Chapter 5
A PROACTIVE ERROR REPORTING SYSTEM

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5.1 A PROACTIVE APPROACH TO ERRORS

Considerable effort has been expended by airline personnel and human factors researchers in trying to identify errors in aviation maintenance. The aviation maintenance environment is a large and complex socio-technical system with many opportunities for error and well established safety systems to prevent error propagation. Inspectors and mechanics must utilize documentation, tools, and other personnel to detect, document, and repair faults within the constraints imposed by both the physical environment and the organizational environment. Since it is the inspectors and mechanics themselves who are ultimately responsible for identifying necessary faults needing repair, and for judging whether repairs are adequate, many errors can be identified at some level as a human error.1 Thus, high importance has been placed on identifying human errors in the maintenance system, and for reducing the possibility for future errors.

The aviation industry and the FAA have identified reducing human error as a major contributor to improving the safety and reliability of aviation. The FAA Office of Aviation Medicine (FAA/AAM) has been conducting research throughout the 1990's on Human Factors in Airline Maintenance. Researchers, ourselves included, have been examining all facets of the airline maintenance environment in an effort to improve performance, reduce errors, and match the abilities of the mechanics with their work, by giving them better tools with which to perform their jobs.

During the last six years, various maintenance and inspection processes have been analyzed through observations, task analyses, and other research efforts to identify potential errors in the system. Audits have been developed for both inspection and maintenance tasks to help identify problems in the system which may result in errors.2 Mechanics have been surveyed, and human factors task forces formed, to help identify more subtle socio-technical problems existing in the maintenance system. In addition, analysis of historical error data has allowed hazard patterns of typical errors to be developed, and latent failures in the maintenance system to be identified. The challenge is to combine these disparate elements into coherent error management systems.

As a starting point for this integration, in 1995, our team examined many errors that are committed in the maintenance environment including: ground damage incidents, paperwork errors, on-the-job injuries (OJIs), rework situations, late finds, etc. For each of these error outcomes, we were able to use a small number of repeating patterns of behavior to classify the errors. Where the data would support it, we used event trees to relate these patterns to underlying human (and other) factors, i.e. root causes. We concluded that there is a relatively small set of common root causes which can lead to different error outcomes in the maintenance environment. Thus, by eliminating (or reducing) these common root causes, it will be possible to prevent mechanics from committing a large number of errors. In order to eliminate the underlying causes of problems, it is necessary to make changes in the maintenance system. The "blame and train" approach is often not sufficient, as it affects only one or two individuals in the system rather than the system itself.

There has also been significant interest in improving the manner in which airline maintenance personnel record errors and track their incidence by location and over time. The Maintenance Error Decision Aid (MEDA), developed by Boeing for use by the airlines, is one tool that has been introduced to help airlines track low-level errors in the maintenance environment. MEDA was initially intended to allow airlines to share error data with the rest of the industry, which would allow airlines to learn from each other. This feature was not widely accepted by the industry, as few maintenance departments were willing to release their error information publicly. However, MEDA does provide maintenance personnel with an additional tool for tracking errors.

In fact, considerable time, effort, and money is spent in the identification and tracking of some errors. For example, there are clerks whose entire job is the checking of paperwork for errors, and programs have been set up within airlines to investigate errors when they occur. Other airlines have invested heavily in the purchase of commercially available error reporting systems.

Our previous research has indicated that airlines typically have many error reporting systems in use simultaneously. Injuries, ground damage, paperwork errors, etc. are all recorded in separate error reporting systems. Some errors, such as rework situations, may not even be explicitly captured in any of the existing error reporting systems. However, maintaining separate reporting systems based on error outcomes is not efficient in monitoring error root causes, since many error outcomes result from a similar set of root causes. For example, if a mechanic drops a wrench on his foot it is recorded as an OJI, but if the wrench is dropped on the aircraft, it is recorded as a ground damage incident. Maintaining different reporting systems requires significantly more effort to identify, and ultimately address, common root causes. In particular, the potential savings associated with an intervention may be considerably underestimated if only a single error outcome is counted.

Another result of our previous research is that the same types of errors occur repeatedly in the airline maintenance environment. These errors are often predictable, and are not unexpected by either the mechanics or management. Maintenance personnel are often familiar with these errors, and management often have tools available to help them identify error-prone situations. However, similar errors continue to occur in the airline maintenance system. This leads to the conclusion that the difficulty is less how to recognize the human factors problems (actual and potential errors), than how to move from recognition and analyses of the problem to usable solutions. Help is needed in guiding maintenance personnel in making changes in the system before errors can repeat.

A Proactive Error Reduction System (PERS) has been developed to meet this need of airline maintenance personnel. PERS can be used to foresee, and thus prevent, typical errors. The system is essentially a database of solutions, which have been shown to successfully address problems in the airline maintenance system. Users can search the database to find potential solutions, either to errors that have occurred, or to known potential error-causing situations.

5.1.1 Goals of PERS

Three distinct functions were identified to ensure PERS is an effective error management tool: an error reporting/tracking function, a means of predicting future errors, and a way to find alternate solutions to error problems. First, PERS must include an error reporting system which, like current reporting systems, allows errors to be investigated and recorded. The error reporting system function should allow many error outcomes to be recorded in one unified system, so that common root causes can be identified and tracked. The system should guide the error investigation to ensure the details of the error, including root causes, are being identified and captured. Interfaces to existing error reporting systems (e.g., MEDA) may facilitate acceptance of PERS by airline maintenance departments already using such systems.

Second, PERS should allow users to import data from other sources, which are not triggered by known errors. Thus, other proactive investigation tools (e.g., Audits, MESH, etc.) can be used to identify potential error-causing situations, and PERS can be used to help prevent these errors from actually occurring.

Finally, PERS is a way of linking a database of maintenance errors with a database of known solutions. It will contain alternative solutions that can be implemented to help reduce the occurrence of these errors. Users will be able to search this database directly, to find possible solutions for problems that are known to exist in the maintenance environment, regardless of whether an error has actually occurred. Within the solution search, information regarding cost, typical implementation time, and success stories should be provided to the user, to allow more educated choices to be made when choosing how to address problems.

These second and third characteristics of proactivity and solution-orientation are what differentiate PERS from existing error investigation systems. Figure 5.1 shows the conceptual structure of PERS, and its central role in an error management system. The multiple entry points are shown at the top, with proactive ones on the left and reactive (event-driven) ones on the right. From either potential or known problems, a set of contributing factors are derived and used to find actual or potential Hazard Patterns. These Hazard Patterns and contributing factors are used with the solution database to find appropriate solutions. The user assesses potential solutions against selection criteria to find a subset of usable solutions, which then become part of an ongoing error control and management system.

5.2 PERS DEVELOPMENT

The three functions of PERS (Section 5.1.1) have been considered as three distinct modules in the PERS program, and their development will be presented in turn, although the core of the PERS program ensures that these modules can interact correctly. The interface to other data sources has not been considered in this phase of the program, except in the recognition that 'gateways' must be left open for such data transfer to occur. For example, PERS must be able to recognize output from proactive tools such as audits, to provide solutions that can prevent errors from occurring. PERS must also be capable of importing data from other error reporting systems, to allow solutions to be found for errors that have already occurred and that have been recorded in an alternate form.

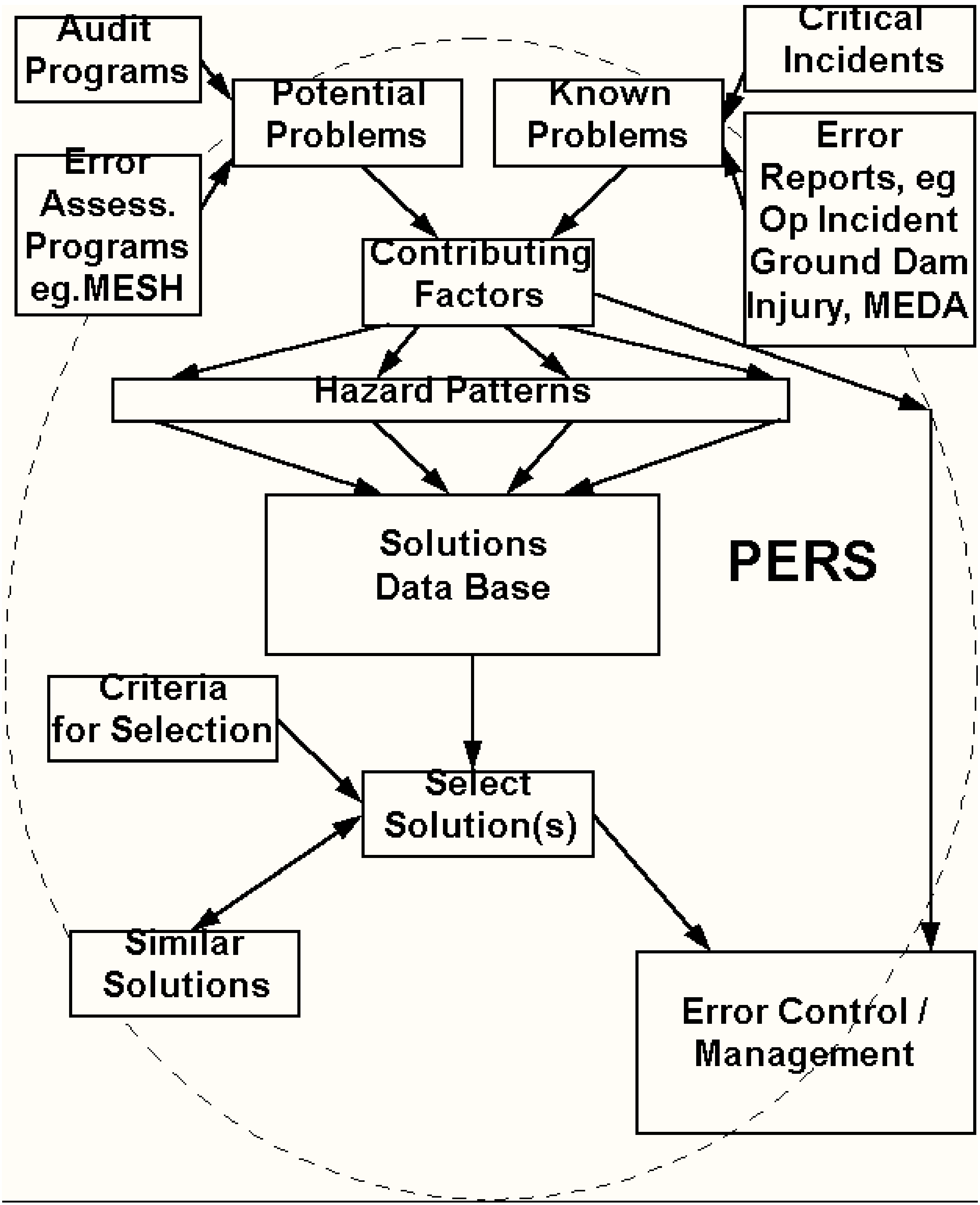
Audit Programs
Error Assess. Programs eg.MESH
Potential Problems
Known Problems
Critical Incidents
Error Reports, eg Op Incident Ground Dam Injury, MEDA
Contributing Factors
Hazard Patterns
Solutions Data Base
PERS
Criteria for Selection
Select Solution(s)
Similar Solutions
Error Control / Management

Figure 5.1 Conceptual Structure of PERS

5.2.1 Error Reporting System

The development of a unified error reporting system is not a trivial problem. It is necessary to balance the need for extensive information about an error, with practical usefulness in an airline maintenance environment. A system must contain enough narrative information to allow root causes to be identified and classified, but should not necessarily require a two day investigation of each error that occurs. It is important, however, to remember that the information gained from an error reporting system reflects the effort that was expended in recording the information. More time and energy spent capturing and recording an error usually results in a richer error report, containing more useful information and leading more obviously to root causes and hence to solutions.

In developing an error reporting system, it is necessary to consider who will be completing the error investigations: maintenance personnel, or human factors professionals, as the tools for these users may look completely different. For example, human factors professionals may be better able to answer general questions based on a human factors model of causal factors (Tools/Operators/Machines/Environment [TOME], Software/ Hardware/ Environment/Liveware [SHEL]), e.g., "Describe how the environmental factors contributed to the error." On the other hand, maintenance personnel may be better suited by questions more tailored to the actual error, e.g., "Was it raining while the task was being performed, and if so, how did the rain affect task performance?" Since most airlines do not have sufficient human factors personnel available to investigate all errors that occur, the second approach may be better suited for the airline maintenance environment.

It is also important to consider the types of responses that will be required of the error investigators. Answers can range from selecting a suitable response from a predetermined list (checklist approach), to requiring investigators to write long narratives describing the situation. Our analysis of existing error databases has indicted that narrative responses usually provide more, and more usable, information than checklist responses. For example, the checklist approach to MEDA has restricted the amount of information recorded about an incident to a point where it is even difficult to reconstruct the chain of events leading to the error. However, narrative responses require personnel to write lengthy descriptions, and writing is not a skill most airline personnel enjoy using. In addition, narrative responses take longer for the investigator to complete, and the data is more difficult to utilize. Narrative responses must be carefully analyzed, and the root causes extracted from the narrative, before the data is in a useful form.

A Unified Error Reporting System was developed as part of our previous research. This system, in paper form, leads users through a narrative based investigation system tailored for particular error outcomes. The questions for each error outcome have been developed based on analysis of historical error data and on the common root causes identified for each type of error. This analysis helps to focus an error investigation on the factors that have been shown to typically result in that type of error. A computerized version of this system will be developed for use in the PERS system.

5.2.2 Solution Database Development

In order to make PERS a proactive error reporting system, users should be provided with information on how to prevent potential errors from occurring. The objective was to gather a large database of errors from the airline maintenance environment, along with solutions that have been used by airlines to address these errors. This would allow users to learn from the mistakes of others and to improve their system before predictable errors can occur.

Unfortunately, it has been a very difficult task to collect this solution information. We have found that few airlines have maintained detailed records of solutions that have been implemented, and even fewer have performed follow-up analyses of these solutions to judge how successful they have been at preventing future errors. Some airlines have implemented solution generation as part of their current error reporting systems, by requiring investigators to recommend solutions at the end of an error investigation. For example, investigators of ground damage incidents are required to make a few recommendations as to how to prevent future incidents. However, these recommendations tend to take the "blame and train" approach, in which the particular maintenance personnel involved in the incident are reprimanded, and additional training is suggested for all personnel. Such a strategy has proven singularly ineffective in reducing systemic errors.

In addition, airlines have implemented wide-scale programs intended to address human factors problems within the organization. Maintenance Resource Management (MRM) programs, Task Analytic Training (TAT) sessions, and Total Quality Management (TQM) techniques (such as teams or project ownership) are being used. Their successes are being documented as global solutions to problems, that are known to exist in airline maintenance systems. Solutions to specific problems, however, are not as well documented.

It is important that the solutions in the PERS database reflect more than obvious solutions to known problems. For example, including a solution to "improve communication" will not be useful to address a problem identified to be "lack of communication between leads on consecutive shifts." A better approach is to include specific solutions that have been shown to work in other airlines, or even in other industries. An example of a more specific solution to the lack of communication problem is to "overlap shift start and end times, and require the two leads to walk around each aircraft to ensure a complete turnover of current work information." We are most interested in airline specific solutions, since airline personnel trust this information more than solutions from other industries. However, other solutions from other industries will be included where applicable to the aircraft maintenance domain.

The collection of solutions to populate the database is ongoing, and it is envisioned that this will in fact be a continuous process. We are still working with our airline contacts to obtain information about solutions that have been implemented and as much detail about these solutions as is available. In addition, we are investigating best practices within the airline industry, to allow recommendations to be made for potentially error-causing situations that have been identified according to the human factors literature. So far, all of the documented solutions from the FAA/AAM Human Factors in Aviation Maintenance conferences have been collected and included.

5.3 PERS STRUCTURE

An overall structure for the PERS software has been developed, leaving "gateways" to the modules of the program which will be developed in the future. Most of the effort concentrated on the solution search aspect of the program, with emphasis on ground damage incidents. Ground damage was chosen for this initial phase since detailed analysis of these incidents has been previously conducted.

The solution search module of PERS has three main components. First, the event leading to an actual error, or to a potential for error must be described. Then, the latent and active failures contributing to the error are identified, and finally possible solutions are suggested to address these failures. The initial screen (Figure 5.2) allows the user to select the appropriate module.

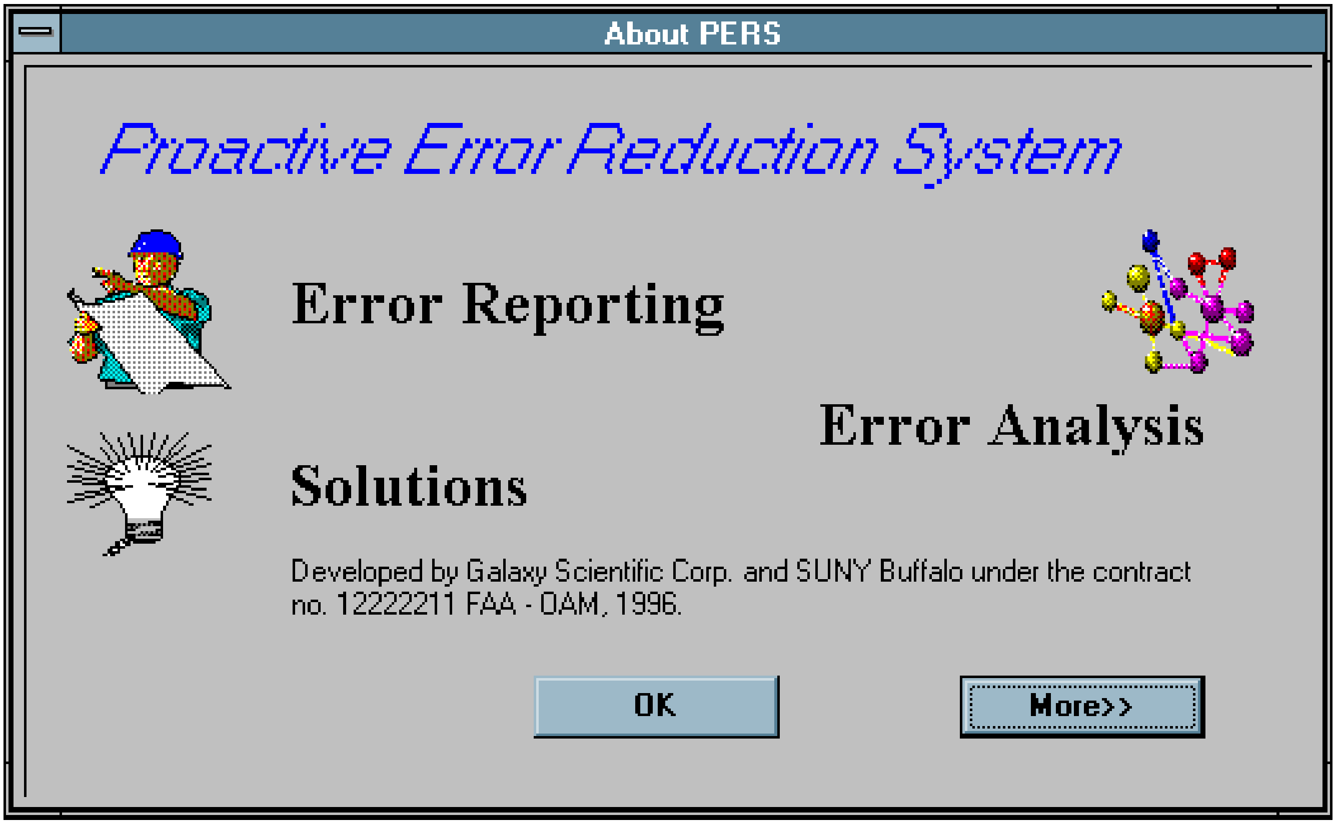

Figure 5.2 Modules of PERS

5.3.1 Error Description and Failure Identification

Ground damage includes damage to aircraft which is caused by airline personnel. It includes damage that is preventable. Damage caused by hail, bird strikes, part failures, and even foreign object damage (FOD) is not recorded as ground damage in the database we analyzed in 1995. This database covered 130 ground damage incidents recorded by a technical operations department of a major airline over a three and a half year period. (This restricted coverage, e. g., not covering FOD, is one of the problems PERS was designed to overcome). It was determined that there were only twelve distinct patterns of error outcomes that covered all of these incidents, as shown in Table 5.1, each of which was considered to be a Hazard Pattern. For example, the center of gravity of the aircraft may change unexpectedly, resulting in Hazard Pattern 1.2.1

Next, each of the incidents were analyzed to determine the specific latent failures that contributed to the incident, and scenarios were developed for each hazard pattern which illustrate the common factors between all of the incidents. From this detailed analysis, typical event trees leading to the twelve hazard patterns were developed, and the common latent and active failures leading to these error outcomes were identified (Figure 5.3). These event trees were used as a framework to guide users to potential solutions for errors often resulting in ground damage incidents. The user is able to navigate through these trees as the event is described, ending at a list of the common failures (root causes) that often contribute to the event.

This approach eliminates the need to carefully investigate each ground damage incident, since the detailed analysis has already been performed, and allows the user to move quickly to possible solutions. Figure 5.4 shows the point in the PERS software where the user can choose the form of analysis. Similar detailed analysis of other incident types must be conducted in the next phase of this project.

Table 5.1 Ground Damage Incident Hazard Patterns

Hazard Pattern	Number of Incidents			% of Total
1. Aircraft is Parked at the Hangar/Gate/Tarmac	81			62.3
1.1 Equipment Strikes Aircraft		51		
1.1.1 Tools/Materials Contact Aircraft			4	
1.1.2 Workstand Contacts Aircraft			23	
1.1.3 Ground Equipment is Driven into Aircraft			13	
1.1.4 Unmanned Equipment Rolls into Aircraft			6	
1.1.5 Hangar Doors Closed Onto Aircraft			5	
1.2 Aircraft (or Aircraft Part) Moves to Contact Object		30		
1.2.1 Position of Aircraft Components Changes			15	
1.2.2 Center of Gravity Shifts			9	
1.2.3 Aircraft Rolls Forward/Backward			6	
2. Aircraft is Being Towed	49			37.7
2.1 Towing Vehicle Strikes Aircraft		5		
2.2 Aircraft is Not Properly Configured for Towing		2		
2.3 Aircraft Contacts Fixed Object/Equipment		42		
2.3.1 Aircraft Contacts Fixed Object/Equipment			13	
2.3.2 Aircraft Contacts Moveable Object/Equipment			29	
Totals	130	130	130	100%

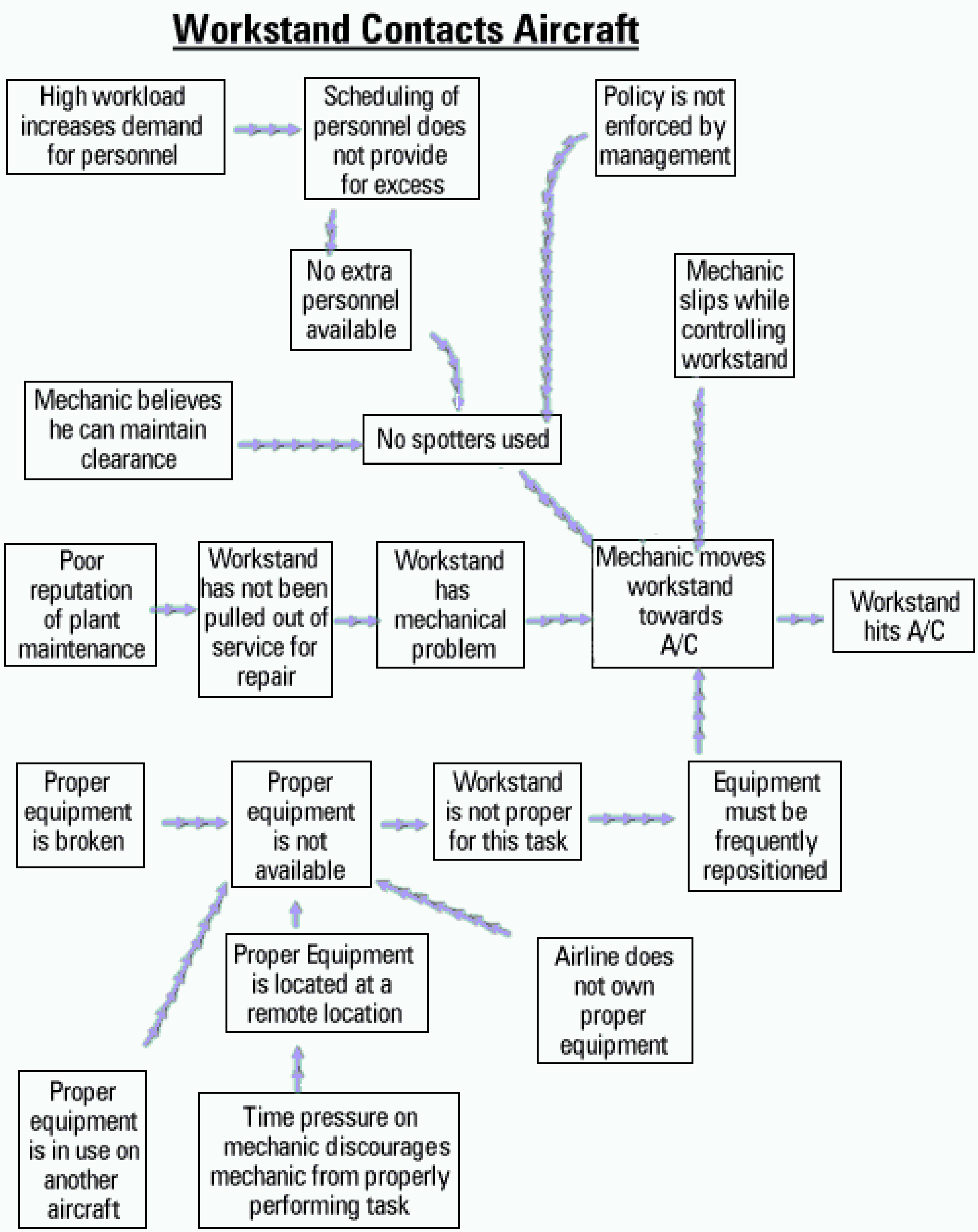

Figure 5.3 Example of Hazard Pattern Event Tree

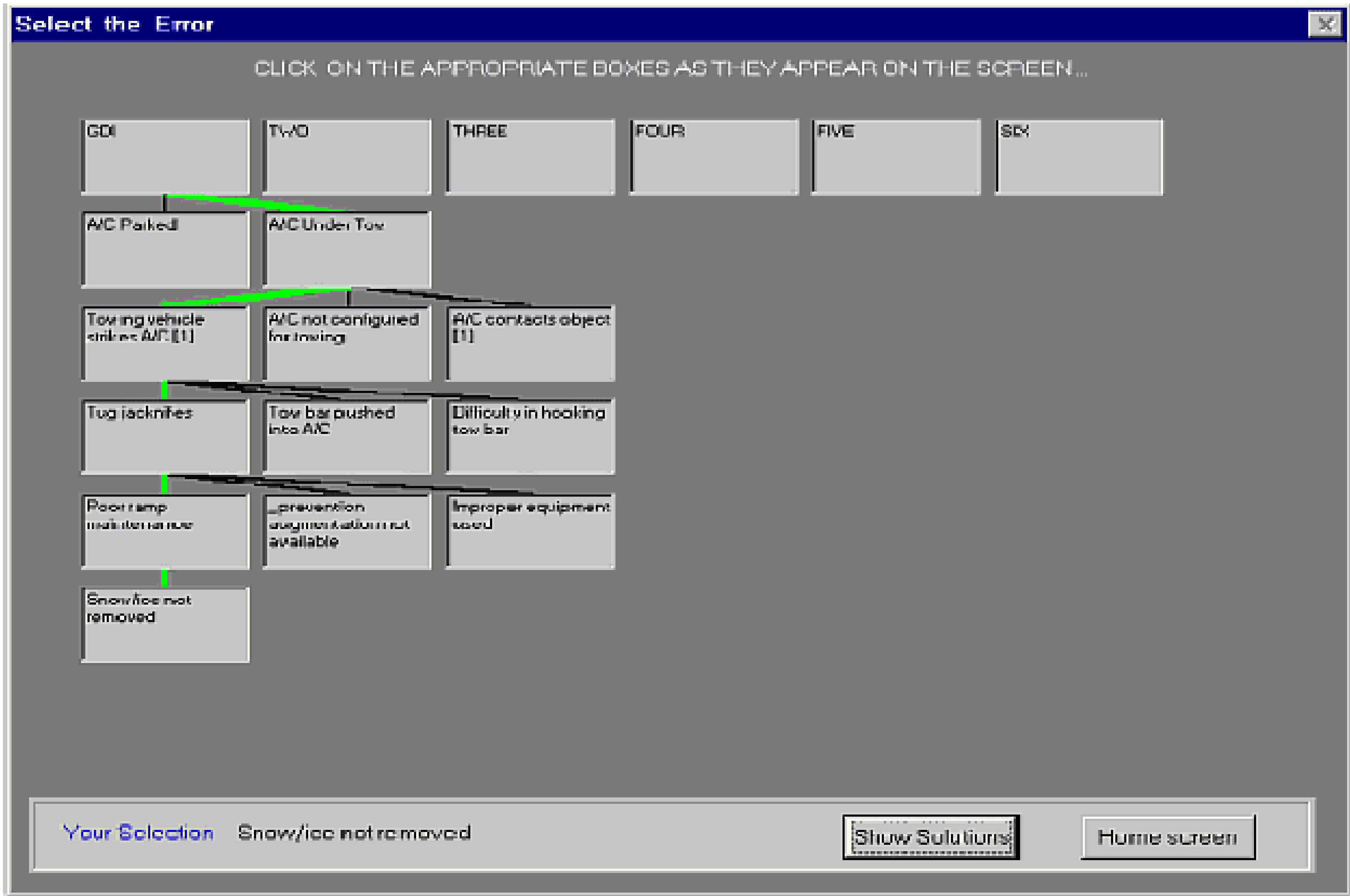

Figure 5.4 GDI Event Description Screen

5.3.2 Solution Search

Once an event has been described and the root causes identified, the user is able to examine possible solutions to each root cause. More detailed information about each solution, including cost, time to implement, and success stories will also be presented, when this information is available. This additional information will allow users to make educated decisions on how to address problems within their facility.

The solutions are indexed within PERS according to causal trees that have been developed. These causal trees describe latent and active failures that may exist, and are independent of errors that have occurred. The causal trees have been developed based on a combination of error classification schemes. The contributing factors from MEDA, performance shaping factors from human reliability analysis in the nuclear industry,[3] causal error taxonomies from safety literature,[4,5,6] and latent failures identified in previous research[7] were reviewed, and some information from each was combined to develop causal trees. The causal trees are a comprehensive classification of all factors that may contribute to an error. Five different causal trees were developed, addressing issues of: Management/Supervision, Communication, Equipment / Tools / Parts, Environment, and Knowledge/Skills/Training. Figure 5.5 illustrates one of the causal trees developed for PERS.

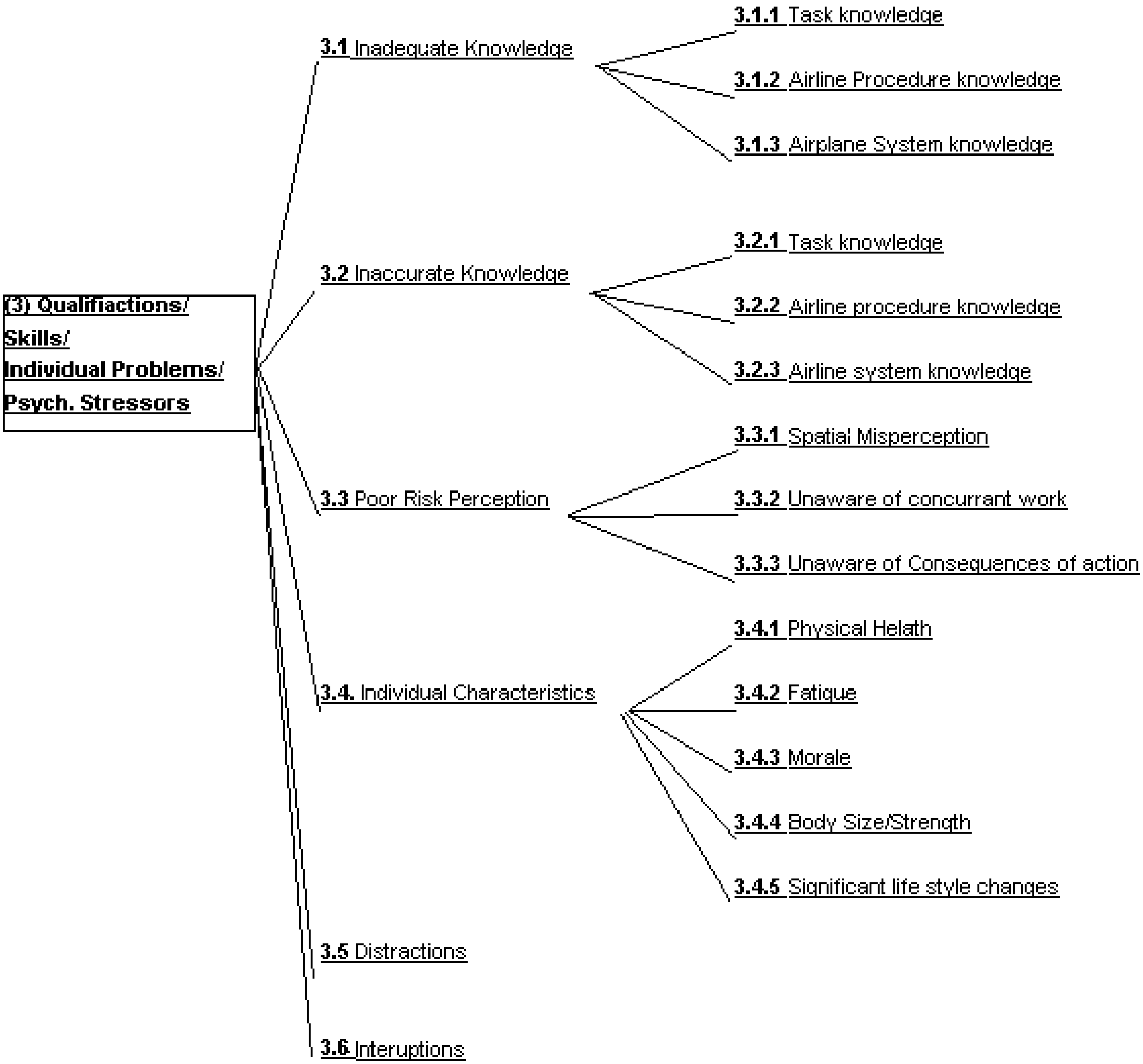

Figure 5.5 Example of a Causal Tree

Each of these causal trees has been embedded in the PERS software, and solutions are tagged to address particular points on these trees. Figure 5.6 shows a typical solution search, with possible solutions identified, in this case derived from prior ground damage incidents (GDI) investigations. More information will then be provided about each of these potential solutions.

In many cases, there may not be solutions that exist for all levels on the causal trees. In this case, the software should allow the user to examine solutions associated with the next higher level on the tree. Thus, users should be able to navigate the causal trees while examining solutions.

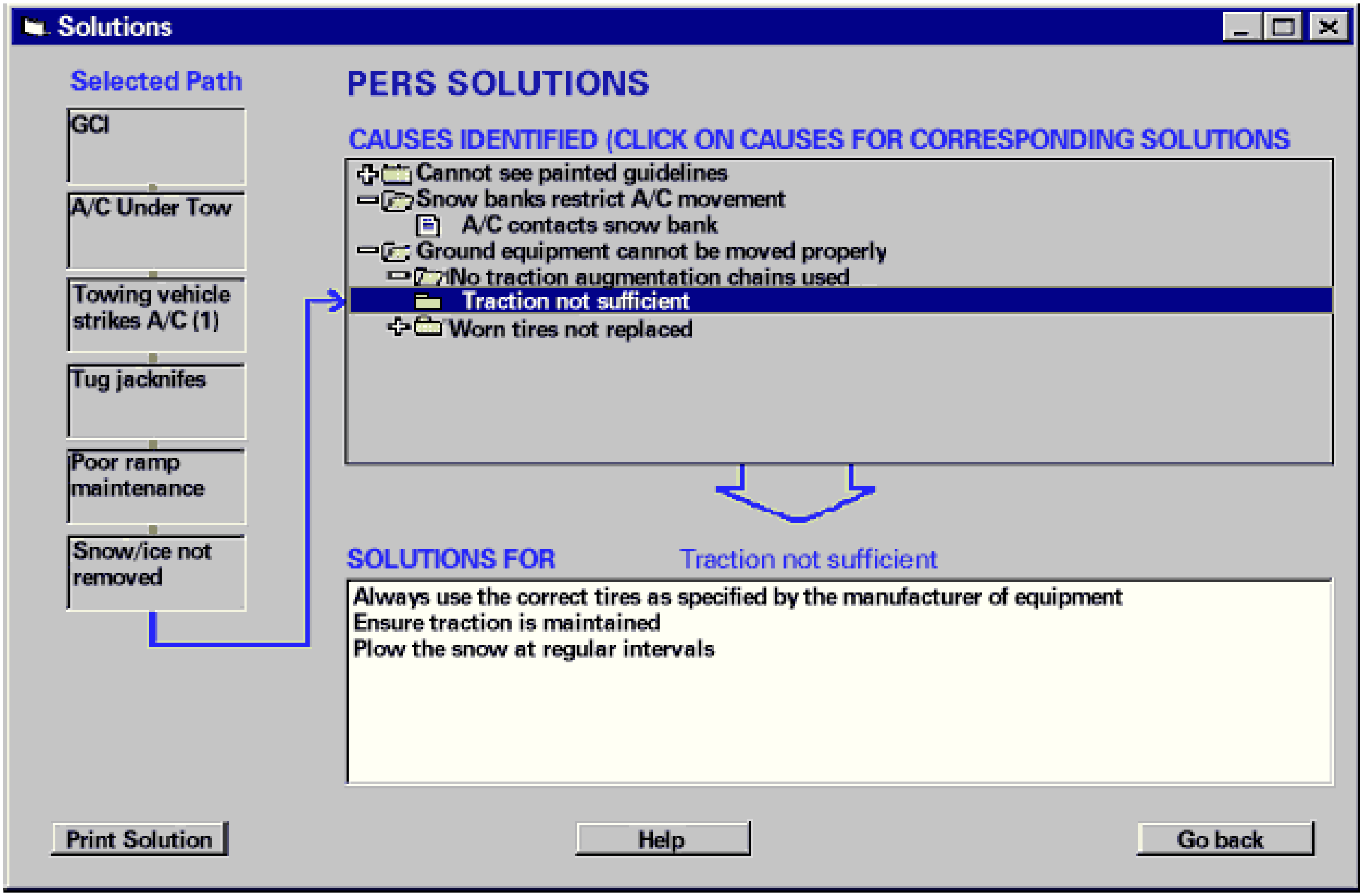

Figure 5.6 Solution Search Screen

5.4 LESSONS LEARNED FROM PERS

At the end of the first year of this two year project, a working prototype has been developed. This showed, on the basis of only one class of error outcomes, that such a system was feasible, in that the logic system could lead to multiple usable interventions based on the active and latent failures encountered. The prototype needs to be further developed in five ways to produce a comprehensive system:

1. The additional error classes need to be included.

2. The proactive aspects, based on audit data, need to be developed and programmed.

3. Links to existing error recording systems need to be programmed.

4. Support aspects, such as on-line help screens and a user's manual, need to be produced.

5. Many more evaluated solutions need to be added to the data base.

Some of those developments are possible immediately. However, two -- additional error classes and more evaluated solutions (Nos. 1 and 5 respectively) -- are not currently possible. Hence, this two year project has been suspended at the end of the first year for two specific reasons:

1. There are insufficient evaluated solutions documented in the industry at present. Despite contacts with the major airlines, the only specific solutions available have been in the published literature, e.g., from previous conferences. In the PERS prototype, these have been supplemented by higher-level solutions from professional good practice, e.g., from the *Human Factors Guide*. Even within GDIs, the solutions are few enough that they do not require an elaborate procedure such as PERS to bring them to the notice of users.

2. For areas other than GDIs, current data bases do not have the depth to support the active failure/latent failure search methodology used in PERS. For PERS to become a universal system, we would have to go back to "long checklist" approach used by current commercial error recording systems as there is too little data to make a reliable transition to our intelligent tree search.

5.5 FUTURE PLANS

Thus, the current status of PERS is that the project is on hold until the data becomes available to fully exploit its structure. If it is reactivated, the other items on the list in Section 5.4 will need to be addressed. Specifically, the "hooks" left to other error types (operational errors, paperwork errors, injuries, etc.) will need to be programmed. In addition the current audit systems such as ERNAP will need to be strengthened to include higher level indicators of human error potential and subsequently coded into PERS. Finally, interfaces to other error recording systems such as TEAM or AMMS will need to be explicitly coded.

At this time, no usability testing was performed on the PERS prototype. Because PERS only covered one area (GDIs), and had so few potential solutions available, it was not considered appropriate to run formal usability trials with industry personnel on the prototype. If PERS is reactivated and developed further, the usability trials can be completed meaningfully.

In summary, PERS as currently developed demonstrates the feasibility of a next generation of error management systems. As current systems develop richer data bases of errors, and as these in turn drive implementation of human factors solutions, the data necessary to resume development of PERS, or a similar system, will exist. Development of PERS to its current level has made the need for such data explicit, and provided the logical framework needed to support a future generation of error management systems.

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