no-data-avail)
    (change-satellite-status pathsat3 red destroyed)
    (change-satellite-status thunder2 red destroyed)
    (change-satellite-status ScoutsatC red destroyed)
    (groundlink-destroyed Kaena-Pt-Hawaii Guam)))


;;; ------ ADDITIONAL TESTS -------


;;; ----- TEST 1 -----

(defrule start-testcase-special-one
   (declare (salience *maximum-salience*))
   (testcase special-one)
=>
   (assert
    (get-priorities major)
    (give-all-plans yes)
    (theater FarEast)
    (conflict-areas (28 29 30 31 32 33 34 35))
    (change-rts-status-yellow  rts-Guam yellow terrorist-attack)
    (groundlink-destroyed Loring-Maine Diego-Garcia)
    (groundlink-destroyed Guam Woomera-Australia)
    (change-satellite-status stormAtlantic unknown no-data-avail)
    (change-ttc-status scoutProspectHarbor unknown no-data-avail)))


;;; ----- TEST 2A -----

(defrule start-scenario-special-two
   (declare (salience *maximum-salience*))
   (testcase special-two)
=>
(assert
   (get-priorities hurricane)
   (give-plans 2)
   (change-data-status stormOffutt red destroyed)
   (change-data-status stormLoring red destroyed)
   (change-ttc-status stormLoring red destroyed)
   (change-satellite-status Pathsat14 red destroyed)
   (change-ttc-status pathDiegoGarcia red destroyed)
   (theater Europe)
   (conflict-areas (14 15 16 17 18 19 20 21 22 23 24))))
```

```
;;; ----- TEST 2B -----

(defrule start-scenario-special-two-test-prune
   (declare (salience *maximum-salience*))
   (testcase special-two-test-prune)
=>
(assert
   (get-priorities wea-nav-comm)
   (give-plans 2)
   (change-data-status stormOffutt red destroyed)
   (change-data-status stormLoring red destroyed)
   (change-ttc-status stormLoring red destroyed)
   (change-satellite-status Pathsat14 red destroyed)
   (change-ttc-status pathDiegoGarcia red destroyed)
   (theater Europe)
   (conflict-areas (14 15 16 17 18 19 20 21 22 23 24))))

;;; ----- TEST 2C -----

(defrule start-scenario-special-two-test-prune-2
   (declare (salience *maximum-salience*))
   (testcase special-two-test-prune-2)
=>
(assert
   (get-priorities special-three)
   (give-plans 2)
   (change-data-status stormOffutt red destroyed)
   (change-data-status stormLoring red destroyed)
   (change-ttc-status stormLoring red destroyed)
   (change-satellite-status Pathsat14 red destroyed)
   (change-ttc-status pathDiegoGarcia red destroyed)
   (theater Europe)
   (conflict-areas (14 15 16 17 18 19 20 21 22 23 24))))


;;; ----- TEST 3 -----

(defrule start-scenario-special-three
   (declare (salience *maximum-salience*))
   (testcase special-three)
=>
(assert
   (get-priorities special-three)
   (give-all-plans yes)
   (conflict-areas (3 4 5 6 7 8 9 10 11 12 13))
   (theater USA)
   (change-ttc-status thunderDiegoGarcia red destroyed)
   (change-ttc-status thunderAscension red destroyed)
   (change-ttc-status scoutAscension red destroyed)))


;;; ----- TEST 4 -----

(defrule start-scenario-special-four
   (declare (salience *maximum-salience*))
   (testcase special-four)
```

```
=>
   (assert
    (get-priorities comm-wea-nav)
    (give-plans 3)
    (conflict-areas (17 18 19 20 21 22 23 24))
    (theater Europe)
    (change-ttc-status thunderAscension red destroyed)
    (change-ttc-status scoutAscension unknown  no-data-avail)
    (change-ttc-status scoutMugu red destroyed)
    (change-satellite-status scoutsatD red destroyed)
    (change-satellite-status pathsat10 red destroyed)
    (change-satellite-status thunder3 red destroyed)
    (change-satellite-status pathsat11 red destroyed)
    (groundlink-destroyed Indian-Ocean Diego-Garcia)
    (groundlink-destroyed Ascension-Island Crete-Greece)))


;;; ----- TEST 5 -----

(defrule start-scenario-special-five
   (declare (salience *maximum-salience*))
   (testcase special-five)
=>
   (assert
    (get-priorities major)
    (give-plans 3)
    (conflict-areas (30 31 32 33 34 35 36 1 2 3 4 5 6 7))
    (theater FarEast)
    (theater Pacific)
    (change-ttc-status thunderGuam red destroyed)
    (change-ttc-status scoutWoomera red destroyed)
    (change-ttc-status rts-IndianOcean red destroyed)
    (change-data-status thunderGuam red destroyed)
    (change-data-status chatterSunnyvale red destroyed)
    (change-satellite-status pathsat16 red destroyed)
    (change-satellite-status pathsat17 red destroyed)
    (groundlink-destroyed Wahiawi-Hawaii Sunnyvale)))


;;; ----- TEST 6 -----

(defrule start-scenario-special-six
  (declare (salience *maximum-salience*))
  (testcase special-six)
=>
  (assert
    (get-priorities limited)
    (theater Pacific)
    (conflict-areas (1 2 3 4 5 31 32 33 34 35 36))
    (give-plans 3)
    (change-rts-status-yellow rts-Guam yellow terrorist-attack)
    (change-satellite-status pathsat2 red destroyed)
    (change-satellite-status chatter1 red destroyed)
    (groundlink-destroyed Wahiawi-Hawaii Sunnyvale)
    (groundlink-destroyed Wahiawi-Hawaii Kaena-Pt-Hawaii)
    (change-satellite-status chatter4 red destroyed)))
```

```
;;; ----- TEST 7 -----

(defrule start-scenario-special-seven
  (declare (salience *maximum-salience*))
  (testcase special-seven)
=>
  (assert
    (get-priorities wea-nav-comm)
    (theater Pacific)
    (theater FarEast)
    (conflict-areas (1 2 3 4 5 24 25 26 27 28
                     29 30 31 32 33 34 35 36))
    (give-plans 3)
    (change-ttc-status chatterWoomera red destroyed)
    (change-ttc-status rts-IndianOcean red destroyed)
    (change-data-status chatterSunnyvale red destroyed)
    (change-data-status thunderAscension red destroyed)
    (change-ttc-status thunderDiegoGarcia red destroyed)
    (change-data-status thunderDiegoGarcia red destroyed)
    (change-satellite-status pathsat14 red destroyed)))


;;; ------ TEST 8 -----

;;;   (CONSISTED OF RUNNING TEST 4,
;;;   SELECTING A PLAN, AND THEN RUNNING TEST 5)



;;; ----- TEST 9 -----


(defrule start-scenario-major-war-test-9
   (declare (salience *maximum-salience*))
   (testcase major-test)
=>
   (assert
    (get-priorities major)
    (give-plans 3)
    (conflict-areas (30 31 32 33))
    (theater FarEast)
    (change-ttc-status thunderGuam red destroyed)
    (change-ttc-status scoutWoomera unknown no-data-avail)
    (change-data-status talkKwajelein unknown no-data-avail)
    (change-data-status thunderGuam red destroyed)
    (change-satellite-status pathsat16 red destroyed)
    (change-satellite-status scoutsatD red destroyed)
    (change-satellite-status pathsat17 red destroyed)))


;;; ----- TEST 10 -----

(defrule start-scenario-limited-war-test-10
   (declare (salience *maximum-salience*))
   (testcase limited-test)
=>
   (assert
    (get-priorities limited)
    (give-plans 3)
```

```
(conflict-areas (17 18 19 20 21 22 23 24))
(theater Europe)
(change-ttc-status thunderAscension red destroyed)
(change-ttc-status pathAscension red destroyed)
(change-satellite-status scoutsatD red destroyed)
(change-satellite-status pathsat9 red destroyed)
(change-satellite-status pathsat10 red destroyed)
(change-satellite-status thunder3 red destroyed)
(change-satellite-status pathsat11 red destroyed)
(groundlink-destroyed Ascension-Island Crete-Greece)))
```

```
;;;-*- Mode:Art; Package:au; Base:10.-*-

;;; FILE:  D:BAP;MAINPROGRAM.ART


;;; FLAG ALL SATELLITES THAT NEED TT&C RESTORATION

(defrule ttc-restoration-flag
   (declare (salience 950000))

   (column 0)

   (schema ?terminal
      (ttc-status red))

   (priority ?nav navigation)
   (priority ?comm communications)
   (priority ?wea weather)

   (schema ?satellite
      (sat-status green)
      (primary-ttc ?terminal))

   (not (ttc-restoration-required ?satellite ?phase))

(case ((schema ?satellite (mission navigation)
                          (not (spare-in-use no)))
       =>
        (assert (update-ttc-service ?satellite))
        (printout t t "Navigation satellite " ?satellite
                " needs ttc restoration." t t)
        (assert (ttc-restoration-required ?satellite ?nav)))

      ((schema ?satellite (mission communications))
       =>
        (assert (update-ttc-service ?satellite))
        (printout t t "Communications satellite " ?satellite
                  " needs ttc restoration." t t)
        (assert (ttc-restoration-required ?satellite ?comm)))

      ((schema ?satellite (mission weather))
       =>
        (assert (update-ttc-service ?satellite))
        (printout t t "Weather satellite " ?satellite
                  " needs ttc restoration." t t)
        (assert (ttc-restoration-required ?satellite ?wea)))))



;;; REMOVE TT&C RESPONSIBILITY FOR A SATELLITE THAT WAS DESTROYED

(defrule satellite-was-destroyed-unload-ttc
   (declare (salience 942000))
   (column 0)
   ?x<-(unload-responsibilities ?satellite)
```

```
   (schema ?satellite
      (primary-ttc ?terminal))

   (schema ?terminal
      (is-ttc-servicing ?is))
=>
   (modify (schema ?terminal
               (is-ttc-servicing =(?is - 1))))
   (retract ?x)

   (assert (check-to-free-data-terminal ?satellite))

   (retract (schema ?terminal
               (primary-ttc-for ?satellite))))


;;; REMOVE TTC RESPONSIBILITY IF SATELLITE OUT FOR OTHER REASON

(defrule satellite-green-but-other-fatal-problems
   (declare (salience 942000))
   (satellite-down ?satellite ~destroyed&~possible)

   (schema ?satellite
      (primary-ttc ?terminal))

   (schema ?terminal
      (primary-ttc-for ?satellite)
      (is-ttc-servicing ?is))
=>
   (modify (schema ?terminal
               (is-ttc-servicing =(?is - 1))))

   (assert (check-to-free-data-terminal ?satellite))

   (retract (schema ?terminal
               (primary-ttc-for ?satellite))))



;;; IF SPARE AND DESTROYED SATELLITE OVERLAP AREAS, PUT SPARE IN USE

(defrule use-spare
   (declare (salience 941999))
   (column 0)
   (or(check-to-free-data-terminal ?satellite)
      (satellite-down ?satellite possible))

   (priority ?pri navigation)

   (schema ?satellite
      (part-of pathfinder)
      (sat-cov-list ?areas))

   (schema ?spare
      (spare-in-use no)
      (part-of pathfinder)
      (sat-status green)
```

```
      (primary-ttc ?terminal)
      (sat-cov-list ?spareas))

  (test ( #l(length (intersection (list$ ?areas)
                                  (list$ ?spareas))) > 0))

 (case ( (and (schema ?terminal
               (is-ttc-servicing ?is)
               (can-ttc-service ?can))
              (test (?can > ?is)))
          =>
         (modify (schema ?spare
                   (spare-in-use yes)))

         (printout t t "Put spare satellite " ?spare " in use " t
                 "because satellite " ?satellite " is down." t t)

         (modify (schema ?terminal
              (is-ttc-servicing =(?is + 1))))
         (printout t t "Use " ?terminal " for TT&C servicing." t t)

         (assert (put-spare-in-use ?spare)))

       (otherwise
        =>
        (assert (ttc-restoration-required ?spare ?pri))
        (assert (update-ttc-service ?satellite))
        (printout t t "Put spare satellite" ?spare t
                    "in use contingent on getting a tt&c slot." t t)
        (assert (put-spare-in-use ?spare))
        (modify (schema ?spare
                    (spare-in-use yes))))))


;;; REMOVE DATA RESPONSIBILITY FOR DESTROYED SATELLITE

(defrule free-data-terminal
   (declare (salience 941998))
   ?r<-(check-to-free-data-terminal ?satellite)

   (schema ?satellite
      (mission ~navigation)
      (part-of ?system))

(case ( (and (schema ?terminal
                (receive-data-from ?satellite)
                (receive-data-for ?system)
                (data-status green)
                (receive-data-from ?sat2&~?satellite))

              (schema ?sat2
                (part-of ?system)))

         =>
         (retract (schema ?terminal
                    (receive-data-from ?satellite))))
```

```
( (schema ?terminal
     (receive-data-from ?satellite)
     (data-status green))
 =>
 (modify (schema ?terminal
           (receive-data-for open)))

 (printout t t "Data terminal " ?terminal " now open." t t)

 (retract (schema ?terminal
           (receive-data-from ?satellite))))))


;;; Assert PHASE ONE

(defrule does-priority-one-need-restoration
   (declare (salience 941000))
   (column 0)
   (priority 1 ?mission)
   (not (phase ?anything))
=>
   (printout t t "Start " ?mission " restoration process." t t)
   (assert (phase 1)))


;;; BYPASS TT&C RESTORATION IF NO PRIORITY ONE SATELLITES NEED IT

(defrule all-green-mission1-sats-get-ttc
   (declare (salience 940000))
   (phase ?phasenum)
   ?m<-(column ?num)
   (test ((?num mod 4) = 0))
   (not (calculator objective-function))

   (priority ?phasenum ?mission1)


 (case  ((exists (ttc-restoration-required ?satellite ?phasenum))
          =>
          (assert (ttc-bypass-mission1 tested)))

        (otherwise
          =>
          (printout t t "No ttc restoration required for "
           ?mission1 " satellites." t t)
          (assert (ttc-restoration-process ?phasenum  done))
          (retract ?m)
          (assert (column =(?num + 2))))))


;;; ONE OF THE ANTENNAS AT A TWO-ANTENNA RTS IS DESTROYED

(defrule one-knocked-out
   (declare (salience 942500))
```

```
   ?x<-(change-rts-status-yellow ?rts yellow ?reason)

   (schema ?rts
      (part-of AFSCF)
      (ttc-status green)
      (number-of-antennas 2))
=>
   (assert (one-antenna-down ?rts ?reason))

   (retract ?x)
   (modify (schema ?rts
              (ttc-status yellow)
              (number-of-antennas 1)
              (can-ttc-service 3))))



;;; YELLOW RTS TERMINAL IS RESPONSIBLE FOR MORE THAN IT CAN HANDLE
;;; TRY TAKING OUT THIRD PRIORITY MISSION RESPONSIBILITIES

(defrule more-than-can-handle-use-mission-3
   (declare (salience 942250))
   (column 0)
   (priority 1 ?mission1)
   (priority 3 ?mission3)
   (conflict-areas ?con)

   (schema ?rts
      (part-of AFSCF)
      (ttc-status yellow)
      (can-ttc-service ?can)
      (is-ttc-servicing ?is))
   (test (?can < ?is))

   (schema ?rts
      (primary-ttc-for ?satellite))

   (schema ?satellite
      (mission ?mission3)
      (sat-cov-list ?areas)
      (not (spare-in-use no)))

 (case  ( (test (#L (length (intersection (list$ ?areas)
                                          (list$ ?con))) = 0))
          =>
          (retract (schema ?rts
                      (primary-ttc-for ?satellite)))

          (assert (ttc-restoration-required ?satellite 3)))

        (otherwise
         =>
          (retract (schema ?rts
                     (primary-ttc-for ?satellite)))

          (assert (ttc-restoration-required ?satellite 3))))
=>
```

```
   (printout t t "One antenna down at " ?rts " and satellite "
                 ?satellite " now needs ttc restoration." t t)
   (assert (update-ttc-service ?satellite))

   (modify (schema ?rts
               (is-ttc-servicing =(?is - 1)))))


;;; TRY TAKING OUT SECOND PRIORITY MISSION RESPONSIBILITIES

(defrule more-than-can-handle-use-mission-2
   (declare (salience 942200))
   (column 0)
   (priority 1 ?mission1)
   (priority 2 ?mission2)
   (conflict-areas ?con)

   (schema ?rts
      (part-of AFSCF)
      (ttc-status yellow)
      (can-ttc-service ?can)
      (is-ttc-servicing ?is))
   (test (?can < ?is))

   (schema ?rts
      (primary-ttc-for ?satellite))

   (schema ?satellite
      (mission ?mission2)
      (not (spare-in-use no))
      (sat-cov-list ?areas))

 (case

     ( (test (#L (length (intersection (list$ ?areas)
                                       (list$ ?con))) = 0))
         =>
         (retract (schema ?rts
                     (primary-ttc-for ?satellite)))
         (assert (ttc-restoration-required ?satellite 2)))

    (otherwise
        =>
         (retract (schema ?rts
                    (primary-ttc-for ?satellite)))

         (assert (ttc-restoration-required ?satellite 2))))

=>
   (printout t t "One antenna down at " ?rts " and satellite "
                 ?satellite " now needs ttc restoration." t t)
   (assert (update-ttc-service ?satellite))

   (modify (schema ?rts
               (is-ttc-servicing =(?is - 1)))))
```

```
;;; LAST RESORT- PULL HIGHEST PRIORITY SATELLITES FROM TT&C

(defrule more-than-can-handle-use-mission-1
   (declare (salience 942150))
   (column 0)
   (priority 1 ?mission1)
   (conflict-areas ?con)

   (schema ?rts
      (part-of AFSCF)
      (ttc-status yellow)
      (can-ttc-service ?can)
      (is-ttc-servicing ?is))
   (test (?can < ?is))

   (schema ?rts
      (primary-ttc-for ?satellite))

   (schema ?satellite
      (mission ?mission1)
      (not (spare-in-use no))
      (sat-cov-list ?areas))

 (case
    ( (test (#L (length (intersection (list$ ?areas) (list$ ?con))) = 0))
        =>
         (retract (schema ?rts
                    (primary-ttc-for ?satellite)))
         (assert (ttc-restoration-required ?satellite 1)))

   (otherwise
        =>
         (retract (schema ?rts
                   (primary-ttc-for ?satellite)))

         (assert (ttc-restoration-required ?satellite 1))))

=>
   (printout t t "One antenna down at " ?rts " and satellite "
               ?satellite " now needs ttc restoration." t t)
   (assert (update-ttc-service ?satellite))

   (modify (schema ?rts
               (is-ttc-servicing =(?is - 1)))))



;;; TRY YOUR OWN SYSTEM FIRST FOR TT&C RESTORATION

(defrule ttc-restoration-own
   (declare (salience 900000))
   (phase ?phasenum)
   ?m<-(column ?num)
   (test (equalp (?num mod 4)  0))

   (ttc-restoration-required ?satellite ?phasenum)
```

```
   (schema ?satellite
      (sat-status green)
      (primary-ttc ?terminal)
      (backup-ttc ?other-term)
      (part-of ?system))

   (schema ?terminal
      (ttc-status red | yellow))

   (schema ?other-term
      (ttc-status green)
      (is-ttc-servicing ?is)
      (can-ttc-service ?can))

   (test (lessp ?is  ?can))
=>
   (hypothesize
         (assert (ttc-restoration ?satellite ?other-term))

         (printout t t "Backup ttc terminal " ?other-term " can provide" t
                   "ttc service to " ?satellite  t t)

         (retract (schema ?satellite
                        (primary-ttc ?terminal)
                        (backup-ttc ?other-term)))
         (assert (schema ?satellite
                        (primary-ttc ?other-term)))

         (assert (schema ?other-term
                        (primary-ttc-for ?satellite)))

         (retract (schema ?other-term
                        (backup-ttc-for ?satellite)))
         (retract ?m)

         (assert (column =(?num + 1)))))



;;; TRY ANOTHER SYSTEM TO RESTORE TT&C

(defrule ttc-restoration-other
    (declare (salience 900000))
    (phase ?phasenum)
    ?m<-(column ?num)
    (test ((?num mod 4) = 0))

    (ttc-restoration-required ?satellite ?phasenum)

   (schema ?satellite
       (sat-status green)
       (primary-ttc ?terminal)
       (part-of ?system)
       (sat-coverage ?area)
       (ttc-transmit-freq ?sattx)
       (ttc-receive-freq ?satrx))

    (schema ?terminal
```

```
      (ttc-status red | yellow))

    (schema ?new-terminal
      (ttc-status green)
      (area ?area)
      (not (part-of ?system))
      (part-of ?other-system)
      (is-ttc-servicing ?is)
      (can-ttc-service ?can))

    (test (lessp ?is ?can))

    (or (and (schema ?new-terminal
               (ttc-receive-freq ?sattx)
               (ttc-transmit-freq ?satrx)))

      (and (schema ?new-terminal
               (ttc-rx-freq-lower ?lowrx)
               (ttc-rx-freq-upper ?hirx)
               (ttc-tx-freq-lower ?lowtx)
               (ttc-tx-freq-upper ?hitx))
           (test (and (>= ?sattx  ?lowrx)
                      (<= ?sattx  ?hirx)
                      (>= ?satrx  ?lowtx)
                      (<= ?satrx  ?hitx)))))

=>

      (hypothesize
          (assert (ttc-restoration ?satellite ?new-terminal))

          (printout t t ?new-terminal
                   "can provide TT&C restoration to " ?satellite t t)

          (retract (schema ?satellite
                      (primary-ttc ?terminal)))

          (assert (schema ?satellite
                      (primary-ttc ?new-terminal)))

          (assert (schema ?new-terminal
                      (primary-ttc-for ?satellite)))
          (retract ?m)

          (assert (column =(?num + 1)))))


;;; MISSION ONE SATELLITES CAN STEAL RESOURCES FROM LESSER
;;; PRIORITY SYSTEMS

(defrule ttc-restoration-takeover
    (declare (salience 899000))
    (phase ?phasenum)
    ?m<-(column ?col)
    (test ((?col  mod 4) = 0))
    (priority ?num ?miss)
    (test (greaterp ?num  ?phasenum))
```

```
    (ttc-restoration-required ?satellite ?phasenum)

    (schema ?satellite
        (sat-status green)
        (primary-ttc ?terminal))

    (schema ?terminal
        (ttc-status red | yellow))

    (schema ?satellite
          (backup-ttc ?other-term))

        (schema ?other-term
          (ttc-status green)
          (is-ttc-servicing ?is)
          (can-ttc-service ?can))

        (schema ?other-satellite&~?satellite
           (mission ?miss)
           (primary-ttc ?other-term)
           (sat-status green))

        (test (equalp ?is  ?can))

        =>
        (hypothesize
            (assert (ttc-restoration ?satellite ?other-term))

            (printout t t "Terminal " ?other-term " will perform ttc service " t
                     "for satellite " ?satellite ", but now satellite "
                     ?other-satellite t "requires ttc restoration" t t)

            (modify (schema ?satellite
                        (primary-ttc ?other-term)))

            (retract (schema ?other-term
                        (primary-ttc-for ?other-satellite)))

            (modify (schema ?other-term
                        (is-ttc-servicing =(?is - 1))))

            (assert (schema ?other-term
                        (primary-ttc-for ?satellite)))

            (assert (ttc-restoration-required ?other-satellite ?num))
            (assert (update-ttc-service ?other-satellite))
            (retract ?m)

            (assert (column =(?col + 1)))))


;;; NO HOPE FOR TT&C RESTORATION

(defrule no-hope-for-ttc-restoration
   (declare (salience 898000))
   (viewpoint ?v1
     (phase ?phasenum)
```

```
      (ttc-restoration-required ?satellite ?phasenum)
      ?m<-(column ?col))

    (test ((?col mod 4) = 0))
   (not (and (viewpoint ?v2
                (ttc-restoration ?satellite ?somehow))
              (test (vp-inherits-from? ?v2 ?v1))))
=>
   (at ?v1
      (hypothesize
          (assert (ttc-restoration ?satellite none))
          (printout t t "No ttc restoration for " ?satellite
                   " in " ?v1  t "Therefore, satellite status
                   of " ?satellite " now red." t t)

          (modify (schema ?satellite
                     (sat-status red)))

          (assert (satellite-down ?satellite no-ttc-available))
          (retract ?m)

          (assert (column =(?col + 1))))))



;;; GET COMBINATIONS OF TT&C RESTORATIONS

(defrule collect-ways-to-restore-ttc
   (declare (salience 875000))
   (phase ?phasenum)
   ?m<-(column ?col)
   (test ((?col mod 4) = 1))

   (forall (ttc-restoration-required ?satellite ?phasenum)
           (ttc-restoration  ?satellite ?terminal))

 =>
   (assert (ttc-restoration-process ?phasenum  done))
   (retract ?m)
   (assert (column =(?col + 1))))


;;; UPDATE TT&C SERVICING FIGURES

(defrule update-ttc-servicing
   (declare (salience 874400))
   (phase ?phasenum)
   (ttc-restoration-process ?phasenum done)
   (ttc-restoration-required ?sat ?phasenum)
   ?y<-(update-ttc-service ?sat)
   (ttc-restoration ?sat ?term&~none)

   (schema ?term
      (is-ttc-servicing ?is))

=>
   (retract ?y)
```

```
   (modify (schema ?term
                (is-ttc-servicing =(?is + 1)))))


;;; CHECK IF MERGING PROCESS PRODUCED INFEASIBLE PLANS

(defrule ttc-station-has-too-much
   (declare (salience 874390))
   (phase ?phasenum)
   (ttc-restoration-process ?phasenum done)
   (column ?col)
   (test ((?col mod 4) = 2))
   (priority 1 ?mission1)
   (priority 2 ?mission2)
   (priority 3 ?mission3)

  (schema ?terminal
     (primary-ttc-for ?satellite)
     (ttc-status green)
     (is-ttc-servicing ?is)
     (can-ttc-service ?can))
   (test (?is > ?can))

   (case ( (and (schema ?satellite (mission ?mission3))
                (test (?phasenum = 3))
                ?x<-(ttc-restoration ?satellite ?somewhere))
          =>

           (retract (schema ?terminal
                        (primary-ttc-for ?satellite)))
           (retract ?x)
           (assert (ttc-restoration ?satellite none))
           (modify (schema ?terminal
                      (is-ttc-servicing =(?is - 1)))))


         ( (and (schema ?satellite (mission ?mission3))
                (test (?phasenum < 3)))
           =>
           (retract (schema ?terminal
                        (primary-ttc-for ?satellite)))
           (assert (ttc-restoration-required ?satellite 3))
           (assert (update-ttc-service ?satellite))
           (modify (schema ?terminal
                      (is-ttc-servicing =(?is - 1)))))


         ( (and (schema ?satellite (mission ?mission2))
                (test (?phasenum = 2))
                ?x<-(ttc-restoration ?satellite ?somewhere))
          =>

           (retract (schema ?terminal
                        (primary-ttc-for ?satellite)))
           (retract ?x)
           (assert (ttc-restoration ?satellite none))
           (modify (schema ?terminal
                      (is-ttc-servicing =(?is - 1)))))
```

```
( (and (schema ?satellite (mission ?mission2))
       (test (?phasenum < 2)))
  =>
  (retract (schema ?terminal
               (primary-ttc-for ?satellite)))
  (assert (ttc-restoration-required ?satellite 2))
  (assert (update-ttc-service ?satellite))
  (modify (schema ?terminal
             (is-ttc-servicing =(?is - 1)))))


( (schema ?satellite
     (mission ?mission1))
  ?x<-(ttc-restoration ?satellite ?somewhere)
 =>

  (retract (schema ?terminal
               (primary-ttc-for ?satellite)))
  (retract ?x)
  (assert (ttc-restoration ?satellite none))
  (modify (schema ?terminal
             (is-ttc-servicing =(?is - 1)))))))


;;; PRINT HOW TT&C WAS RESTORED

(defrule print-how-ttc-restored
   (declare (salience 999990))
   (viewpoint ?v1
       (column 1 | 5 | 9)
       (ttc-restoration-required ?satellite ?phasenum)
       (ttc-restoration ?satellite ?how))
=>
   (printout t t "Satellite " ?satellite " restored by " t
                ?how " in " ?v1 t t))


;;; ELIMINATE TTC-RESTORATION-REQUIRED FACTS

(defrule get-rid-of-ttc-rest-reqd
   (declare (salience 874380))
   (phase ?phasenumber)
   (ttc-restoration-process ?phasenumber  done)
   ?y<-(ttc-restoration-required ?satellite ?phasenumber)
=>
   (retract ?y))


;;; POISON CERTAIN COMBINATIONS OF TT&C RESTORATIONS

(defcontradiction ttc-restoration-different-ways-on-one
   (schema ?satellite
       (sat-status green)
       (primary-ttc ?terminal))
   (schema ?satellite
       (primary-ttc ~?terminal)))
```

```
;;; FIRST STEP OF OBJECTIVE FUNCTION CALCULATIONS

(defrule calculate-objective-function-phase1
   (declare (salience 999500))
   (phase 1)
   (column 4)
   (data-restoration-process 1  done)
=>
   (assert (calculator objective-function)))


(defrule calculate-objective-function-phase2
   (declare (salience 999450))
   (phase 2)
   (column 8)
   (priority 1 ?first)
   (data-restoration-process 2  done)
=>
   (assert (calculator objective-function))
   (assert (bypass-calculation ?first)))



(defrule calculate-objective-function-phase3
   (declare (salience 999400))
   (phase 3)
   (column 12)
   (priority 2 ?second)
   (data-restoration-process 3  done)
=>
   (assert (calculator objective-function))
   (assert (bypass-calculation ?second)))


;;; CLEAR OUT VARIABLES

(defrule define-empty-list
   (declare (salience *maximum-salience*))
   (calculator objective-function)
   (not (empty-list set))
=>
   (assert (critical-paths-out 0))
   (assert (all-paths-out 0))
   (setq ?*weather*  #l '())
   (setq ?*stormcov* #l '())
   (setq ?*thundercov* #l '())
   (setq ?*scoutareas* #l '())
   (setq ?*allPathareas* #l '())
   (assert (empty-list set)))



(defrule get-coverage-areas-for-storm
```

```
   (declare (salience 999990))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation weather))

   (schema ?satellite
      (part-of storm)
      (sat-status green)
      (can-get-data-down yes)
      (sat-cov-list ?areas))

   (not (ttc-restoration ?satellite none))

   (not (ttc-restoration-required ?satellite ?later))

=>
   #L (setq ?*stormcov* (append ?*stormcov* (list$ ?areas))))


(defrule get-coverage-areas-for-thunder
   (declare (salience 999990))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation weather))

   (schema ?satellite
     (part-of thunder)
     (sat-status green)
     (can-get-data-down yes)
     (sat-cov-list ?areas))
   (not (ttc-restoration ?satellite none))

   (not (ttc-restoration-required ?satellite ?later))
=>
   #l (setq ?*thundercov* (append ?*thundercov* (list$ ?areas))))


(defrule accumulate-areas-can-see-scout
   (declare (salience 999990))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))

   (schema ?satellite
      (part-of scout)
      (sat-status green)
      (sat-cov-list ?areas))
   (not (ttc-restoration ?satellite none))
   (not (ttc-restoration-required ?satellite ?somephase))
=>
   #l(setq ?*scoutareas* (append ?*scoutareas* (list$ ?areas))))


(defrule accumulate-all-pathfinder-areas
   (declare (salience 999990))
   (calculator objective-function)
   (empty-list set)
```

```
   (not (bypass-calculation navigation))

   (schema ?satellite
      (part-of pathfinder)
      (sat-status green)
      (not (spare-in-use no))
      (sat-cov-list ?areas))
   (not (ttc-restoration ?satellite none ))
   (not (ttc-restoration-required ?satellite ?somephase))
=>
   #l(setq ?*allPathareas* (append ?*allPathareas* (list$ ?areas))))


(defrule get-conflict-paths-out
   (declare (salience 999990))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
   (comm-path-restoration-required ?from ?to ?when)
   (not (comm-path-restoration-done ?from ?to ?anywhere&~none))
   (critical-pair ?from ?to)
=>
   (assert (found-one-critical ?from ?to)))


(defrule get-global-paths-out
   (declare (salience 999990))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
   (comm-path-restoration-required ?from ?to ?when)
   (not (comm-path-restoration-done ?from ?to ?anywhere&~none))
=>
   (assert (found-one-global ?from ?to)))


;;; FIND CRITICAL UNAVAILABLE PATHS

(defrule collect-unavailable-paths-conflict
   (declare (salience 999985))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
   ?y<-(critical-paths-out ?num)
   ?x<-(found-one-critical ?from ?to)
=>
   (retract ?x ?y)
   (assert (critical-paths-out =(?num + 1))))


;;; FIND ALL UNAVAILABLE PATHS

(defrule collect-all-unavailable-paths
   (declare (salience 999985))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
```

```
   ?x<-(all-paths-out ?num)
   ?y<-(found-one-global ?from ?to)

  =>
   (retract ?x ?y)
   (assert (all-paths-out =(?num + 1))))


;;; UNDUP LISTS

(defrule undup-global-lists-weather
   (declare (salience 999987))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation weather))
=>
   (modify (schema storm
              (coverage-areas =(seq$ (for area on ?*stormcov*
                                       collect (car area)
                                       unless (member (car area)
                                                      (cdr area)))))))
   (modify (schema thunder
              (coverage-areas =(seq$ (for area on ?*thundercov*
                                       collect (car area)
                                       unless (member (car area)
                                                      (cdr area))))))))


(defrule undup-global-lists-navigation
   (declare (salience 999987))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))
=>

    (modify (schema scout
              (coverage-areas =(seq$ (for area on ?*scoutareas*
                                       collect (car area)
                                       unless (member (car area)
                                                      (cdr area)))))))

    (modify (schema pathfinder
              (coverage-areas =(seq$ (for area on ?*allPathareas*
                                       collect (car area)
                                       unless (member (car area)
                                                      (cdr area))))))))


(defrule get-areas-that-can-see-3-pathsats
   (declare (salience 999986))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))
=>
  (assert (path3areas = (seq$ (for areanum from 1 to 36
                                collect areanum
```

```
                                      unless
              #l(lessp (difference (length ?*allPathareas*)
                       (length (remq areanum ?*allPathareas*))) 3))))))


(defrule get-areas-that-can-see-4-pathsats
   (declare (salience 999986))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))
=>
   (assert (path4areas = (seq$ (for areanum from 1 to 36
                                    collect areanum
                                    unless
               #l(lessp (difference (length ?*allPathareas*)
                        (length (remq areanum ?*allPathareas*))) 4)))))

   (assert (calculator navstep2)))


(defrule get-global-coverage-weather
    (declare ( salience 999985))
    (calculator objective-function)
    (e--ty-list set)
   (no  'bypass-calculation weather))

    (schema storm
        (coverage-areas ?scov))

    (schema thunder
        (coverage-areas ?tcov))
=>

   #l(setq ?*weather* (append (list$ ?scov) (list$ ?tcov)))

   (assert (calculator step2)))



(defrule make-fact-from-list
   (declare (salience 999980))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation weather))

   ?x<-(calculator step2)
=>
   (assert (weather-coverage-areas
             =(seq$ (for area on ?*weather*
                     collect (car area)
                     unless (member (car area) (cdr area))))))

   (assert (calculator step3))
   (retract ?x))
```

```
;;; GET PERCENTAGES COMMUNICATION CONFLICT PERFECT

(defrule get-percentages-communication-unity-conflict
   (declare (salience 999975))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
   (critical-pair-count 0)
 =>
   (assert (conflict-comm-percent 1.0)))


;;; GET PERCENTAGES COMMUNICATION CONFLICT

(defrule get-percentages-comm-conflict
   (declare (salience 999975))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
   (critical-paths-out ?critout)
   (critical-pair-count ?critcount&~0)
 =>
   (assert (conflict-comm-percent
           =#L(difference 1.0 (quotient (float ?critout)
                                        (float ?critcount))))))


;;; GET PERCENTAGES COMMUNICATION GLOBAL

(defrule get-percentages-comm-global
   (declare (salience 999975))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))
   (all-paths-out ?allout)
=>
   (assert (global-comm-percent
        =#L(difference 1.0 (quotient (float ?allout) 118.0)))))


;;; GET GLOBAL PERCENTAGE FOR WEATHER

(defrule get-percentages-weather
   (declare (salience 999975))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation weather))

   ?y<-(calculator step3)
   ?x<-(weather-coverage-areas ?act)
   (conflict-areas ?con)
=>
   (assert (global-weather-percent
           =#l(quotient (float (length$ ?act)) 36.0)))
```

```
   (assert (conflict-weather-percent
       =#L(quotient (float (length (intersection (list$ ?act)
            (list$ ?con)))) (float (length$ ?con)))))
   (assert  (weather-percentages done))
   (retract ?y ?x))


;;; GET GLOBAL AND CONFLICT PERCENTAGES FOR NAVIGATION

(defrule get-percentages-navigation
   (declare (salience 999975))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))
   ?x<-(calculator navstep2)

   (schema scout
      (coverage-areas ?scoutareas))

   ?a<-(path3areas ?path3)
   ?b<-(path4areas ?path4)
   (conflict-areas ?con)
=>
   (assert (global-scout-percent
            =#l(quotient (float (length$ ?scoutareas)) 36.0)))

   (assert (conflict-scout-percent
                =#l(quotient (float (length (intersection
                                                 (list$ ?scoutareas)
                                                 (list$ ?con) )))
                            (float (length$ ?con))) ))

   (assert (global-path3-percent
            =#l(quotient (float (length$ ?path3)) 36.0)))

   (assert (conflict-path3-percent
            =#l(quotient (float (length (intersection (list$ ?path3)
                                                      (list$ ?con) )))
                            (float (length$ ?con))) ))


   (assert (global-path4-percent
            =#l(quotient (float (length$ ?path4)) 36.0)))

   (assert (conflict-path4-percent
            =#l(quotient (float (length (intersection (list$ ?path4)
                                                         (list$ ?con) )))
                            (float (length$ ?con))) ))

   (retract ?x ?a ?b))


;;; COMPUTE WEATHER CONTRIBUTION TO OBJECTIVE FUNCTION

(defrule compute-objective-function-weather
```

```
   (declare (salience 999970))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation weather))

   ?a<-(global-weather-percent ?gw)
   ?b<-(conflict-weather-percent ?cw)

   (weight-global weather ?wtgw)
   (weight-conflict weather ?wtcw)
   (phase ?phasenum)
   (priority ?num weather)

   (case ( (test (?num > ?phasenum))
            =>
            (retract ?a ?b))
          (otherwise
           =>))
=>
   (assert (value-added weather =((?wtgw * ?gw) + (?wtcw * ?cw)))))


;;; COMPUTE NAVIGATION PERCENTAGES

(defrule compute-objective-percents-navigation
   (declare (salience 999973))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))

   ?c<-(global-scout-percent ?gsc)
   ?d<-(conflict-scout-percent ?csc)
   ?e<-(global-path3-percent ?gp3)
   ?f<-(conflict-path3-percent ?cp3)
   ?g<-(global-path4-percent ?gp4)
   ?h<-(conflict-path4-percent ?cp4)

   (sub-global scout 1 ?subgls)
   (sub-conflict scout 1 ?subcons)
   (sub-global path 3 ?glpath3)
   (sub-conflict path 3 ?conpath3)
   (sub-global path 4 ?glpath4)
   (sub-conflict path 4 ?conpath4)
=>

   (assert (global-navigation-percent
                   =(?subgls * ?gsc + ?glpath3 * ?gp3
                     + ?glpath4 * ?gp4)))

   (assert (conflict-navigation-percent
                   =(?subcons * ?csc + ?conpath3 * ?cp3
                     + ?conpath4 * ?cp4)))
   (retract  ?c ?d ?e ?f ?g ?h))


;;; COMPUTE NAVIGATION CONTRIBUTION TO OBJECTIVE FUNCTION
```

```
(defrule compute-value-added-navigation
   (declare (salience 999970))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation navigation))

   ?a<-(global-navigation-percent ?glp)
   ?b<-(conflict-navigation-percent ?conp)
   (weight-global navigation ?wtgnav)
   (weight-conflict navigation ?wtcnav)
   (phase ?phasenum)
   (priority ?num navigation)

 (case ( (test (?num > ?phasenum))
         =>
         (retract ?a ?b))

       (otherwise
        =>))
=>
   (assert (value-added navigation
              =(?wtgnav * ?glp + ?wtcnav * ?conp))))


;;; COMPUTE COMMUNICATION CONTRIBUTION TO OBJECTIVE FUNCTION

(defrule compute-objective-function-communications
   (declare (salience 999970))
   (calculator objective-function)
   (empty-list set)
   (not (bypass-calculation communications))

   ?i<-(global-comm-percent ?gc)
   ?j<-(conflict-comm-percent ?cc)
   ?x<-(critical-paths-out ?num)
   ?y<-(all-paths-out ?all)

   (weight-global communications ?wtgcomm)
   (weight-conflict communications ?wtccomm)
   (phase ?phasenum)
   (priority ?pri communications)

  (case ( (test (?pri > ?phasenum))
          =>
          (retract ?i ?j ?x ?y))

        (otherwise
         =>))
=>
   (assert (value-added communications
              =((?wtgcomm * ?gc) + (?wtccomm * ?cc)))))


;;; COMBINE VALUE-ADDED'S

(defrule compute-obj-2
```

```
   (declare (salience 999968))
   (viewpoint ?whichplan
    (calculator objective-function)
    (empty-list set)
    (phase ?phasenum)
    (value-added weather ?wea)
    (value-added navigation ?nav)
    (value-added communications ?comm))
=>
 (at ?whichplan
   (assert (objective-function-value =(?wea + ?nav + ?comm) ?phasenum))
   (assert (get-ranked-values yes)))
   (printout t t "Values in " ?whichplan t)
   (printout t  "weather value is " ?wea t)
   (printout t  "navigation value is " ?nav t )
   (printout t  "communications value is " ?comm t t))


;;; COLLECT OBJECTIVE FUNCTION VALUES AND PUT INTO ROOT

(defrule collect-objective-function-values
   (declare (salience 500000))
  (viewpoint ?vp
   (calculator objective-function)
   (empty-list set)
   (phase ?phasenum)
   (column 4 | 8 | 12)
   (objective-function-value  ?number ?phasenum)
   ?x<-(get-ranked-values yes))

  (viewpoint ?root
   ?y<-(objective-values ?accum))
=>
  (at ?vp
     (retract ?x))

  (at ?root
     (retract ?y)
     (assert (find-the-best yes))
     (assert (objective-values
               =(seq$ #L(append (list$ ?accum) (list ?number))))))



;;; FIND BEST VALUE AND RUNNERS-UP

(defrule find-best-value-now
   (declare (salience 490000))
  (viewpoint ?root
    ?x<-(find-the-best yes)
    (objective-values ?accum)
    ?a<-(best ?first)
    ?b<-(second-best ?sec)
    ?c<-(third-best ?third))

 (case ( (test #L(lessp (length (list$ ?accum)) 2))
        =>
```

```
          (at ?root
             (retract ?x ?a)
             (assert (best =#L(car (sort (list$ ?accum) 'greaterp))))))

       ( (test #L(lessp (length (list$ ?accum)) 3))
          =>
          (at ?root
             (retract ?x ?a ?b)
             (assert (best =#L(car (sort (list$ ?accum) 'greaterp))))
             (assert (second-best =#L(cadr (sort (list$ ?accum) 'greaterp))))))

       ( (test #L(greaterp (length (list$ ?accum)) 2.5))
          =>
         (at ?root
             (retract ?x ?a ?b ?c)
             (assert (best =#L(car (sort (list$ ?accum) 'greaterp))))
             (assert (second-best =#L(cadr (sort (list$ ?accum) 'greaterp))))
             (assert (third-best =#L(caddr (sort (list$ ?accum) 'greaterp)))))))

;;; START PRUNING

(defrule lets-prune
   (declare (salience 485000))
   (viewpoint ?vp
      (phase ?phasenum)
      (calculator objective-function)
      (empty-list set)
      (objective-function-value ?value ?phasenum))
=>
   (at ?vp
      (assert (prune ?phasenum))))


;;; PRUNING ALGORITHM

(defrule prune-phase1
   (declare (salience 480000))

   (phase 1)
   (column 4)
   (prune 1)
   (objective-function-value ?value 1)

   (priority 1 ?mission1)
   (priority 2 ?mission2)
   (priority 3 ?mission3)
   (value-added ?mission1 ?actual)
   (weight-global ?mission2 ?gl2)
   (weight-global ?mission3 ?gl3)
   (weight-conflict ?mission2 ?con2)
   (weight-conflict ?mission3 ?con3)
   (third-best ?third)

   (test ((?actual + ?gl2 + ?gl3 + ?con2 + ?con3) < ?third))
=>
    (printout t t "Pruning one branch of search tree." t t)
     (poison "pruning process"))
```

```
(defrule prune-phase2
   (declare (salience 480000))
   (phase 2)
   (column 8)
   (prune 2)
   (objective-function-value ?value 2)

   (priority 1 ?mission1)
   (priority 2 ?mission2)
   (priority 3 ?mission3)
   (value-added ?mission1 ?actual1)
   (value-added ?mission2 ?actual2)
   (weight-global ?mission3 ?gl3)
   (weight-conflict ?mission3 ?con3)
   (third-best ?third)

   (test ((?actual1 + ?actual2 + ?gl3 + ?con3) < ?third))
=>
   (printout t t "Pruning one branch of search tree." t t)

   (poison "pruning process"))



;;;START PHASE 2

(defrule update-phase-number-1-to-2
   (declare (salience 400000))
   ?calc<-(calculator objective-function)
   ?e<-(empty-list set)
   (priority 2 ?second)
   (priority 3 ?third)
   ?valn<-(value-added ?second ?value)
   ?valc<-(value-added ?third ?comm)
   ?m<-(phase 1)
   ?x<-(prune 1)
=>
   (printout t t "Starting " ?second " restoration process." t t)
   (retract ?m ?x ?calc ?e ?valn ?valc)
   (assert (phase 2)))


;;; START PHASE 3

(defrule update-phase-number-2-to-3
   (declare (salience 300000))
   ?calc<-(calculator objective-function)
   ?e<-(empty-list set)
   (priority 3 ?third)
   ?valn<-(value-added ?third  ?value)
   ?m<-(phase 2)
   ?x<-(prune 2)
=>
   (printout t t "Starting " ?third " restoration process." t t)
   (retract ?m ?x ?calc ?e ?valn)
```

```
   (assert (phase 3)))

;;; RESTORATION PROCESS FINISHED

(defrule restoration-finished
   (declare (salience 200000))
 (viewpoint ?vp
     ?calc<-(calculator objective-function)
     ?e<-(empty-list set)
     ?m<-(phase 3)
     ?x<-(prune 3))
=>
   (at ?vp
   (assert (restoration-finished ?vp))))



;;;  POISON CERTAIN COMBINATIONS OF WEATHER DATA RESTORATION

(defcontradiction data-restoration-different-ways-on-one
   (schema ?satellite
      (sat-status green))
   (data-restoration ?satellite ?terminal)
   (data-restoration ?satellite ~?terminal))



;;; SEE IF WEATHER SATELLITES CAN GET DATA TO EARTH TERMINAL

(defrule can-get-data-down
   (declare (salience 800000))
   (phase ?phasenum)
   (column 2 | 6 | 10)

   (schema  ?satellite
      (sat-status green)
      (mission weather))


   (not (data-dn-checked ?satellite))
   (schema ?data-terminal
            (receive-data-from ?satellite)
            (data-status green))
 =>
   (assert (data-dn-checked ?satellite))
   (assert (schema ?satellite
              (can-get-data-down yes))))


;;; BYPASS DATA RESTORATION IF NAVIGATION

(defrule skip-data-rest-for-navigation
   (declare (salience 780001))
   (phase ?phasenum)
   ?m<-(column ?col)
```

```
   (test ((?col mod 4) = 2))
   (priority ?phasenum navigation)
=>
   (retract ?m)
   (assert (column =(?col + 2)))
   (assert (data-restoration-process ?phasenum  done)))



;;; BYPASS DATA RESTORATION IF NOT REQUIRED

(defrule all-green-weather-sats-send-down-data
   (declare (salience 780000))
   (phase ?phasenum)
   ?m<-(column ?col)
   (test ((?col mod 4) = 2))
   (priority ?phasenum weather)
   (forall (schema ?satellite
               (is-a satellite)
               (mission weather))
           (or  (schema ?satellite (sat-status green)
                                   (can-get-data-down ?somewhere))
                (schema ?satellite (sat-status red | unknown))))
=>
   (assert (data-restoration-process ?phasenum  done))
   (printout t t "No weather data restoration required." t t)
   (retract ?m)
   (assert (column =(?col + 2))))


;;; FLAG WEATHER SATELLITES THAT CANNOT GET DATA DOWN

(defrule identify-problem-sats-for-data-weather
   (declare (salience 775000))
 (viewpoint ?whichplan
   (column 2 | 6 | 10)
   (priority ?wea weather)

    (schema ?satellite
           (sat-status green)
           (mission weather)
           (not (can-get-data-down yes))))

=>

    (printout t t "Weather satellite " ?satellite
           " needs data restoration in " ?whichplan  t t)
   (at ?whichplan
       (assert (needs-data-restoration ?satellite ?wea))))


;;; rule try-other-system-to-get-data-down located in file tryother.art


;;; COLLECT PLANS TO RESTORE DATA
```

```
(defrule collect-ways-to-restore-data-mission1
   (declare (salience 690000))
   (phase ?phasenum)
   ?m<-(column ?col)
   (test ((?col mod 4 ) = 3))
   (forall
           (needs-data-restoration ?satellite ?phasenum)
           (data-restoration ?satellite ?somewhere))
=>
   (retract ?m)
   (assert (data-restoration-process ?phasenum done))
   (assert (column =(?col + 1))))


;;; TIDY UP FACTS

(defrule get-rid-of-needs-data-restoration
   (declare (salience 670000))
   (phase ?phasenumber)
   (data-restoration-process ?phasenumber done)
   ?x<-(needs-data-restoration ?satellite ?phasenumber)
=>
   (retract ?x))


(defrule get-rid-of-checked-data-dn
   (declare (salience 670000))
   (phase ?phasenum)
   (data-restoration-process ?phasenum done)
   ?x<-(data-dn-checked ?satellite)
=>
   (retract ?x))
```

```
;;; -*-Mode:Art; Package:ART-USER; Base:10 -*-


;;; FILE: D:BAP;TRYOTHER.ART


;;; TRY ANOTHER SYSTEM TO GET DATA DOWN

(defrule try-other-system-to-get-data-down
   (declare (salience 750000))
   (phase ?phasenum)
   ?m<-(column ?col)
   (test ((?col mod 4) = 2))
   (needs-data-restoration ?satellite ?phasenum)
   (priority 1 ?miss1)
   (priority 2 ?miss2)
   (priority 3 ?miss3)

   (schema ?satellite
      (data-transmit-freq ?sattx)
      (part-of ?system)
      (sat-coverage ?area))


   (schema ?other-term
       (data-status green)

       (area ?area)
       (location ?place))

   (or (schema ?other-term
                (data-receive-freq ?sattx))

       (and (schema ?other-term
                (data-rx-freq-lower ?lowrx)
                (data-rx-freq-upper ?hirx))
            (test (and (?sattx >= ?lowrx)
                       (?sattx <= ?hirx))))

       (and (schema ?other-term
                (data-rx-freq-lower2 ?low2rx)
                (data-rx-freq-upper2 ?hi2rx))
            (test (and (?sattx >= ?low2rx)
                       (?sattx <= ?hi2rx)))))

   (exists (or (schema ?ownterm
                  (use data)
                  (part-of ?system)
                  (location ?place))

                (and (schema ?ownterm
                       (use data)
                       (part-of ?system)
                       (location ?spot))
                     (link ?place ?spot))))

;;;  FIRST TRY TO USE AN UNDEDICATED TERMINAL
```

```
(case (  (schema ?other-term
              (receive-data-for open))

           =>
          (hypothesize
                (assert (data-restoration ?satellite ?other-term)
                        (send-over-data ?other-term))

                (assert (schema ?other-term
                            (receive-data-from ?satellite)))
                (retract ?m)

                (assert (column =(?col + 1)))

                (modify (schema ?other-term
                             (receive-data-for ?system)))))


;;; TRY TO GET DATA DOWN TO A LESSER PRIORITY TERMINAL


      ( (and  (schema ?other-term
                (receive-data-for ?sys2&~?system))

              (schema ?sys2
                (mission ?s2miss))

              (priority ?rank ?s2miss)
              (test (?rank > ?phasenum)))
           =>
          (hypothesize
                (assert (data-restoration ?satellite ?other-term)
                        (send-over-data ?other-term))
                (retract ?m)

                (assert (column =(?col + 1)))

                (assert (schema ?other-term
                            (receive-data-from ?satellite)))

                (assert (gave-away-data-slot ?other-term ?sys2))

                (modify (schema ?other-term
                             (receive-data-for ?system)))))

;;; TRY TO GET DATA DOWN TO AN EQUAL PRIORITY TERMINAL


     (  (and (schema ?other-term
                (receive-data-for ?sys2&~?system))

             (schema ?sys2
                (mission ?s2miss))
             (priority ?rank ?s2miss)
             (test (?rank = ?phasenum)))
           =>
          (hypothesize
                (assert (data-restoration ?satellite ?other-term)
                        (send-over-data ?other-term))
```

```
                (retract ?m)

                (assert (column =(?col + 1)))

                (assert (schema ?other-term
                        (receive-data-from ?satellite)))

                (assert (gave-away-data-slot ?other-term ?sys2))

                (modify (schema ?other-term
                         (receive-data-for ?system))))) ) )


;;; IF NO DATA RESTORATION BRANCHES EXIST, NO HOPE FOR DATA RESTORATION

(defrule no-hope-for-data-restoration
   (declare (salience 740000))
   (phase ?phasenum)

   (viewpoint ?v1
      (needs-data-restoration ?satellite ?phasenum)
      ?m<-(column ?col))
      (test ((?col mod 4) = 2))

   (not (viewpoint ?v2
         (data-restoration ?satellite ?anywhere)))
=>
   (at ?v1
       (hypothesize
                (assert (data-restoration ?satellite none))

                (modify (schema ?satellite
                         (sat-status red)))

                (assert (satellite-down ?satellite no-data-down-capability))
                (retract ?m)

                (assert (column =(?col + 1))))))


;;; FIND SATELLITES THAT CORRESPOND TO GAVE-AWAY-DATA-SLOT

(defrule find-data-stricken-satellites
   (declare (salience 720000))
   (column 3 | 7 | 11)
   (gave-away-data-slot ?terminal ?system)
   (schema ?terminal
       (receive-data-from ?satellite))

   (schema ?satellite
      (part-of ?system))
=>
   (retract (schema ?terminal (receive-data-from ?satellite)))
   (assert (check-for-other-data-dn ?satellite)))
```

```
;;; TAKE OUT LINKS IF COMM TERMINAL USED FOR WEATHER

(defrule comm-terminal-given-to-weather
   (declare (salience 720000))
   (column 3 | 7 | 11)
   (gave-away-slot ?terminal ?system)
   (schema ?terminal
    (mission communications))
=>
   (assert (take-out-links ?terminal)))



;;; CHECK IF SATELLITES CAN STILL GET DATA SOMEWHERE

(defrule see-what-sats-can-still-send-data
   (declare (salience 710000))
   ?m<-(column ?col)
   (phase ?phasenum)

   ?x<-(check-for-other-data-dn ?satellite)

   (schema ?satellite
      (mission weather))

   (priority ?rank weather)

(case ( (schema ?terminal
           (receive-data-from ?satellite))

         =>
         (retract ?x))

      (otherwise
        =>
      (assert (needs-data-restoration ?satellite ?rank))
      (retract ?m)
      (assert (column =(?col + 1))))))
```

```
;;;-*- mode:Art; Package:au; Base:10.-*-

;;; FILE: D:BAP;FORLINK.ART


;;; CUT LINKS WHEN SATELLITE DOWN

(defrule cut-links-when-satellite-destroyed
   (declare (salience 941998))
   ?r<-(check-to-free-data-terminal ?satellite)

   (schema ?satellite
      (mission communications))

   (split (?y<-(successor ?anywhere ?satellite ?other)
           =>
           (retract ?y))

          (?x<-(successor ?anywhere  ?other ?satellite)
           =>
           (retract ?x))))


;;; CUT LINKS WHEN DATA TERMINAL DOWN

(defrule cut-links-when-data-terminal-down
   (declare (salience 941992))
   (take-out-links ?terminal)

   (schema ?terminal
      (mission communications))

  (split (?x<-(successor ?anywher ?terminal ?other)
          =>
          (retract ?x))

         (?y<-(successor ?anywhere ?other ?terminal)
          =>
          (retract ?y)))

  (case ((schema ?other
           (is-a satellite))
          =>
         (assert (check-stranded ?other)))

        (otherwise
          =>)))


;;; ELIMINATE PATHS THAT CONTAINED DESTROYED TERMINAL

(defrule remove-appropriate-paths
   (declare (salience 941991))
   (take-out-links ?terminal)

   ?x<-(path ?a ?b ?c ?d)
   (test #1(member ?terminal (list$ ?d)))
```

```
=>
   (retract ?x))


;;; ELIMINATE PATHS THAT USED A LANDLINE THAT HAS BEEN DESTROYED

(defrule remove-paths-due-to-cut-landline
   (declare (salience 941995))
   (groundlink-destroyed ?from ?to)
   ?x<-(path ?how ?b ?c ?d)
   (test #l(member ?from (list$ ?d)))
   (test #l(member ?to (list$ ?d)))

(case ( (and (test #l(greaterp (length (member ?from (list$ ?d)))
                               (length (member ?to (list$ ?d)))))
             (test #l(equalp (cadr (member ?from (list$ ?d))) ?to)))
        =>
        (retract ?x))

      ( (and (test #l(greaterp (length (member ?to (list$ ?d)))
                               (length (member ?from (list$ ?d)))))
             (test #l(equalp (cadr (member ?to (list$ ?d))) ?from)))
        =>
        (retract ?x))))



;;; ELIMINATE PATHS THAT CONTAINED DESTROYED SATELLITE

(defrule remove-paths-due-to-red-sat
   (declare (salience 941997))
   ?r<-(check-to-free-data-terminal ?satellite)

   (schema ?satellite
      (mission communications))

   ?y<-(path ?a ?b ?c ?d)

   (test #l(member ?satellite (list$ ?d)))
=>
   (retract ?y))


;;; DETERMINE IF RESTORATION IS REQUIRED

(defrule see-what-links-are-missing
   (declare (salience 941500))
   (priority ?phase communications)

   (port ?continent ?terminal)
   (port ?othercont&~?continent ?otherterm)

   (not (path ?how ?terminal ?otherterm ?trail))
 =>
    (printout t t "New communications path required between "
              ?terminal " and " ?otherterm  t t)
```

```
    (assert (comm-path-restoration-required ?terminal ?otherterm ?phase)))

;;; CHECK IF SATELLITE IS STRANDED (NO LINKS)

(defrule is-satellite-stranded
   (declare (salience 941450))
   ?m<-(check-stranded ?satellite)

(case ( (and(successor ?anywhere ?x ?satellite)
            (successor ?somewhere ?satellite ?y&~?x))
         =>
         (retract ?m))

       (otherwise
        =>
        (retract ?m)
        (assert (satellite-down ?satellite no-data-links-to-ground))
        (printout t t "Communications satellite "
                       ?satellite " has no comm links to ground." t
                      "Status of satellite " ?satellite " set to red." t t)
        (assert (schema ?satellite
                      (sat-status red))))))

;;; FIND ANOTHER PATH TO RESTORE AT ROOT

(defrule find-another-path-at-root
   (declare (salience 941400))
   (column 0)

   (comm-path-restoration-required ?from ?to ?phasenum)
   (not (comm-path-restoration-done ?from ?to ?anywhere))
=>
   (assert (retrieve-path ?from ?to 0)))

;;; NO COMMUNICATIONS PATH FOUND AT ROOT

(defrule no-comm-path-found-root
   (declare (salience 941398))
   (column 0)
   (comm-path-restoration-required ?from ?to ?phasenum)
   (not (comm-path-restoration-done ?from ?to 0))
=>
   (assert (comm-path-restoration-done ?from ?to none)))

;;; FIND ANOTHER PATH TO RESTORE IN CORRECT PHASE

(defrule find-another-path
   (declare (salience 800000))
   (phase ?phasenum)
   (column ?col)
   (test ((?col mod 4) = 2))

   (comm-path-restoration-required ?from ?to ?phasenum)
   (not (comm-path-restoration-done ?from ?to ?anywhere))
```

```
=>
   (assert (retrieve-path ?from ?to ?phasenum)))


;;; CLEAN UP USED-LINK FACTS IN ROOT

(defrule clean-up-used-link-facts-in-root
   (declare (salience 900001))
   (column 0)
   (comm-path-restoration-done ?from ?to ?phasenum)
   ?x<-(used-link ?node ?othernode)
=>
   (retract ?x))


;;; CLEAN UP USED-LINK FACTS

(defrule clean-up-used-link-facts
   (declare (salience 850000))
   (comm-path-restoration-done ?from ?to ?phasenum)
   ?x<-(used-link ?node ?othernode)
=>
   (retract ?x))


;;; NO COMMUNICATIONS PATH FOUND

(defrule no-comm-path-found-phase
   (declare (salience 795000))
   (phase ?phasenum)
   ?x<-(column ?col)
   (test ((?col mod 4) = 2))
   (priority ?phasenum communications)
   (comm-path-restoration-required ?from ?to ?phasenum)
   (not (comm-path-restoration-done ?from ?to ?somehow))
=>
   (assert (comm-path-restoration-done ?from ?to none)))


;;; COMMUNICATIONS PATH RESTORATION FINISHED, UPDATE COLUMN

(defrule move-on-from-comm-rest-to-obj-fcn
   (declare (salience 790000))
   (phase ?phasenum)
   ?x<-(column ?col)
   (test ((?col mod 4) = 2))
   (priority ?phasenum communications)

   (forall
        (comm-path-restoration-required ?from ?to ?phasenum)
        (comm-path-restoration-done ?from ?to ?somehow))
=>
   (retract ?x)
   (assert (column =(?col + 2)))
   (assert (data-restoration-process ?phasenum done)))
```

```
;;; -*-Mode:Art; Package:ART-USER; Base:10. -*-

;;; FILE: D:BAP;STARTUP.ART


;;; EUROPEAN THEATER CRITICAL PAIRS

(defrule critical-pairs-European-theater
   (declare (salience *maximum-salience*))
   ?x<-(theater Europe)
   ?y<-(critical-pair-count ?number)
=>
   (assert (critical-pair Sunnyvale Crete-Greece)
           (critical-pair Point-Mugu Crete-Greece)
           (critical-pair Colorado-Springs Crete-Greece)
           (critical-pair Norfolk-Virginia Crete-Greece)
           (critical-pair Prospect-Harbor-Maine Crete-Greece)
           (critical-pair Thule-Greenland Crete-Greece))
   (retract ?x ?y)
   (assert (critical-pair-count =(?number + 12))))


;;; ASIAN THEATER

(defrule critical-pairs-Asian-theater
   (declare (salience *maximum-salience*))
   ?x<-(theater Asia)
   ?y<-(critical-pair-count ?number)
=>
   (assert (critical-pair Sunnyvale Indian-Ocean)
           (critical-pair Point-Mugu Indian-Ocean)
           (critical-pair Colorado-Springs Indian-Ocean)
           (critical-pair Norfolk-Virginia Indian-Ocean)
           (critical-pair Prospect-Harbor-Maine Indian-Ocean )
           (critical-pair Thule-Greenland Indian-Ocean)

           (critical-pair Sunnyvale Diego-Garcia)
           (critical-pair Point-Mugu Diego-Garcia)
           (critical-pair Colorado-Springs Diego-Garcia)
           (critical-pair Norfolk-Virginia Diego-Garcia)
           (critical-pair Prospect-Harbor-Maine Diego-Garcia)
           (critical-pair Thule-Greenland Diego-Garcia))
   (retract ?x ?y)
   (assert (critical-pair-count =(?number + 24))))


;;; FAR EASTERN THEATER

(defrule critical-pairs-FarEastern-theater
   (declare (salience *maximum-salience*))
   ?x<-(theater FarEast)
   ?y<-(critical-pair-count ?number)
=>
   (assert (critical-pair Sunnyvale Woomera-Australia)
           (critical-pair Point-Mugu Woomera-Australia)
           (critical-pair Colorado-Springs Woomera-Australia)
```

```
          (critical-pair Norfolk-Virginia Woomera-Australia)
          (critical-pair Prospect-Harbor-Maine Woomera-Australia)
          (critical-pair Thule-Greenland Woomera-Australia)

          (critical-pair Sunnyvale Guam)
          (critical-pair Point-Mugu Guam)
          (critical-pair Colorado-Springs Guam)
          (critical-pair Norfolk-Virginia Guam)
          (critical-pair Prospect-Harbor-Maine Guam)
          (critical-pair Thule-Greenland Guam)

          (critical-pair Sunnyvale Kwajelein-Island)
          (critical-pair Point-Mugu Kwajelein-Island)
          (critical-pair Colorado-Springs Kwajelein-Island)
          (critical-pair Norfolk-Virginia Kwajelein-Island)
          (critical-pair Prospect-Harbor-Maine Kwajelein-Island)
          (critical-pair Thule-Greenland Kwajelein-Island))
   (retract ?x ?y)
   (assert (critical-pair-count =(?number + 36))))


;;; PACIFIC THEATER

(defrule critical-pairs-Pacific-theater
   (declare (salience *maximum-salience*))
   ?x<-(theater Pacific)
   ?y<-(critical-pair-count ?number)
=>
   (assert (critical-pair Sunnyvale Wahiawi-Hawaii)
          (critical-pair Point-Mugu Wahiawi-Hawaii)
          (critical-pair Colorado-Springs Wahiawi-Hawaii)
          (critical-pair Norfolk-Virginia Wahiawi-Hawaii)
          (critical-pair Prospect-Harbor-Maine Wahiawi-Hawaii)
          (critical-pair Thule-Greenland Wahiawi-Hawaii))
   (retract ?x ?y)
   (assert (critical-pair-count =(?number + 12))))


;;; START TT&C RESTORATION

(defrule start-up-ttc-required
   (declare (salience *maximum-salience*))
   ?x<-(change-ttc-status ?terminal  red  ?reason)
=>
   (retract ?x)

   (modify (schema ?terminal
                (ttc-status red)))

   (assert (ttc-capability-down ?terminal ?reason)))



;;; TT&C STATUS UNKNOWN

(defrule unknown-ttc-status
   (declare (salience *maximum-salience*))
   ?x<-(change-ttc-status ?terminal unknown ?reason)
```

```
(case
    ( (schema ?terminal
        (ttc-status red))
       =>
      (retract ?x))

    ( (schema ?terminal
        (is-a earth-terminal)
        (not (primary-ttc-for ?anywhere)))
       =>
       (modify (schema ?terminal (ttc-status red)))
       (assert
        (ttc-capability-down ?terminal unknown-assumed-destroyed))
       (retract ?x))

    ( (exists (schema ?terminal
                (primary-ttc-for ?satellite))
               (schema ?satellite
                (sat-status green))
               (not (change-satellite-status
                     ?satellite red | unknown ?reason)))
      =>
      (retract ?x))

   (otherwise
    =>
    (retract ?x)
    (modify (schema ?terminal (ttc-status red)))
    (assert
     (ttc-capability-down ?terminal unknown-assumed-destroyed))))


;;; START DATA RESTORATION

(defrule start-up-data-required
   (declare (salience *maximum-salience*))
   ?x<-(change-data-status ?terminal red | unknown ?reason)

   (split ((schema ?terminal
             (mission communications))
            =>
           (assert (take-out-links ?terminal)))

           ((schema ?terminal
             (mission ~communications))
           =>))

=>
   (retract ?x)

   (modify (schema ?terminal
                (data-status red)))

   (assert (data-capability-down ?terminal ?reason)))
```

```
;;; SATELLITE NEEDS RESTORATION

(defrule start-up-satellite-down
   (declare (salience *maximum-salience*))
   ?x<-(change-satellite-status ?satellite red  ?reason)
=>
   (retract ?x)

   (modify (schema ?satellite
               (sat-status red)))

   (assert (satellite-down ?satellite destroyed))
   (assert (unload-responsibilities ?satellite)))


;;; SATELLITE STATUS UNKNOWN

(defrule satellite-status-unknown
   (declare (salience *maximum-salience*))
   ?x<-(change-satellite-status ?satellite unknown ?reason)
=>
   (retract ?x)
   (modify (schema ?satellite
               (sat-status unknown)))
   (assert (satellite-down ?satellite possible)))


;;; GROUNDLINK-DESTROYED

(defrule start-up-underground-link-destroyed
   (declare (salience *maximum-salience*))
   (groundlink-destroyed ?from ?to)
   ?y<-(link ?from ?to)
   ?z<-(link ?to ?from)
   ?a<-(successor landline ?from ?to)
   ?b<-(successor landline ?to ?from)
=>
   (retract ?a ?b ?y ?z))
```

```
;;; -*- Mode:Art; Package:au; Base:10. -*-

;;; FILE: D:BAP;REPORTS.ART

;;; OUTPUT BEST PLAN

(defrule output-best-one
   (declare (salience 230000))
   (viewpoint ?vp
      (give-plans ?num)
      (best ?value)
      (objective-function-value ?value 3)
      (restoration-finished ?vp)
      (not (output-viewpoint ?vp)))
=>
   (at ?vp
   (assert (output-viewpoint ?vp)))
   (printout t t t "BEST RESTORATION PLAN:" t t))


;;; OUTPUT SECOND BEST PLAN

(defrule output-second-one
   (declare (salience 228000))
   (viewpoint ?root
     (give-plans ?num)
     (second-best ?value))
   (test (?num > 1))

   (viewpoint ?vp
      (objective-function-value ?value 3)
      (restoration-finished ?vp)
      (not (output-viewpoint ?vp)))
=>
   (at ?vp
      (assert (output-viewpoint ?vp)))
   (printout t t t "SECOND BEST RESTORATION PLAN:" t t))


;;; OUTPUT THIRD BEST PLAN

(defrule output-third-one
   (declare (salience 226000))
  (viewpoint ?root
     (give-plans ?num)
     (third-best ?value))
   (test (?num > 2))
  (viewpoint ?vp
     (objective-function-value ?value 3)
     (restoration-finished ?vp)
     (not (output-viewpoint ?vp)))
=>
 (at ?vp
   (assert (output-viewpoint ?vp)))
   (printout t t t "THIRD BEST RESTORATION PLAN" t t))
```

```
;;; OUTPUT ALL PLANS

(defrule output-all-plans
   (declare (salience 224000))
   (viewpoint ?vp
      (restoration-finished ?vp)
      (phase 3)
      (give-all-plans yes)
      (not (output-viewpoint ?vp)))
=>
 (at ?vp
   (assert (output-viewpoint ?vp)))
   (printout t t t "RESTORATION PLAN:" ?vp t t))


;;; PRINT HEADER

(defrule output-all-steps-header
   (declare (salience 250000))
   (viewpoint ?vp
      (restoration-finished ?vp)
      (output-viewpoint ?vp)
      (value-added navigation ?valnav)
      (value-added communications ?valcomm)
      (value-added weather ?valwea)
      (global-weather-percent ?gw)
      (global-navigation-percent ?gn)
      (global-comm-percent ?gc)
      (conflict-weather-percent ?cw)
      (conflict-navigation-percent ?cn)
      (conflict-comm-percent ?cc)
      (objective-function-value ?value 3))
=>
   (printout t t ?vp " Restoration plan has value " ?value t t)
   (printout t "Communications Value: " ?valcomm t
             "Navigation Value:     " ?valnav t
             "Weather Value:        " ?valwea t t)
   (printout t "Communications Percentages: Conflict Area: " ?cc t
             "                            Global:        " ?gc t t)
   (printout t "Navigation Percentages:     Conflict Area: " ?cn t
             "                            Global:        " ?gn t t)
   (printout t "Weather Percentages:        Conflict Area: " ?cw t
             "                            Global:        " ?gw t t)

   (printout t "Resources not operational
              and reason for red status:" t t ))


;;; PRINT SATELLITES WITH RED STATUS

(defrule satellites-down-output
   (declare (salience 248000))
   (viewpoint ?vp
     (output-viewpoint ?vp)
     (satellite-down ?satellite ?reason))
```

```
=>
   (printout t "Satellite " ?satellite "   Reason: " ?reason t))


;;; PRINT TTC TERMINALS WITH RED STATUS

(defrule ttc-terminals-down-output
   (declare (salience 247000))
   (viewpoint ?vp
      (output-viewpoint ?vp)
      (ttc-capability-down ?terminal ?reason))
=>
   (printout t "TT&C Terminal " ?terminal "   Reason: " ?reason t))


;;; PRINT DATA TERMINALS WITH RED STATUS

(defrule data-terminal-down-output
   (declare (salience 246000))
   (viewpoint ?vp
      (output-viewpoint ?vp)
      (data-capability-down ?terminal ?reason))
=>
   (printout t "Data Terminal " ?terminal "   Reason: " ?reason t))


;;; PRINT RTS TERMINAL WITH DEGRADED STATUS

(defrule yellow-rts-output
   (declare (salience 245000))
   (viewpoint ?vp
      (output-viewpoint ?vp)
      (one-antenna-down ?rts ?reason))
=>
   (printout t "One antenna down at " ?rts "    Reason: " ?reason t))


;;; PRINT IF THERE IS NO COMM CONNECTION

(defrule no-connection-between
   (declare (salience 244800))
   (viewpoint ?vp
      (comm-path-restoration-done ?from ?to none)
      (output-viewpoint ?vp))
=>
   (printout t "No communications link from " ?from " to " ?to t t))


;;; HEADER FOR RESTORATION STEPS

(defrule output-steps
   (declare (salience 244000))
   (viewpoint ?vp
      (output-viewpoint ?vp))
```

```
=>
   (printout t t ?vp " Restoration Steps to Implement: " t )
   (printout t "- - - - - - - - - - - - - - - - - - - - - - " t t))


;;; PRINT PUT SPARE IN USE

(defrule spare-step
   (declare (salience 243000))
   (viewpoint ?vp
     (output-viewpoint ?vp)
     (put-spare-in-use ?spare)
     (schema ?spare
        (sat-status green)
        (primary-ttc ?terminal)))


=>
   (printout t "Put spare satellite " ?spare " in use" t
               "and use " ?terminal " for TT&C servicing." t ))


;;; PRINT TTC RESTORATION STEPS

(defrule ttc-step
   (declare (salience 242000))
   (viewpoint ?vp
     (output-viewpoint ?vp)
     (ttc-restoration ?satellite ?terminal&~none))
=>
   (printout t "Use " ?terminal " terminal for satellite " ?satellite
               " TT&C servicing." t))


;;; PRINT DATA RESTORATION STEPS

(defrule data-step
   (declare (salience 241000))
   (viewpoint ?vp
      (output-viewpoint ?vp)
      (data-restoration ?satellite ?terminal&~none)
      (send-over-data ?terminal)
      (schema ?satellite
           (part-of ?system)))
=>
   (printout t "Terminal " ?terminal " will receive data " t
            "from satellite " ?satellite " and send data over to a "
             t ?system " data terminal via landline." t))


;;; PRINT NEW PATHS FOR COMMUNICATIONS

(defrule path-step
   (declare (salience 240000))
   (viewpoint ?vp
      (output-viewpoint ?vp)
      (comm-path-restoration-done ?from ?to ?num&~none)
```

```
      (path ?how ?from ?to ?trail)
      (not (path-was-printed ?from ?to)))
=>
   (printout t t "New communications path from " ?from " to " ?to " :" t)
   (at ?vp
     (assert (print-path-list ?trail))
     (assert (path-was-printed ?from ?to))))



;;; STEP THROUGH LIST FOR PATH

(defrule step-through-path-print
   (declare (salience 999999))
   ?x<-(print-path-list ?trail)
   (test ((length$ ?trail) > 1))
=>
   (bind ?first #L(car (list$ ?trail)))
   (printout t ?first t)
   (retract ?x)
   (assert (print-path-list =#l(seq$ (cdr(list$ ?trail))))))


;;; LAST ELEMENT OF PATH ENCOUNTERED

(defrule found-destination-in-path-print
   (declare (salience 999999))
   ?x<-(print-path-list ?trail)
   (test ((length$ ?trail) = 1))
=>
   (retract ?x)
   (bind ?first #L(car (list$ ?trail)))
   (printout t ?first t t t))



;;; MOVE ON TO ANOTHER PLAN

(defrule finished-with-print-plan
   (declare (salience 235000))
   (viewpoint ?vp
     (output-viewpoint ?vp))
=>
   (printout t "- - - - - - - - - - - - - - - - - - - - " t)
   (printout t t "* * * * * * * * * * * * * * * * * * * * *" t t))
```

```
;;; -*- Mode:Art; Package:ART-USER; Base:10. -*-


;;; FILE: D:BAP;FORBREADTH.ART


;;; BREADTH FIRST SEARCH ROUTINE USED TO GET NEW COMMUNICATIONS PATHS


;;; SET UP VARIABLES FOR SEARCH (ALL POSSIBLE WAYS)

(defrule get-new-path-all
   (declare (salience 999000))
   (comm-path-restoration-required ?start ?finish ?phasenum)
   (not (comm-path-restoration-done ?start ?finish ?anywhere))
   (retrieve-path ?start ?finish ?when)
=>
   (assert (accumulate-path all ?start ?finish))
   (assert (expand-on =(seq$ #L(list ?start))))
   (assert (partials =(seq*$ #L(list (list ?start)))))
   (assert (collect-hold =(seq$ #L'()) )))



;;; COLLECT EXPANSIONS OF FIRST ELEMENT IN PARTIALS LIST (ALL WAYS)

(defrule collect-expansions-all
   (declare (salience 999500))
   (accumulate-path all ?start ?finish)
   (expand-on ?takeoff)
   (successor chatter | talk | landline | mixed ?start
              ?next&:(not #l(member ?next (list$ ?takeoff))))
   (not (used-link ?start ?next))
   ?x<-(collect-hold ?group)
=>
   (retract ?x)
   (assert (used-link ?start ?next))

   (assert (collect-hold
               =(seq*$ #L(append (list (append (list ?next)
                                                (list$ ?takeoff)))
                                          (list*$ ?group))))))


;;; ADD EXPANSIONS TO LIST OF PARTIAL PATHS (ALL)

(defrule add-on-expansions-all
   (declare (salience 999450))
   (accumulate-path all ?start ?finish)
   ?x<-(partials ?queue)
   ?b<-(collect-hold ?additions)

(case ( (test #L(equalp '() (list$ ?additions)))
        =>
        (retract ?b ?x)
        (assert (partials =(seq*$ #L(cdr (list*$ ?queue))))))

      (otherwise
```

```
        =>
        (retract ?x ?b)
        (assert (partials =(seq*$ #L(append (cdr (list*$ ?queue))
                                            (list*$ ?additions)))))))
```

```
;;; GET NEXT GROUP OF EXPANSIONS (ALL)

(defrule get-next-start-all
   (declare (salience 999440))
   ?c<-(accumulate-path all ?start ?finish)
   (partials ?queue)
=>
   (retract ?c)
   (assert (expand-on =(seq$ #L(car (list*$ ?queue)))))
   (assert (accumulate-path all =#L(car (car (list*$ ?queue))) ?finish))
   (assert (collect-hold =(seq$ #L '()))))

;;; DESTINATION FOUND, PATH COMPLETE (ALL)

(defrule found-destination-all
   (declare (salience 999520))
   ?c<-(expand-on ?what)
   ?x<-(collect-hold ?group)
   ?y<-(accumulate-path all ?start ?finish)
   (test #L(equalp (caar (list*$ ?group)) ?finish))
   ?a<-(retrieve-path ?begin ?end ?when)
=>
   (retract ?x ?y ?c ?a)
   (assert (clean-up links))
   (assert (comm-path-restoration-done
                             =#L(car (reverse (car (list*$ ?group))))
                                                     ?finish ?when))
   (assert (path all =#L(car (reverse (car (list*$ ?group))))  ?finish
          =(seq$ #L(reverse (car (list*$ ?group)))))))


;;; GET NEW PATH VIA RESPECTIVE IF REVERSE PATH IS RESPECTIVE

(defrule get-new-path-via-reverse
   (declare (salience 999700))
   (comm-path-restoration-required ?start ?finish ?phasenum)
   (not (comm-path-restoration-done ?start ?finish ?anytime))
   ?a<-(retrieve-path ?start ?finish ?when)
   (path chatter | talk | respective | landline | backwards
        ?finish ?start ?trail)
=>
   (retract ?a)
   (assert (comm-path-restoration-done ?start ?finish ?when))
   (assert (path backwards ?start ?finish
                 =(seq$ #L(reverse (list$ ?trail))))))


;;; SET UP VARIABLES FOR SEARCH (RESPECTIVE SYSTEMS)

(defrule get-new-path-respective
   (declare (salience 999600))
```

```
   (comm-path-restoration-required ?start ?finish ?phasenum)
   (not (comm-path-restoration-done ?start ?finish ?anytime))
   (retrieve-path ?start ?finish ?when)
=>
   (assert (accumulate-path respective ?start ?finish))
   (assert (expand-on =(seq$ #L(list ?start))))
   (assert (partials =(seq*$ #L(list (list ?start)))))
   (assert (collect-hold =(seq$ #L'()) )))


;;; COLLECT EXPANSIONS OF FIRST ELEMENT IN PARTIALS LIST (RESPECTIVE)

(defrule collect-expansions-respective
   (declare (salience 999990))
   (accumulate-path respective ?start ?finish)
   (expand-on ?takeoff)
   (successor chatter | talk | landline  ?start
             ?next&:(not #l(member ?next (list$ ?takeoff))))
   (not (used-link ?start ?next))
   ?x<-(collect-hold ?group)
=>
   (retract ?x)
   (assert (used-link ?start ?next))

   (assert (collect-hold
               =(seq*$ #L(append (list (append (list ?next)
                                               (list$ ?takeoff)))
                                          (list*$ ?group))))))


;;; ADD EXPANSIONS TO LIST OF PARTIAL PATHS (RESPECTIVE)

(defrule add-on-expansions-respective
   (declare (salience 999980))
   (accumulate-path respective ?start ?finish)
   ?x<-(partials ?queue)
   ?b<-(collect-hold ?additions)

 (case ( (test #L(equalp '() (list$ ?additions)))
         =>
         (retract ?b ?x)
         (assert (partials =(seq*$ #L(cdr (list*$ ?queue))))))

        (otherwise
         =>
         (retract ?x ?b)
         (assert (partials =(seq*$ #L(append (cdr (list*$ ?queue))
                                             (list*$ ?additions))))))))


;;; GET NEXT GROUP OF EXPANSIONS (RESPECTIVE)

(defrule get-next-start-respective
   (declare (salience 999975))
```

```
   ?c<-(accumulate-path respective ?start ?finish)
   ?z<-(expand-on ?what)
   (partials ?queue)
=>
   (retract ?c ?z)
   (assert (expand-on =(seq$ #L(car (list*$ ?queue)))))
   (assert (accumulate-path respective
           =#L(car (car (list*$ ?queue))) ?finish))
   (assert (collect-hold =(seq$ #L '()))))


;;; DESTINATION FOUND, PATH COMPLETE

(defrule found-destination-respective
   (declare (salience 999995))
   ?c<-(expand-on ?what)
   ?x<-(collect-hold ?group)
   ?y<-(accumulate-path respective ?start ?finish)
   (test #L(equalp (caar (list*$ ?group)) ?finish))
   ?a<-(retrieve-path ?begin ?end ?when)
=>
   (retract ?x ?y ?c ?a)
   (assert (clean-up links))
   (assert (comm-path-restoration-done
              =#L(car (reverse (car (list*$ ?group))))
                                          ?finish ?when))
   (assert (path respective
           =#L(car (reverse (car (list*$ ?group))))
           ?finish
           =(seq$ #L(reverse (car (list*$ ?group)))))))


;;; CLEAN UP USED-LINKS

(defrule search-cleaner-1
   (declare (salience 999998))
   (clean-up links)
   ?x<-(used-link ?node ?other)
=>
   (retract ?x))

(defrule search-cleaner-2
   (declare (salience 999997))
   ?x<-(clean-up links)
   ?y<-(partials ?somehow)
=>
   (retract ?x ?y))
```

```
;;; -*- Mode:Art; Package:au; Base:10. -*-


;;; FILE:  D:BAP;CHOOSEPLAN.ART

(defrule ask-which-plan-was-chosen-1
   (declare (salience 500))
=>
   (assert (count-plans 1))
   (printout t t "Choose from the following plans:" t t))


(defrule ask-about-the-plans
   (declare (salience 450))
   ?x<-(count-plans ?num)
   (viewpoint ?vp
      (restoration-finished ?vp)
      (not (number-when-presented ?any)))

=>
   (printout t t "For " ?vp " type # " ?num t t)
   (at ?root
      (retract ?x)
      (assert (count-plans =(?num + 1))))
   (at ?vp
      (assert (number-when-presented ?num))))


(defrule ask-which-number
   (declare (salience 400))
=>
   (printout t t "Type the number associated with the plan "
               t "you wish to adopt. " t t)
   (at ?root
    (assert (plan-was-chosen =(read)))))


(defrule implement-plan-now
   (declare (salience 250))
   (viewpoint ?root
     (plan-was-chosen ?num))
   (viewpoint ?vp
     (number-when-presented ?num))
=>
   (at ?vp
    (assert (believe-this-plan yes))))


(defrule now-believe
   (declare (salience 150))
   (believe-this-plan yes)
=>
   (believe ?root "Plan was chosen")
   (assert (clear-out junk)))


(defrule sweep-1
```

```
   (clear-out junk)
   ?x<-(column ?va)
   ?y<-(objective-values ?vb)
   ?z<-(critical-pair-count ?vc)
   ?a<-(critical-paths-out ?vd)
   ?b<-(all-paths-out ?ve)
   ?c<-(best ?vf)
   ?d<-(second-best ?vg)
   ?e<-(third-best ?vh)
=>
   (retract ?a ?b ?c ?d ?e ?x ?y ?z))


(defrule sweep-2
   (clear-out junk)
   ?a<-(give-priorities ?x)
=>
   (retract ?a))


(defrule sweep-3
   (clear-out junk)
   ?b<-(give-plans ?x)
=>
   (retract ?b))


(defrule sweep-4
   (clear-out junk)
   ?a<-(give-all-plans ?any)
=>
   (retract ?a))


(defrule sweep-5
   (clear-out junk)
   ?a<-(take-out-links ?x)
=>
   (retract ?a))


(defrule sweep-6
   (clear-out junk)
   ?a<-(phase ?any)
=>
   (retract ?a))


(defrule sweep-7
   (clear-out junk)
   ?a<-(theater ?x)
=>
  (retract ?a))


(defrule sweep-8
   (clear-out junk)
   ?a<-(conflict-areas ?seq)
=>
```

```
   (retract ?a))

(defrule sweep-9
   (clear-out junk)
   ?a<-(critical-pair ?x ?y)
=>
   (retract ?a))

(defrule sweep-10
   (clear-out junk)
   ?a<-(ttc-restoration-process ?phase ?any)
=>
   (retract ?a))

(defrule sweep-11
   (clear-out junk)
   ?a<-(bypass-calculation ?any)
=>
   (retract ?a))

(defrule sweep-12
   (clear-out junk)
   ?a<-(value-added ?val ?thing)
=>
   (retract ?a))

(defrule sweep-13
   (clear-out junk)
   ?a<-(data-restoration-process ?phase ?any)
=>
   (retract ?a))

(defrule sweep-14
   (clear-out junk)
   ?a<-(objective-function-value ?what ?phase)
=>
   (retract ?a))

(defrule sweep-15
   (clear-out junk)
   ?a<-(restoration-finished ?wher)
=>
   (retract ?a))

(defrule sweep-16
   (clear-out junk)
   ?a<-(needs-data-restoration ?sat ?when)
=>
   (retract ?a))

(defrule sweep-17
```

```
   (clear-out junk)
   ?a<-(ttc-restoration ?x ?y)
=>
  (retract ?a))


(defrule sweep-18
   (clear-out junk)
   ?a<-(comm-path-restoration-required ?f ?t ?w)
=>
   (retract ?a))


(defrule sweep-19
   (clear-out junk)
   ?a<-(comm-path-restoration-done ?f ?t ?w)
=>
   (retract ?a))


(defrule sweep-20
   (clear-out junk)
   ?a<-(check-to-free-data-terminal ?sat)
=>
   (retract ?a))


(defrule sweep-21
   (clear-out junk)
   ?a<-(priority ?x ?y)
=>
   (retract ?a))


(defrule sweep-22
   (clear-out junk)
   ?a<-(weight-global ?miss ?wt)
   ?b<-(weight-conflict ?miss ?any)
=>
   (retract ?a ?b))


(defrule sweep-23
   (clear-out junk)
   ?a<-(sub-global ?x ?y ?z)
=>
   (retract ?a))


(defrule sweep-24
   (clear-out junk)
   ?a<-(sub-conflict ?x ?y ?z)
=>
   (retract ?a))


(defrule sweep-25
   (clear-out junk)
   ?a<-(testcase ?x)
```

```
=>
   (retract ?a))

(defrule sweep-26
   (clear-out junk)
   ?a<-(number-when-presented ?x)
=>
   (retract ?a))

(defrule sweep-27
   (clear-out junk)
   ?a<-(can-get-data-down ?x ?y)
=>
   (retract ?a))

(defrule sweep-28
   (clear-out junk)
   ?a<-(path-was-printed ?x ?y)
=>
   (retract ?a))

(defrule sweep-29
   (clear-out junk)
   ?a<-(count-plans ?x)
=>
   (retract ?a))

(defrule sweep-30
   (clear-out junk)
   ?a<-(output-viewpoint ?x)
=>
   (retract ?a))

(defrule sweep-31
   (clear-out junk)
   ?a<-(prune ?x)
=>
   (retract ?a))

(defrule sweep-32
   (clear-out junk)
   ?a<-(conflict-weather-percent ?x)
   ?b<-(global-weather-percent ?y)
   ?c<-(conflict-navigation-percent ?z)
   ?d<-(global-navigation-percent ?u)
   ?e<-(conflict-comm-percent ?v)
   ?f<-(global-comm-percent ?w)
=>
   (retract ?a ?b ?c ?d ?e ?f))

(defrule sweep-33
   (clear-out junk)
   ?a<-(calculator objective-function)
   ?b<-(empty-list set)
```

```
=>
   (retract ?a ?b))

(defrule sweep-34
   (clear-out junk)
   ?a<-(partials ?sq)
=>
   (retract ?a))


(defrule now-reinitialize
   (declare (salience -500))
   ?x<-(clear-out junk)
=>
   (retract ?x)
   (assert
      (column 0)
      (objective-values ())
      (critical-pair-count 0)
      (critical-paths-out 0)
      (all-paths-out 0)
      (best 0)
      (second-best 0)
      (third-best 0)))


(defrule new-begin
   (declare (salience -1000))
=>
   (printout t t "The plan you have chosen has updated the data " t
         " base.  Assert another testcase with studio." t t))
```

Appendix D: Test Outputs

```
-------------------------------------------
     OUTPUT FOR LIMITED WAR SCENARIO
-------------------------------------------

BEST RESTORATION PLAN:


PLAN-4 Restoration plan has value 88.0411111

Communications Value: 75.2
Navigation Value:     8.04333334
Weather Value:        4.797777776

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.2999999998
                            Global:        0.830555556

Weather Percentages:        Conflict Area: 0.3333333333
                            Global:        0.861111111

Resources not operational and reason for red status:

Satellite THUNDER4   Reason: DESTROYED
Satellite PATHSAT18   Reason: POSSIBLE
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
Satellite PATHSATSPARE3   Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal RTS-GUAM   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-4 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Use SCOUTDIEGOGARCIA terminal for satellite SCOUTSATD TT&C servicing.
- - - - - - - - - - - - - - - - - - - -

* * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
------------------------------------
    OUTPUT FOR MAJOR WAR SCENARIO
------------------------------------

BEST RESTORATION PLAN:


PLAN-2 Restoration plan has value 87.6388889

Communications Value: 40.0
Navigation Value:     39.75
Weather Value:        7.888888888

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.7625
                            Global:        0.925

Weather Percentages:        Conflict Area: 0.75
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite TALKSATB   Reason: DESTROYED
Satellite SCOUTSATC   Reason: DESTROYED
Satellite PATHSAT11   Reason: POSSIBLE
Satellite PATHSAT10   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal THUNDERDIEGOGARCIA   Reason: DESTROYED
TT&C Terminal RTS-OAKHANGER   Reason: DESTROYED
Data Terminal CHATTERCRETE   Reason: DESTROYED

PLAN-2 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use THUNDERGUAM terminal for satellite THUNDER4 TT&C servicing.

New communications path from THULE-GREENLAND to CRETE-GREECE :
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from THULE-GREENLAND to DIEGO-GARCIA :
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA

New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
```

INDIAN-OCEAN

New communications path from THULE-GREENLAND to WOOMERA-AUSTRALIA :
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND

New communications path from WOOMERA-AUSTRALIA to THULE-GREENLAND :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND

New communications path from CRETE-GREECE to THULE-GREENLAND :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND

New communications path from DIEGO-GARCIA to THULE-GREENLAND :
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND

New communications path from WAHIAWI-HAWAII to CRETE-GREECE :
WAHIAWI-HAWAII
TALKWAHIAWI
TALKSATD
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

```
New communications path from SUNNYVALE to CRETE-GREECE :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from POINT-MUGU to CRETE-GREECE :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to CRETE-GREECE :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from NORFOLK-VIRGINIA to CRETE-GREECE :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from NORFOLK-VIRGINIA to INDIAN-OCEAN :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
```

```
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from CRETE-GREECE to INDIAN-OCEAN :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from CRETE-GREECE to WOOMERA-AUSTRALIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

New communications path from CRETE-GREECE to WAHIAWI-HAWAII :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
TALKSATD
TALKWAHIAWI
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from CRETE-GREECE to SUNNYVALE :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

New communications path from CRETE-GREECE to POINT-MUGU :
```

```
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from CRETE-GREECE to COLORADO-SPRINGS :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from CRETE-GREECE to NORFOLK-VIRGINIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to NORFOLK-VIRGINIA :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to CRETE-GREECE :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKCRETE
CRETE-GREECE
```

```
New communications path from WOOMERA-AUSTRALIA to CRETE-GREECE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

- - - - - - - - - - - - - - - - - - - -
```

Central War Scenario

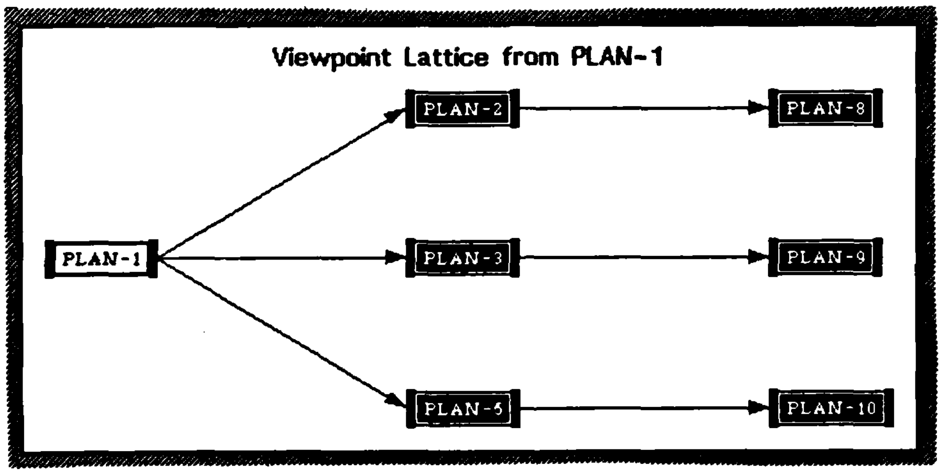


Figure D.1 Central War Viewpoint Structure

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    OUTPUT FOR  CENTRAL WAR SCENARIO
--------------------------------------


BEST RESTORATION PLAN:


PLAN-8 Restoration plan has value 97.53030306

Communications Value: 60.0
Navigation Value:     27.53030305
Weather Value:        10.0

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.9181818184
                            Global:        0.916666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        1.0

Resources not operational and reason for red status:

Satellite SCOUTSATC   Reason: DESTROYED
Satellite THUNDER2   Reason: DESTROYED
Satellite PATHSAT3   Reason: DESTROYED
Satellite PATHSAT10   Reason: POSSIBLE
Satellite CHATTER1   Reason: DESTROYED
Satellite PATHSATSPARE1   Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERASCENSION   Reason: UNKNOWN-ASSUMED-DESTROYED
TT&C Terminal CHATTERWAHIAWI   Reason: DESTROYED
TT&C Terminal CHATTERMUGU   Reason: DESTROYED
Data Terminal THUNDERASCENSION   Reason: NO-DATA-AVAIL
Data Terminal CHATTERWAHIAWI   Reason: DESTROYED
Data Terminal CHATTERMUGU   Reason: DESTROYED

PLAN-8 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use RTS-KAENA terminal for satellite CHATTER4 TT&C servicing.

New communications path from WAHIAWI-HAWAII to POINT-MUGU :
WAHIAWI-HAWAII
SUNNYVALE
POINT-MUGU

New communications path from WAHIAWI-HAWAII to NORFOLK-VIRGINIA :
WAHIAWI-HAWAII
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
```

```
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from POINT-MUGU to CRETE-GREECE :
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CRETE-GREECE

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to WOOMERA-AUSTRALIA :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from POINT-MUGU to KWAJELEIN-ISLAND :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKKWAJELEIN
KWAJELEIN-ISLAND

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
```

DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to WOOMERA-AUSTRALIA :
COLORADO-SPRINGS
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to WOOMERA-AUSTRALIA :
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to KWAJELEIN-ISLAND :
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKKWAJELEIN
KWAJELEIN-ISLAND

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from POINT-MUGU to WAHIAWI-HAWAII :
POINT-MUGU
SUNNYVALE
WAHIAWI-HAWAII

New communications path from NORFOLK-VIRGINIA to WAHIAWI-HAWAII :
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE

```
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

New communications path from CRETE-GREECE to POINT-MUGU :
CRETE-GREECE
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from WOOMERA-AUSTRALIA to POINT-MUGU :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from KWAJELEIN-ISLAND to POINT-MUGU :
KWAJELEIN-ISLAND
TALKKWAJELEIN
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
```

COLORADO-SPRINGS

New communications path from WOOMERA-AUSTRALIA to COLORADO-SPRINGS :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
COLORADO-SPRINGS

New communications path from WOOMERA-AUSTRALIA to NORFOLK-VIRGINIA :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA

New communications path from KWAJELEIN-ISLAND to NORFOLK-VIRGINIA :
KWAJELEIN-ISLAND
TALKKWAJELEIN
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA

New communications path from WAHIAWI-HAWAII to WOOMERA-AUSTRALIA :
WAHIAWI-HAWAII
TALKWAHIAWI
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from WOOMERA-AUSTRALIA to WAHIAWI-HAWAII :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKWAHIAWI
WAHIAWI-HAWAII

- -

* *

BEST RESTORATION PLAN:

PLAN-9 Restoration plan has value 97.53030306

```
Communications Value: 60.0
Navigation Value:     27.53030305
Weather Value:        10.0

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.9181818184
                            Global:        0.916666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        1.0

Resources not operational and reason for red status:

Satellite SCOUTSATC   Reason: DESTROYED
Satellite THUNDER2   Reason: DESTROYED
Satellite PATHSAT3   Reason: DESTROYED
Satellite PATHSAT10   Reason: POSSIBLE
Satellite CHATTER1   Reason: DESTROYED
Satellite PATHSATSPARE1   Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERASCENSION   Reason: UNKNOWN-ASSUMED-DESTROYED
TT&C Terminal CHATTERWAHIAWI   Reason: DESTROYED
TT&C Terminal CHATTERMUGU   Reason: DESTROYED
Data Terminal THUNDERASCENSION   Reason: NO-DATA-AVAIL
Data Terminal CHATTERWAHIAWI   Reason: DESTROYED
Data Terminal CHATTERMUGU   Reason: DESTROYED

PLAN-9 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use RTS-GUAM terminal for satellite CHATTER4 TT&C servicing.

New communications path from WAHIAWI-HAWAII to POINT-MUGU :
WAHIAWI-HAWAII
SUNNYVALE
POINT-MUGU

New communications path from WAHIAWI-HAWAII to NORFOLK-VIRGINIA :
WAHIAWI-HAWAII
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
```

LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from POINT-MUGU to CRETE-GREECE :
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CRETE-GREECE

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to WOOMERA-AUSTRALIA :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from POINT-MUGU to KWAJELEIN-ISLAND :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKKWAJELEIN
KWAJELEIN-ISLAND

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to WOOMERA-AUSTRALIA :
COLORADO-SPRINGS
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM

WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to WOOMERA-AUSTRALIA :
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to KWAJELEIN-ISLAND :
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKKWAJELEIN
KWAJELEIN-ISLAND

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from POINT-MUGU to WAHIAWI-HAWAII :
POINT-MUGU
SUNNYVALE
WAHIAWI-HAWAII

New communications path from NORFOLK-VIRGINIA to WAHIAWI-HAWAII :
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA

VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

New communications path from CRETE-GREECE to POINT-MUGU :
CRETE-GREECE
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from WOOMERA-AUSTRALIA to POINT-MUGU :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from KWAJELEIN-ISLAND to POINT-MUGU :
KWAJELEIN-ISLAND
TALKKWAJELEIN
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from WOOMERA-AUSTRALIA to COLORADO-SPRINGS :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
COLORADO-SPRINGS

New communications path from WOOMERA-AUSTRALIA to NORFOLK-VIRGINIA :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA

New communications path from KWAJELEIN-ISLAND to NORFOLK-VIRGINIA :
KWAJELEIN-ISLAND
TALKKWAJELEIN
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA

New communications path from WAHIAWI-HAWAII to WOOMERA-AUSTRALIA :
WAHIAWI-HAWAII
TALKWAHIAWI
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from WOOMERA-AUSTRALIA to WAHIAWI-HAWAII :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKWAHIAWI
WAHIAWI-HAWAII

- -

* *

BEST RESTORATION PLAN:

PLAN-10 Restoration plan has value 97.53030306

Communications Value: 60.0
Navigation Value: 27.53030305
Weather Value: 10.0

Communications Percentages: Conflict Area: 1.0
Global: 1.0

Navigation Percentages: Conflict Area: 0.9181818184
Global: 0.916666667

Weather Percentages: Conflict Area: 1.0
Global: 1.0

Resources not operational and reason for red status:

Satellite SCOUTSATC Reason: DESTROYED
Satellite THUNDER2 Reason: DESTROYED
Satellite PATHSAT3 Reason: DESTROYED
Satellite PATHSAT10 Reason: POSSIBLE
Satellite CHATTER1 Reason: DESTROYED
Satellite PATHSATSPARE1 Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERASCENSION Reason: UNKNOWN-ASSUMED-DESTROYED
TT&C Terminal CHATTERWAHIAWI Reason: DESTROYED
TT&C Terminal CHATTERMUGU Reason: DESTROYED
Data Terminal THUNDERASCENSION Reason: NO-DATA-AVAIL
Data Terminal CHATTERWAHIAWI Reason: DESTROYED
Data Terminal CHATTERMUGU Reason: DESTROYED

PLAN-10 Restoration Steps to Implement:
- -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use CHATTERWOOMERA terminal for satellite CHATTER4 TT&C servicing.

New communications path from WAHIAWI-HAWAII to POINT-MUGU :
WAHIAWI-HAWAII
SUNNYVALE
POINT-MUGU

New communications path from WAHIAWI-HAWAII to NORFOLK-VIRGINIA :
WAHIAWI-HAWAII
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

```
New communications path from POINT-MUGU to CRETE-GREECE :
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CRETE-GREEC

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to WOOMERA-AUSTRALIA :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from POINT-MUGU to KWAJELEIN-ISLAND :
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKKWAJELEIN
KWAJELEIN-ISLAND

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to WOOMERA-AUSTRALIA :
COLORADO-SPRINGS
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to WOOMERA-AUSTRALIA :
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from NORFOLK-VIRGINIA to KWAJELEIN-ISLAND :
```

NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKKWAJELEIN
KWAJELEIN-ISLAND

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from POINT-MUGU to WAHIAWI-HAWAII :
POINT-MUGU
SUNNYVALE
WAHIAWI-HAWAII

New communications path from NORFOLK-VIRGINIA to WAHIAWI-HAWAII :
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

New communications path from CRETE-GREECE to POINT-MUGU :

CRETE-GREECE
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from WOOMERA-AUSTRALIA to POINT-MUGU :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from KWAJELEIN-ISLAND to POINT-MUGU :
KWAJELEIN-ISLAND
TALKKWAJELEIN
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from WOOMERA-AUSTRALIA to COLORADO-SPRINGS :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
COLORADO-SPRINGS

New communications path from WOOMERA-AUSTRALIA to NORFOLK-VIRGINIA :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA

New communications path from KWAJELEIN-ISLAND to NORFOLK-VIRGINIA :
KWAJELEIN-ISLAND

```
TALKKWAJELEIN
TALKSATD
TALKSUNNYVALE
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA

New communications path from WAHIAWI-HAWAII to WOOMERA-AUSTRALIA :
WAHIAWI-HAWAII
TALKWAHIAWI
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from WOOMERA-AUSTRALIA to WAHIAWI-HAWAII :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKWAHIAWI
WAHIAWI-HAWAII

- - - - - - - - - - - - - - - - - - - - - - - - - -
```

Scenario for Test 2a

```
;;; ----- TEST 2A -----

(defrule start-scenario-special-two
   (declare (salience *maximum-salience*))
   (testcase special-two)
=>
(assert
   (get-priorities hurricane)
   (give-plans 2)
   (change-data-status stormOffutt red destroyed)
   (change-data-status stormLoring red destroyed)
   (change-ttc-status stormLoring red destroyed)
   (change-satellite-status Pathsat14 red destroyed)
   (change-ttc-status pathDiegoGarcia red destroyed)
   (theater Europe)
   (conflict-areas (14 15 16 17 18 19 20 21 22 23 24))))



;;; DEFAULT PRIORITIES (WEA-COMM-NAV)

(defrule default-priorities-weather-first
   (declare (salience *maximum-salience*))
   (get-priorities hurricane)
=>
   (assert
    (priority 1 weather)
    (priority 2 communications)
    (priority 3 navigation)
    (weight-global weather 10.0)
    (weight-conflict weather 60.0)
    (weight-global navigation 2.0)
    (weight-conflict navigation 12.0)
    (weight-global communications 11.0)
    (weight-conflict communications 5.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))
```

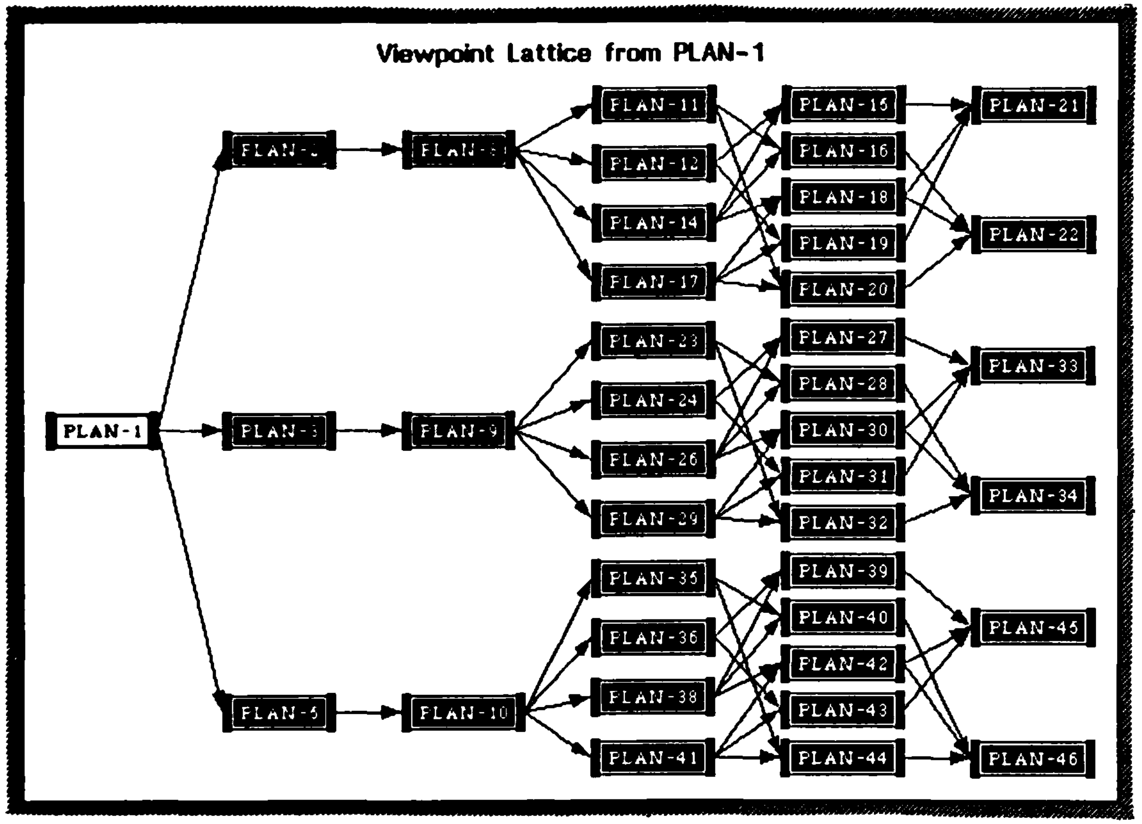


Figure D.2 Test 2a Viewpoint Structure

```
----------------------------
    OUTPUT FOR TEST 2A
----------------------------

BEST RESTORATION PLAN:


PLAN-46 Restoration plan has value 99.98333335

Communications Value: 16.0
Navigation Value:     13.983333334
Weather Value:        70.0

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 1.0
                            Global:        0.991666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        1.0

Resources not operational and reason for red status:

Satellite PATHSAT14   Reason: DESTROYED
TT&C Terminal PATHDIEGOGARCIA   Reason: DESTROYED
TT&C Terminal STORMLORING   Reason: DESTROYED
Data Terminal STORMLORING   Reason: DESTROYED
Data Terminal STORMOFFUTT   Reason: DESTROYED

PLAN-46 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use.
Put spare satellite PATHSATSPARE3 in use.
Use RTS-OAKHANGER terminal for satellite STORMATLANTIC TT&C servicing.
Use RTS-OAKHANGER terminal for satellite PATHSAT12 TT&C servicing.
Use RTS-INDIANOCEAN terminal for satellite PATHSAT13 TT&C servicing.
Use RTS-GUAM terminal for satellite PATHSAT15 TT&C servicing.
Terminal THUNDEROFFUTT will receive data
from satellite STORMATLANTIC and send data over to a
STORM data terminal via landline.
- - - - - - - - - - - - - - - - - - - -
```

* *

BEST RESTORATION PLAN:

PLAN-34 Restoration plan has value 99.98333335

```
Communications Value: 16.0
Navigation Value:     13.983333334
Weather Value:        70.0

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 1.0
                            Global:        0.991666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        1.0
```

Resources not operational and reason for red status:

Satellite PATHSAT14   Reason: DESTROYED
TT&C Terminal PATHDIEGOGARCIA   Reason: DESTROYED
TT&C Terminal STORMLORING   Reason: DESTROYED
Data Terminal STORMLORING   Reason: DESTROYED
Data Terminal STORMOFFUTT   Reason: DESTROYED

PLAN-34 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use.
Put spare satellite PATHSATSPARE3 in use.
Use RTS-THULE terminal for satellite STORMATLANTIC TT&C servicing.
Use RTS-OAKHANGER terminal for satellite PATHSAT12 TT&C servicing.
Use RTS-INDIANOCEAN terminal for satellite PATHSAT13 TT&C servicing.
Use RTS-GUAM terminal for satellite PATHSAT15 TT&C servicing.
Terminal THUNDEROFFUTT will receive data
from satellite STORMATLANTIC and send data over to a
STORM data terminal via landline.
- - - - - - - - - - - - - - - - - - - -

```
* * * * * * * * * * * * * * * * * * * * * * * * * * *


BEST RESTORATION PLAN:


PLAN-22 Restoration plan has value 99.98333335

Communications Value: 16.0
Navigation Value:     13.983333334
Weather Value:        70.0

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 1.0
                            Global:        0.991666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        1.0

Resources not operational and reason for red status:

Satellite PATHSAT14   Reason: DESTROYED
TT&C Terminal PATHDIEGOGARCIA   Reason: DESTROYED
TT&C Terminal STORMLORING   Reason: DESTROYED
Data Terminal STORMLORING   Reason: DESTROYED
Data Terminal STORMOFFUTT   Reason: DESTROYED

PLAN-22 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use.
Put spare satellite PATHSATSPARE3 in use.
Use RTS-NEWHAMP terminal for satellite STORMATLANTIC TT&C servicing.
Use RTS-OAKHANGER terminal for satellite PATHSAT12 TT&C servicing.
Use RTS-INDIANOCEAN terminal for satellite PATHSAT13 TT&C servicing.
Use RTS-GUAM terminal for satellite PATHSAT15 TT&C servicing.
Terminal THUNDEROFFUTT will receive data
from satellite STORMATLANTIC and send data over to a
STORM data terminal via landline.
- - - - - - - - - - - - - - - - - - - -

* * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Scenario for Test 4

```
;;; ----- TEST 4 -----

(defrule start-scenario-special-four
   (declare (salience *maximum-salience*))
   (testcase special-four)
=>
   (assert
    (get-priorities comm-wea-nav)
    (give-plans 3)
    (conflict-areas (17 18 19 20 21 22 23 24))
    (theater Europe)
    (change-ttc-status thunderAscension red destroyed)
    (change-ttc-status scoutAscension unknown  no-data-avail)
    (change-ttc-status scoutMugu red destroyed)
    (change-satellite-status scoutsatD red destroyed)
    (change-satellite-status pathsat10 red destroyed)
    (change-satellite-status thunder3 red destroyed)
    (change-satellite-status pathsat11 red destroyed)
    (groundlink-destroyed Indian-Ocean Diego-Garcia)
    (groundlink-destroyed Ascension-Island Crete-Greece)))



;;; DEFAULT PRIORITIES (COMM-WEA-NAV)

(defrule default-priorities-comm-weather-nav
   (declare (salience *maximum-salience*))
   (get-priorities comm-wea-nav)
=>
   (assert
    (priority 2 weather)
    (priority 3 navigation)
    (priority 1 communications)
    (weight-global weather 20.0)
    (weight-conflict weather 10.0)
    (weight-global navigation 5.0)
    (weight-conflict navigation 10.0)
    (weight-global communications 30.0)
    (weight-conflict communications 25.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))
```

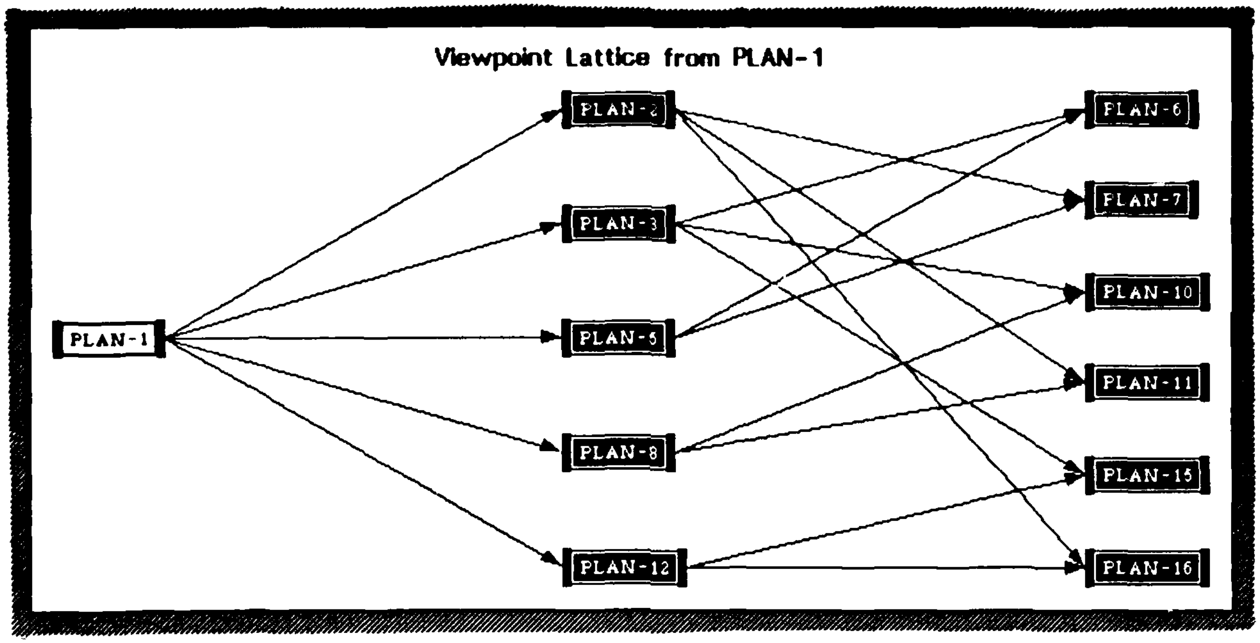
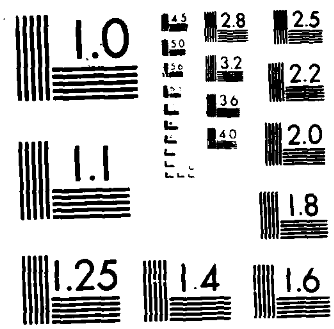


Figure D.3 Test 4 Viewpoint Structure

AD-A179 336 A PROTOTYPE KNOWLEDGE-BASED SYSTEM TO AID SPACE SYSTEM 4/4
RESTORATION MANAGEMENT(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI B A PHILLIPS
UNCLASSIFIED DEC 86 AFIT/GOR/OS/86-12 F/G 22/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

```
--------------------------------
     OUTPUT FOR TEST 4
--------------------------------

BEST RESTORATION PLAN:


PLAN-15 Restoration plan has value 94.9305556

Communications Value: 55.0
Navigation Value:     13.541666664
Weather Value:        26.3888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8875
                            Global:        0.933333333

Weather Percentages:        Conflict Area: 0.75
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED

PLAN-15 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWOOMERA terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTPROSPECTHARBOR terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
```

OUTPUT FOR TEST 4

BEST RESTORATION PLAN:

PLAN-15 Restoration plan has value 94.9305556

```
Communications Value: 55.0
Navigation Value:     13.541666664
Weather Value:        26.3888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8875
                            Global:        0.933333333

Weather Percentages:        Conflict Area: 0.75
                            Global:        0.9444444445
```

Resources not operational and reason for red status:

```
Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
```

PLAN-15 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWOOMERA terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTPROSPECTHARBOR terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK

THULE-GREENLAND

New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

- - - - - - - - - - - - - - - - - - - -

* *

BEST RESTORATION PLAN:

PLAN-16 Restoration plan has value 94.9305556

Communications Value: 55.0
Navigation Value: 13.541666664
Weather Value: 26.3888889

Communications Percentages: Conflict Area: 1.0
Global: 1.0

Navigation Percentages: Conflict Area: 0.8875
Global: 0.933333333

Weather Percentages: Conflict Area: 0.75
Global: 0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED
Satellite PATHSAT10 Reason: DESTROYED
Satellite SCOUTSATD Reason: DESTROYED
TT&C Terminal SCOUTMUGU Reason: DESTROYED
TT&C Terminal THUNDERASCENSION Reason: DESTROYED

PLAN-16 Restoration Steps to Implement:

- -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWAHIAWI terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTPROSPECTHARBOR terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND

New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

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* *

BEST RESTORATION PLAN:

PLAN-10 Restoration plan has value 94.9305556

```
Communications Value: 55.0
Navigation Value:     13.541666664
Weather Value:        26.3888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8875
                            Global:        0.933333333

Weather Percentages:        Conflict Area: 0.75
                            Global:        0.9444444445
```

Resources not operational and reason for red status:

```
Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
```

PLAN-10 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWOOMERA terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTASCENSION terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND

```
New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA


- - - - - - - - - - - - - - - - - - - - -


* * * * * * * * * * * * * * * * * * * * * * * * * * * *


BEST RESTORATION PLAN:


PLAN-6 Restoration plan has value 94.9305556

Communications Value: 55.0
Navigation Value:     13.541666664
Weather Value:        26.3888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8875
                            Global:        0.933333333

Weather Percentages:        Conflict Area: 0.75
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
```

PLAN-6 Restoration Steps to Implement:

\- -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWOOMERA terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTROSEMOUNT terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND

New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

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* *

BEST RESTORATION PLAN:

PLAN-11 Restoration plan has value 94.9305556

Communications Value: 55.0
Navigation Value: 13.541666664
Weather Value: 26.3888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.8875
	Global:	0.933333333
Weather Percentages:	Conflict Area:	0.75
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED
Satellite PATHSAT10 Reason: DESTROYED
Satellite SCOUTSATD Reason: DESTROYED
TT&C Terminal SCOUTMUGU Reason: DESTROYED
TT&C Terminal THUNDERASCENSION Reason: DESTROYED

PLAN-11 Restoration Steps to Implement:
- -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWAHIAWI terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTASCENSION terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND

```
New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA


- - - - - - - - - - - - - - - - - - - -


* * * * * * * * * * * * * * * * * * * * * * * * * * *


BEST RESTORATION PLAN:


PLAN-7 Restoration plan has value 94.9305556

Communications Value: 55.0
Navigation Value:     13.541666664
Weather Value:        26.3888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8875
                            Global:        0.933333333

Weather Percentages:        Conflict Area: 0.75
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED

PLAN-7 Restoration Steps to Implement:
```

- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWAHIAWI terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTROSEMOUNT terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND

New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

- - - - - - - - - - - - - - - - - - - -

Scenario for Test 7

```
;;; ----- TEST 7 -----

(defrule start-scenario-special-seven
  (declare (salience *maximum-salience*))

  (testcase special-seven)
=>
  (assert
    (get-priorities wea-nav-comm)
    (theater Pacific)
    (theater FarEast)
    (conflict-areas (1 2 3 4 5 24 25 26 27 28
                    29 30 31 32 33 34 35 36))
    (give-plans 3)
    (change-ttc-status chatterWoomera red destroyed)
    (change-ttc-status rts-IndianOcean red destroyed)
    (change-data-status chatterSunnyvale red destroyed)
    (change-data-status thunderAscension red destroyed)
    (change-ttc-status thunderDiegoGarcia red destroyed)
    (change-data-status thunderDiegoGarcia red destroyed)
    (change-satellite-status pathsat14 red destroyed)))



;;; DEFAULT PRIORITIES (WEA-NAV-COMM)

(defrule default-priorities-weather-nav-comm
   (declare (salience *maximum-salience*))
   (get-priorities wea-nav-comm)
=>
   (assert
    (priority 1 weather)
    (priority 2 navigation)
    (priority 3 communications)
    (weight-global weather 20.0)
    (weight-conflict weather 30.0)
    (weight-global navigation 15.0)
    (weight-conflict navigation 15.0)
    (weight-global communications 15.0)
    (weight-conflict communications 5.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))
```

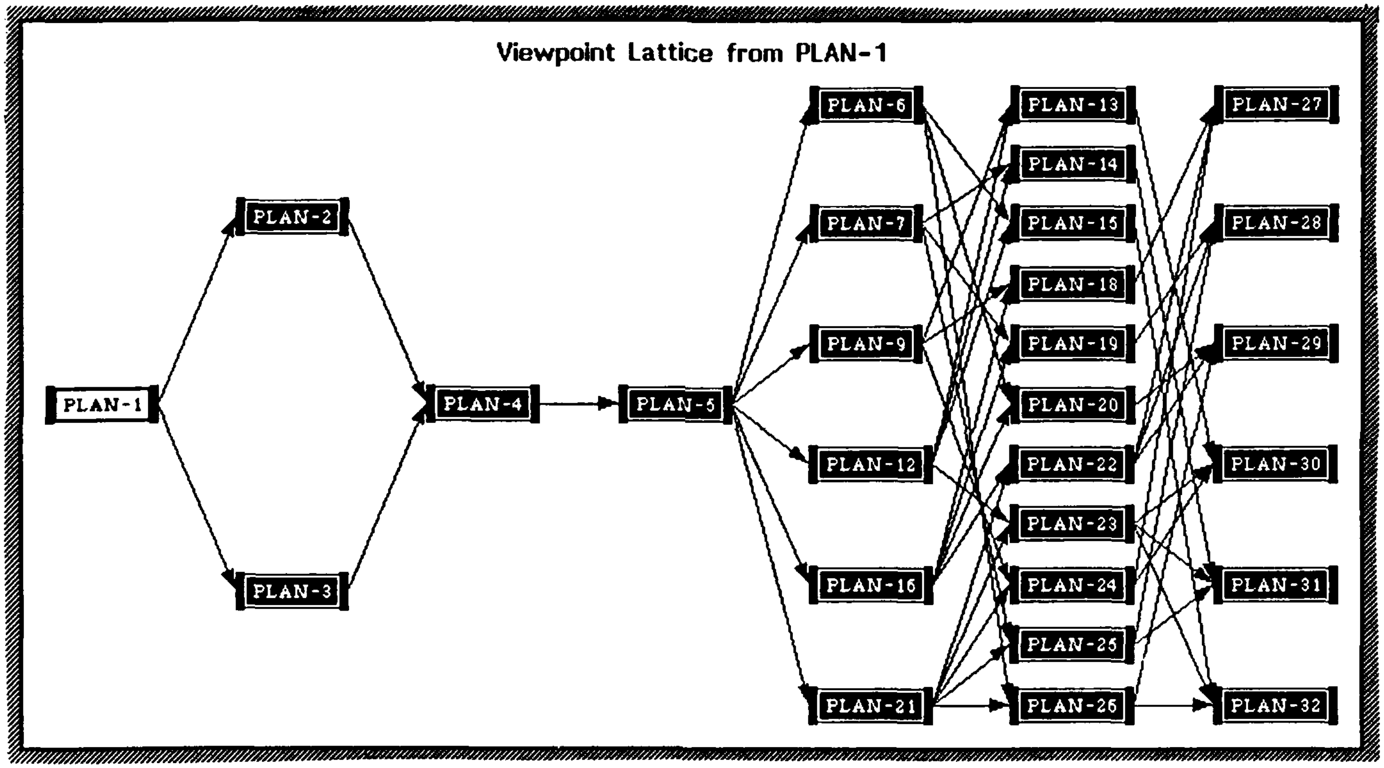

Figure D.4 Test 7 Viewpoint Structure

TEST 7

BEST RESTORATION PLAN:

PLAN-32 Restoration plan has value 98.5138889

Communications Value: 20.0
Navigation Value: 29.625
Weather Value: 48.8888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.9833333334
	Global:	0.991666667
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT14 Reason: DESTROYED
Satellite THUNDER3 Reason: NO-DATA-DOWN-CAPABILITY
Satellite CHATTER3 Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERDIEGOGARCIA Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN Reason: DESTROYED
TT&C Terminal CHATTERWOOMERA Reason: DESTROYED
Data Terminal THUNDERDIEGOGARCIA Reason: DESTROYED
Data Terminal THUNDERASCENSION Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE Reason: DESTROYED

PLAN-32 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use THUNDERASCENSION terminal for satellite THUNDER3 TT&C servicing.
Use THUNDERGUAM terminal for satellite THUNDER4 TT&C servicing.
Use STORMLORING terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
WAHIAWI-HAWAII
CHATTERWAHIAWI

CHATTER4
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER4
CHATTERWAHIAWI
WAHIAWI-HAWAII
SUNNYVALE

New communications path from KWAJELEIN-ISLAND to INDIAN-OCEAN :
KWAJELEIN-ISLAND
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to INDIAN-OCEAN :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to CRETE-GREECE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from INDIAN-OCEAN to CRETE-GREECE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE

New communications path from INDIAN-OCEAN to NORFOLK-VIRGINIA :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA

NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to KWAJELEIN-ISLAND :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM

KWAJELEIN-ISLAND

New communications path from INDIAN-OCEAN to WOOMERA-AUSTRALIA :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to WOOMERA-AUSTRALIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to INDIAN-OCEAN :
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from NORFOLK-VIRGINIA to INDIAN-OCEAN :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

- - - - - - - - - - - - - - - - - - - -

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BEST RESTORATION PLAN:

PLAN-27 Restoration plan has value 98.5138889

```
Communications Value: 20.0
Navigation Value:     29.625
Weather Value:        48.8888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.9833333334
                            Global:        0.991666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        0.9444444445
```

Resources not operational and reason for red status:

```
Satellite PATHSAT14   Reason: DESTROYED
Satellite THUNDER3   Reason: NO-DATA-DOWN-CAPABILITY
Satellite CHATTER3   Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERDIEGOGARCIA   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal CHATTERWOOMERA   Reason: DESTROYED
Data Terminal THUNDERDIEGOGARCIA   Reason: DESTROYED
Data Terminal THUNDERASCENSION   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
```

PLAN-27 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use THUNDERASCENSION terminal for satellite THUNDER3 TT&C servicing.
Use THUNDERGUAM terminal for satellite THUNDER4 TT&C servicing.
Use RTS-OAKHANGER terminal for satellite TALKSATB TT&C servicing.
Use RTS-GUAM terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :

SUNNYVALE
WAHIAWI-HAWAII
CHATTERWAHIAWI
CHATTER4
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER4
CHATTERWAHIAWI
WAHIAWI-HAWAII
SUNNYVALE

New communications path from KWAJELEIN-ISLAND to INDIAN-OCEAN :
KWAJELEIN-ISLAND
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to INDIAN-OCEAN :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to CRETE-GREECE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from INDIAN-OCEAN to CRETE-GREECE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE

New communications path from INDIAN-OCEAN to NORFOLK-VIRGINIA :
INDIAN-OCEAN

DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to KWAJELEIN-ISLAND :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA

TALKSATC
TALKGUAM
GUAM
KWAJELEIN-ISLAND

New communications path from INDIAN-OCEAN to WOOMERA-AUSTRALIA :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to WOOMERA-AUSTRALIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to INDIAN-OCEAN :
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from NORFOLK-VIRGINIA to INDIAN-OCEAN :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

INDIAN-OCEAN

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BEST RESTORATION PLAN:

PLAN-28 Restoration plan has value 98.5138889

Communications Value: 20.0
Navigation Value: 29.625
Weather Value: 48.8888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.9833333334
	Global:	0.991666667
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT14 Reason: DESTROYED
Satellite THUNDER3 Reason: NO-DATA-DOWN-CAPABILITY
Satellite CHATTER3 Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERDIEGOGARCIA Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN Reason: DESTROYED
TT&C Terminal CHATTERWOOMERA Reason: DESTROYED
Data Terminal THUNDERDIEGOGARCIA Reason: DESTROYED
Data Terminal THUNDERASCENSION Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE Reason: DESTROYED

PLAN-28 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use THUNDERASCENSION terminal for satellite THUNDER3 TT&C servicing.
Use THUNDERGUAM terminal for satellite THUNDER4 TT&C servicing.
Use RTS-THULE terminal for satellite TALKSATB TT&C servicing.
Use RTS-GUAM terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
WAHIAWI-HAWAII
CHATTERWAHIAWI
CHATTER4
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER4
CHATTERWAHIAWI
WAHIAWI-HAWAII
SUNNYVALE

New communications path from KWAJELEIN-ISLAND to INDIAN-OCEAN :
KWAJELEIN-ISLAND
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to INDIAN-OCEAN :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to CRETE-GREECE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from INDIAN-OCEAN to CRETE-GREECE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE

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New communications path from INDIAN-OCEAN to NORFOLK-VIRGINIA :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to KWAJELEIN-ISLAND :
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INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
KWAJELEIN-ISLAND

New communications path from INDIAN-OCEAN to WOOMERA-AUSTRALIA :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to WOOMERA-AUSTRALIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to INDIAN-OCEAN :
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from NORFOLK-VIRGINIA to INDIAN-OCEAN :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
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OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

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BEST RESTORATION PLAN:

PLAN-30 Restoration plan has value 98.5138889

Communications Value: 20.0
Navigation Value:     29.625
Weather Value:        48.8888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.9833333334
                            Global:        0.991666667

Weather Percentages:        Conflict Area: 1.0
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT14   Reason: DESTROYED
Satellite THUNDER3   Reason: NO-DATA-DOWN-CAPABILITY
Satellite CHATTER3   Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERDIEGOGARCIA   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal CHATTERWOOMERA   Reason: DESTROYED
Data Terminal THUNDERDIEGOGARCIA   Reason: DESTROYED
Data Terminal THUNDERASCENSION   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED

PLAN-30 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use THUNDERASCENSION terminal for satellite THUNDER3 TT&C servicing.
Use THUNDERGUAM terminal for satellite THUNDER4 TT&C servicing.
Use RTS-OAKHANGER terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
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OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
WAHIAWI-HAWAII
CHATTERWAHIAWI
CHATTER4
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER4
CHATTERWAHIAWI
WAHIAWI-HAWAII
SUNNYVALE

New communications path from KWAJELEIN-ISLAND to INDIAN-OCEAN :
KWAJELEIN-ISLAND
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to INDIAN-OCEAN :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to CRETE-GREECE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE

New communications path from INDIAN-OCEAN to CRETE-GREECE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
```

THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE

New communications path from INDIAN-OCEAN to NORFOLK-VIRGINIA :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE

DIEGO-GARCIA

New communications path from INDIAN-OCEAN to KWAJELEIN-ISLAND :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
KWAJELEIN-ISLAND

New communications path from INDIAN-OCEAN to WOOMERA-AUSTRALIA :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to WOOMERA-AUSTRALIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to INDIAN-OCEAN :
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from NORFOLK-VIRGINIA to INDIAN-OCEAN :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

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BEST RESTORATION PLAN:

PLAN-31 Restoration plan has value 98.5138889

Communications Value: 20.0
Navigation Value: 29.625
Weather Value: 48.8888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.9833333334
	Global:	0.991666667
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT14 Reason: DESTROYED
Satellite THUNDER3 Reason: NO-DATA-DOWN-CAPABILITY
Satellite CHATTER3 Reason: NO-TTC-AVAILABLE
TT&C Terminal THUNDERDIEGOGARCIA Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN Reason: DESTROYED
TT&C Terminal CHATTERWOOMERA Reason: DESTROYED
Data Terminal THUNDERDIEGOGARCIA Reason: DESTROYED
Data Terminal THUNDERASCENSION Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE Reason: DESTROYED

PLAN-31 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use THUNDERASCENSION terminal for satellite THUNDER3 TT&C servicing.
Use THUNDERGUAM terminal for satellite THUNDER4 TT&C servicing.
Use RTS-THULE terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

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New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
WAHIAWI-HAWAII
CHATTERWAHIAWI
CHATTER4
CHATTERWOOMERA
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
CHATTERWOOMERA
CHATTER4
CHATTERWAHIAWI
WAHIAWI-HAWAII
SUNNYVALE

New communications path from KWAJELEIN-ISLAND to INDIAN-OCEAN :
KWAJELEIN-ISLAND
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to INDIAN-OCEAN :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKDIEGOGARCIA
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WOOMERA-AUSTRALIA to CRETE-GREECE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATC
TALKCRETE
CRETE-GREECE
```

New communications path from INDIAN-OCEAN to CRETE-GREECE :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE

New communications path from INDIAN-OCEAN to NORFOLK-VIRGINIA :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from INDIAN-OCEAN to COLORADO-SPRINGS :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
COLORADO-SPRINGS

New communications path from INDIAN-OCEAN to POINT-MUGU :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from INDIAN-OCEAN to WAHIAWI-HAWAII :
INDIAN-OCEAN
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
VANDENBERG
SUNNYVALE
WAHIAWI-HAWAII

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
OFFUTT-NEBRASKA
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from POINT-MUGU to DIEGO-GARCIA :

```
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to KWAJELEIN-ISLAND :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
KWAJELEIN-ISLAND

New communications path from INDIAN-OCEAN to WOOMERA-AUSTRALIA :
INDIAN-OCEAN
DIEGO-GARCIA
TALKDIEGOGARCIA
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to WOOMERA-AUSTRALIA :
CRETE-GREECE
TALKCRETE
TALKSATC
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from CRETE-GREECE to INDIAN-OCEAN :
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from NORFOLK-VIRGINIA to INDIAN-OCEAN :
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from COLORADO-SPRINGS to INDIAN-OCEAN :
COLORADO-SPRINGS
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

New communications path from POINT-MUGU to INDIAN-OCEAN :
POINT-MUGU
NORFOLK-VIRGINIA
OFFUTT-NEBRASKA
LORING-MAINE
```

DIEGO-GARCIA
INDIAN-OCEAN

New communications path from WAHIAWI-HAWAII to INDIAN-OCEAN :
WAHIAWI-HAWAII
SUNNYVALE
VANDENBERG
OFFUTT-NEBRASKA
LORING-MAINE
DIEGO-GARCIA
INDIAN-OCEAN

\- -

Scenario for Test 8

```
;;; ------ TEST 8 -----

;;;   (CONSISTED OF RUNNING TEST 4,
;;;   SELECTING A PLAN, AND THEN RUNNING TEST 5)


;;; ----- TEST 5 -----

(defrule start-scenario-special-five
   (declare (salience *maximum-salience*))
   (testcase special-five)
=>
   (assert
    (get-priorities major)
    (give-plans 3)
    (conflict-areas (30 31 32 33 34 35 36 1 2 3 4 5 6 7))
    (theater FarEast)
    (theater Pacific)
    (change-ttc-status thunderGuam red destroyed)
    (change-ttc-status scoutWoomera red destroyed)
    (change-ttc-status rts-IndianOcean red destroyed)
    (change-data-status thunderGuam red destroyed)
    (change-data-status chatterSunnyvale red destroyed)
    (change-satellite-status pathsat16 red destroyed)
    (change-satellite-status pathsat17 red destroyed)
    (groundlink-destroyed Wahiawi-Hawaii Sunnyvale)))


;;; DEFAULT PRIORITIES FOR MAJOR WAR  (NAV-COMM-WEA)

(defrule default-priorities-major
   (declare (salience *maximum-salience*))
   (get-priorities major)
=>
   (assert
    (priority 1 navigation)
    (priority 2 communications)
    (priority 3 weather)
    (weight-global weather 2.0)
    (weight-conflict weather 8.0)
    (weight-global navigation 10.0)
    (weight-conflict navigation 40.0)
    (weight-global communications 15.0)
    (weight-conflict communications 25.0)
    (sub-global scout 1 0.3)
    (sub-global path 3 0.4)
    (sub-global path 4 0.3)
    (sub-conflict scout 1 0.2)
    (sub-conflict path 3 0.5)
    (sub-conflict path 4 0.3)))
```

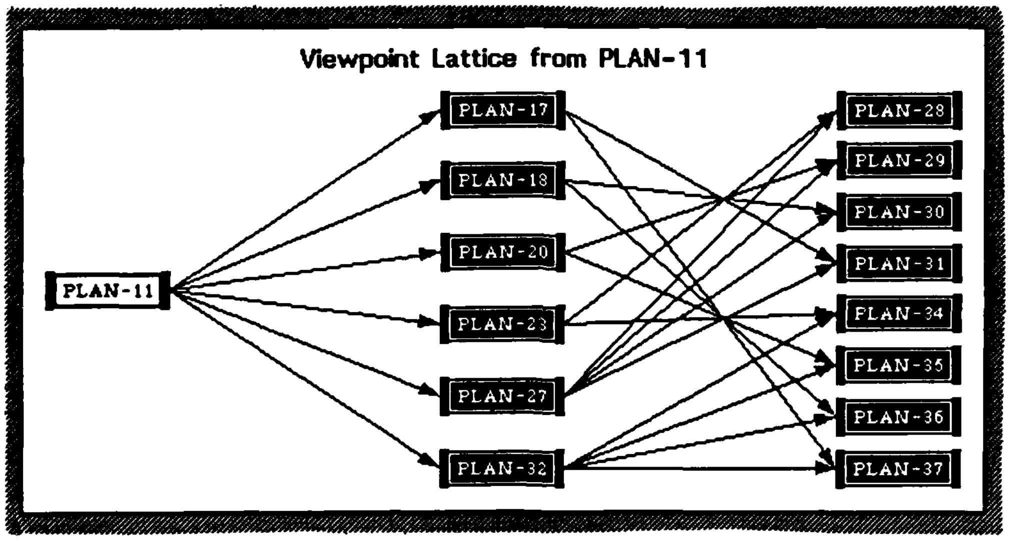

Figure D.5 Test 8 Viewpoint Structure

TEST 8: SPECIAL-FOUR FOLLOWED BY SPECIAL-FIVE

NOTE: PLAN-11 FROM TEST 4 WAS CHOSEN AS THE PLAN TO ADOPT

BEST RESTORATION PLAN:

PLAN-11 Restoration plan has value 94.9305556

Communications Value: 55.0
Navigation Value: 13.541666664
Weather Value: 26.3888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.8875
	Global:	0.933333333
Weather Percentages:	Conflict Area:	0.75
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED
Satellite PATHSAT10 Reason: DESTROYED
Satellite SCOUTSATD Reason: DESTROYED
TT&C Terminal SCOUTMUGU Reason: DESTROYED
TT&C Terminal THUNDERASCENSION Reason: DESTROYED

PLAN-11 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Use SCOUTWAHIAWI terminal for satellite SCOUTSATA TT&C servicing.
Use SCOUTASCENSION terminal for satellite SCOUTSATB TT&C servicing.

New communications path from POINT-MUGU to DIEGO-GARCIA :
POINT-MUGU
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from NORFOLK-VIRGINIA to DIEGO-GARCIA :
NORFOLK-VIRGINIA
PROSPECT-HARBOR-MAINE
LORING-MAINE
DIEGO-GARCIA

New communications path from INDIAN-OCEAN to THULE-GREENLAND :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CRETE-GREECE
OAKHANGER-UK
THULE-GREENLAND

New communications path from THULE-GREENLAND to INDIAN-OCEAN :
THULE-GREENLAND
OAKHANGER-UK
CRETE-GREECE
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from DIEGO-GARCIA to POINT-MUGU :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA
POINT-MUGU

New communications path from DIEGO-GARCIA to NORFOLK-VIRGINIA :
DIEGO-GARCIA
LORING-MAINE
PROSPECT-HARBOR-MAINE
NORFOLK-VIRGINIA

- -

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Choose from the following plans:

For PLAN-15 type # 1

For PLAN-16 type # 2

For PLAN-10 type # 3

For PLAN-6 type # 4

```
For PLAN-11 type # 5

For PLAN-7 type # 6

Type the number associated with the plan
you wish to adopt.

5

The plan you have chosen has updated the data
 base.  Assert another testcase with studio.

No applicable rules.
 => assert
Enter a fact: (TESTCASE SPECIAL-FIVE)

 => pop
 => pop
 => run


BEST RESTORATION PLAN:


PLAN-31 Restoration plan has value 94.3174603

Communications Value: 40.0
Navigation Value:     44.42857143
Weather Value:        9.88888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8857142855
                            Global:        0.9

Weather Percentages:        Conflict Area: 1.0
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-31 Restoration Steps to Implement:
```

- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use STORMLORING terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

- - - - - - - - - - - - - - - - - - - -

* *

BEST RESTORATION PLAN:

```
PLAN-30 Restoration plan has value 94.3174603

Communications Value: 40.0
Navigation Value:     44.42857143
Weather Value:        9.88888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8857142855
                            Global:        0.9

Weather Percentages:        Conflict Area: 1.0
                            Global:        0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-30 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use RTS-THULE terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA
```

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

- - - - - - - - - - - - - - - - - - - -

* *

BEST RESTORATION PLAN:

PLAN-29 Restoration plan has value 94.3174603

Communications Value: 40.0
Navigation Value: 44.42857143
Weather Value: 9.88888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.8857142855
	Global:	0.9
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED
Satellite PATHSAT10 Reason: DESTROYED
Satellite SCOUTSATD Reason: DESTROYED
Satellite PATHSAT17 Reason: DESTROYED
Satellite PATHSAT16 Reason: DESTROYED
TT&C Terminal SCOUTMUGU Reason: DESTROYED
TT&C Terminal THUNDERASCENSION Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA Reason: DESTROYED

TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-29 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use PATHASCENSION terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

- - - - - - - - - - - - - - - - - - - -

* *

BEST RESTORATION PLAN:

PLAN-28 Restoration plan has value 94.3174603

Communications Value: 40.0
Navigation Value: 44.42857143
Weather Value: 9.88888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.8857142855
	Global:	0.9
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED
Satellite PATHSAT10 Reason: DESTROYED
Satellite SCOUTSATD Reason: DESTROYED
Satellite PATHSAT17 Reason: DESTROYED
Satellite PATHSAT16 Reason: DESTROYED
TT&C Terminal SCOUTMUGU Reason: DESTROYED
TT&C Terminal THUNDERASCENSION Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA Reason: DESTROYED
TT&C Terminal THUNDERGUAM Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE Reason: DESTROYED
Data Terminal THUNDERGUAM Reason: DESTROYED

PLAN-28 Restoration Steps to Implement:
- -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use RTS-OAKHANGER terminal for satellite TALKSATB TT&C servicing.
Use PATHDIEGOGARCIA terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE

TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

- -

* *

BEST RESTORATION PLAN:

PLAN-37 Restoration plan has value 94.3174603

Communications Value: 40.0
Navigation Value: 44.42857143
Weather Value: 9.88888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.8857142855
	Global:	0.9
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED
Satellite PATHSAT10 Reason: DESTROYED
Satellite SCOUTSATD Reason: DESTROYED
Satellite PATHSAT17 Reason: DESTROYED

```
Satellite PATHSAT16   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-37 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use STORMLORING terminal for satellite TALKSATB TT&C servicing.
Use RTS-GUAM terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

- - - - - - - - - - - - - - - - - - - -
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BEST RESTORATION PLAN:

PLAN-36 Restoration plan has value 94.3174603

```
Communications Value: 40.0
Navigation Value:     44.42857143
Weather Value:        9.88888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8857142855
                            Global:        0.9

Weather Percentages:        Conflict Area: 1.0
                            Global:        0.9444444445
```

Resources not operational and reason for red status:

```
Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED
```

PLAN-36 Restoration Steps to Implement:
- -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use RTS-THULE terminal for satellite TALKSATB TT&C servicing.
Use RTS-GUAM terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3

CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

- -

* *

BEST RESTORATION PLAN:

PLAN-35 Restoration plan has value 94.3174603

Communications Value: 40.0
Navigation Value: 44.42857143
Weather Value: 9.88888889

Communications Percentages:	Conflict Area:	1.0
	Global:	1.0
Navigation Percentages:	Conflict Area:	0.8857142855
	Global:	0.9
Weather Percentages:	Conflict Area:	1.0
	Global:	0.9444444445

Resources not operational and reason for red status:

Satellite PATHSAT11 Reason: DESTROYED
Satellite THUNDER3 Reason: DESTROYED

```
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED

PLAN-35 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use PATHASCENSION terminal for satellite TALKSATB TT&C servicing.
Use RTS-GUAM terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE
```

- - - - - - - - - - - - - - - - - - - -

* *

BEST RESTORATION PLAN:

PLAN-34 Restoration plan has value 94.3174603

```
Communications Value: 40.0
Navigation Value:     44.42857143
Weather Value:        9.88888889

Communications Percentages: Conflict Area: 1.0
                            Global:        1.0

Navigation Percentages:     Conflict Area: 0.8857142855
                            Global:        0.9

Weather Percentages:        Conflict Area: 1.0
                            Global:        0.9444444445
```

Resources not operational and reason for red status:

```
Satellite PATHSAT11   Reason: DESTROYED
Satellite THUNDER3   Reason: DESTROYED
Satellite PATHSAT10   Reason: DESTROYED
Satellite SCOUTSATD   Reason: DESTROYED
Satellite PATHSAT17   Reason: DESTROYED
Satellite PATHSAT16   Reason: DESTROYED
TT&C Terminal SCOUTMUGU   Reason: DESTROYED
TT&C Terminal THUNDERASCENSION   Reason: DESTROYED
TT&C Terminal RTS-INDIANOCEAN   Reason: DESTROYED
TT&C Terminal SCOUTWOOMERA   Reason: DESTROYED
TT&C Terminal THUNDERGUAM   Reason: DESTROYED
Data Terminal CHATTERSUNNYVALE   Reason: DESTROYED
Data Terminal THUNDERGUAM   Reason: DESTROYED
```

PLAN-34 Restoration Steps to Implement:
- - - - - - - - - - - - - - - - - - - -

Put spare satellite PATHSATSPARE2 in use
and use PATHASCENSION for TT&C servicing.
Put spare satellite PATHSATSPARE3 in use
and use RTS-GUAM for TT&C servicing.
Use RTS-OAKHANGER terminal for satellite TALKSATB TT&C servicing.
Use RTS-GUAM terminal for satellite TALKSATC TT&C servicing.

New communications path from SUNNYVALE to INDIAN-OCEAN :
SUNNYVALE
POINT-MUGU
NORFOLK-VIRGINIA
CHATTERNORFOLK

```
CHATTER2
CHATTERCRETE
CHATTER3
CHATTERINDIANOCEAN
INDIAN-OCEAN

New communications path from SUNNYVALE to WOOMERA-AUSTRALIA :
SUNNYVALE
TALKSUNNYVALE
TALKSATD
TALKGUAM
GUAM
WOOMERA-AUSTRALIA

New communications path from INDIAN-OCEAN to SUNNYVALE :
INDIAN-OCEAN
CHATTERINDIANOCEAN
CHATTER3
CHATTERCRETE
CHATTER2
CHATTERNORFOLK
NORFOLK-VIRGINIA
POINT-MUGU
SUNNYVALE

New communications path from WOOMERA-AUSTRALIA to SUNNYVALE :
WOOMERA-AUSTRALIA
GUAM
TALKGUAM
TALKSATD
TALKSUNNYVALE
SUNNYVALE

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Bibliography

1. Andriole, Stephen J. "Artificial Intelligence and National Defense: An Agenda and a Prognosis," Applications in Artificial Intelligence, edited by Stephen J. Andriole. Princeton NJ: Petrocelli Books, Inc., 1985.

2. Benoit, J. W. and others. KBS: An Expert Planning System for Crisis Response. RADC-TR-82-217. MITRE Corporation, McLean, VA, August 1982 (AD-A121-445).

3. Bond, Fred E. "Future Trends in Commercial and Military Systems," Proceedings of the IEEE Conference on Communications, 2. 882-887. IEEE Press, New York, 1983.

4. Bonissone, Piero P. and Richard M. Tong. "Editorial: Reasoning With Uncertainty in Expert Systems," International Journal of Man-Machine Studies, 22: 241-248 (March 1985).

5. Braham, H. S. "FLTSATCOM - Current and Future," Proceedings of the 1982 IEEE International Communications Conference, Vol 3. 6H.3.1-6H.3.5. IEEE Press, New York, 1982.

6. Brandon, William F. "Evolution of the Defense Satellite Communications System," Proceedings of the IEEE Military Communications Conference. 418-422. IEEE Press, New York, 1985.

7. Callero, Monti et al. TATR: A Prototype Expert System for Tactical Air Targeting. RAND Corporation, Santa Monica, CA, Aug 1984 (R-3096-ARPA).

8. Carter, Ashton B. "Satellites and Anti-Satellites: The Limits and the Possible," International Security, 10: 46-98 (Spring 1986).

9. Clayton, Bruce D. ART Programming Tutorial Volume One: Elementary ART Programming. Inference Corporation, Los Angeles, CA, 1986.

10. Clayton, Bruce D. ART Programming Tutorial Volume Two: A First Look at Viewpoints. Inference Corporation, Los Angeles, CA, 1986.

11. Clayton, Bruce D. ART Programming Tutorial Volume Three: Advanced Topics. Inference Corporation, Los Angeles, CA, 1986.

12. Cochran, Lt Col Curtis D. and others, editors. Space Handbook. AU-18. Maxwell AFB, AL: Air University Press, January 1985.

13. Cohen, Marvin S. and others. Design Principles for Personalized Decision Aiding: An Application to Tactical Air Force Route Planning. RADC-TR-85-140. Decision Sciences Consortium, Inc., Falls Church, VA, July 1985 (AD-A159-508).

14. de Pedro, H. et al. "Multimedia Networking Techniques to Enhance Communications Survivability," Proceedings of the IEEE Military Communications Conference. 308-311. IEEE Press, New York, 1985.

15. Descotte, Yannick and Jean-Claude Latombe. "Making Compromises Among Antagonist Constraints in a Planner," Artificial Intelligence An International Journal, 27: 183-207 (Nov 1985).

16. Engleman, C. et al. "KNOBS: An Integrated AI Interactive Planning Architecture," Proceedings of the AAAI Computers in Aerospace IV Conference. 450-462. Oct 1983.

17. Feigenbaum, E.A. Knowledge Engineering for the 1980's. Computing Science Department, Stanford University, 1982.

18. Freeman, Gene G. "GPS L-Band Communications Concept," Proceedings of the 1981 National Telecommunications Conference. E9.5.1 - E9.5.3. IEEE Press, New York, 1981.

19. Garvey, Thomas P. and John D. Lowrance. Issues and Approaches to Uncertainty. Contract N00014-81-C-0115. SRI International, Nov 84 (AD-A150-727).

20. Gozzo, Capt Lorraine M. Applications of Artificial Intelligence to the Strategic Defense Initiative's Battle Management / Command and Control Objective. MS thesis, GSM/LSY/85S-13. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, Sept 1985 (AD-A161 738).

21. Grant, T. J. "Lessons for OR from AI: A Scheduling Case Study," Journal of the Operational Research Society, 37: 41-57 (Jan 1986).

22. Harmon, Paul and David King. Expert Systems: Artificial Intelligence in Business. New York: John Wiley and Sons, Inc, 1985.

23. Hayes-Roth, Frederick and others, editors. Building Expert Systems. Reading, Massachusetts: Addison-Wesley Publishing Company, 1983.

24. Hedgeman, Capt Calvin G. A Decision Aid for Restoration of Force Enhancement Space Systems. MS thesis, GST/OS/86M. School of Engineering, Air Force Institute of Technology (AU), Wright-Patterson AFB, OH, March 1986.

25. Hobbs, Benjamin F. "A Comparison of Weighting Methods in Power Plant Siting," Decision Sciences, 11: 725-737 (1980).

26. Inference Corporation. ART Reference Manual, ART Version 2.0. Inference Corporation, Los Angeles, CA, April 1986.

27. Jain, Pravin C. Lecture materials distributed in Trends in Military Satellite Communication Systems. Space Systems and Technology, Inc., Falls Church, Virginia, September, 1982.

28. Karas, Thomas. The New High Ground. New York: Simon and Schuster, 1983.

29. Kuchinski, Michael J. Battle Management Systems Control Rule Optimization Using Artificial Intelligence. NSWC MP 84-329. Naval Surface Weapons Center, June 1985 (AD-B095-153).

30. Lange, Thomas. Space Battle Management. Contract F04690-82-C-0005. Ford Aerospace and Communications Corporation, Colorado Springs, Colorado, Sept 1985.

31. Martin, James. Communications Satellite Systems. Englewood Cliffs, NJ: Prentice-Hall, 1978.

32. McLucas, John and Pascall, Lt. Gen. Lee. "Commercial Satcom Interoperability Issues," Proceedings of the IEEE Military Communications Conference. 209-212. IEEE Press, New York, 1984.

33. Pratt, Timothy and Charles W. Bostian. Satellite Communications. New York: John Wiley and Sons, 1986.

34. Rebman, Jack and Lt Col James Landucci. "The 'Transparent' Earth Station," Proceedings of the IEEE Military Communications Conference. 206-208. IEEE Press, New York, 1984.

35. Rich, Elaine. Artificial Intelligence. New York: McGraw Hill Book Company, 1983.

36. Rosenberg, Steven. Understanding in Incomplete Worlds. Contract N00014-75-C-0643. Report AI-M-475. Artificial Intelligence Laboratory, Cambridge, MA, May 1978 (AD-A062364).

37. Saaty, Thomas L. Decision Making for Leaders. Belmont, California: Lifetime Learning Publications, 1982.

38. Shapiro, Daniel G. and others. TEMPLAR (Tactical Expert Mission Planner) Design. RADC-TR-84-134. Advanced Information and Decision Systems, Mountain View, CA, June 1984 (AD-B088-429).

39. Slagle, James R. and Henry Hamburger. "An Expert System for a Resource Allocation Problem," Communications of the ACM, 28: 994-1004 (Sept 1985).

40. Slagle, James R. and others. Decision Support System for Fire Support System Command and Control. Navy Center for Applied Research in Artificial Intelligence, Naval Research Laboratory, 30 Dec 1983 (AD-B088-198).

41. Space Missions Group. SCF Orientation - AFSCF Training Manual. Course 203. Contract F04690-81-C-0004. Ford Aerospace and Communications Corporation, Sunnyvale CA, July 1985.

42. Smart Systems Technology, Inc. Intelligent Advisors for Cross-Country Route Planning: Final Report. Contract DAAK 70-83-P-3175. Smart Systems Technology, Inc, McLean, Virginia, May 1984 (AD-A143-922).

43. Stablow, Eric, Technical Consultant. Telephone interview. Inference Corporation, Los Angeles, CA, 29 October 1986.

44. Stefik, Mark. "Strategic Computing at DARPA: Overview and Assessment," Communications of the ACM, 28: 690-704 (July 1985).

45. Strohm, R. B. Air Force Satellite Control Facility Space/Ground Interface. Report No. TOR-0059(6110-01)-3 Reissue G. Contract No. F04701-83-C-0084. Aerospace Corporation, El Segundo CA.

46. Wall, Rajendra et al. An Evaluation of Expert System Building Tools. DARPA Contract No. N00039-85-C-0001. Texas Instruments Incorporated, Dallas, TX, Nov 1985.

47. Waterman, Donald A. A Guide to Expert Systems. Reading, Massachusetts: Addison-Wesley Publishing Company, 1986.

48. Wylie, C. Dennis and Robert R. Mackie. Technology Transfer and Artificial Intelligence, User Considerations in the Acceptance and Use of AI Decision Aids. TR 521231-1. Human Factors Research, Goleta, CA, Nov 1985 (AD-A166 035).

49. Zahedi, Fatemeh. "The Analytic Hierarchy Process - A Survey of the Method and its Applications," Interfaces, 16: 96-108 (July-August 1986).

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This research effort investigates the application of Artificial Intelligence knowledge-based techniques to the problem of space system restoration management. A prototype decision aid was developed to demonstrate the feasibility of a knowledge-based decision aid capable of assisting the Commander of the US Space Command in maximizing the use of remaining space resources following wartime losses and degradation of space systems. Programmed with the Automated Reasoning Tool (ART), the prototype decision aid generates alternative restoration plans based on the mission priorities specified by the user. To rank the alternative plans by their effectiveness, the prototype uses an objective function which encompasses the multiple objectives of restoring communications, navigation, and weather mission capabilities. The prototype decision aid also contains provisions to handle uncertain data and uses a branch and bound pruning algorithm to eliminate inferior partial plans and thereby hasten the solution process.

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