The Ohio State University

PB97-105100

SAFETY FIRST: A Fault Tree Expert System for Construction Falls

Volume III: The Knowledge Base

Sponsor: National Institute of Safety and Health (NIOSH)
Centers for Disease Control and Prevention (CDC)
Grant Number: 1 K01 OH00115-01A1

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December 30, 1995

50272-101

PB97-105100

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3.

4. Title and Subtitle Safety First: A Fault Tree Expert System for Construction Falls, Volume III: The Knowledge Base	5. Report Date 1995/12/30
	6.
7. Author(s) Hadipriono, F. C., C. A. Vargas, and W. H. Yoo	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Construction Laboratory for Automation and System Simulation, Department of Civil Engineering, Ohio State University	10. Project/Task/Work Unit No.
	11. Contract (C) or Grant(G) No. (C) (G) K01-OH-00115
12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words) SAFETY FIRST was developed as an expert system to identify fall safety problems that may result in a fall accident and to investigate the causes of a fall accident that has already occurred. In this volume of the three volume set, construction of the knowledge base of SAFETY FIRST was discussed. This step included developing the user interface, which needed a systematic design of screens displaying the queries prompted to the users. The queries are used to obtain evidence and information that may verify the cause of a fall. The fault tree models were converted into decision trees arranged in tabular form. These decision trees were developed from the fault tree pattern to include the evidence and information about conditions which existed during the fall. Potential users tested the system for efficiency and logic, and experts validated its accuracy, completeness, applicability and how well the system solved a problem. This volume also included a formal evaluation of a representative subsystem of SAFETY FIRST by independent experts and potential users.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms NIOSH-Publication, NIOSH-Grant, Grant-Number-K01-OH-00115, End-Date-09-29-1995, Traumatic-injuries, Accident-analysis, Safety-research, Accident-prevention, Construction-workers, Construction-industry

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages 211
	22. Security Class (This Page)	22. Price

(See ANSI-Z39.18) *See Instructions on Reverse* **OPTIONAL FORM 272(4-77)** (Formerly NTIS-35) Department of Commerce

ACKNOWLEDGMENTS

This project was supported by grant 1 K01 OH00115-01A1 from the National Institute for Occupational Safety and Health (NIOSH) of the Centers for Disease Control. Dr. Roy M. Fleming (Grants Program Director), Dr. S. Price Connor (Program Officer), Mr. Ronald L. Stanevich (Project Advisor), and Ms. Barbara Wedding (Grants Program Advisor) from NIOSH have in many ways furnished their invaluable advice in completing SAFETY FIRST throughout the project period. The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health.

The authors wish to express their gratitude to the following professionals who participated as our experts in this research: Mr. Dan Feeney, Dr. Richard E. Larew, Mr. Greg Mathers, Mr. John Sahayda, and Mr. Mike Ypsilantis. Their knowledge was invaluable to this project and their cooperation was greatly appreciated.

Thanks also go to the following professionals who evaluated and tested the program at various stages of development: Mr. Richard L. Burns from the Occupational Safety and Health Administration (OSHA), Mrs. Meg Conlon and Stacy McAllister from the safety division of the Builders Exchange (BX), Mr. Martin D. Mostin from Turner Construction Co., Mr. J. Bruce Mounts from Complete Carpentry Inc., Mr. Matt Ogle from Stephen B. Ogle & Associates, Inc. (Safety Consultants), Mr. Scott Parker from Edwards Steel Erectors, Mr. Terrence J. Siemer from the Ohio Bureau of Workers Compensation, Mr. Robert W. Tullett, PE from EXXCEL Contract Management. Their comments and suggestions were essential to the improvement of the SAFETY FIRST system.

Further appreciations are due to all the members of the Construction Laboratory for Automation and System Simulation (CLASS). Their comments and assistance throughout this project development were very valuable. Finally, the authors wish to thank Mr. Bruce W. Rogers for his editorial work during the writing of this report.

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EXECUTIVE SUMMARY

VOLUMES I, II, AND III

Construction falls have been identified as the most frequent cause of deaths and injuries of workers during construction operations. These falls can be categorized into falls from higher elevation, from the same elevation, and slips. While the frequency in which the latter two categories occur is higher than that of the first, the consequence of falls from higher elevation is the most severe of all. During construction, falls can occur from any working platforms. However, this study reveals that such accidents frequently occur from floor edges, floor openings, wall openings, tops of walls, steel beams, roofs, ladders, and scaffoldings. These hazardous platforms (components) are the focus of this study.

The study's objectives are to develop a tool to diagnose the causes of falls and to identify potential causes prior to fall occurrences. In addition, such a tool can be used for training purposes. Safety organizations and industry alike have recommended the development of such a tool, particularly one that can mimic the thought process of safety experts in determining the cause(s) of a fall. Very often, experts conclude such a cause heuristically, based on their experiential judgment, rules-of-thumb, educated guesses, and assumptions. For the above reasons an expert system, SAFETY FIRST, was developed.

The first major step in developing SAFETY FIRST was the acquisition of knowledge. Throughout the project period, numerous experts contributed their expertise directly and indirectly to the development of the expert system. Other knowledge was also acquired from literature recommended by experts including fall- and safety-related cases, codes, and regulations. During the knowledge acquisition process, the study revealed that while literature provides some knowledge for building the system, much more had to be gained from domain experts in order for SAFETY FIRST to meet its objectives. Through their extensive practical experience these experts have provided a wealth of detailed knowledge about construction falls that cannot be found in literature.

The next major development step was structuring the acquired knowledge using fault tree models. These models are furnished with numerous branches, each of which represents a path indicating the sequence of events and causes an expert may have gone through when diagnosing a fall case and concluding the basic cause(s) of the fall. Furthermore, these models reveal the causes of the events that contributed to a fall. By themselves, these models can be used as a visual template for training novices to analyze the cause of a fall by the method of deduction. When used to structure the knowledge for SAFETY FIRST these models classify causes of falls into a pattern of enabling, triggering, and support-related events or causes.

Constructing the knowledge base of SAFETY FIRST was the final major step of this study. This step includes the development of the user interface, which calls for a systematic design of screens displaying the queries prompted to the users. These queries are prompted to obtain evidence and information that may verify the cause of a fall. For this purpose, the fault tree models were converted into decision trees arranged in tabular form. While fault trees show the causal relationships among contributing events or causes to a fall, the decision trees were developed following the fault tree pattern to include the evidence and information about conditions which existed during the fall. Once the decision trees were constructed, the knowledge base was implemented by developing frames, production rules, and other properties following the pattern laid out by the decision trees.

Throughout the development of SAFETY FIRST, numerous tests were conducted by the knowledge engineers, experts, and potential users. The knowledge engineers evaluated SAFETY FIRST for its efficiency and logic, while experts validated its accuracy, completeness, applicability, and how well the system solves a problem. Potential users tested the system checking for user convenience and interface with the system. Further, to maintain the objectivity of the knowledge contained in the system, tests were also conducted by independent experts who encountered the system for the first time upon testing it. Both formal and informal evaluations were performed by experts and users alike. The results indicate that the system has a great potential of being a useful training tool for the construction industry.

In the last volume of this report, the results of a final and formal evaluation of a representative subsystem of SAFETY FIRST by independent experts and potential users is presented. All evaluation criteria (adequacy of conclusion, clarity of queries, user friendliness, efficiency, ease of use, and usefulness of the system), including the overall performance of the subsystem, have been rated as good or better than good.

Despite a successful effort in completing this study, like any other expert system, SAFETY FIRST does have limitations. First, the often innumerable variables needed in solving a fall case frequently limit the system to producing general conclusions. Hence, more specific conclusions requiring other domains of expertise are needed to refine the system. Second, a more efficient and refined system can be developed as an extension of this study by separating the knowledge base of SAFETY FIRST into diagnostic and prognostic modules. Third, at this stage, SAFETY FIRST is furnished with limited sound and graphic capabilities; further development of the system to include the multi-media components will enhance the user interface of SAFETY FIRST. These limitations could become the focus of an immediate extension of the system. In fact, plans have been set for the principal investigator of this project and his doctoral student to continue developing SAFETY FIRST in a multi-media environment. New results will be reported as research progresses.

ABSTRACT

VOLUME III

The final task in developing SAFETY FIRST was the development of the expert system's knowledge base. This task entailed taking the knowledge acquired during the first two tasks and incorporating it into the knowledge base. To do this, the fault trees developed were converted into decision structures which combined decision tree and decision table approaches to provide more organized structures to evaluate the evidence and other information obtained from the construction site at the time of the fall. These structures had the advantage of being easily converted into frames and production rules. Furthermore, these decision structures also provide a well defined flow for the development of the system's user interface.

Given that the first impression a user gets from a program is controlled by the interface properties, a major consideration during the development of SAFETY FIRST was the user interface development. For this system, we take advantage of the expert system's shell Graphic User Interface (GUI) facilities by using a question and answer scheme in which the user only has to select the correct answer by using the mouse. Furthermore, the displays structure and components (i.e., buttons, menu bar, etc.) were designed to be as informative and practical as possible.

As for the knowledge base, all of the events and causes in the decision structures are represented as either classes, attributes, or instances in the knowledge base, all of which are contained in frames. Finally, the logical relationships among these events or causes are represented by using either production rules or "demons" of the form IF (action) THEN (consequence).

As for the control and execution of the program, the inference engine in SAFETY FIRST uses a forward chaining strategy to reach a conclusion. Given the information about the real world (obtained from the user through the user interface) and the knowledge (facts) contained in the knowledge base about fall accidents, the inference engine matches a fact in the knowledge base with a condition in the real world, and directs the system reasoning. A forward chaining strategy implies that the facts contained on the IF side of the rule must be true in order for those on the THEN side to be true.

The system was tested throughout all its stages of development. The knowledge engineers tested the logic of the system and verified that all its rules complied with the knowledge structures previously designed. Furthermore, experts and users tested the system for accuracy, completeness, applicability and user friendliness in informal and formal validations. As a result of this testing, the system was modified and improved at all stages of development. Furthermore, the results of the validations indicate that the system has the potential of being a very useful tool for the industry.

CHAPTER 1
INTRODUCTION

1.1 Introduction

In Volume I of this report, the authors discuss the process of acquiring knowledge from experts and literature regarding the causes of unintentional construction falls, including falls from higher elevations, falls from the same level, and slips (not fall). The role of safety devices in avoiding such falls is also presented. The knowledge obtained in Volume I was organized, represented, and structured into fault tree models.

Volume II emphasizes and elaborates on the development of these models, which represent cases of falls from floor edges, floor openings, roofs, tops of walls, wall openings, steel beams, ladders, and scaffoldings. The purpose of fault tree models is to establish a "bridge" between the experts' knowledge and the body of knowledge incorporated into SAFETY FIRST. Since the models systematically and efficiently represent the reasoning paths of the experts, they have become the guidelines to write programs and develop the knowledge base for SAFETY FIRST.

In Volume III, the last volume of this report, the authors elaborate on the development of the knowledge base of SAFETY FIRST. The work in this volume involved establishing decision trees, production rules, user-interface, other facilities provided for the system, and testing and validating the system.

1.2 Limitations of SAFETY FIRST

The time and effort spent in this project has produced a prototype expert system that is capable of determining the causes of unintentional construction falls and in acting as a consulting tool to check if fall protection devices used are adequate according to OSHA standards.

While the objectives of this project have been reached, like any other expert system development, continuous refinement and modification of the system is needed. As new technology in materials, erection methods, safety devices, and regulations emerge, much effort is needed to enhance and improve the system. Since an expert system also depends on computer technology, the continuing changes in this technology also calls for updates and upgrades in the system requirements.

Without extensively repeating the limitations described earlier in Volume I of this report, we wish to note that numerous variables often exist when a fall occurs, often limiting the system to furnish a general conclusion. This is particularly true when a user wishes to obtain a more specific cause (e.g., specific type of illness, structural strength of a safety device, etc.,) which is beyond the scope of this study. While these specific causes are important, our system requires other domains of knowledge (e.g., medical, structural engineering, etc.). This can certainly become an extension of SAFETY FIRST in the future.

1.3 Organization

This volume contains five additional chapters. Chapter 2 provides a basic overview of expert systems and preliminary studies conducted by the authors. Chapter 3 starts with a description of the architecture of SAFETY FIRST and the modules that make up the system. The major emphasis of this chapter is the discussion about the development of the knowledge base of the system. This includes a conversion from the fault tree models to decision structures and from decision trees to production rules. For brevity, only the decision structures for falls from floor edges are discussed in detail in this chapter, those for other hazardous components are provided in Appendix III-D of this volume. Chapter 4 describes the user interface for the system and illustrates display examples. A discussion of the validation process and results of the system is presented in Chapter 5. Finally, Chapter 6, summarizes and concludes our study, and recommends future improvements and extensions of SAFETY FIRST. References cited in this volume are given in Appendix III-A, a glossary for definitions of terminology used in this volume is furnished in Appendix III-B, a list of abbreviations used here is provided on Appendix III-C, all other decision structures not included in the body of this report are included on Appendix III-D, the name and affiliation of the professionals who evaluated SAFETY FIRST is included on Appendix III-E, and finally, a list of current and future publications related to the topic of this volume is provided on Appendix III-F.

CHAPTER 2

EXPERT SYSTEMS AND PRELIMINARY STUDIES

2.1 Introduction

Expert systems are a branch of the artificial intelligence (AI) field in computer science. Early efforts in AI dealt with the representation of non-numeric symbols and emulation of information processing, heuristic search, problem solving, and knowledge structure, among others. The following historical background of AI was obtained from Simon's *Expert Systems and Micros* book [1985].

The firsts version of AI may be dated to 1936 when Alan Turing developed the general "Turing machine" which became the basis of the theory of computing. Later in 1943, the first electronic computer, Colossus, was developed at Bletchley. Taking advantage of these advances, in later years, computers were used in several applications in which they showed some of the capabilities that are perceived as human-like intelligence. On the other hand, these early machines could also be perceived as powerful calculators requiring instructions on what to do and without any real intelligence. By 1956, John McCarthy had developed the LISP (List Processing) language and the interest on the topic of "how to simulate human intelligence" was at its peak. This motivated the "Dartmouth conference" where the importance of the artificial intelligence field was recognized. In the years after the conference up until the 1970s, the only major progress in the area was the development of the general problem solver by Newell, Shaw, and Simon. At this point, AI scientists recognized that knowledge is an essential part of intelligence. They also recognized that the amount of knowledge a computer would have to store to have human-like intelligence was infinitely large. On the other hand, they also found that if the sector of expertise was more focused towards a narrow sector of expertise, computers could still be used to simulate human expertise. This more focused area of AI includes the systems known as "expert systems" and "knowledge-based systems."

2.2 Expert Systems

Expert systems allow for the automation of solutions to problems which require heuristic human knowledge such as rules of thumb, judgments, intuition, or experience. Specifically, an expert system can be defined as "a computer program that relies on a body of knowledge to perform a somewhat difficult task usually performed only by a human expert. The principal power of an expert system is derived from the knowledge the system embodies rather than from search algorithms and specific reasoning methods. An expert system successfully deals with problems for which clear algorithmic solutions do not exist" [Parsaye and Chignell 1988].

The objective of an expert system is to simulate the reasoning process of a human expert, so that if faced with the same problem in a specific area of study, both the human expert and the system would reach a similar conclusion. In order for an expert system to do that, it should contain a large enough base of knowledge so that, if given some information, it would be able to decide on the best solution to the problem. The knowledge stored in the system is mainly obtained from literature and experts through a knowledge acquisition process (described in Volume I) and structured as fault tree models (described in Volume II).

Many of the early expert systems were developed using computer languages like LISP (List Processing) and PROLOG (programming logic language); however, these programs required a great deal of computer programming knowledge in the field of AI. This made it difficult for professionals in other areas to develop expert systems. Furthermore, the implementation of a program with these languages meant the misuse of the programmer's efforts, since facilities like help screens and forward and backward chaining inference mechanisms had to be developed from scratch for each system.

Nowadays, expert systems are developed with the help of expert system "shells" which can be regarded as "a reasoning system out of which all the knowledge has been emptied" [Parsaye and Chignell 1988]. An expert system is created once the base of knowledge about a specific domain has been coded and input into the shell. A good expert shell should provide the facilities to assist the developer in the creation of the knowledge base, contain an inference mechanism to control the reasoning process, and include a user interface mechanism to support the users' consultation with the expert system by providing the users with explanations and conclusions. Other important factors in the expert system shell are the ease of translation from language into computer code, the flexibility of the program regarding the addition of new facts and rules, and the operating and interfacing time (speed to respond to users' commands).

The use of expert systems has been very popular in all areas of study where human expertise and judgment are required to solve problems. For example, in the medical field, MYCIN was developed at Stanford University [Buchanan and Shortliffe 1984] to help physicians diagnose bacterial infections and prescribe treatments for them, INTERNIST was created to relate symptoms and diseases in internal medicine [Pople 1977], and so on. Expert systems have also been used in areas like chemistry (e.g., DENDRAL [Buchanan and Feigenbaum 1978]) and civil engineering (e.g., HI-RISE [Mather and Fenves 1985] and CONXPRT [AISC 1996]).

2.3 Preliminary Studies in Expert Systems

Numerous expert systems have been developed by the first author in cooperation with other researchers in the past ten years. For brevity only selected systems are highlighted in this section.

Among the first models developed was the Fuzzy Reasoning Expert System (FRES) for assessing the damage level of US Air Force Base protective structures due to bomb blasts [Hadipriono 1986]. FRES consists of independent knowledge bases representing the structural integrity, functionality, and reparability of the structures. These studies were sponsored by the US Air Force Office of Scientific Research [Hadipriono 1986, Hadipriono 1988a]. A FRES knowledge base for structural integrity was first constructed for assessing the integrity of structural components [Hadipriono and Ross 1987, 1988]. Here, structural integrity is defined as the stability or capacity of a structure or its component(s) to perform its intended function. The components of US Air Force Base protective structures are walls and slabs (these protective structures do not have columns). Variables affecting the integrity of these components are deformation, displacement, and/or separation. The damage level is used to measure the extent of damage of the structural components.

Based on the above study, another knowledge base model for functionality was developed [Hadipriono 1988b, 1988c]. In this study, functionality is the intended function of the structure, which is to protect equipment and occupants from blast effects. The variables of functionality included equipment vulnerability, equipment damage level, occupant vulnerability, and occupant level of injury. In the final stage of completing FRES, a knowledge base for the reparability of protective structures was established to assess the structure's damage level [Hadipriono and Ross 1988, 1991]. Here, reparability is defined as the extent of repair required for a damaged structure. In the study, the structure is assumed damaged by the impact of an explosive load and, subsequently, requires repair to restore it to the original or acceptable condition. The variables considered are the amount of repair, repair time, repair cost, and resource availability. The values for the variables in each knowledge base were established based on assessment of experts and our analysis. These values were incorporated into production rules and contained in the knowledge base of FRES. In cases where conflicting rules occurred, fuzzy averaging operations were used to solve the problem. A deductive fuzzy logic, namely, *fuzzy modus ponens* was employed to partially match the user's input to the production rules.

Another prototype expert system by a student of the first author at the Ohio State University is the Expert Erection (EXPERECT) which can be used to determine alternative selection of bridge girder erection method [Sekii 1992]. The development of EXPERECT was motivated by the fact that an erector's experience plays an important role in successfully erecting a precast, prestressed, concrete girder bridge. Commonly, the experienced erector establishes the method and sequence of the erection process heuristically, based on educated guesses, experiential judgment, and assumptions. EXPERECT introduces itself, its scope and limitations, and furnishes the user with substantial help statements; it informs the user as to why and how a particular erection method was chosen; and it furnishes the user with step-by-step recommendations in order to reach interim and final conclusions. In addition, EXPERECT presents the user with an animation of each erection method.

The Basement Failure Diagnosis Expert System (BAFDES) was developed to determine the causes of basement failures in residential buildings in Ohio by a student of the first author [Diaz 1992]. In this study, the signs of basement failures, leading to the causes of basement failures were classified. These signs were evaluated in relation to soil movement on basement walls and floor slab, lateral forces on basement walls, and chemical and physical reactions on the concrete. Examples of failure signs included flexural deformation of basement structural components, cracking due to shear or flexural stresses, excessive vertical settlements, and moisture movement through the walls. The causes of basement failures were classified into pre- and post-construction causes. Pre-construction causes emphasized errors in design and construction; while post-construction dealt with soil movement during occupancy. The system was built by using LEVEL5 OBJECT Version 2.5, an object-oriented expert system shell which provided all the facilities and functions needed to create an efficient and at the same time user friendly system (e.g., the use of the highly interactive Windows environment and the use of hypermedia--hyperregions and hypertext).

An expert system more related to the research topic of this report (construction falls safety) was developed by Hadipriono [1992a and 1992b]. In this study, a fault tree expert system for construction fall (FTES-FALL) was developed to simulate and investigate unintentional construction falls from floor openings. Fault tree models constructed were used as the knowledge structure for FTES-FALL. The knowledge base accommodates expertise obtained from experts and literature. A step-by-step process in developing the knowledge base was presented. Prompts were designed to lead the user to finding information/evidence needed to reach a conclusion. Parameters were identified and classified, leading to the establishment of frame-subframe relations. Each frame contains production rules that represent the expert knowledge. In addition, abundant help statements were provided to guide the user through the consultation process. The system was built using the Personal PCPlus Version 4.0 expert shell, which provided features needed for the system development like access to an interactive environment, an inference engine, external software, and graphic display ability. Despite these advantages, the system also had some limitations, namely, the use of the restrictive DOS environment by the PCPlus shell and the limited body of knowledge used for its development.

CHAPTER 3

SAFETY FIRST: THE EXPERT SYSTEM

3.1 Introduction

Knowledge acquired and structured for SAFETY FIRST encompassed both heuristic knowledge such as rules of thumb and written knowledge such as codes. This knowledge is stored in the system's knowledge base in the form of facts which describe aspects of the domain knowledge; production rules (IF-THEN rules) which tell the system what information can be obtained from such facts; and the inference engine or inference mechanism (forward or backward chaining), which combines the rules and facts in the knowledge base to reach a conclusion, much the same way experts reach a conclusion from available facts and previous experiences in dealing with similar problems. In order for the system to reach a conclusion, it must have specific information about the domain problem (evidence). This information is obtained from the system's user through the user interface. In addition to obtaining information from the user, the user interface acts as the contact between the expert system and the user; therefore, through it the system's user can get explanations regarding the information required, terms used, or conclusions obtained. The knowledge base, inference mechanism, and user interface form the major components of the architecture of SAFETY FIRST.

3.2 Architecture of SAFETY FIRST

The architecture of SAFETY FIRST was established prior to the development of its knowledge base. As illustrated in Figure III-3.1, it is composed of five components: the knowledge base, the inference engine, the user interface, the external files interface, and the external files. The first four components are contained within the expert system shell selected to develop the system.

3.2.1 Knowledge Base

In the realm of artificial intelligence, Harmon and Sawyer [1990] define knowledge as "an integrated collection of facts and relationships which, when exercised, produces competent performance." It can be classified into procedural knowledge, which is composed of a specific set of steps that can be followed to achieve a specific result, and declarative knowledge, which only concerns the logical or empirical relationships between two or more terms. For example, in conventional data processing, a program would be the procedural knowledge while the data in a database would be the declarative knowledge.

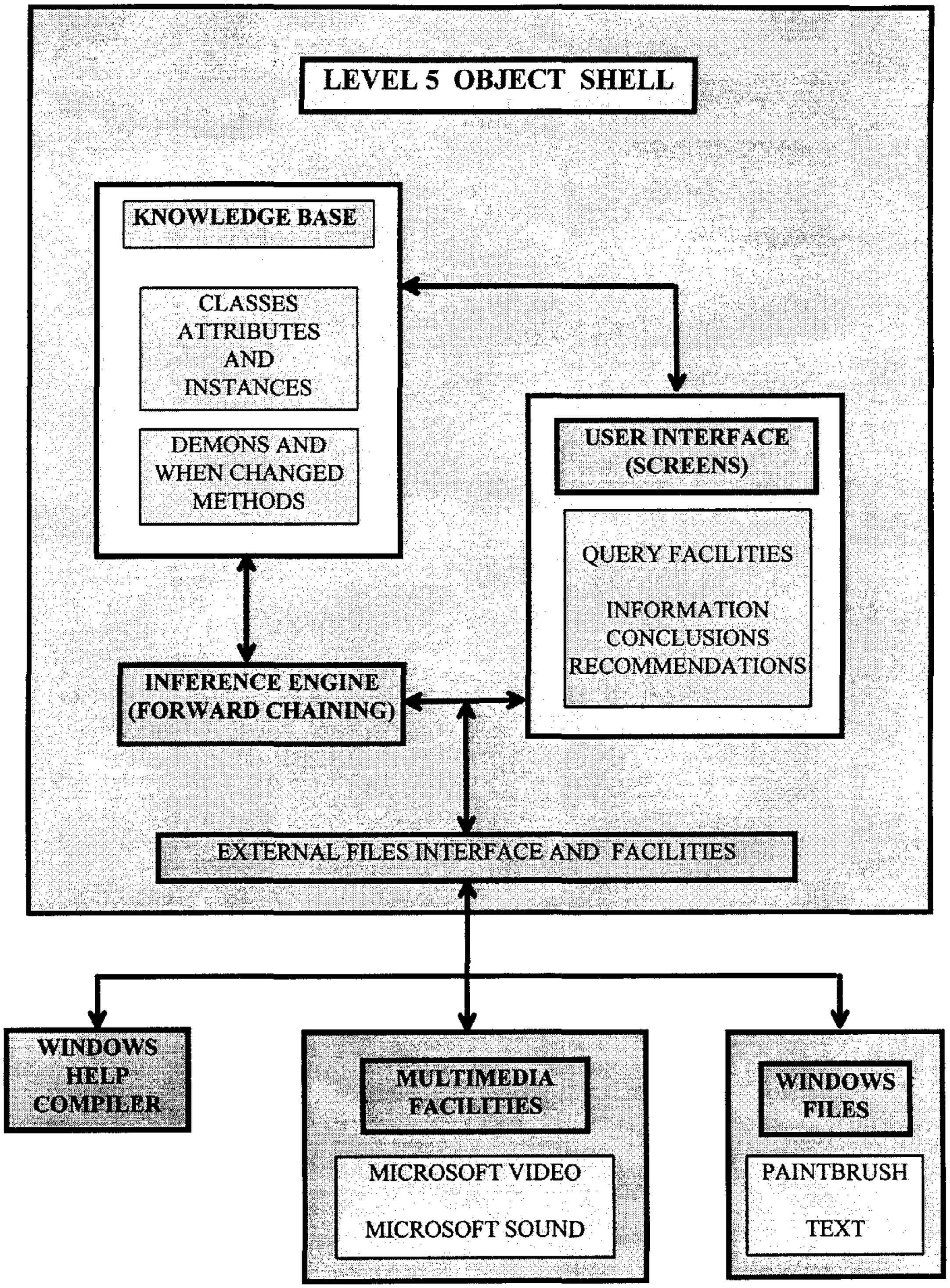


Figure III-3.1. The Architecture of SAFETY FIRST

Declarative knowledge includes both definitional and heuristic knowledge. "Definitional relationships are defined by common agreement about how words are to be used" [Harmon and Sawyer 1990]. On the other hand, a heuristic is a rule-of-thumb that allows the assignment of a value to or a judgment of a variable that would otherwise be unpredictable. Declarative knowledge is used by experts to reach decisions. Therefore, it is also the knowledge used by expert systems to handle complex and vaguely defined problems which conventional programs cannot handle easily.

An expert system usually stores the declarative knowledge in its knowledge base, while the knowledge code that controls its inference and search procedures is kept in an inference engine which actually is "an algorithm that dynamically directs or controls the system when it searches its knowledge base" [Harmon and Sawyer 1990]. This separation of declarative and inference knowledge guarantees that the system can respond in a more flexible manner. Furthermore, it lets the developer focus on getting the declarative knowledge (expert knowledge) that goes in the knowledge base, leaving the development of a specific search strategy to the inference mechanism (provided by expert system shells).

The knowledge base of SAFETY FIRST contains declarative knowledge concerning the causes of construction falls and the process they follow to identify these causes (mainly heuristic knowledge) and written knowledge from literature and codes concerning the minimum requirements for adequacy of a safety device. All of the events and causes are represented as either classes, attributes, or instances in the knowledge base. These classes, attributes, and instances are contained in frames. The logical or empirical relationships among these events or causes are represented in the knowledge base by using either production rules or "demons." In order to facilitate the knowledge base development, the knowledge contained in the fault tree structures discussed in Volume II of this report was converted into decision structures. These structures facilitated the conversion of the knowledge into rules and facts. The knowledge base development process is discussed in more detail in Chapter 4 of this volume.

Depending on the particular attributes of the declarative knowledge, there are several schemes that could be used to represent it in the knowledge base. These schemes could either be used alone or in combination according to the knowledge engineer's needs. In addition, the choice of a method may be restricted by the inference engine available in the expert system shell. The opposite is also true. The choice of a given method may require a specific type of inference engine. The knowledge representation schemes that we used for developing SAFETY FIRST are production rules, frames, and "demons."

3.2.2.1 Production Rules

Rule-based knowledge representation is the most popular tool for coding knowledge into a knowledge base. People tend to express their knowledge in the form of rules. In fact, when explaining their jobs, experts frequently use statements about "what to do" under certain conditions. These statements are represented in terms of "IF (condition) THEN (action)" rules. The "IF" section of the rule is alluded to as the premise, antecedent, or condition side, while the "THEN" section is referred as the conclusion, consequent, or action side. Given a real condition, the inference engine tries to match it with one of the "IF" conditions in the rules of the knowledge base. If this is done then the action on the "THEN" side of the rule occurs. Examples of what the action may implicate are opening and checking other rules, executing certain command(s), and so on.

A rule-based system has the advantage of "being easily modified (modularity) and having a consistent rule-base structure (uniformity). The knowledge engineer can change rules independent of their relationship to other rules. The change may affect the performance of the system but will not affect the knowledge encoded in other rules" [Carrico et al. 1989]. However, if very simple rules are used, they can also be disadvantageous in that a rigid form of representation may result. This problem can be prevented by using a highly modular approach, each rule behaving like an independent piece of knowledge. However, there is an inverse relationship between a program's flexibility and its running time, high modularity may lead to problems with a program's execution time and vice versa. Furthermore, in large and complex systems that have been updated several times, conflicts between rules may occur in specific cases.

3.2.2.2 Frames or Object-Oriented Knowledge Representation

"A frame is a group of attributes that describes a given object. Each attribute is stored in a slot, which may contain default values, rules, or procedures for changing the values attached to the attributes" [Martin and Oxman 1988]. The procedures in a given slot are executed when the information contained in it are changed.

Each object or frame is a block of data that is more or less independent of any other block of data in the program application. An object contains both data and procedures (methods) belonging to it and pointers to one or more of its parents containing data or procedures that the object can access if necessary. Furthermore, each block of information within the frame is contained in specific slots. Examples of data are attributes typically associated with the object, while methods are ways for the object to request or provide information from other objects.

A very specific property of object-oriented programs is that of "inheritance" which allows objects to acquire or inherit information from other objects to which they are linked. The process works as follows: "when an object receives a 'message' that requests it to provide data about itself, it begins by checking for the necessary data within its 'unique part.' If it fails to find it there, it then checks with its inherited part, thus turning to its parents to see if they contain the data" [Harmon and Sawyer 1990].

Object-oriented systems have the advantage of being simple in grouping data according to its natural properties. By doing this, these systems also provide a way to organize knowledge into modules which can be used without modification in different applications. Given its modularity, the relationship among data within the system will be clearer and therefore easier to maintain.

3.2.2.3 Demons

Also referred to as "When modified" or "When accessed" functions, demons are "functions which are not invoked explicitly, but hibernate until a pre-defined condition occurs. This technique allows one to represent knowledge at a global level without following the protocol of rules within the knowledge system" [Carrico et al. 1989]. It is either a process that runs in the background or a procedure attached to a slot on a frame which can be executed any time the slot's value changes. It has the advantages of allowing knowledge to be stored in modules. It also allows the integration of different knowledge representation and inference mechanisms into one. A specific problem related to this system is that it is hard to understand and implement.

3.2.2 Inference Engine

The inference engine or inference mechanism is responsible for the control and execution of the reasoning strategies used by an expert system. It is the part of the system that does the reasoning. The main goal of the engine is to be able to recognize that a fact in the knowledge base matches a condition in the real world, and lead the system reasoning (i.e., get more information about the real world or produce a conclusion, if any). This reasoning is goal-directed in some way and therefore computations within an inference engine relies on proving goals [Parsaye and Chignell 1988]. Among the reasoning strategies most used in expert systems are the backward and forward chaining schemes.

The backward chaining inference method (sometimes called goal-directed, top-down, or consequent-driven reasoning) starts with a specific fact or hypothesis (goal) to prove and works its way to all the facts or actions that can lead to that goal's occurrence. The system operates from the assumption that the THEN portion of a rule contains the goals to be achieved. Once a rule is chosen, the system goes to the IF section and finds the condition(s) that may lead to the goal.

Also known as data-driven, bottom-up, or antecedent-driven; the forward chaining inference scheme can be thought of as the opposite to backward chaining since it focuses in the IF side of rules rather than their conclusions. In general, this reasoning method goes forward from the facts (on the antecedent or IF side of the rule) to the conclusions they generate along the way. The conversion from fault trees to decision trees has made it easier for us to employ the forward chaining process in developing the knowledge base of SAFETY FIRST. This is especially true since we programmed the knowledge starting from the facts up till the conclusions.

The inference engine interfaces with the user through the user interface in order to get information about the conditions in the construction site at the time of the accident. Next, the inference engine matches these facts with the facts stored in the system's knowledge base. Depending on the stage of the consultation, the system may fire all the rules that match the IF conditions, or may fire the first rule encountered. For example, for the determination of the fall safety system adequacy, the system has to check all of the factors used to determine the system's fitness for use. Therefore, the system will fire all the rules that match the antecedent side of the rule. In contrast, for the investigation of the causes of a fall the system will go through the causes sequentially as designed. As soon as the system identifies a problem according to the user input then it fires the rule that applies.

The inference engine also interacts with the external files interface in order to determine what text, graphics, or multimedia files need to be presented in each display. The file selection depends on the facts being asked from the user at the given display. In addition, the engine allows the user to access the help command from any place in the system.

3.2.3 User Interface

In order to reach a conclusion (causes of a fall accident or potential problems in a construction site), the system needs to know the conditions in the construction site at the time the fall occurred or the current safety conditions in the site being evaluated. This is the main task of the user interface mechanism: prompting the user for the information required to solve a problem. Other tasks of this component are to provide help to the user, to explain why a given conclusion has been reached, and to provide recommendations on how to avoid future fall occurrences. To do this, the user interface has to be able to interact with all the other modules of the system. It interacts with the inference engine and the knowledge base to determine what information should be required from the user. Finally, it interacts with external files to provide a more user-friendly system, including help statements and multimedia capabilities. The user interface design considerations and components included within the program displays are discussed in more detail in Chapter 5 of this volume.

3.2.4 External Files Interface and External Files

Finally, through the external files interface facilities allows the system to read the external files needed during a consultation. The inference engine determines which of these files should be called depending on the information provided or requested by the system's user. At this point, the system uses three types of external files: help files, text files, and bitmap files.

The SAFETY FIRST system uses the windows help compiler to provide users with clear and friendly explanation facilities (the structure of the SAFETY FIRST help file is discussed in Chapter 5). In addition, the system retrieves text files containing the comments used in the displays, and the conclusions and recommendations. Furthermore, all of the inputs within a consultation are stored within text files outside the program; these files are used when the program has to jump from one module to the next or when the user chooses to save a consultation for later reference. All the graphics used inside the program are stored in bitmap files outside the program and are called by the program as they are needed. At this point, the system incorporates limited audio facilities (e.g., a beeper sound when the user tries to continue a consultation without answering the question in the display). However, in the future, in order to make the system even more user-friendly, multimedia facilities like video (using Microsoft Video), and sound (using Microsoft Sound) will be incorporated into the system.

3.3 Implementation Tool

A good expert system shell provides the facilities to assist the developer in the creation of the knowledge base containing the domain specific facts and heuristic knowledge. In addition, it should at least contain inference and user interface mechanisms. The inference mechanism controls the reasoning process of the expert system so that given certain explicit knowledge, it can reach specific conclusions by using varying inference strategies (e.g., backward or forward chaining). The user interface mechanism supports the users' consultation with the expert system by prompting them for the information, displaying and explaining conclusions, and providing other explanation facilities. Other important factors in an expert system shell are the ease of translation from language into computer code, the availability of a debugging tool, and the flexibility of the program regarding the addition of new facts and rules.

Given the factors mentioned above, we decided to use the LEVEL5 v. 3.5 expert system shell (professional edition) to develop SAFETY FIRST [Information Builders 1993, 1993a]. Out of the shells surveyed, this shell proved to be the one within a reasonable price range which fulfilled all of our requirements of providing all the necessary facilities to assist the developer in the construction of the knowledge base, and allowing for the development of a user-friendly program.

The following are some of the properties of the LEVEL5 v. 3.5 shell:

- Windows based environment. The most widely used operating system.
- Simple and easy to understand syntax
- Object-oriented programming
- Designs tools for point and click design
- Library of objects to use in the application
- Debugging tools
- Interface with other windows application programs
- It does not require the user to do memory management
- It allows for the creation of a runtime version of the system

With this shell, the development of SAFETY FIRST's knowledge base was implemented. In the next chapter, restructuring the fault trees into decision trees and the conversion of these trees into IF-THEN rules are presented.

CHAPTER 4
THE KNOWLEDGE BASE

4.1 Introduction

The SAFETY FIRST system's knowledge base was designed so it will first determine the cause or combination of causes leading to a fall accident or slip; and, second, evaluate the conditions in a construction site and determine if existing fall protection conditions are adequate to prevent falls (fall protection device) or protect the worker from injury if a fall occurs (fall arresting system).

With a few exceptions, most falls in a construction site are due to a combination of conditioning causes related to safety problems and basic causes, which are related to the support structure, or the worker and the environment surrounding him or her at the time of the accident. Therefore, a fall investigation system has to consider both of these causes (i.e., conditioning and basic). However, for a site evaluation, the emphasis is on the safety conditions existent in the site at a given time and their adequacy to protect workers from falls. Consequently, the system was structured to evaluate the conditioning causes first and the basic causes next. In this way, the user may use the system to evaluate the physical fall protection facilities and, if he or she wants, ignore the section of the program aimed at the basic cause determination.

As alluded to before, fault trees are useful in illustrating the causality relationships among the causes but often exclude the variables and parameters that exist in the case of a construction fall. A decision structure and knowledge base have been developed for each of the fault trees developed before. For brevity, in this volume, we discuss the knowledge base development process of a floor edge. The decision structures for other knowledge bases are included in Appendix III-D of this volume.

4.2 Decision Structures for a Floor Edge

In general, the system investigates a floor edge fall by first analyzing the conditioning causes of a fall and then the basic causes (Figure III-4.1). However, if the fall is related to the collapse of the supporting structure (this fact would be easily recognizable after a forensic visit to the site), there is no need to investigate the conditioning causes of fall. Therefore, the first question asked by the system is whether or not the fall is due to the floor collapse. If it is, the system will determine in general terms if the main cause of the floor collapse was due to a floor triggering (FEBas 1), floor enabling (FEBas 2), joist triggering (FEBas 3), joists enabling (FEBas 4), or joists support related (FEBas 5). If the user knows the fall was due to the floor collapse, but cannot determine the specific cause leading to the floor failure, then the system will indicate this fact (FEBas 6).

If the floor collapse was not a factor in the fall or a fall safety investigation is being conducted, the system will proceed to ask whether or not there was any fall protection device in the site when the fall occurred. If the answer to this question is "no," then such a problem is considered a conditioning cause of the fall (Con 1) and the system will proceed to evaluate the basic causes. On the other hand, if the answer to the question is "yes," then the system will ask the user to select from a list of devices used on the floor edge and then will proceed to analyze their adequacy.

The following fall protection devices have been deemed adequate to protect the worker around a floor edge: a standard guardrail, a catch platform, a fall arrest system, a safety net system, a warning line system, and a Controlled Access Zone (CAZ). These devices are analyzed in the order listed, which is also the order in which they are preferred or used in construction sites. The guardrail system is the most desirable because it doesn't require the active participation of the worker for its success in preventing falls and its ease of erection. In contrast to belt and body harness systems, which require worker involvement and depend on several components working together for its success. Therefore, once the user has indicated that a fall protection/prevention device was being used in the site, the system will check if that system is a guardrail; if it is, then the system it will proceed to evaluate its adequacy. If it is not, then it will check whether the device installed is a warning line system. If the answer is "yes," the system will evaluate its adequacy, otherwise it will go on to the catch platform system and so on until the CAZ is reached. In case none of the listed fall protection devices is the one provided on the site, the system also provides the "other" option which allows the user to specify the device and analyze its adequacy according to OSHA standards.

There are some limitations in the combination of devices that may be used at the same time. The guardrail and catch platform systems cannot be selected at the same time given that they perform the same function (i.e., the catch platform's guardrail acts as a fall protection system). Similarly, a catch platform and a safety net cannot be erected to protect the same floor edge due to space limitations. The controlled access zone can only be used when none of the other devices can be used and therefore, if this device is used, then none of the others is chosen. Finally, if the other device option is chosen, the system assumes that none of the other options provided apply. These constraints are reflected in the decision structure developed.

If the guardrail system is installed, then the system will proceed to analyze it. The first question asked of the user is whether any of the guardrail's regular components is missing and to identify any problematic condition according to the Decision Table III-4.1. If the user indicates that both the top and middle rails are missing in the guardrail system, the system will indicate that without those components there is no guardrail and the user should go back and indicate so. The lack of a top rail is a significant problem because without it the guardrail is not high enough to be able to prevent the worker from falling (Prob 1). The lack of an intermediate rail is significant because the space between the top rail and the ground is too large and the worker may fall through it (Prob 2). The lack of posts is significant because the rails at the mid point may not be high enough to prevent the worker fall (due to sag at mid-point). In addition, depending on the material, the lack of support every 8 feet (2.4 m) may reduce the strength resistance of the rail (Prob 3). Finally, the lack of toeboard is significant if the basic cause of a fall was a worker slip. In such a case, the worker may slide under the middle rail and fall due to the lack of this barrier (Prob 4).

Decision Table III-4.1 Guardrail components missing

Top Rail	Mid-Rail	Posts	Toe Board	Conclusion
x	x	x	x	no guardrail
x	x	x		no guardrail
x		x	x	Prob 3, Prob 4
x	x		x	no guardrail
	x	x	x	Prob 2, Prob 3, Prob 4
x	x			no guardrail
x		x		Prob 1, Prob 3
x			x	Prob 1, Prob 4
	x	x		Prob 2, Prob 3
	x		x	Prob 2, Prob 4
		x	x	Prob 3, Prob 4
x				Prob 1
	x			Prob 2
		x		Prob 3
			x	Prob 4
				o.k.

Next, the system will ask the user about the top and middle rail elevations, which should be 42 +/- 3 inches (1100 +/- 80 mm) and 21 +/- 1.5 inches (550 +/- 40 mm) in order to be able to stop a worker from falling. In this case if the top rail is too low (less than 39 inches or 1.02 m high) the worker may trip over the rail and fall (Prob 6). Furthermore, if the top rail is too high (above 45 inches or 1.18 m high), there are two possible problems: the space between the top and mid rail is too large (Prob 7) or the space between the mid-rail and toeboard/ground is too large (Prob 8). In either case the worker may fall through the opening. The final case is if the top rail elevation is adequate but the mid-rail is too low (Prob 7) or too high (Prob 8). All of these combinations are portrayed in Decision Table III-4.2. The system's next question regards the posts spacing (Decision Table III-4.3). If the spacing is less than 8.5 feet (2.6 m), it is adequate. Otherwise, the spacing is too large and sagging and strength problems may occur (Prob 9).

Decision Table III-4.2 Guardrail elevations

Top Rail	Mid-Rail	Conclusion
42 +/- 3 inches (1100 +/- 80 mm)	21 +/- 3 inches (550+/- 40 mm)	o. k.
42 +/- 3 inches (1100 +/- 80 mm)	> 21 + 3 inches (> 550 + 40 mm)	Prob 7
42 +/- 3 inches (1100 +/- 80 mm)	< 21 - 3 inches (< 550 - 40 mm)	Prob 8
> 42 + 3 inches (> 1100 + 80 mm)	21 +/- 3 inches (550 +/- 40 mm)	Prob 7
> 42 + 3 inches (> 1100 + 80 mm)	> 21 + 3 inches (> 550 + 40 mm)	Prob 8
> 42 + 3 inches (> 1100 + 80 mm)	< 21 - 3 inches (< 550 - 40 mm)	Prob 7
< 42 - 3 inches (< 1100 - 80 mm)	21 +/- 3 inches (550 +/- 40 mm)	Prob 6
< 42 - 3 inches (< 1100 - 80 mm)	> 21 + 3 inches (> 550 + 40 mm)	Prob 6
< 42 - 3 inches (< 1100 - 80 mm)	< 21 - 3 inches (< 550 - 40 mm)	Prob 6

Decision Table III-4.3 Post spacing

Post Spacing	Conclusion
< 8 - 0.5 ft (2.4 -.2 m)	o.k.
> 8 + 0.5 ft (2.4 +.2 m)	Prob 9

Subsequently, the system starts to evaluate the guardrail strength. To do this, the system uses the type of material used and the cross-section or diameter of the top and middle rails and the posts. Therefore, if the material used to build the guardrail is wood the cross-sectional measures of the top rail should be at least 2 x 4 inches (50 x 100 mm) and the cross section of the mid-rail should be at least 1 x 6 inches (25 x 150 m). If the size of any of these component sections is smaller than the one specified, the undersized component of the system is not strong enough to support the worker impact (Prob 10 and Prob 12). All of the possible decisions are depicted in Decision Tables III-4.4 and III-4.5.

If the material used to build the guardrail is pipe (Decision Table III-4.6), then the diameter of the rail cross section should be at least 1.5 inches (40 mm) for all the components (top and middle rails, and posts). If this diameter is less than that, then the system's strength will be inadequate (Prob 12).

If L-shaped structural steel is used to build the guardrail, then the cross section should be at least 2 x 2 x 0..375 inches (50x50x11 mm) in order to be strong enough to support a worker impact load and prevent him from falling. This lack of strength, if present, will be considered a conditioning cause of a fall (Prob 13) and may occur in the different forms depicted in Decision Table III-4.7.

If the material used for the rails is wire rope, then we know that this material complies with the strength standards set by OSHA and so the system will go on to evaluate the posts materials. Furthermore, if the materials used for the rails are made up of steel or plastic bands, it is already known that these materials are not adequate to for fall protection; therefore, the system will conclude that their use is a problem (Prob 14). If none of the previously named materials was the one used for the guardrail, the user is allowed to indicate the material used and determine if it complies with strength requirements. The top rail should be able to withstand with a minimum deflection a load of 200 pounds (890 N), while the intermediate rail should be able to stand a load of 150 pounds (666 N) without breaking. Based on these requirements the user can judge the guardrail and reach a conclusion regarding its adequacy (Decision Table III-4.8).

Decision Table III-4.4 Wood top rail cross section

Width	Height	Conclusion
2 inches (50 mm)	4 inches (100 mm)	o.k.
2 inches (50 mm)	< 4 inches (< 100 mm)	Prob 10
2 inches (50 mm)	> 4 inches (> 100 mm)	o.k.
< 2 inches (< 50 mm)	4 inches (100 mm)	Prob 10
< 2 inches (< 50 mm)	< 4 inches (< 100 mm)	Prob 10
< 2 inches (< 50 mm)	> 4 inches (> 100 mm)	Prob 10
> 2 inches (> 50 mm)	4 inches (100 mm)	o.k.
> 2 inches (> 50 mm)	< 4 inches (< 100 mm)	Prob 10
> 2 inches (> 50 mm)	> 4 inches (> 100 mm)	o.k.

Decision Table III-4.5 Wood mid-rail cross section

Width	Height	Conclusion
1 inch (25 mm)	6 inches (150 mm)	o.k.
1 inch (25 mm)	< 6 inches (< 150 mm)	Prob 11
1 inch (25 mm)	> 6 inches (> 150 mm)	o.k.
< 1 inch (< 25 mm)	6 inches (150 mm)	Prob 11
< 1 inch (< 25 mm)	< 6 inches (< 150 mm)	Prob 11
< 1 inch (< 25 mm)	> 6 inches (> 150 mm)	Prob 11
> 1 inch (> 25 mm)	6 inches (150 mm)	o.k.
> 1 inch (> 25 mm)	< 6 inches (< 150 mm)	Prob 11
> 1 inch (> 25 mm)	> 6 inches (> 150 mm)	o.k.

Decision Table III-4.6 Pipe rail diameter

Diameter (In)	Conclusion
1.5 inches (40 mm)	o.k.
< 1.5 inches (< 40 mm)	Prob 12
> 1.5 inches (> 40 mm)	o.k.

Decision Table III-4.7 L-shaped steel rails

Width	Height	Depth	Conclusion
2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 13
2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 13
2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
< 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	< 2 inches (5 mm)	> 0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
< 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 13
> 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
> 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 13
> 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
> 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 13
> 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 13
> 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.

Decision Table III-4.8 Other material rails

Rail Material up to Strength Standards	Conclusion
Yes	o.k.
No	Prob 15
Don't know	o.k.

As for the guardrail post materials, their strength is evaluated in the same way. If wood is being used, then the post's cross-section should be at least two by four inches (50x100 mm) (Decision Table III-4.9). If the cross-section is smaller than that, then the posts are deemed inadequate (Prob 16). For posts made of pipe material (Decision Table III-4.10), as long as the pipe diameter is more than 1.5 inches (40 mm) the posts are adequate; otherwise, it will fail strength requirements (Prob 17). Further, if the posts material is L-shaped structural steel (Decision Table III-4.11), the posts will fail to be adequate if their cross sectional measures are smaller than 2x2x0.375 inches (50x50x11 mm) (Prob 18). Finally, if any other material is used (Decision Table III-4.12), the posts should be able to withstand a 200 pound (890 N) load. Failure to do so, will be deemed a strength problem (Prob 19).

Finally, the system will evaluate whether the guardrail components are secured well to each other and to the working surface (Decision Tables III-4.13 and III-4.14) and whether these components were in good condition or showed any signs of rust, corrosion, wear, etc. (Decision Table III-4.15).

Decision Table III-4.9 Wood posts cross section

Width	Height	Conclusion
2 inches (50 mm)	4 inches (100 mm)	o.k.
2 inches (50 mm)	< 4 inches (< 100 mm)	Prob 16
2 inches (50 mm)	> 4 inches (> 100 mm)	o.k.
< 2 inches (< 50 mm)	4 inches (100 mm)	Prob 16
< 2 inches (< 50 mm)	< 4 inches (< 100 mm)	Prob 16
< 2 inches (< 50 mm)	> 4 inches (> 100 mm)	Prob 16
> 2 inches (> 50 mm)	4 inches (100 mm)	o.k.
> 2 inches (> 50 mm)	< 4 inches (< 100 mm)	Prob 16
> 2 inches (> 50 mm)	> 4 inches (> 100 mm)	o.k.

Decision Table III-4.10 Pipe posts diameter

Diameter	Conclusion
1.5 inches (40 mm)	o.k.
< 1.5 inches (< 40 mm)	Prob 17
> 1.5 inches (> 40 mm)	o.k.

Decision Table III-4.11 L-shaped steel posts

Width	Height	Depth	Conclusion
2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 18
2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 18
2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
< 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
< 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 18
> 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
> 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 18
> 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
> 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 18
> 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 18
> 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.

Decision Table III-4.12 Other material posts

Posts Material up to Strength Standards	Conclusion
Yes	o.k.
No	Prob 19
Don't know	o.k.

Decision Table III-4.13 Rails secured to posts

Rails well secured to posts	Conclusion
Yes	o.k.
No	Prob 20
Don't know	o.k.

Decision Table III-4.14 Posts secured to surface

Posts well secured to surface	Conclusion
Yes	o.k.
No	Prob 21
Don't know	o.k.

Decision Table III-4.15 Guardrail components wear

Guardrail components show signs of wear or fatigue	Conclusion
Yes	o.k.
No	Prob 22
Don't know	o.k.

After this, the guardrail evaluation is completed and the system will proceed to evaluate either another safety device adequacy (if more than one fall protection device was being used) or the basic causes.

If the fall protection device installed is a catch platform, the system will ask the user to indicate the horizontal distance between the catch platform inner edge and the floor edge. If this distance is more than one ft (304.7 mm), then the distance will be considered too large, given that a worker may fall through it (Prob 23)

Next, the system will inquire about the position of the catch platform floor with respect to the working surface floor (Decision Table III-4.17). If the CP's floor is at a level above the one of the work surface, the worker may trip on it (Prob 24). If it is below it, then a distracted worker may also trip due to the sudden level change (Prob 25). If both floors are at the same level, then the catch platform erection is adequate in that aspect.

Decision Table III-4.16 Distance to edge

Horizontal distance between CP and floor edge	Conclusion
Less than 1 ft (304 mm)	o.k.
Larger than or equal to 1 (304 mm)	Prob 23

Decision Table III-4.17 Catch platform location

CP floor location with respect to the working area floor	Conclusion
Above	Prob 24
Below	Prob 25
Same level	o.k.

Next, the system will ask the user if the platform was installed according to OSHA standards and the manufacturers specifications. If it is not, the structure may fail to perform its functions (Prob 26). The strength of the structure is also checked. The platform should be able to withstand four times the maximum load that will be applied to it. If the system fails to do so, it will be deemed to have a strength problem (Prob 27). Related to the platform's strength is the strength of its floor, if the floor is not made up of scaffold grade wood or metal sheet, it may not be strong enough and therefore likely to fail (Prob 28). Finally, if the platform components showed some signs of wear or fatigue, then it may fail under unexpected loads (Prob 29).

Decision Table III-4.18 Catch platform installation

CP installed according to manufacturers specifications	Conclusion
Yes	o.k.
No	Prob 26
Don't know	o.k.

Decision Table III-4.19 Catch platform strength

Catch platform strength adequate	Conclusion
Yes	o.k.
No	Prob 27
Don't know	o.k.

Decision Table III-4.20 Catch platform floor materials

CP's floor made of scaffold grade wood or metal sheet	Conclusion
Yes	o.k.
No	Prob 28
Don't know	o.k.

Decision Table III-4.21 Catch platform components wear

CP components show signs of wear or fatigue	Conclusion
Yes	Prob 29
No	o.k.
Don't know	o.k.

Given that the catch platform has to perform the same functions as the guardrail system, the next step is to evaluate the catch platform's guardrail. The lack of a guardrail system in the platform is considered a conditioning problem (Prob 30) that may lead to a fall accident. If a guardrail is installed to protect the catch platform, it will be evaluated for the same conditions, the guardrail system for a working surface edge was evaluated. Therefore, the individual decision making factors will not be discussed again here. However, they are portrayed in Decision Tables III-4.22 to III-4.36.

Decision Table III-4.22 CP's guardrail components missing

Top Rail	Mid-Rail	Posts	Toe Board	Conclusion
x	x	x	x	no guardrail
x	x	x		no guardrail
x		x	x	Prob 31, Prob 32
x	x		x	no guardrail
	x	x	x	Prob 32 , Prob 33, Prob 34
x	x			no guardrail
x		x		Prob 31, Prob 33
x			x	Prob 31, Prob 34
	x	x		Prob 32, Prob 33
	x		x	Prob 32, Prob 34
		x	x	Prob 33, Prob 34
x				Prob 31
	x			Prob 32
		x		Prob 33
			x	Prob 34
				o.k.

Decision Table III-4.23 CP's guardrail rail elevations

Top Rail	Mid-Rail	Conclusion
42 +/- 3 inches (1100 +/- 80 mm)	21 +/- 3 inches (550 +/- 40 mm)	o. k.
42 +/- 3 inches (1100 +/- 80 mm)	> 21 + 3 inches (> 550 + 40 mm)	Prob 36
42 +/- 3 inches (1100 +/- 80 mm)	< 21 - 3 inches (< 550 - 40 mm)	Prob 37
> 42 + 3 inches (> 1100 + 80 mm)	21 +/- 3 inches (550 +/- 40 mm)	Prob 36
> 42 + 3 inches (> 1100 + 80 mm)	> 21 + 3 inches (> 550 + 40 mm)	Prob 37
> 42 + 3 inches (> 1100 + 80 mm)	< 21 - 3 inches (< 550 - 40 mm)	Prob 36
< 42 - 3 inches (< 1100 - 80 mm)	21 +/- 3 inches (550 +/- 40 mm)	Prob 35
< 42 - 3 inches (< 1100 - 80 mm)	> 21 + 3 inches (> 550 + 40 mm)	Prob 35
< 42 - 3 inches (< 1100 - 80 mm)	< 21 - 3 inches (< 550 - 40 mm)	Prob 35

Decision Table III-4.24 CP's guardrail post spacing

Post Spacing	Conclusion
< 8 - 0.5 ft (2.4 -.2 m)	o.k.
> 8 + 0.5 ft (2.4 +.2 m)	Prob 9

Decision Table III-4.25 CP's guardrail wood top rail cross section

Width	Height	Conclusion
2 inches (50 mm)	4 inches (100 mm)	o.k.
2 inches (50 mm)	< 4 inches (< 100 mm)	Prob 39
2 inches (50 mm)	> 4 inches (> 100 mm)	o.k.
< 2 inches (< 50 mm)	4 inches (100 mm)	Prob 39
< 2 inches (< 50 mm)	< 4 inches (< 100 mm)	Prob 39
< 2 inches (< 50 mm)	> 4 inches (> 100 mm)	Prob 39
> 2 inches (> 50 mm)	4 inches (100 mm)	o.k.
> 2 inches (> 50 mm)	< 4 inches (< 100 mm)	Prob 39
> 2 inches (> 50 mm)	> 4 inches (> 100 mm)	o.k.

Decision Table III-4.26 CP's guardrail wood mid-rail cross section

Width (in)	Height (in)	Conclusion
1 inch (25 mm)	6 inches (150 mm)	o.k.
1 inch (25 mm)	< 6 inches (< 150 mm)	Prob 40
1 inch (25 mm)	> 6 inches (> 150 mm)	o.k.
< 1 inch (< 25 mm)	6 inches (150 mm)	Prob 40
< 1 inch (< 25 mm)	< 6 inches (< 150 mm)	Prob 40
< 1 inch (< 25 mm)	> 6 inches (> 150 mm)	Prob 40
> 1 inch (> 25 mm)	6 inches (150 mm)	o.k.
> 1 inch (> 25 mm)	< 6 inches (< 150 mm)	Prob 40
> 1 inch (> 25 mm)	> 6 inches (> 150 mm)	o.k.

Decision Table III-4.27 CP's guardrail pipe rail diameter

Diameter	Conclusion
1.5 inches (40 mm)	o.k.
< 1.5 inches (< 40 mm)	Prob 41
> 1.5 inches (> 40 mm)	o.k.

Decision Table III-4.28 CP's guardrail L-shaped steel rails

Width	Height	Depth	Conclu sion
2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 42
2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 42
2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
< 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
< 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 42
> 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
> 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 42
> 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
> 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 42
> 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 42
> 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.

Decision Table III-4.29 CP's guardrail other material rails

Rail Material up to Strength Standards	Conclusion
Yes	o.k.
No	Prob 43
Don't know	o.k.

Decision Table III-4.30 CP's guardrail wood posts cross section

Width	Height	Conclusion
2 inches (50 mm)	4 inches (100 mm)	o.k.
2 inches (50 mm)	< 4 inches (< 100 mm)	Prob 44
2 inches (50 mm)	> 4 inches (> 100 mm)	o.k.
< 2 inches (< 50 mm)	4 inches (100 mm)	Prob 44
< 2 inches (< 50 mm)	< 4 inches (< 100 mm)	Prob 44
< 2 inches (< 50 mm)	> 4 inches (> 100 mm)	Prob 44
> 2 inches (> 50 mm)	4 inches (100 mm)	o.k.
> 2 inches (> 50 mm)	< 4 inches (< 100 mm)	Prob 44
> 2 inches (> 50 mm)	> 4 inches (> 100 mm)	o.k.

Decision Table III-4.31 CP's guardrail pipe posts diameter

Diameter (In)	Conclusion
1.5 inches (40 mm)	o.k.
< 1.5 inches (< 40 mm)	Prob 45
> 1.5 inches (> 40 mm)	o.k.

Decision Table III-4.32 CP's guardrail L-shaped steel posts

Width	Height	Depth	Conclusion
2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 46
2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 46
2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
< 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
< 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 46
> 2 inches (50 mm)	2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
> 2 inches (50 mm)	2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	< 2 inches (50 mm)	0.375 inches (11 mm)	Prob 46
> 2 inches (50 mm)	< 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
> 2 inches (50 mm)	< 2 inches (50 mm)	> 0.375 inches (11 mm)	Prob 46
> 2 inches (50 mm)	> 2 inches (50 mm)	0.375 inches (11 mm)	o.k.
> 2 inches (50 mm)	> 2 inches (50 mm)	< 0.375 inches (11 mm)	Prob 46
> 2 inches (50 mm)	> 2 inches (50 mm)	> 0.375 inches (11 mm)	o.k.

Decision Table III-4.33 CP's guardrail other material posts

Posts Material up to Strength Standards	Conclusion
Yes	o.k.
No	Prob 47
Don't know	o.k.

Decision Table III-4.34 CP's guardrail rails secured to posts

Rails well secured to posts	Conclusion
Yes	o.k.
No	Prob 48
Don't know	o.k.

Decision Table III-4.35 CP's guardrail posts secured to platform

Posts well secured to platform	Conclusion
Yes	o.k.
No	Prob 49
Don't know	o.k.

Decision Table III-4.36 CP's guardrail components wear

Guardrail components show signs of wear or fatigue	Conclusion
Yes	Prob 50
No	o.k.
Don't know	o.k.

Fall arrest systems can be grouped into the following: vertical lifeline and lanyard, horizontal lifeline, and self-retracting lines. The system will analyze the one that is being used in the site. For a vertical lifeline and lanyard, the first factor considered is the falling distance allowed by the system and the distance to the ground or the closest surface (Decision Table III-4.37). If the falling distance is above 6 feet (1.8 m) the risk of injury is too great (Prob 51). In addition, if the falling distance allowed by the system is larger than the distance to the nearest surface, then the fall arrest usefulness will be defeated given that the worker will impact this surface (Prob 52). Next, the system will check the system's anchorage point strength (Decision Table III-4.38). The anchor has to be able to withstand a load of 5000 pounds (22.2 kN) per employee attached (Prob 53) and no guardrails or hoists devices should be used as anchors (Prob 54). Furthermore, the system lifelines and lanyard should be able to withstand a load of 5000 pounds (22.2 kN) (Decision Table III-4.39) and the deerings and snaphooks a load of 3600 pounds (16 kN) (Decision Table III-4.40). If locking snaphooks are not being used, then there is a risk that the snaphook will accidentally open, especially if certain given conditions occur in the system (Decision Table III-4.41). Furthermore, if the fall arrest force is larger than 1800 pounds (8 kN) and the deceleration distance is larger than 3.5 feet (1.07 m), the worker may be injured (Prob 62). Finally, the system will check for wear and fatigue (Decision Table III-4.43).

If the fall arrest system is a horizontal lifeline the system will still check the distance to the ground and falling distance (Decision Table III-4.37), whether the horizontal line was designed and installed under engineering supervision (Decision Table III-4.44), the line and lanyard strength (Decision Table III-4.39), the use of locking snaphooks (Decision Table III-4.45) the fall arrest force and deceleration distance (Decision Table III-4.42), and the wear and fatigue of the system's components (Decision Table III-4.43).

If the fall arrest system is a self-retracting line, the system will still check the free falling distance allowed by the system (Decision Table III-4.46), the line strength (Decision Table III-4.39), the deerings and snaphooks strength, the locking snaphook conditions (Decision Table III-4.41) the fall arrest force and deceleration distance (Decision Table III-4.42), and the wear and fatigue of the system's components (Decision Table III-4.43).

Decision Table III-4.37 Fall arrest falling distance

Fall arrest falling distance	Conclusion
Larger than 6 ft (1.8 m)	Prob 51
Larger than distance to ground or nearest surface	Prob 52
Less than 6 ft (1.8 m)	o.k.

Decision Table III-4.38 Fall arrest anchorage point

Anchorage Point	Conclusion
can withstand 5000 pounds (22.2 kN)	o.k.
cannot withstand 5000 pounds (22.2 kN)	Prob 53
guardrail and hoist device used as anchor	Prob 54

Decision Table III-4.39 Fall arrest lifeline and lanyard strength

Lifeline and lanyard strength larger than 5000 pounds (22.2 kN)	Conclusion
Yes	o.k.
No	Prob 55
Don't know	o.k.

Decision Table III-4.40 Fall arrest deerings and snaphooks strength

Deerings and snaphooks can withstand a 3600 lbs (16 kN) load	Conclusion
Yes	o.k.
No	Prob 56
Don't know	o.k.

Decision Table III-4.41 Fall arrest snaphook conditions

Snaphooks conditions	Conclusion
Snaphook sizes not compatible with connected members	Prob 57
Snaphooks connected directly to webbing or rope or wire rope	Prob 58
Snaphooks connected to each other	Prob 59
Two snaphooks connected to the same deering	Prob 60
Snaphook connected to a horizontal lifeline	Prob 61

Decision Table III-4.42 Fall arrest force and deceleration distance

Force and deceleration distance smaller than 1800 pound (8 kN) and 3.5 feet (1.07 m)	Conclusion
Yes	o.k.
No	Prob 62
Don't know	o.k.

Decision Table III-4.43 Fall arrest components wear

Did the system components showed any signs of wear	Conclusion
Yes	Prob 62
No	o.k.
Don't know	o.k.

Decision Table III-4.44 Fall arrest horizontal lifeline installation

Lifeline designed and installed under engineer supervision	Conclusion
Yes	o.k.
No	Prob 63
Don't know	o.k.

Decision Table III-4.45 Fall arrest horizontal lifeline locking snaphooks

Locking snaphooks used for horizontal lifeline	Conclusion
Yes	o.k.
No	Prob 64
Don't know	o.k.

Decision Table III-4.46 Fall arrest self-retracting line free falling distance

Did the device limit the worker's free fall to less than 2 feet (0.61 m)	Conclusion
Yes	o.k.
No	Prob 65
Don't know	o.k.

If a safety net system was installed, the program will check the falling distance to the net and the net's outward extension (Decision Table III-4.47). If the falling distance is less than five feet (1.5 m), then the outward extension should be eight feet (2.4 m). If the falling distance is between 5 and 10 feet (1.5 and 3 m), then the extension should be at least 10 feet (3 m). Finally, if the falling distance is between 10 and 30 feet (3 and 9.1 m), the extension should be 13 feet (3.96 m). If the falling distance is larger than thirty feet (9.1 m), it is considered a problem because the worker may injure itself even if falling into the net.

Next, the system will ask the user about whether the clearance underneath the net is adequate to prevent the net from hitting the ground or nearest surface (Decision Table III-4.48). The program also checks whether debris is regularly cleared from the net (Decision Table III-4.49). If the user answers that the net is not cleared regularly, this is considered a problem which may result in workers injuries (Prob 68). After that, the program evaluates whether the net was fastened well to its supports and its panels well connected to each other (Decision Tables III-4.50 and III-4.51). Otherwise the net or one of its sections may fall apart under the falling worker impact. Finally, the system checks if the original net materials were strong enough to support the worker impact (Decision Table III-4.21) and if they are still strong enough or they show any signs of wear, break down, or fatigue (Decision Table III-4.22).

Decision Table III-4.47 Safety net distances

Vertical distance from surface to net	Safety net outward extension (ft)	Conclusion
< 5 ft (1.5 m)	> 8 ft (2.4 m)	o.k.
< 5 ft (1.5 m)	<= 8 ft (2.4 m)	Prob 66
5 - 10 ft (1.5 - 3 m)	> 10 ft (3 m)	o.k.
5 - 10 ft (1.5 - 3 m)	<= 10 ft (3 m)	Prob 66
10 - 30 ft (3 - 9.1 m)	> 13 ft (3.96 m)	o.k.
10 - 30 ft (3 - 9.1 m)	<= 13 ft (3.96 m)	Prob 66
> 30 ft (9.1 m)	----	Prob 67

Decision Table III-4.48 Safety net debris

Safety Net debris cleared regularly from net	Conclusion
Yes	o.k.
No	Prob 68
Don't know	o.k.

Decision Table III-4.49 Safety net clearance

Clearance underneath the net adequate	Conclusion
Yes	o.k.
No	Prob 69
Don't know	o.k.

Decision Table III-4.50 Safety net fastened to support

Safety net well fastened to supports	Conclusion
Yes	o.k.
No	Prob 70
Don't know	o.k.

Decision Table III-4.51 Safety net panels connection

Net panels well connected to each other	Conclusion
Yes	o.k.
No	Prob 71
Don't know	o.k.

Decision Table III-4.52 Safety net strength

Net adequate strength	Conclusion
Yes	o.k.
No	Prob 72
Don't know	o.k.

Decision Table III-4.53 Safety net materials wear

Signs of wear or fatigue	Conclusion
Yes	o.k.
No	Prob 73
Don't know	o.k.

If the fall protection device installed is a warning line system, then the evaluation will start by asking the user the distance from the edge to the warning line and whether or not any mechanical equipment was being operated in the working area (Decision Table III-4.54). If there was equipment, then the line distance should be at least 10 feet (3.5 m). If no equipment was present in the area, then this distance can be reduced to 6 feet (1.8 m). Any time the line distance is below the measures given, the worker may get too close to the edge and fall (Prob 74 and Prob 75).

Furthermore, the warning line elevation (distance from working surface to line) should be between 34 and 39 inches (0.90 and 1.02 m). If the line is too high, it may fail to warn the worker if he or she is getting too close to the edge (Prob 76). In contrast, if it is too low, it may cause the worker to trip (Prob 77). A combination of these two problems may also occur if the line is too high at the stanchions and too low at the sag point (Decision Table III-4.55).

Next, the system will check if the line is attached properly to the stanchions so that no deflection in a section of the line (between two stanchions) will occur if another section is impacted (Decision Table III-4.56). The warning line should also be able to stand a tipping force of at least 16 pounds (71 N) applied horizontally against the stanchion (post) at a height 30 inches (0.8 m) above the working surface. This will assure that the line will provide enough resistance to prevent a distracted worker from going toward the floor edge. The lack of strength is considered a problem with the line (Prob

79). Finally, if any material showed signs of fatigue, it may not be of adequate strength (Prob 80).

Decision Table III-4.54 Warning Line Edge Distance

Equipment Operating on Surface	Distance from Edge to Line (Ft)	Conclusion
No	6 (1.8 m)	o.k.
No	< 6 (1.8 m)	Prob 74
No	> 6 (1.8 m)	o.k.
Yes	10 (3 m)	o.k.
Yes	< 10 (3 m)	Prob 75
Yes	>10 (3 m)	o.k.

Decision Table III-4.55 Warning line elevations

Lowest Point Elevation	Highest Point Elevation	Conclusion
34 - 39 inches (900 - 1020 mm)	34 - 39 inches (900 - 1020 mm)	o.k.
34 - 39 inches (900 - 1020 mm)	< 34 inches (< 900 mm)	Error Message
34 - 39 inches (900 - 1020 mm)	> 39 (> 1020 mm)	Prob 76
< 34 inches (< 900 mm)	34 - 39 inches (900 - 1020 mm)	o.k.
< 34 inches (< 900 mm)	< 34 inches (< 900 mm)	Prob 76
< 34 inches (< 900 mm)	> 39 (> 1020 mm)	Prob 76, Prob 77
> 39 (> 1020 mm)	34 - 39 inches (900 - 1020 mm)	Prob 77
> 39 (> 1020 mm)	< 34 inches (< 900 mm)	Error Message
> 39 (> 1020 mm)	> 39 (> 1020 mm)	Prob 76

Decision Table III-4.56 Warning line installation

Adequate Attachment to Stanchions	Conclusion
Yes	o.k.
No	Prob 78
Don't know	o.k.

Decision Table III-4.57 Warning line strength

Adequate strength	Conclusion
Yes	o.k.
No	Prob 79
Don't know	o.k.

Decision Table III-4.58 Warning line materials wear

Signs of wear or fatigue	Conclusion
Yes	o.k.
No	Prob 80
Don't know	o.k.

The controlled access zones (CAZ) are only used when none of the devices discussed above can be used and under certain specific conditions. If none of these conditions is present, the CAZ should not have been used (Decision Table III-4.59). In addition, the distance between the CAZ and the floor edge should be within the ranges allowed by OSHA otherwise, the area enclosed may be too small (Prob 82) or too large (Prob 83). Furthermore, the CAZ should be installed parallel to the edge, should protect the entire edge of the floor, and should be connected at each side to a guardrail or a side wall (Decision Table III-4.61). As with the warning line, the CAZ line should be erected at certain height to be effective (Decision Table III-4.62). If it is too high it may not prevent workers from entering the restricted area. If too low, may cause distracted workers to trip. The system also considers the line strength (Decision Table III-4.63) and the wear or fatigue it shows (Decision Table III-4.64). Finally, if the CAZ is used, a safety monitor should be in the work zone (Prob 89). This monitor should have all employees within visual and audio range (Decision Table III-4.65) and his or her only function should be to monitor the workers safety (Decision Tree 66).

Decision Table III-4.59 CAZ conditions

CAZ conditions	Conclusion
Leading edge work	o.k.
Edge overhand bricklaying work	o.k.
Edge precast concrete erection work	o.k.
Use of conventional fall protection devices was unfeasible	o.k.
Use of conventional fall protection devices was more hazardous	o.k.
None of the above	Prob 81

Decision Table III-4.60 CAZ edge distance

CAZ distance to edge	Conclusion
Too short	Prob 82
Too large	Prob 83
Adequate	o.k.

Decision Table III-4.61 CAZ installation

Adequate CAZ installation	Conclusion
Yes	o.k.
No	Prob 84
Don't know	o.k.

Decision Table III-4.62 CAZ elevations

CAZ elevations	Conclusion
Too high	Prob 85
Too low	Prob 86
Adequate	o.k.

Decision Table III-4.63 CAZ strength

CAZ strength is adequate	Conclusion
Yes	o.k.
No	Prob 87
Don't know	o.k.

Decision Table III-4.64 CAZ wear

CAZ signs of wear or fatigue	Conclusion
Yes	o.k.
No	Prob 88
Don't know	o.k.

Decision Table III-4.65 CAZ monitor range

All employees within monitor visual and audio range	Conclusion
Yes	o.k.
No	Prob 90
Don't know	o.k.

Decision Table III-4.66 CAZ monitor functions

Monitor only function is monitoring employee safety	Conclusion
Yes	o.k.
No	Prob 91
Don't know	o.k.

Decision Table III-4.67 Other fall protection device strength

Adequate lanyard and accessories	Conclusion
Yes	o.k.
No	Prob 92
Don't know	o.k.

Decision Table III-4.68 Other device wear

Signs of wear or fatigue	Conclusion
Yes	o.k.
No	Prob 93
Don't know	o.k.

Finally, if none of the previously listed devices were installed in the site, then the program will allow the user to specify the "other device" option which will be evaluated as to whether the device is adequate according to OSHA standards (Decision Table III-4. 67) and the materials used to build it did not show any defects like corrosion or wear (Decision Table III-4.68).

Once all of the safety devices in the site have been evaluated by the expert system, a preliminary conclusion is reached listing all of the problems identified during the consultation. If the user is only evaluating the fall safety in the site, he or she does not have to continue further. However, if a fall accident is being investigated, then the user must go on to evaluate which of the problems found (if any) was a conditioning cause to the fall accident, and to determine the basic cause of the fall. If no problems were found the system will go on to evaluate the possible basic causes of a fall. If safety problems were detected, the system will evaluate if these problems are a conditioning cause of the fall.

Assuming that problems were identified, the system will start to evaluate the conditioning causes of fall depending on the specific problems identified (Decision Tables 69 to 75). For example, if the system identified that the top rail of the guardrail installed was undersized, then it will ask the user if the guardrail structure was as installed (i.e., did not collapse). If it is, this will confirm that the under sized (under strength) problem was in fact a conditioning cause of the fall. If it did not, then the problem identified was not a conditioning cause of the fall.

Decision Table III-4.69 Guardrail problems

PROBLEMS	YES	NO	CONCLUSION
IF Prob 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22. Guardrail or guardrail component failed under the impact load?	x		Cond 2
IF Prob 1, 6. Guardrail as installed and worker toppled over the top rail?	x		Cond 3
IF Prob 2, 3, 4, 7. Guardrail as installed and worker fell though the space between the top rail and the mid rail?	x		Cond 4
IF Prob 4, 2, 8. Guardrail as installed and worker fell though the space between the top rail and the toeboard or floor?	x		Cond 5
IF Prob 4, 7. Guardrail as installed and worker fell though the space between the mid rail and the toe board or floor?	x		Cond 6

Decision Table III-4.70 Catch platform problems

PROBLEMS	YES	NO	CONCLUSION
IF Prob 23. Worker fell through the opening between the floor edge and the catch platform inner edge?	x		Cond 7
IF Prob 26, 27, 29. Catch platform collapsed under worker impact?	x		Cond 8
IF Prob 28, 29. Catch platform's floor failed under worker impact?	x		Cond 9
IF Prob 30.	x		Cond 10
IF Prob 39, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50. Catch platform's guardrail or guardrail component failed under the impact load?	x		Cond 11
IF Prob 31, 36. Catch platform's guardrail as installed and worker toppled over the top rail?	x		Cond 12
IF Prob 32, 33, 34, 37. Catch platform's guardrail as installed and worker fell though the space between the top rail and the mid rail?	x		Cond 13
IF Prob 34, 32, 38. Catch platform's guardrail as installed and worker fell though the space between the top rail and the toeboard or floor?	x		Cond 14
IF Prob 34, 37. Catch platform's guardrail as installed and worker fell though the space between the mid rail and the toe board or floor?	x		Cond 15

Decision Table III-4.71 Fall arrest problems

PROBLEMS	YES	NO	CONCLUSION
IF Prob 51, 65. Fall injury due to the impact load?	x		Cond 16
IF Prob 53, 54, 55, 56, 62, 63, 65. Fall injury due to the failure of a component of the fall arrest system under the impact load?	x		Cond 17
IF Prob 57, 58, 59, 60, 61, 64. Fall injury due to non-locking snaphooks rolled out?	x		Cond 18

Decision Table III-4.72 Safety net problems

PROBLEMS	YES	NO	CONCLUSION
IF Prob 67.	x		Cond 19
IF Prob 66. Worker momentum carried him or her pass the net?	x		Cond 20
IF Prob 69. Net hit ground after impact deflection?	x		Cond 21
IF Prob 68 Worker hit a piece of scrap material on the net?	x		Cond 22
IF Prob 70, 71, 72, 73. The net or a net component collapsed under the worker impact?	x		Cond 23

Decision Table III-4.73 Warning line problems

PROBLEMS	YES	NO	CONCLUSION
Worker performing a job between the line and floor edge?	x		Cond 24
IF Prob 74, 75, 77 AND Worker performing a job between the line and floor edge is No. Worker tripped on the line?	x		Cond 25
IF Prob 74, 75, 76 AND Worker performing a job between the line and floor edge is No Worker passed underneath the line?	x		Cond 26
IF Prob 74, 75, 78 AND Worker performing a job between the line and floor edge is No. Line deflected under worker impact?	x		Cond 27
IF Prob 74, 75, 79, 80 AND Worker performing a job between the line and floor edge is NO Line collapsed under worker impact?	x		Cond 28
IF Prob 74, 75, 79, 80 AND Worker performing a job between the line and floor edge is NO Line collapsed under material impact?	x		Cond 29
IF Prob 74, 75, 79, 80 AND Worker performing a job between the line and floor edge is NO Line collapsed under equipment impact?	x		Cond 30

Decision Table III-4.74 Controlled access zone problems

PROBLEMS	YES	NO	CONCLUSION
IF Prob 86 AND Worker authorized to be in CAZ is No. Worker tripped on the line?	x		Cond 31
IF Prob 85 AND Worker authorized to be in CAZ is No. Worker passed underneath the line?	x		Cond 32
IF Prob 84 AND Worker authorized to be in CAZ is No. Line deflected under worker impact?	x		Cond 33
IF Prob 87, 88 AND Worker authorized to be in CAZ is No. Line collapsed under worker impact?	x		Cond 34
IF Prob 87, 88 AND Worker authorized to be in CAZ is No. Line collapsed under material impact?	x		Cond 35
IF Prob 87, 88 AND Worker authorized to be in CAZ is No. Line collapsed under equipment impact?	x		Cond 36
IF Prob 81	x		Cond 37
IF Prob 90, 91 AND Worker authorized to be in CAZ is Yes. Worker failed to comply with monitor warnings?	x		Cond 38
IF Prob 90, 91 AND Worker authorized to be in CAZ is Yes. Worker failed to hear monitor warnings?	x		Cond 39
IF Prob 90, 91 AND Worker authorized to be in CAZ is Yes. Monitor failed to warn worker of hazard?	x		Cond 40

Decision Table III-4.75 Other safety device problems

PROBLEMS	YES	NO	CONCLUSION
IF Prob 92	x		Cond 41
IF Prob 93	x		Cond 42

Once all of the fall safety devices have been evaluated, the system will proceed to investigate all of the possible basic causes that may have lead to the fall accident from the floor edge. To begin this evaluation, the system will check if the cause was due to equipment impact. If it is, the system will check whether the equipment and worker operating areas were marked. If they were (FEBas 7) and the worker was within the equipment operating area, then part of the fall responsibility is the worker's. If the worker was not within the equipment operating area, an equipment failure or the equipment operator may have contributed to the fall accident. Further, if the working areas were not marked, then this is a contributing factor to the fall (FEBas 8). Other factors that may have played a role in the accident are the following: poor visibility (FEBas 45), worker distracted (FEBas 46, FEBas 47, and FEBas 48), and worker experience and training (FEBas 49 and FEBas 34).

If the fall was not due to equipment impact, the system will check if the fall was due to falling materials impact. Regarding this cause, the following are the significant factors: was overhead protection provided? (FEBas 9), did the falling material hit the worker on the head? (FEBas 10), if it did, was a hard hat provided to the worker? (FEBas 11), and if it was, was the hard hat worn by the worker at the time of the accident? (FEBas 12 and FEBas 13).

If a basic cause has not been found, the system will check next whether or not the cause of fall was due to another worker impact. If this was the cause of the fall, the system will ask the user to indicate if both workers were supposed to be on the work area (FEBas 14). If they were not, then the worker who was outside his or her work area was one of the factors leading to the fall accident (FEBas 15 and FEBas 16).

If the fall was not due to impact-related problems and the working surface from which the fall occurred was exposed to weather, then the system will check if any weather related factor led to the fall by causing the worker to slip (if there was rain, or snow on the day of the accident {FEBas 17 and FEBas 18}), by causing the worker to collapse due to dehydration (if hot conditions were predominant at the time of the accident {FEBas 19}), or by hitting the worker and directly causing the fall (if there were extremely gusty conditions {FEBas 16}).

Furthermore, if slip hazards like liquid substances (FEBas 22 and FEBas 23) or small materials such as gravel are present on the floor (FEBas 20 and FEBas 21), or if there were excessively sloped surfaces on the floor (FEBas 23 and FEBas 24), then the system will ask the user whether slipping was the primary cause of fall. If it was, then it will check the safety measures implemented (if any) regarding these hazards. If no safety cautions were implemented, then their absence is a contributing factor to the accident.

If the worker did not slip, the system will check if hazards such as sudden changes in elevation (FEBas 26 and FEBas 27), floor holes (FEBas 28 and FEBas 29), tools or materials left on the floor (FEBas 30 and FEBas 31) are present in the site, the system will ask whether they caused the worker to trip. If the answer is yes, these conditions are the basic cause of the fall, even if the proper cautions have been taken to reduce their occurrence.

If none of the factors above led to the fall, then the system will check for the possible enabling causes that may have led to the fall such as health problems which could be chronic (e.g., the worker had an epilepsy attack or any other disease that may have caused him or her to faint or lose physical control of his or her body [FEBas 32]) or acute (e.g., the worker had a heart attack {FEBas 33}). On the other hand, the worker may have collapsed, lost control, or acted irrationally due to his or her being intoxicated with alcohol (FEBas 34) or drugs (FEBas 35). Finally, the worker may have also been drowsy or not as alert as he or she should be due to his or her taking an over-the-counter drug such as a cold medicine (FEBas 36).

In addition, the worker may have failed to notice the fall hazard or that he or she was getting too close to the floor edge due to poor visibility (FEBas 38), his or her being distracted (i.e., due to personal problems {FEBas 41}, extreme weather conditions {FEBas 39}, or an occurrence on the working area surroundings {FEBas 40}). Another factor considered is whether the worker followed orders well and behaved reasonably (FEBas 42) in the site without taking unnecessary risks (i.e., acting recklessly). Finally the worker's experience and training are important in allowing him or her to recognize hazards and avoid them. Therefore, the lack of these may be a considerable factor in a fall accident (FEBas 43 and FEBas 44).

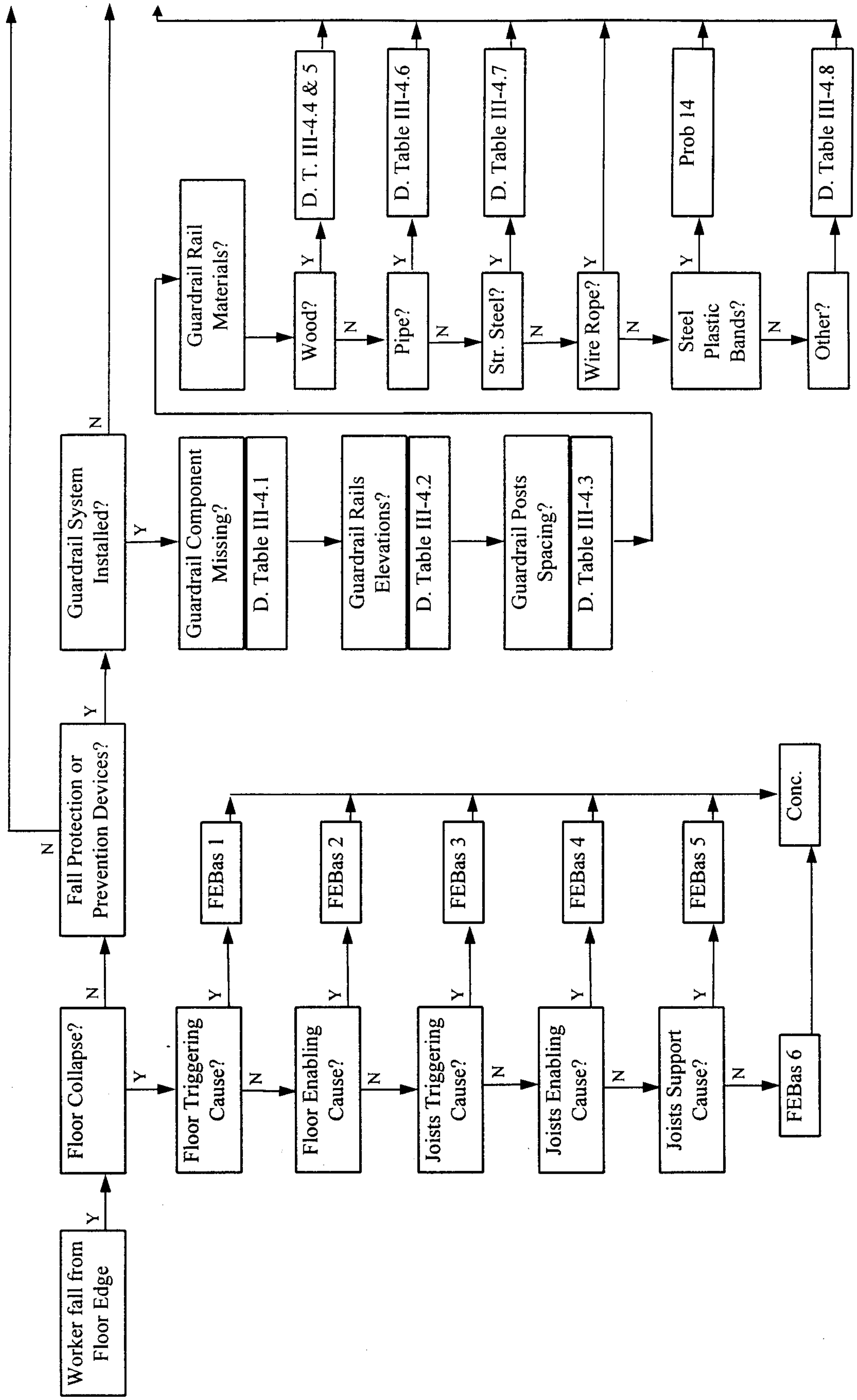


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge

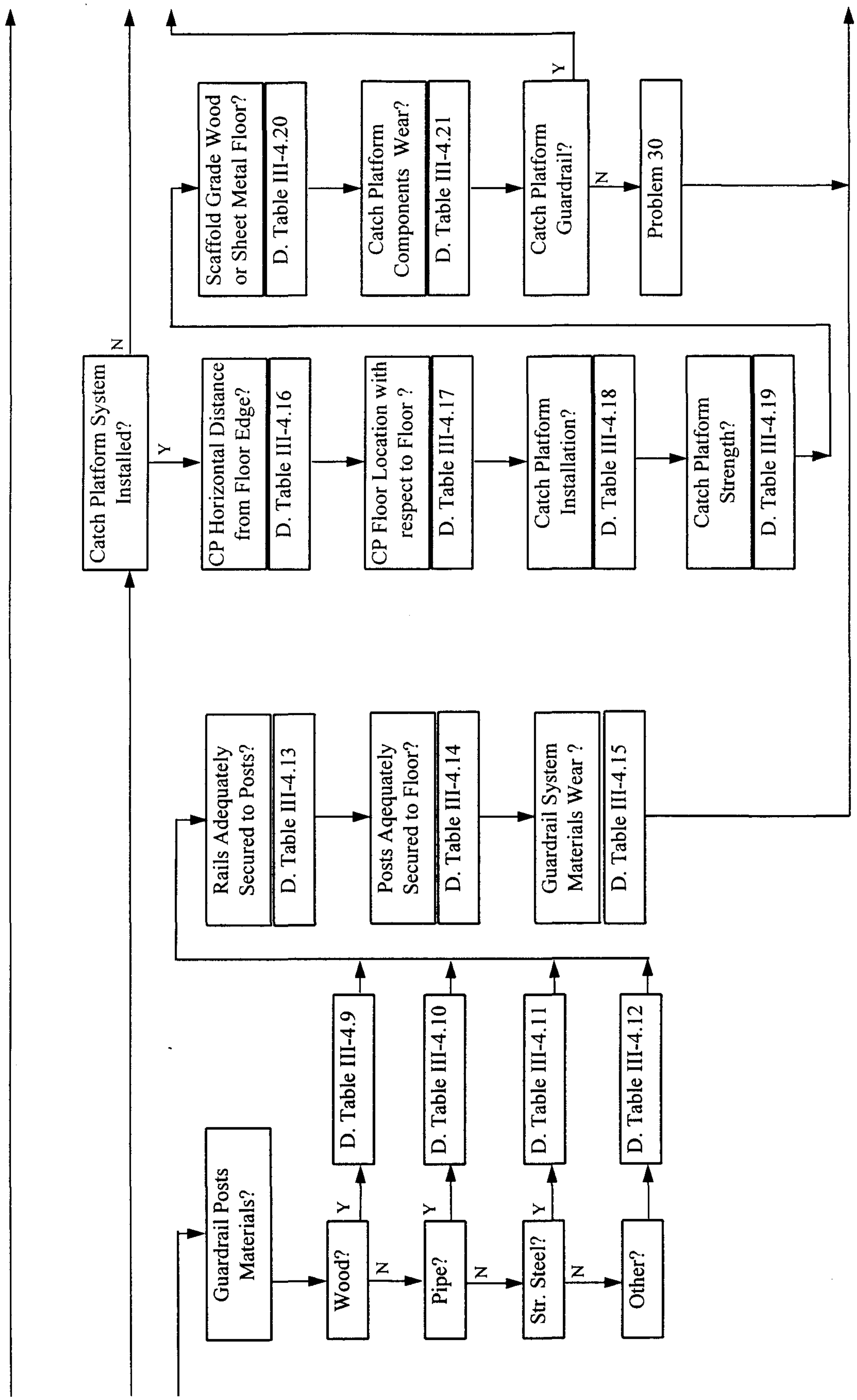


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

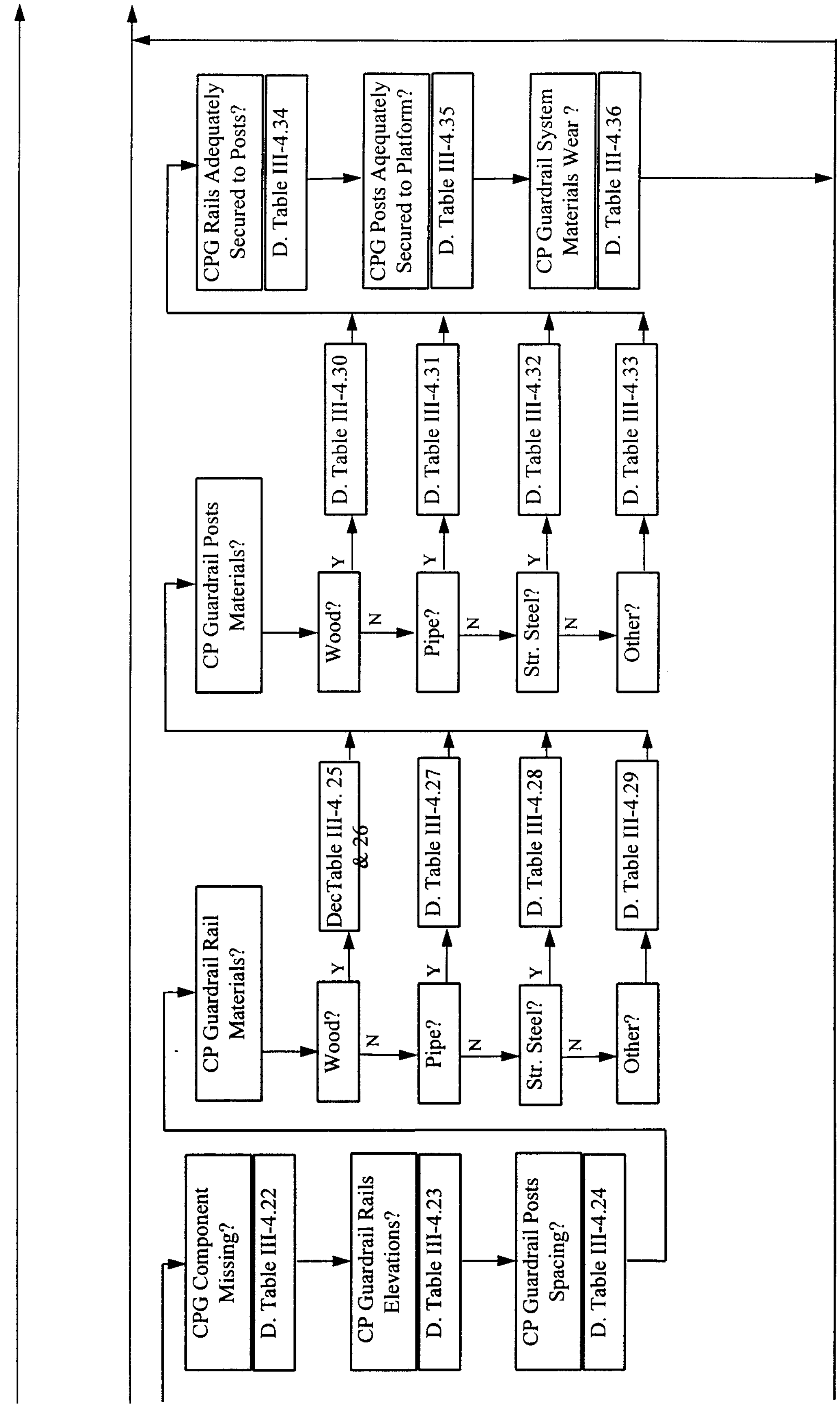


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

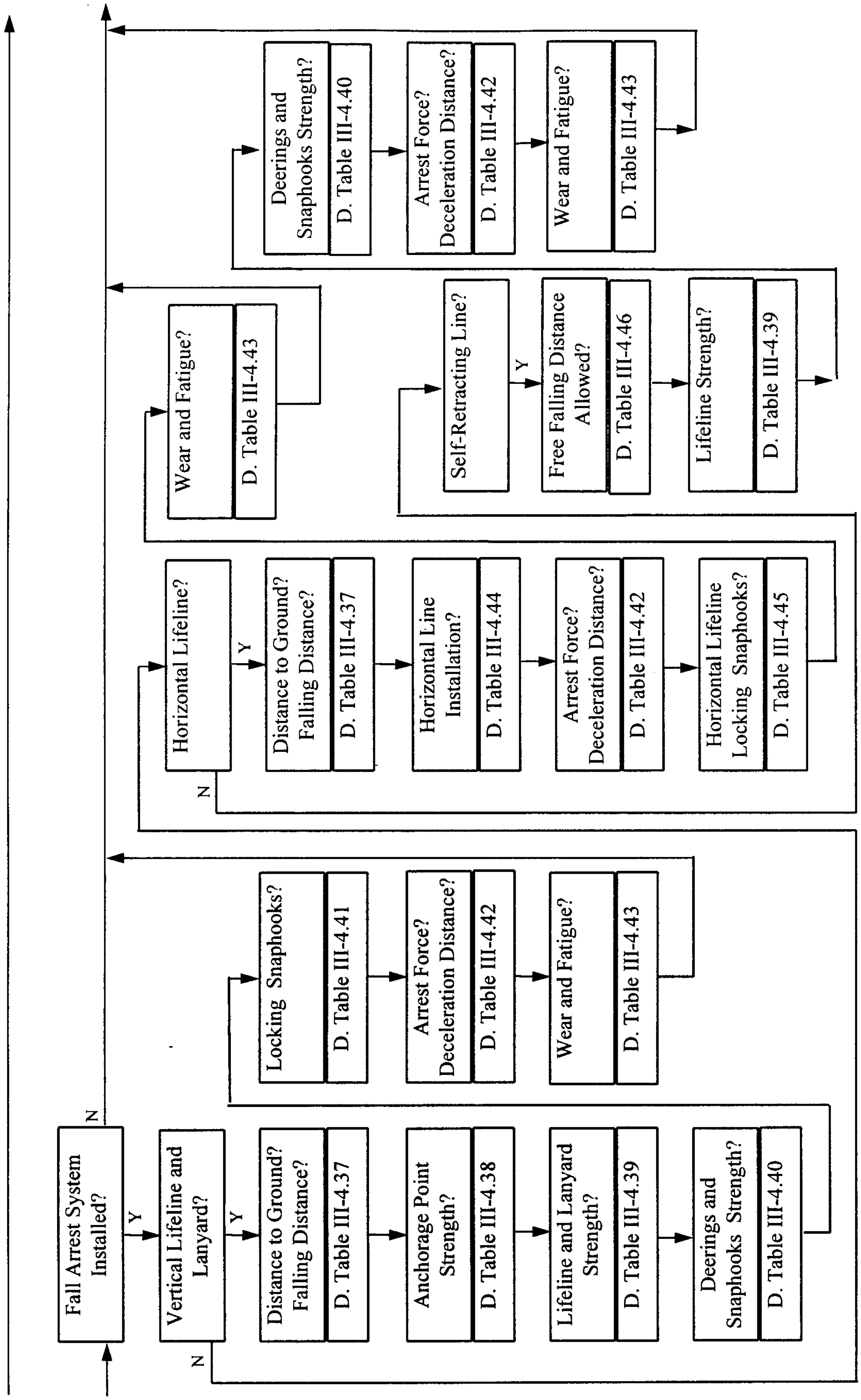


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

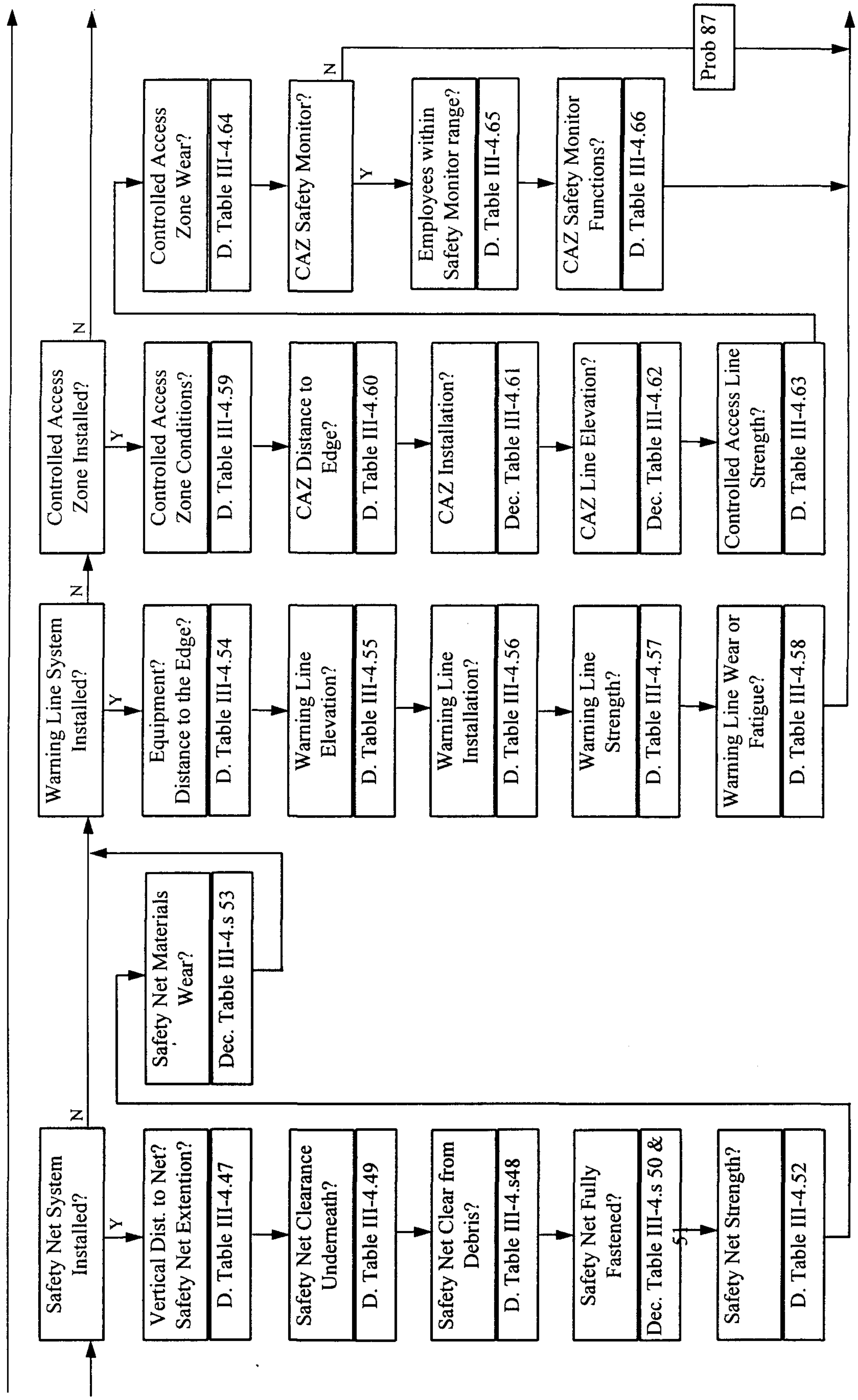


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

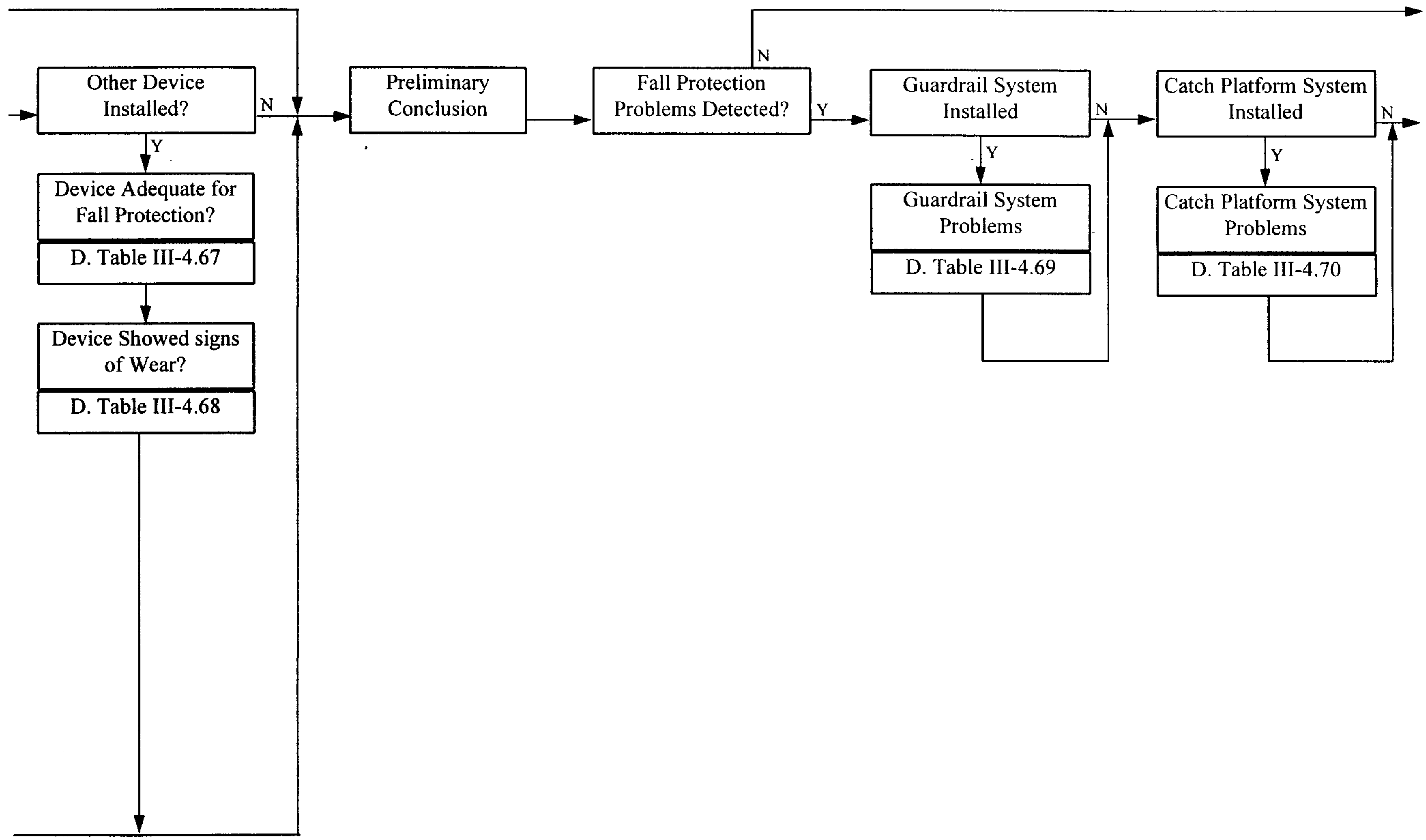


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

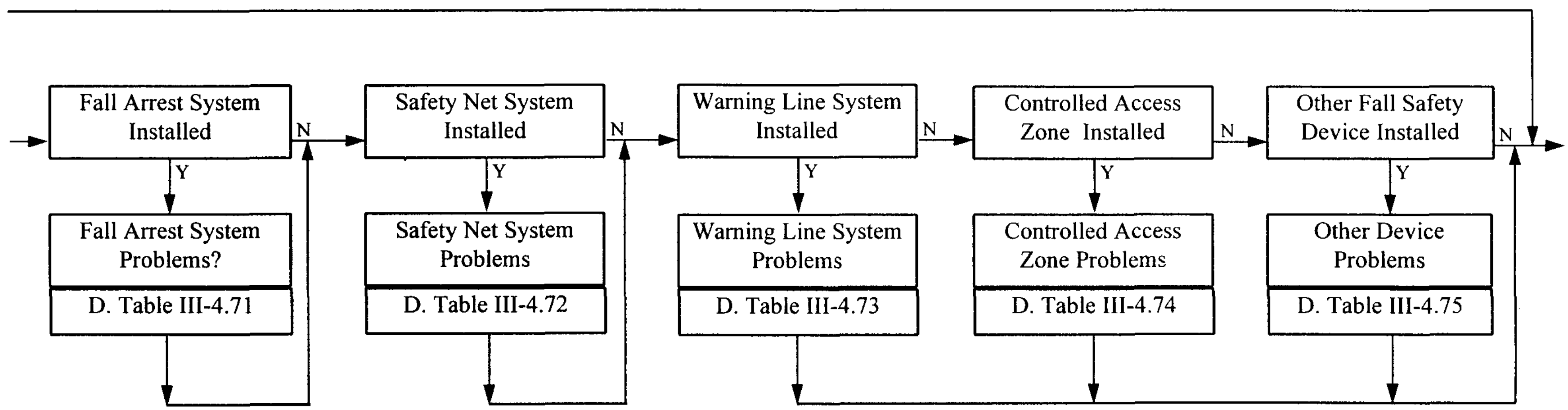


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

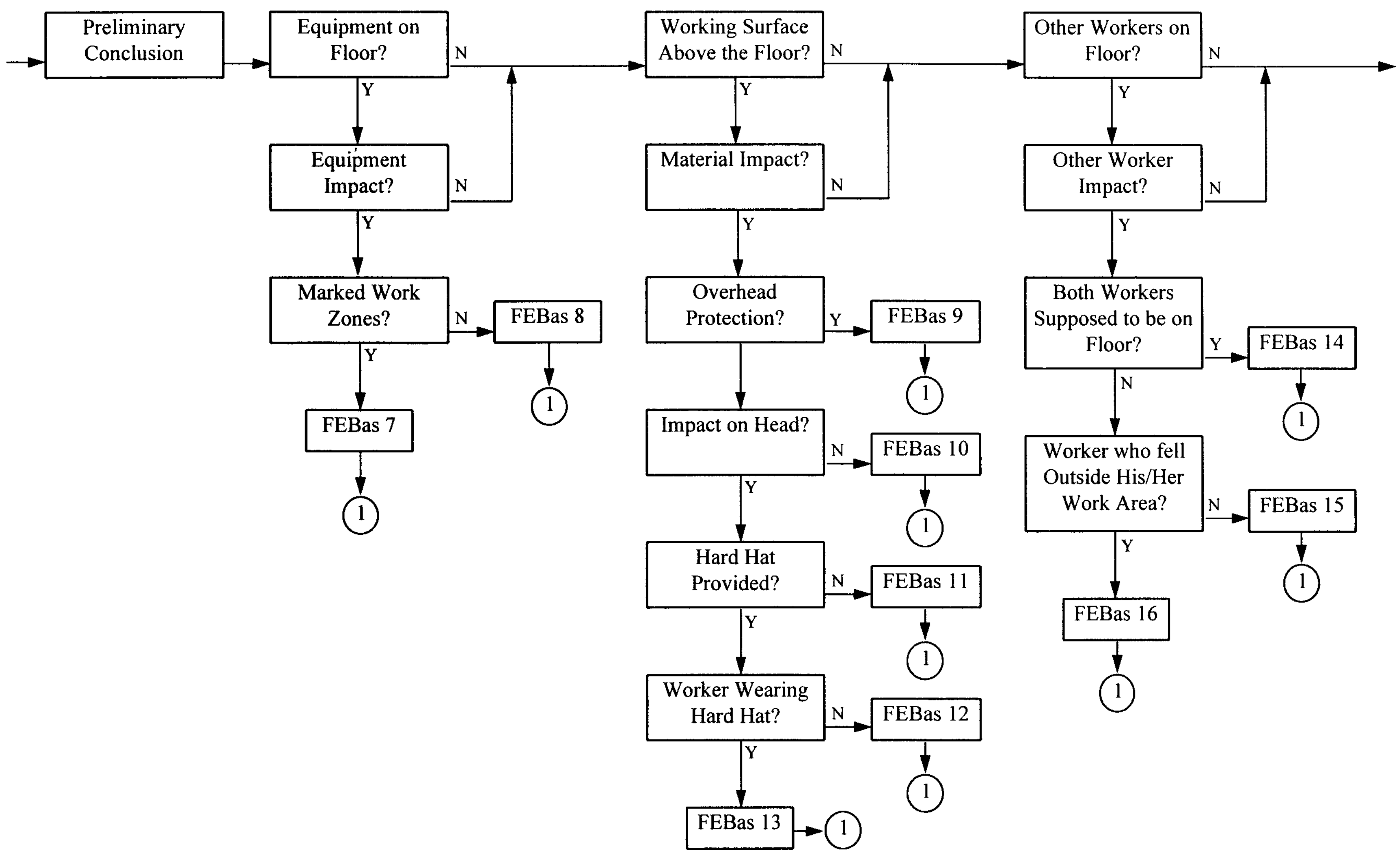


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

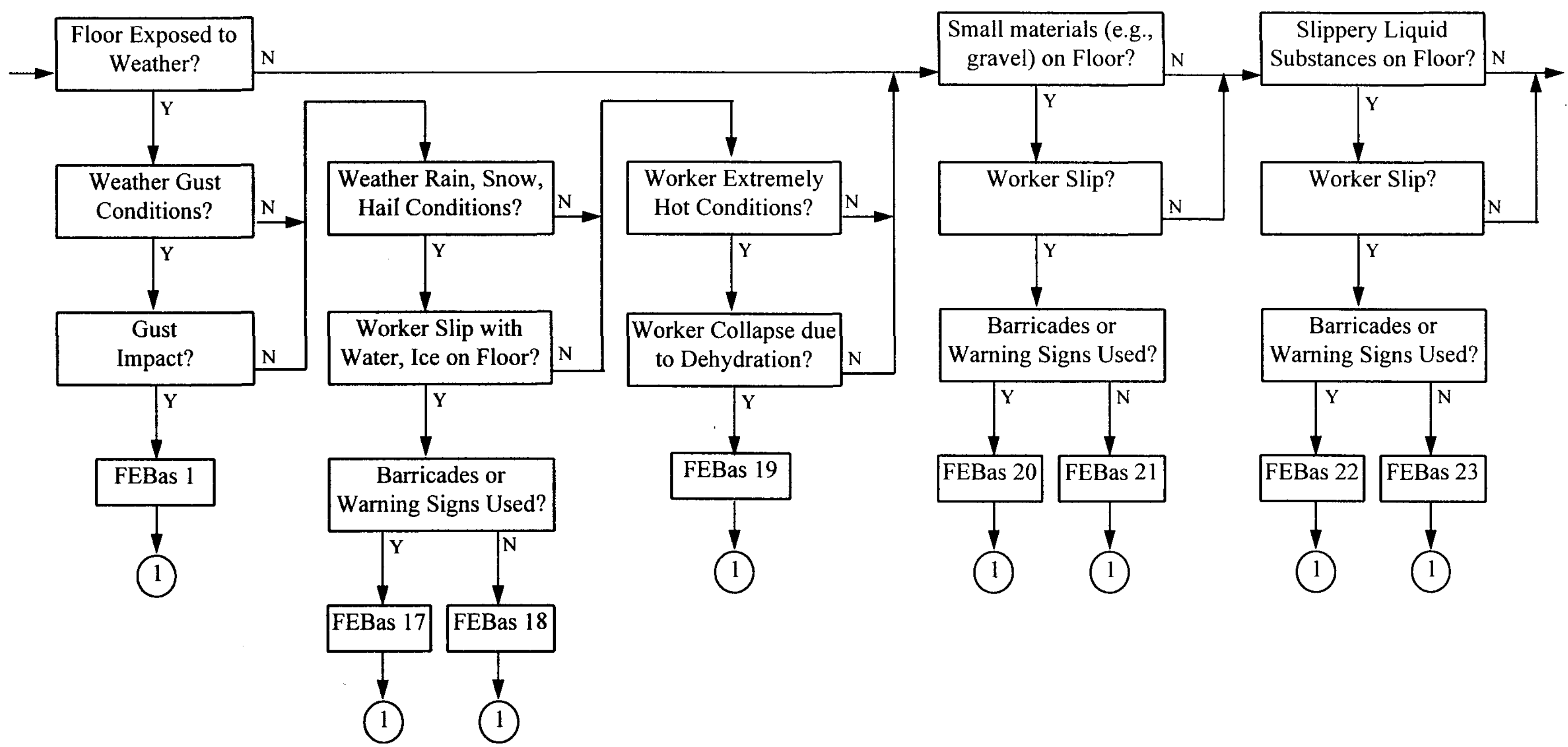


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

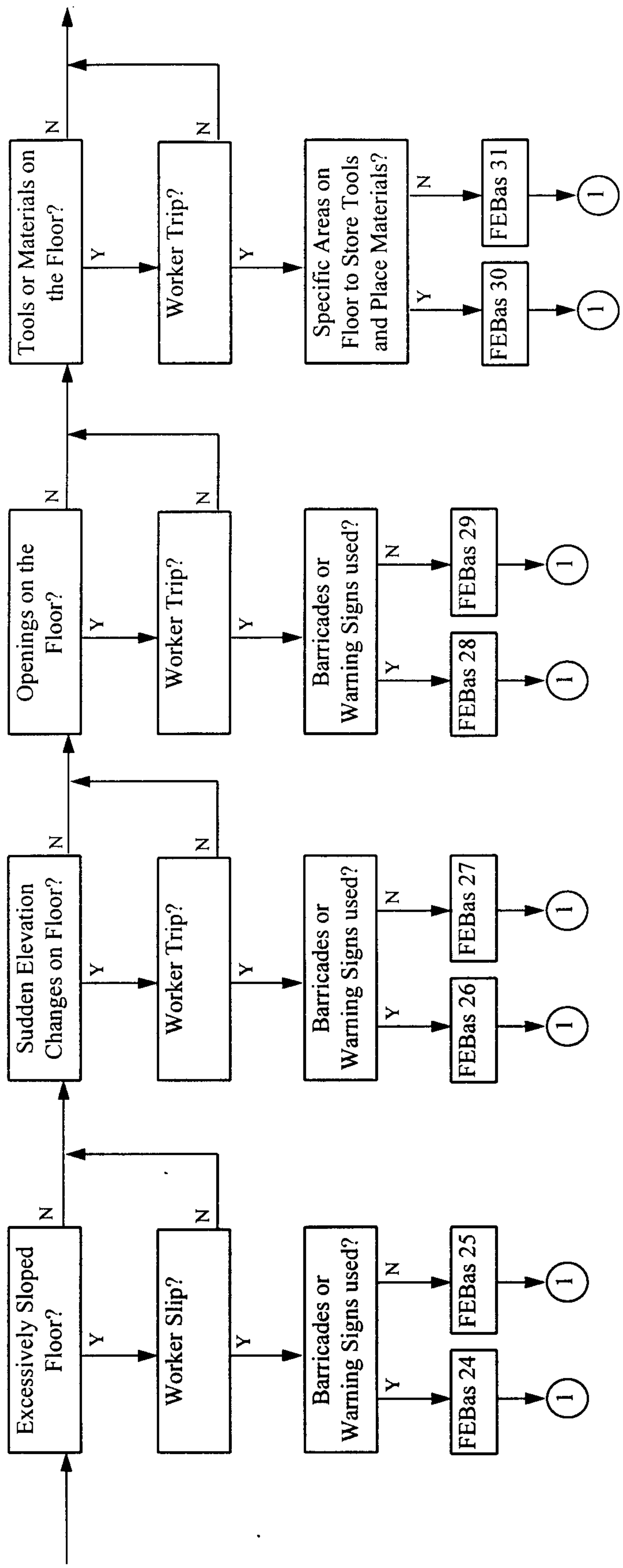


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

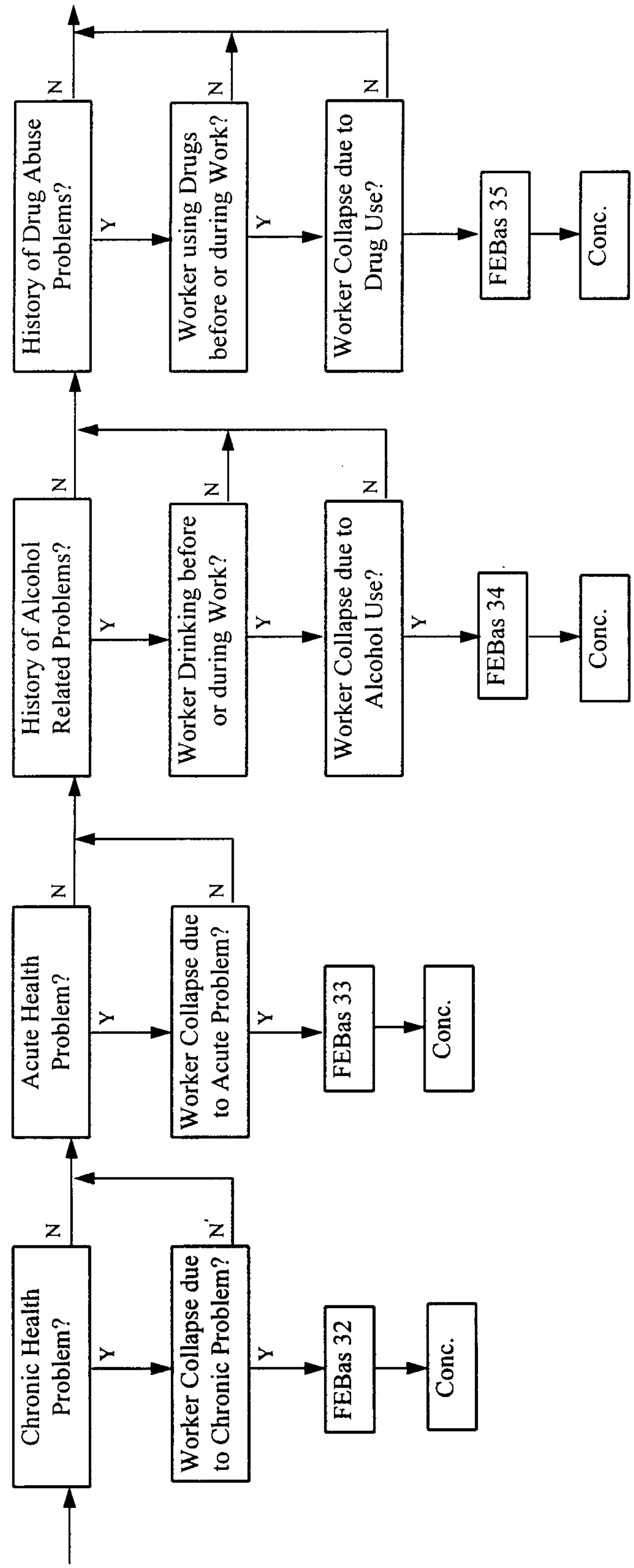


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

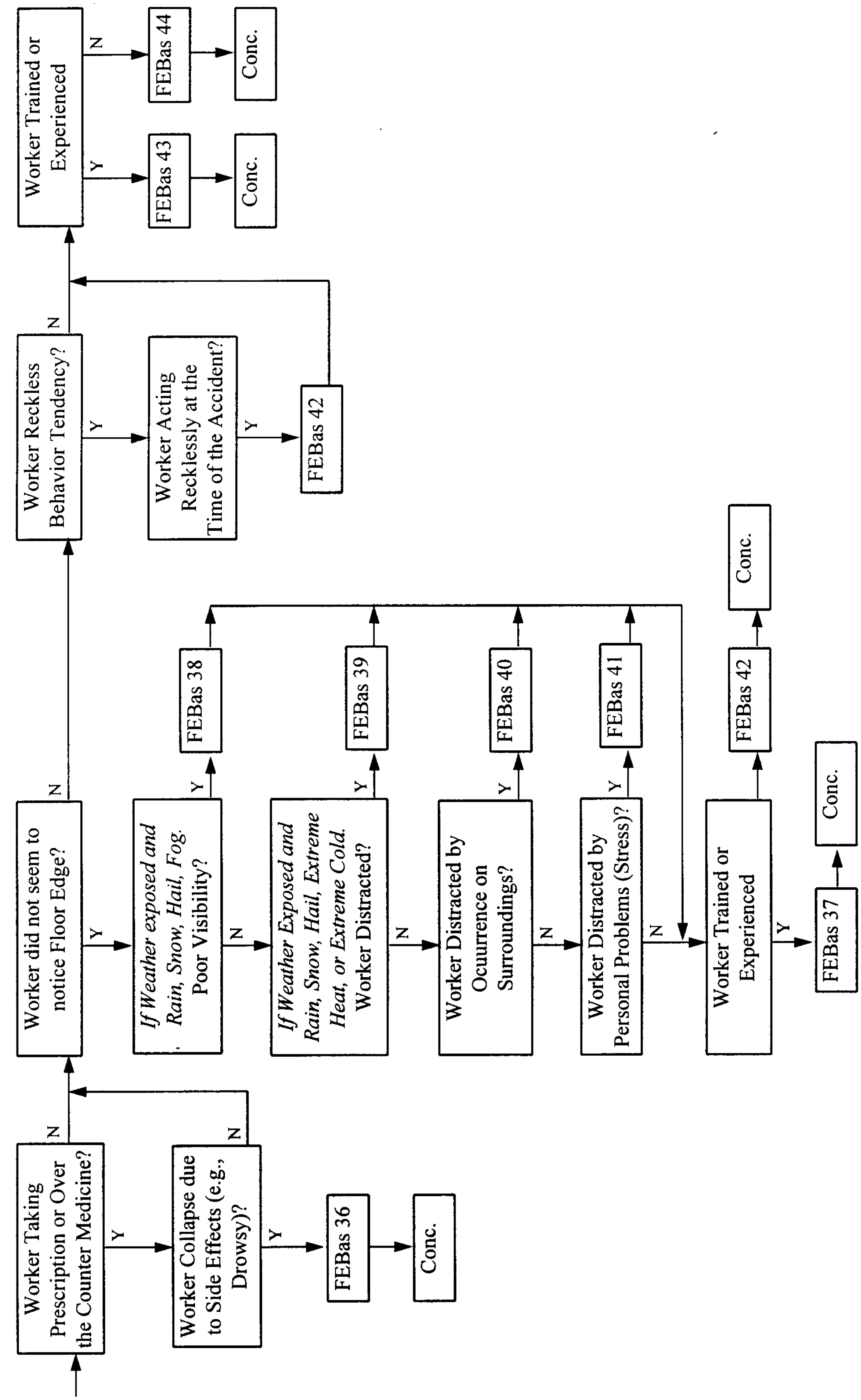


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

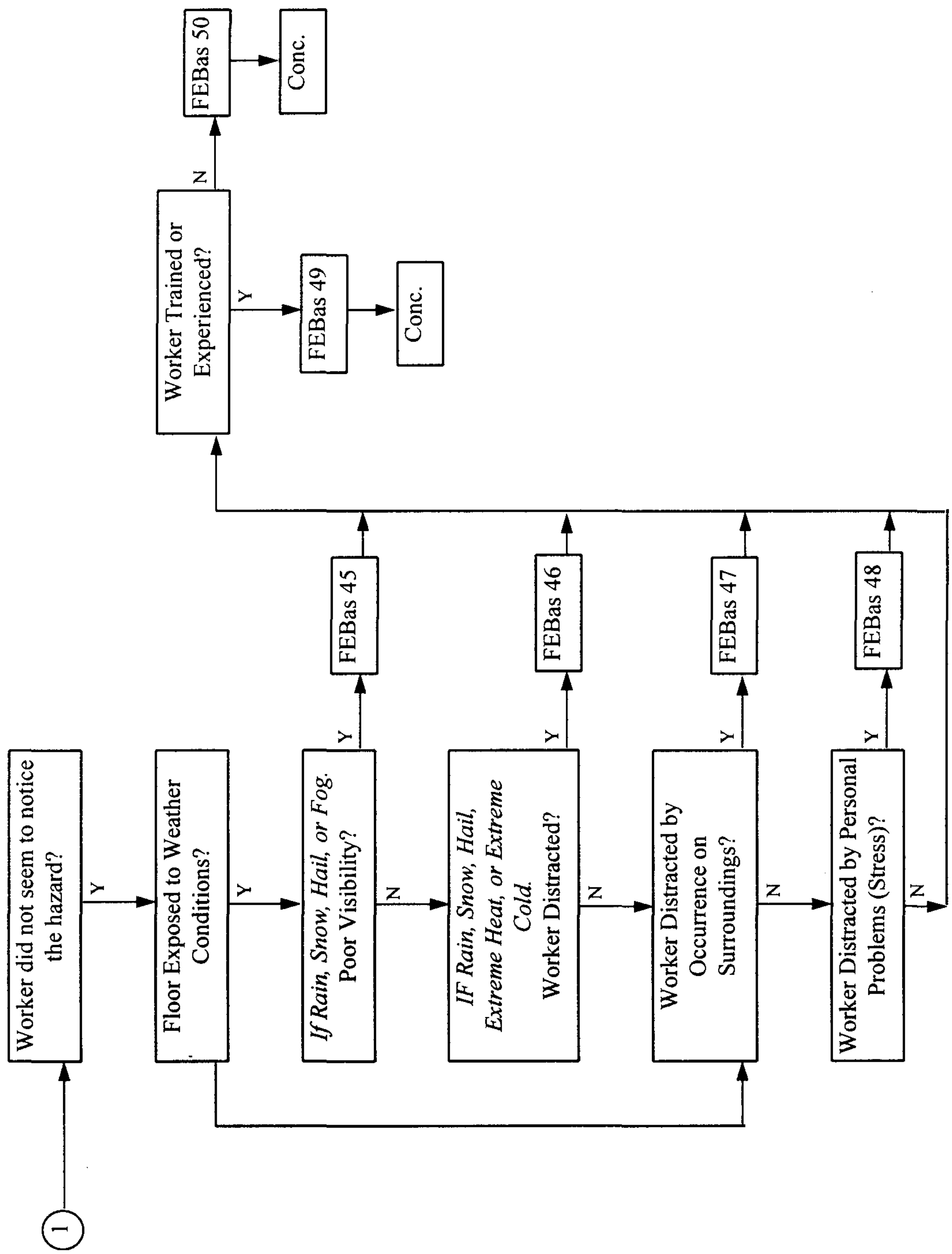


Figure III-4.1 Decision Structure for Worker Fall from Floor Edge (Cont'd)

4.3 The Production Rules

In general, the knowledge contained in the knowledge base consists of facts and rules in a specific domain. Through this knowledge and depending on the inference mechanism and the user inputs about the current conditions in the construction site, the system will infer new knowledge which will be used to get more information about the problem domain, until a conclusion is reached. Throughout the development of the knowledge base of SAFETY FIRST, decision trees were converted into production rules.

SAFETY FIRST takes advantage of LEVEL-5 (expert system shell) object oriented properties by representing facts as classes, attributes, or instances in the system. These objects are linked through the use of production rules. Production rules are of the following form:

IF (antecedent) THEN (consequence)

In essence, these rules were established by converting decision structures into IF-THEN statements. As alluded to before, the system uses a forward chaining inference engine; hence, if the antecedent of the rule is true then the consequence of it is also true. The consequence will provide new information to be searched and which eventually will lead to a conclusion. The following is an example of two rules fired in succession by the system:

IF the top rail cross-section is undersized THEN the top rail strength is not adequate

IF the top rail strength is not adequate AND the guardrail collapsed under worker impact THEN the conditioning cause of fall is the top rails lack of strength.

This is a simple case in which only one rule was fired; however, in some cases several problems will be identified by the system, and therefore, the antecedent side of several rules will match the world conditions. In those cases, the system's inference engine will control the way the rules are fired.

While the development of the system's knowledge base is one of the most important and significant stage in constructing SAFETY FIRST, the adequacy of the interface between the user and the system is essential. The latter will be elaborated in the following chapter.

CHAPTER 5

THE USER INTERFACE

5.1 Introduction

In order to reach a conclusion when investigating the causes of a fall, the system needs to know the conditions in the construction site at the time the fall occurred or the current safety conditions in the site being evaluated. This is the main task of the user interface mechanism: prompting the user for the information required to solve a problem. In addition to this task, the displays in the system should be designed so as to provide as much help on how to use the system, definitions and information about the terms used in the system, and explanations regarding why a given question is asked or information is required from the user. Furthermore, once a conclusion is reached the system should explain the reasoning behind the conclusion obtained, and present recommendations on how to avoid future fall occurrences.

To perform all of these functions, the user interface component has to be able to interact with all the other modules of the system and with the user. The user interface module interfaces with the inference engine and the knowledge base to determine what information should be required from and provided to the user of the system. It also interfaces with external files to provide a more user-friendly system, including help statements and multimedia capabilities. All messages included within the displays are read from text files outside the system. The conclusions and recommendations are also stored in text files which are retrieved as needed. The inference engine determines which of these files should be called depending on the information provided or requested by the system's user. In addition, all inputs provided by the user are stored in outside files which are available for the user to recall in order to check his or her inputs during the consultation.

Furthermore, the expert system interfaces with the user through the different consultation screens in the program. Given that these displays are the first point of reference the usèr has to evaluate the program, a great deal of care has been taken in their design. The display should be aesthetically pleasing and user-friendly while performing its functions efficiently. Further, the displays should provide the users with the adequate information they may require without overwhelming them. In addition, the displays operation and components should be clear to the user; therefore, we have made the components and regions in all displays as standard and predictable as possible so that the user knows where to look for every component or utility he or she needs at any time in a consultation.

5.2 Moving Around The System

SAFETY FIRST is designed to lead the user to a conclusion by asking questions regarding the conditions in the construction site and evidence obtained from eyewitness of the accident. The user provides the information requested by the system through its displays. Once he or she has done that, a forward (>>) button is provided to allow the user to move forward in the consultation. The user must answer all questions given on the display in order for the button to be active and allow him or her to continue. The color of the label (>>) in an active button is black while the color in an inactive or blocked button is dark gray. If the user attempts to go on with the consultation while the button is blocked a beep sound will warn him or her of that fact. A backward (<<) button is also provided on each display to permit the user to go back to previous displays and change any of the previously furnished information.

In addition, all displays in the system contain an Exit button to end the consultation at any time. Once the user selects the Exit button, the user will get a message to confirm the command. If the answer is yes, then the system will ask the user if he or she wants to save the consultation (yes or no). Once an answer has been provided by the user, the system's consultation will end.

There are also some specific buttons included in some selected displays whose objective is to make the system more user-friendly. For example, the welcome display contains a "How to use SAFETY FIRST" button which allows a first-time user to go directly to the Help screen and learn how to move around in the system. Two more examples are the "Recommendations" button located in the conclusion display and the "Restart" button located in the recommendations display. Both are included to make it easier for the user to identify the more obvious options available to him or her at that given time in the consultation.

In order to move around the program the user may also take advantage of the menu bar commands located on the top of the display. These commands are discussed later in this chapter.

5.3 User Interface Structures

SAFETY FIRST consists of three different types of structures, which depend on the type of fall and component being investigated (e.g., elevated component fall vs. same level fall) or the objective of the user's consultation (i.e., evaluation of fall safety in the site vs. investigation of a fall accident). These three user interface structures are portrayed in Figures III-5.1, III-5.2, and III-5.3. The system starts with a welcome display which provides the user with the option of getting information about how to use the system. Next, the system provides an introductory display which informs the user about the systems limitations and the information required in order to use the system. After that, the system goes through a set of displays where the user may or may not input preliminary information about the investigator who gathered the information used in the system, the company under whose responsibility was the construction site being investigated, the site location, information about the worker who suffered the fall accident (if performing a fall accident investigation - the user does not have to answer if only evaluating the fall protection devices in the site), and determination about the type of fall and structure component being analyzed.

After the above displays, depending on the consultation's objective, the system will start the consultation to go through as many displays as required for the system to either assess the cause of the fall accident or determine the adequacy of the fall protection devices used in the site (this function is available only for elevated components). Regardless of the consultation's objective, for all elevated components (portable ladders are the exception given that no fall protection devices are required for them), the system will evaluate the adequacy of the fall protection devices used in the site (Figure III-5.1). Once this is done, the system will provide a preliminary conclusion indicating the results of this evaluation (i.e., problems identified, if any).

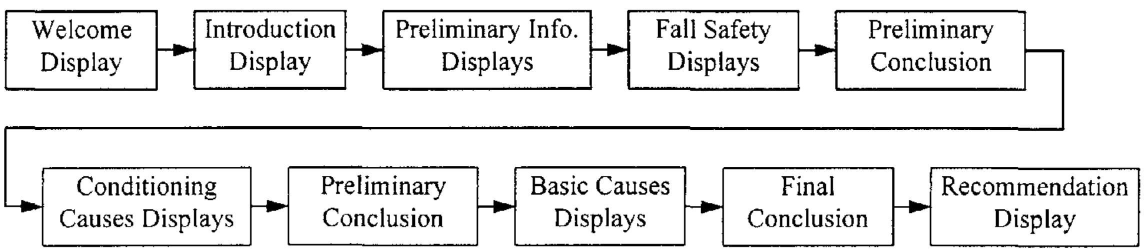


Figure III-5.1 Structure of User Interface for Elevated Components when fall safety problem is detected.

Next, if the user is investigating a fall accident and some problems were identified with the fall safety (Figure III-5.1), then the system will lead him or her through a new set of displays which will try to determine if any of the problems identified were a conditioning cause of fall (a preliminary conclusion will follow this consultation) and then evaluate the basic causes of fall until a final conclusion is reached.

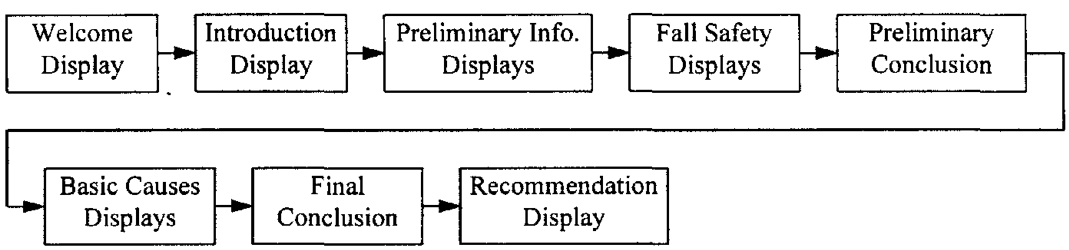


Figure III-5.2. Structure of User Interface for Elevated Components when fall safety problem is not detected.

If the user is investigating a fall accident and no fall safety problems were identified (Figure III-5.2), the system will go from the fall safety evaluation displays and their preliminary condition to the set of displays used by the system to evaluate the possible basic causes of fall. The system will then proceed to the final conclusion and recommendation displays.

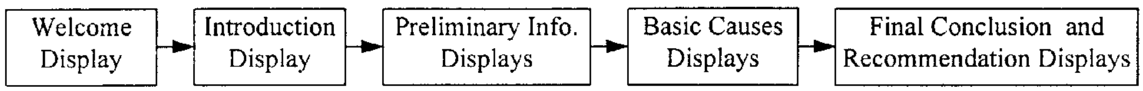


Figure III-5.3. Structure of User Interface for Falls from Portable Ladders

For same level fall, slips, and portable ladder fall investigations, the system will jump directly from the preliminary information displays to the displays required by the system to evaluate the basic causes of the fall (Figure III-5.3). These displays will be followed by displays stating the final conclusion from the consultation and system's recommendations.

5.4 The Displays

From these structures, we recognize that there are two main types of displays in the system: those that are part of the inference process of gathering evidence on the basis of which a conclusion is reached and those without which a conclusion could still be reached by the system.

5.4.1. Utility Displays

The utility displays are the ones which contain information that has no direct bearing on the system's conclusion. The main function of these displays is to provide the user with information about the system, gather general information, or display the results of the consultation. Within this display category, the following displays are included: the welcome display, the introduction display, the preliminary information displays, the preliminary and final conclusion displays, and the recommendation displays.

The welcome display (Figure III-5.4) is the first display the user encounters when entering SAFETY FIRST, its main objective is to provide the user with a chance to get some information about the system before going on further. He or she can do that by clicking the "How to use SAFETY FIRST" button. From this display, the user can choose to go on with the consultation (go to Introduction display) or exit the system.

The introduction display (Figure III-5.5) has the function of informing the user of the scope and limitations of SAFETY FIRST and the cases in which it can be used. It also

Figure III-5.4 Welcome display

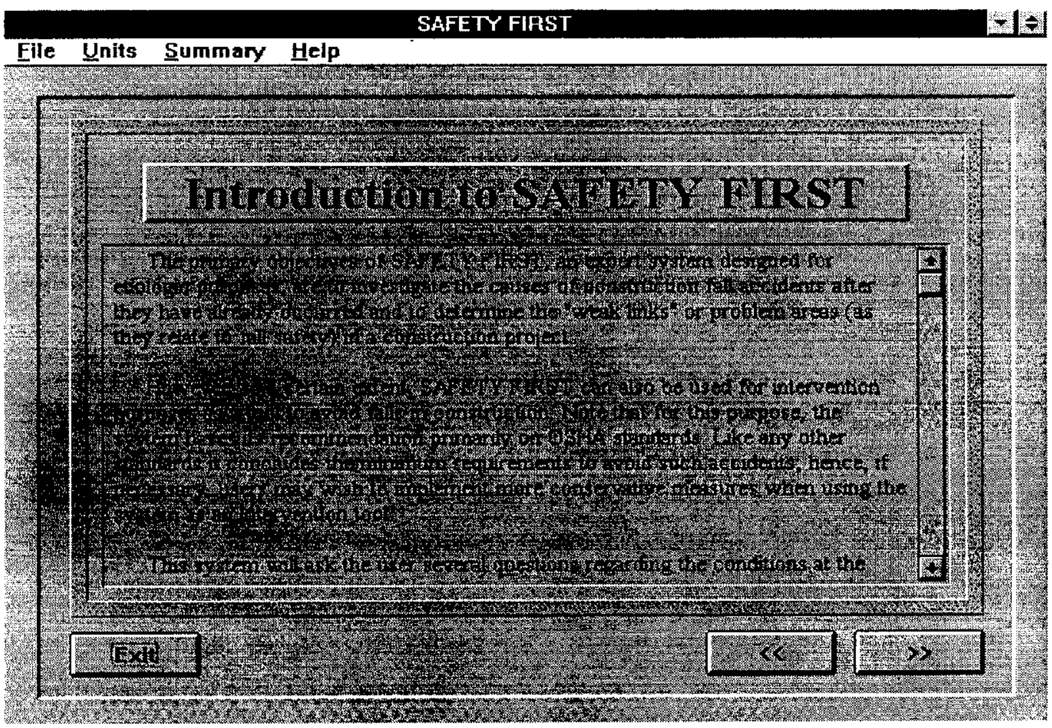


Figure III-5.5 Introduction to SAFETY FIRST display

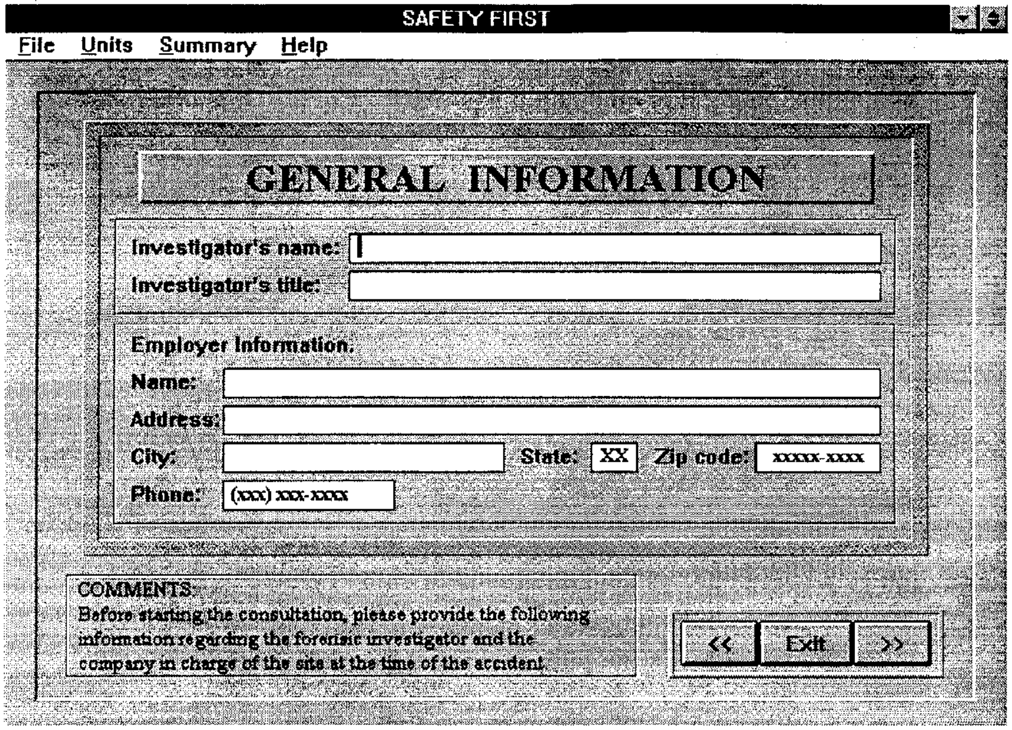


Figure III-5.6 Preliminary information display

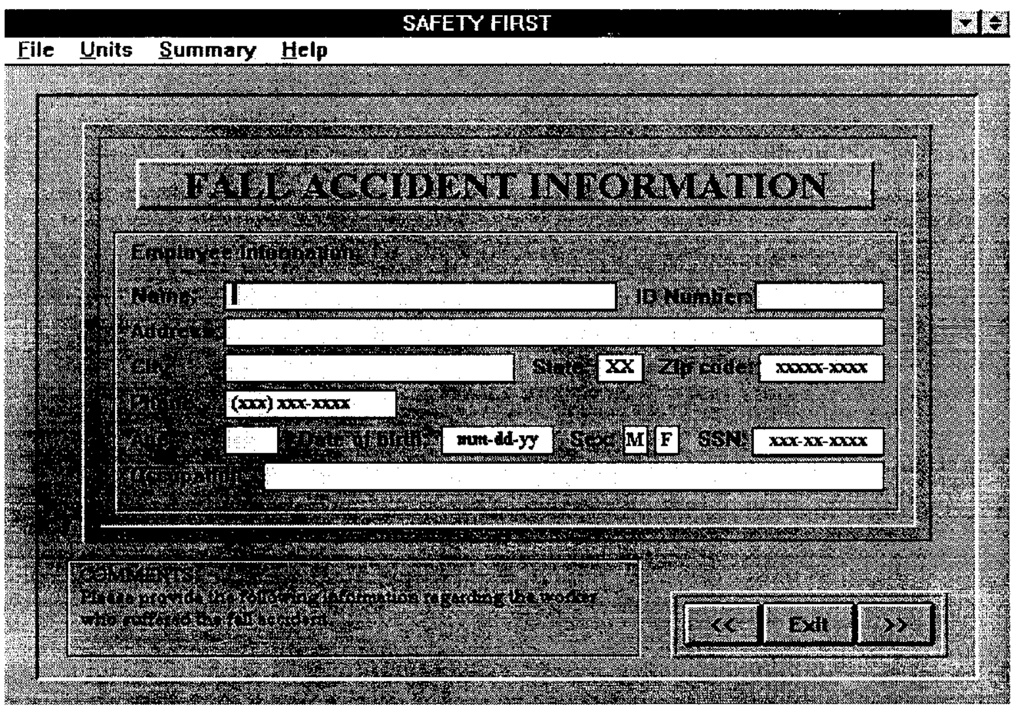


Figure III-5.7 Preliminay information display II informs the user about the information he or she will need in order to successfully use the system. This information is provided before the user starts the consultation so that if he or she does not have it, he or she can exit the system and get the required information before starting the consultation. From this display, the user can move to the preliminary information displays, exit, or move back to the welcome display.

The preliminary displays (Figures III-5.6 and III-5.7) give the user the option of inputting general information such as the name and title of the investigator and the name and address of the company in charge of the construction site being investigated. They also allow the user to input some relevant information about the fall accident (if a fall accident investigation is the objective of the consultation), such as the location of the site where the fall accident occurred, the name of the worker who fell, and so on. After these displays, if the user chooses to go on, the system will require the user to identify the type of fall and the elevated component (Figure III-5.8) he or she wants to investigate and then go on with the consultation.

As shown in the previous section (user interface structure), during a consultation the system will provide preliminary and final conclusions that provide the user with the consultation results and an explanation of why these results have been obtained. Figures III-5.9 and III-5.10 display samples of preliminary and final conclusions given by the system.

5.4.2. Consultation Displays

The consultation displays (Figures III-5.11 to III-5.14) include all of the displays used for the evaluation of fall safety, conditioning causes, and basic causes. In all of these displays, the user is requested to answer some question(s) or provide some information to the system in order for it to reach a conclusion. The order in which these displays appear during the consultation is determined by the system's inference engine according to the knowledge base structure.

These displays have been designed to be as standard as possible so that once the user is familiar with the display's structure, he or she will know where in the display he or she is expected to provide information, where he can get information, and where he can find the functions that allow him or her to go on with the consultation. In general, the consultation displays consist of six specific modules located in different places within the display, as follows:

1. The menu bar located at the top section of the display. This bar is standard for all the displays and will be described in detail in the next section.
2. The message on the top right corner of the display which identifies the structure component being investigated (e.g., Floor Edge Fall).
3. The message located above the main body of the display (dark gray color fonts) which identifies the type of cause/problem that is being investigated in the current display (e.g., Basic {Support Related: Floor Collapse} cause).

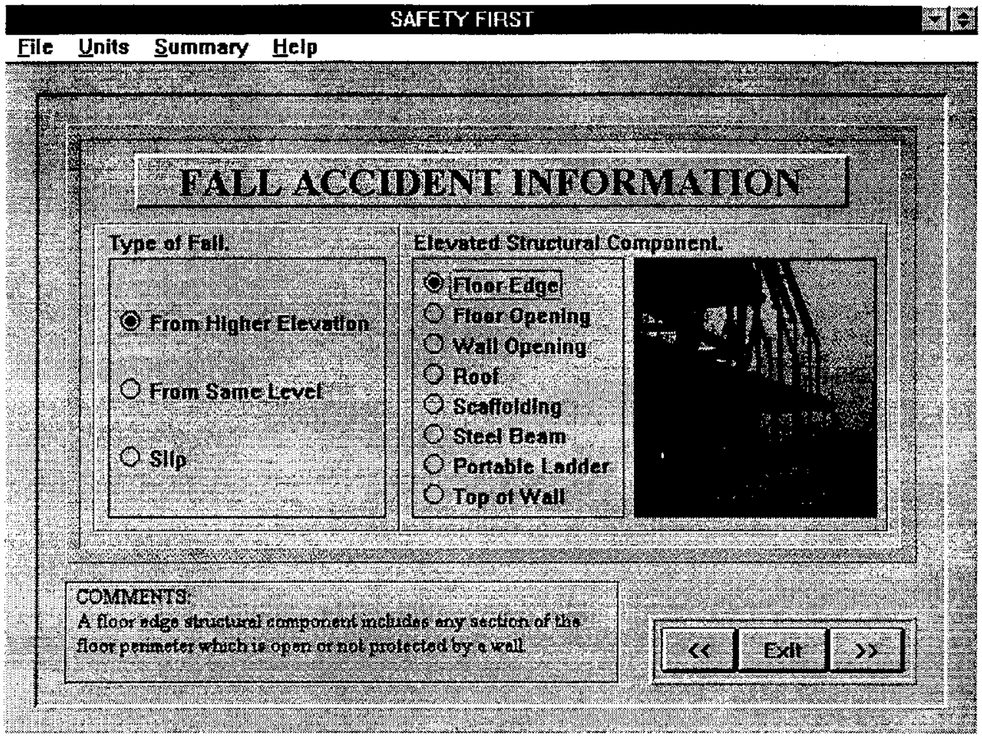


Figure III-5.8 Type of fall and component selection display

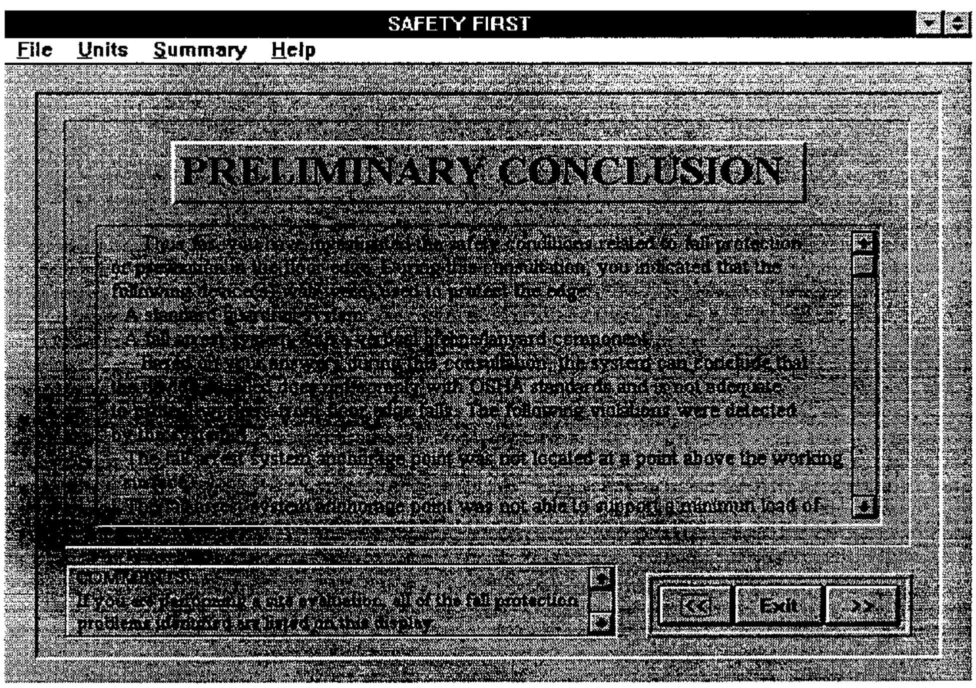


Figure III-5.9 Preliminary conclusion display

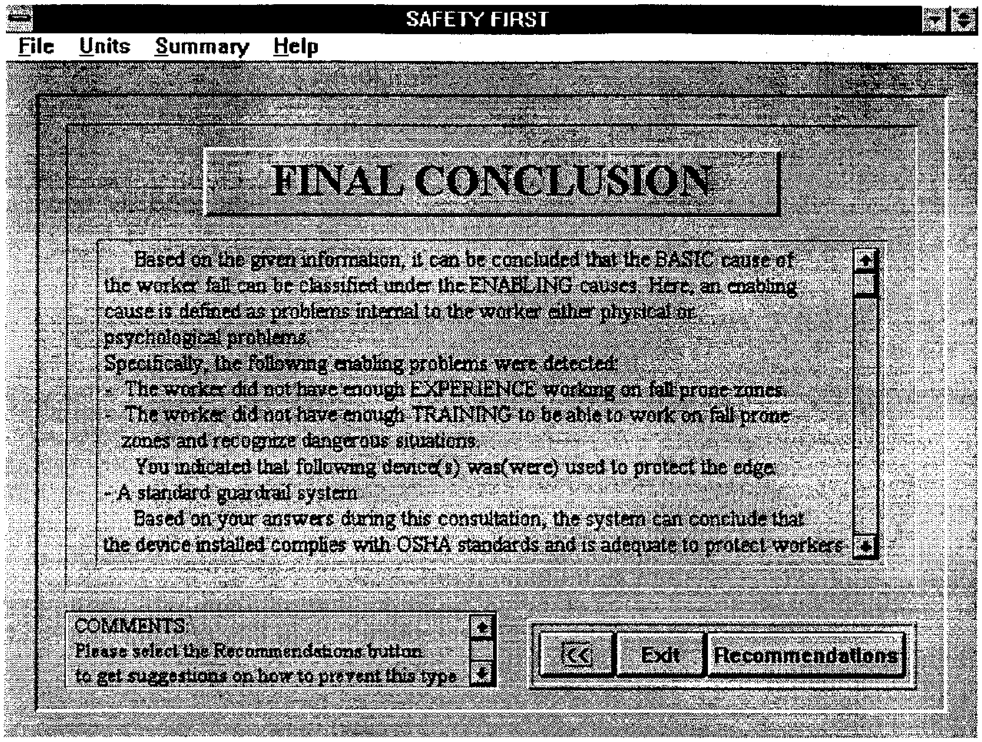


Figure III-5.10 Final conclusion display

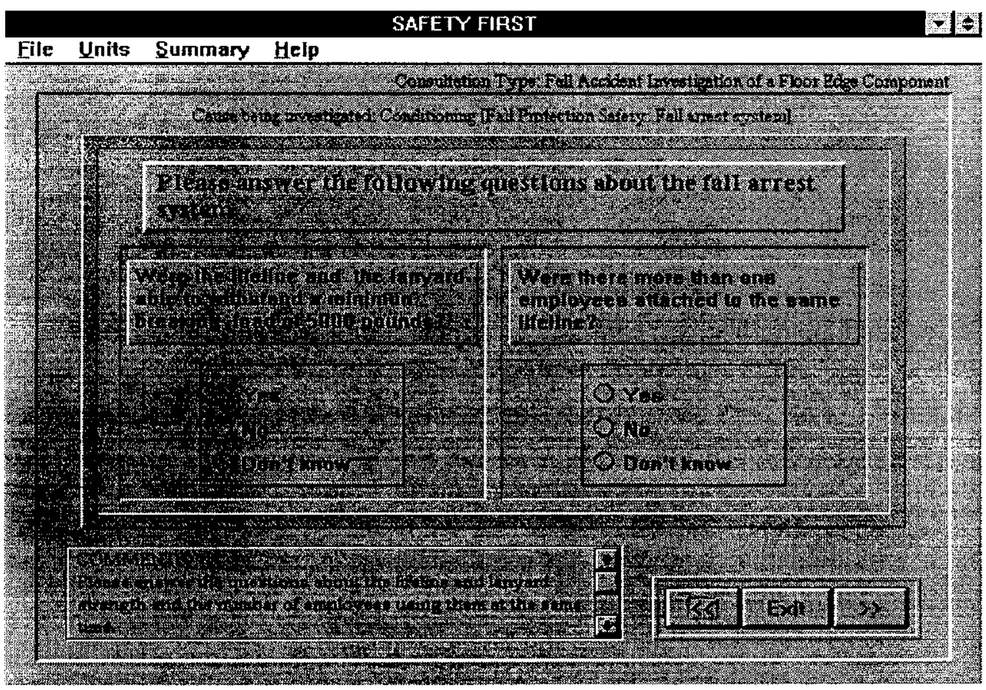


Figure III-5.11 Sample of radiobutton input display

4. The main body located at the center of the display. It contains the questions the user has to answer in order for the system to determine the problems or causes of fall in the site. It also contains the possible input options the user has for the given question. For these inputs we take advantage of LEVEL-5 Graphics User Interface which provides input mechanisms, such as radio-buttons, and check-boxes where the user only has to point to the right answer and click to select it.
5. On the lower right corner of the display, there are three push-buttons which allow quick movement around the system (i.e., the backward, exit, and forward buttons).
6. Finally, on the lower left corner of the display, there is a COMMENTS box which contains any information that may pertain to the current display and be required by the user in order to successfully use the system, including instructions on how to answer the given questions and definitions of unfamiliar terms.

5.5. Input Mechanisms

Given that we decided to use a question and answer format to obtain the information from the users, the Graphic User Interface (GUI) input mechanisms were deemed to be the best for the user to provide answers to the systems questions. By using these input devices the user only has to point the mouse to the right answer and select it by clicking the mouse on it. SAFETY FIRST provides three main types of GUI input mechanisms:

1. Radio buttons (Figure III-5.11) are provided if only one possible answer applies to the given question.
2. Check boxes (Figure III-5.12) are used if more than one of the options provided may be the answer to the given question. In a check box the user may choose as many options as they apply; however, the system may put some limitations on the inputs if the selected answers are conflicting with each other or previous answers.
3. Scroll buttons (Figure III-5.14) are used when the user has to modify any of the numerical default values provided by the system, such as the posts spacing for the guardrail system.

Whenever too many answers may apply to a given question, the developer does not have enough information to predict the possible answers, or the system needs additional refinements to a given answer, the system provides prompt boxes (Figure III-5.13) in which the user has to type information in response to a given question.

5.6 The Menu Bar

The menu bar is located at the top of all the displays in the system and contains all the commands required to operate the program. The commands used in the system are generally consistent with other windows commands. In some cases, specific commands were made clear enough so as to give the user an idea of their functions. The menu bar consists of the following commands: File, Units, Summary, and Help.

The File option contains the commands related to the operation of a system consultation file, such as *New* to start a new consultation in the system, *Open* to open a previous consultation file, *Save as* to save a consultation, *Print screen* to print a display within a consultation, and *Exit* to end a consultation.

The Units menu option is only active on those displays where the user is asked to provide some numerical input. With this option, the user can specify whether he or she wants to provide these numerical inputs in *English* or *SI* units.

The Summary command will allow the user to see a list of all the input selections he or she has made during the consultation until that point.

Finally, the Help command contains three items: *Help Contents*, *Acknowledgments*, and *About SAFETY FIRST*. The *Help Contents* command contains instructions on how to use help and how to operate SAFETY FIRST, background information about SAFETY FIRST, and a glossary of technical terms used in the system. The Acknowledgment command thanks the project sponsors and people involved on the system's development. Finally, the *About SAFETY FIRST* (Figure III-5.15) command provides information regarding the system developers.

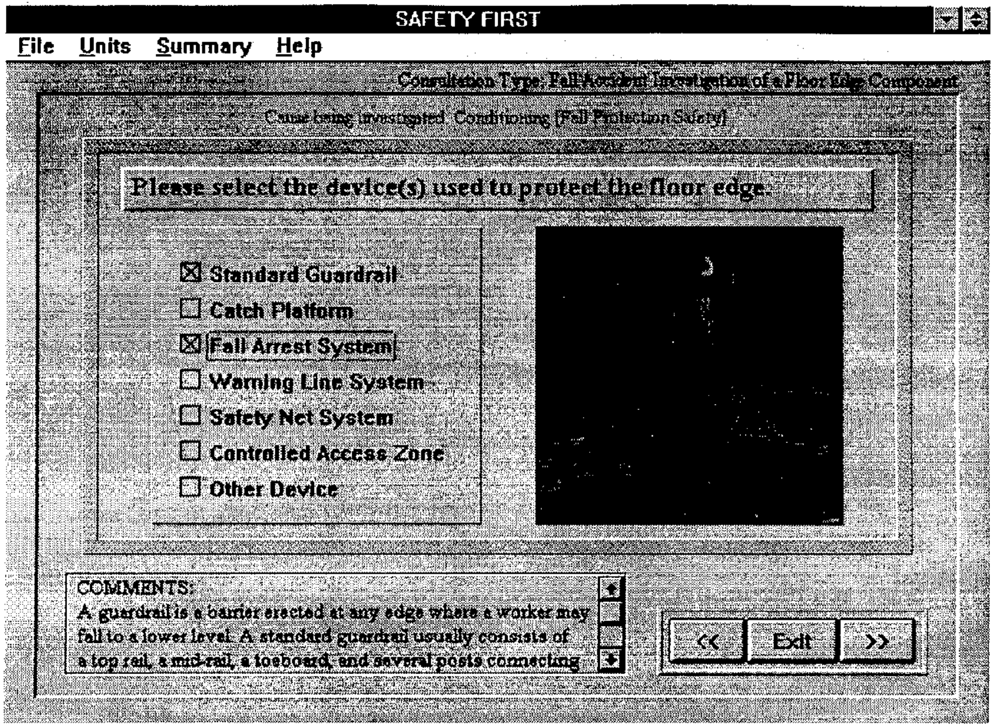


Figure III-5.12 Sample of display containing check box input

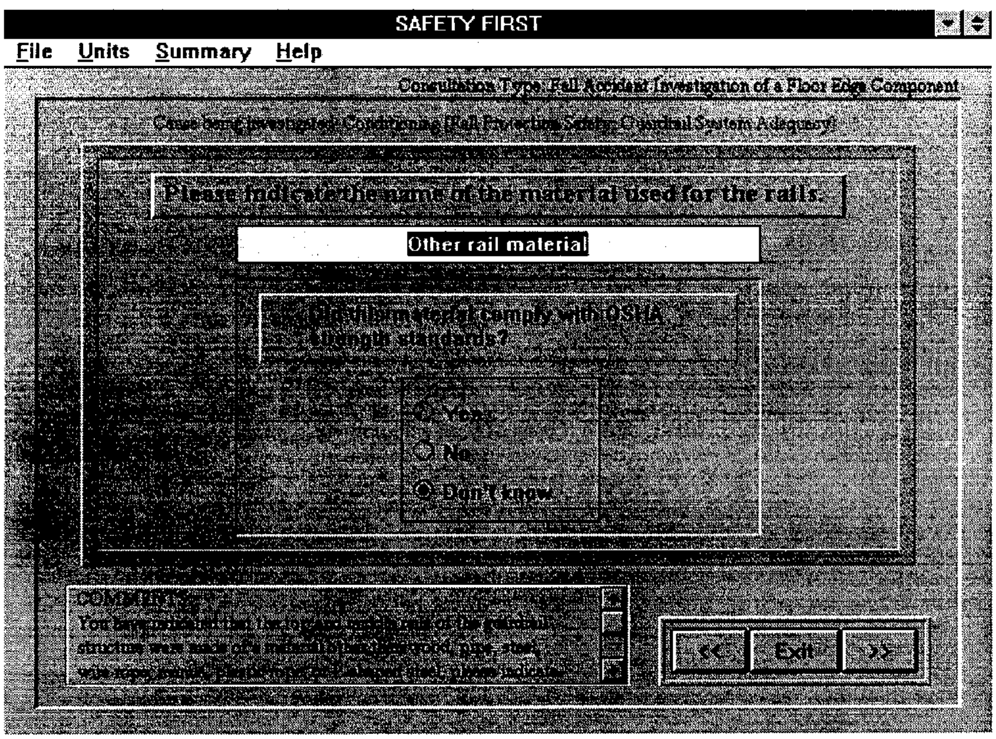


Figure III-5.13 Sample of display containing promptbox input

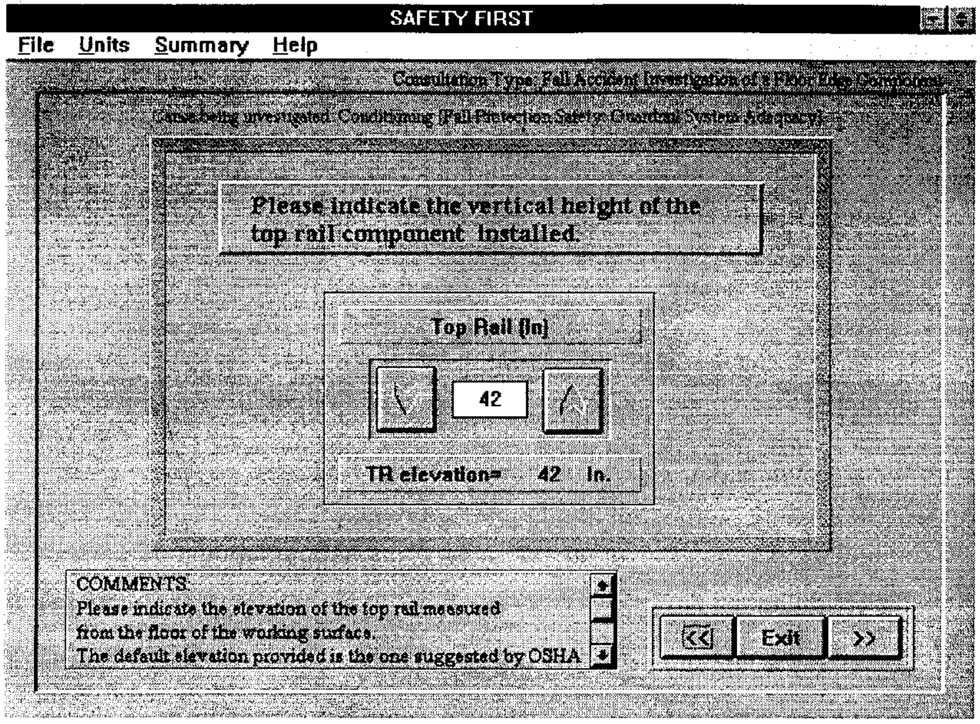


Figure III-5.14 Sample of display using scrollbutton input

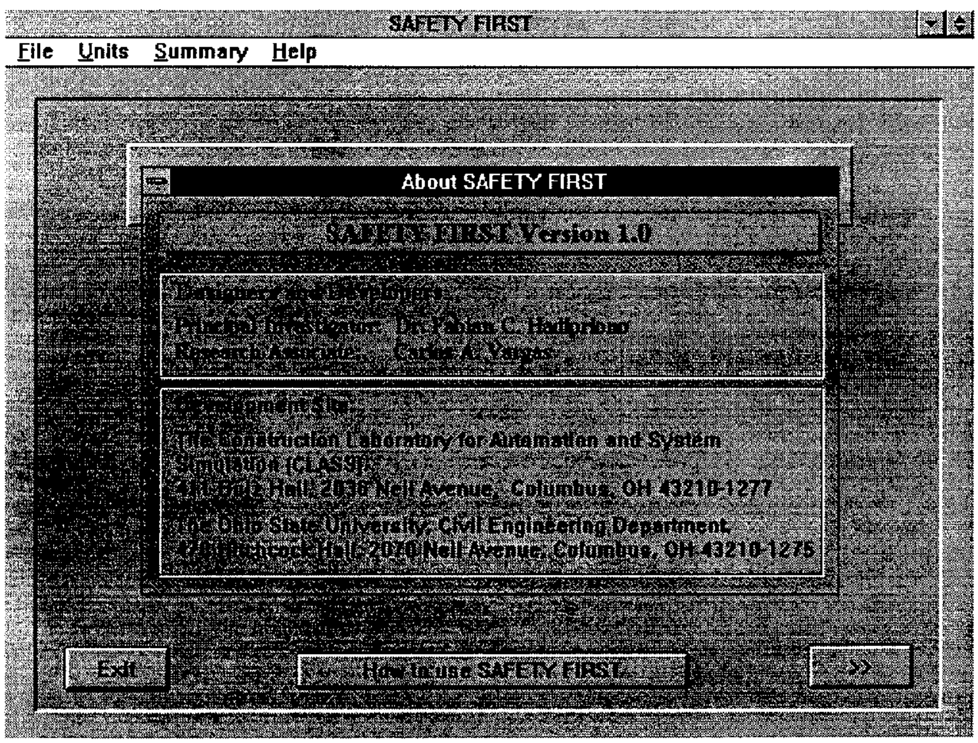


Figure III-5.15 "About Safety First" display

CHAPTER 6
TESTING AND EVALUATION

6.1. Introduction

Usually, developing a good system is a continuous iterative process and the program developed has to be updated or upgraded several times. In order to ensure that SAFETY FIRST can be used for its intended purposes, evaluation and testing by experts and users was conducted at all stages of its development. The knowledge engineers tested and evaluated the system at several stages of development to detect weaknesses in the system, such as features that did not perform their intended function, unclear instructions, conditions that were not previously considered by the system, and additional features required as suggested by the experts. This continuous evaluation has made major modifications less likely, particularly at the later stages of the development process.

6.2. SAFETY FIRST Evaluation and Testing

The evaluation and testing of SAFETY FIRST was performed in three stages: first, during the preliminary stages of development, the knowledge engineers had to determine whether the expert system technology was the most adequate to use to handle the given problem as supposed to other more traditional programming languages. This first test is done to ensure the applicability of the system. Since the knowledge required for SAFETY FIRST is mostly heuristic (based on experts knowledge of the world: rules of thumb, previous experiences), earlier evaluation and justification revealed that it is best handled by an expert system. This conclusion is also supported by the fact that we concentrated on a specific domain area with specific boundaries (scope and limitations); where the significant knowledge required for the system development could be acquired.

In the second stage, the knowledge acquired for the system development was checked by the knowledge engineers and participating experts. At this stage, the knowledge structures developed to represent the knowledge were also checked to determine whether or not they represent the experts' knowledge (i.e., this evaluation process was performed during the knowledge acquisition stage described in Volume II of this report).

As for the expert system itself, the early stages of its development were spent in developing the knowledge base. At these stages, the system was checked informally but continuously by the knowledge engineers and participating experts to determine whether the knowledge base structure reflects the knowledge structures previously developed. In addition, all rules were checked to ensure that no errors were made while inputting the knowledge (i.e., facts and rules) into the system's knowledge base.

Later, in the middle and later stages of the system development and once a defined structure for the user interface was developed, a formal evaluation sheet was created for evaluating and testing the system (the evaluation sheet and its parts will be discussed in the next section). The evaluation was performed by both participating experts, whose knowledge was represented in SAFETY FIRST, and independent experts, whose knowledge was not represented in the system.

6.3. Formal Evaluation and Testing

Throughout its development, the system was continuously checked by both the knowledge engineers an experts to guarantee its usefulness and the accuracy of the system's logic and conclusions. In addition, from the middle to later stages, the system was also evaluated by independent experts and potential users. To perform this evaluation, a system evaluation form was developed (Figure III-6.1) The system was evaluated in terms of the conclusions accuracy and completeness and other system's characteristics, such as the user interface (ease of use), the system's questions during a consultation (clarity of questions), the system's efficiency (capability and efficacy of the consultation scheme), the system's applicability (the practicability and potential usefulness of the system in the field), and finally, the system's overall performance (overall impression of the system).

Five expressions were provided for the evaluation of each of the above ratings: **very good, good, fair, poor**, and **very poor**. The following are the guidelines given to the user as to how to use the rating:

- **Very good:** little or no improvement is required
- **Good:** some improvement is required but no major mistakes are detected.
- **Fair:** some problems are detected but performance is satisfactory.
- **Poor:** major changes are required.
- **Very poor:** redevelopment is required.

The system was tested at several stages of its development. At each step, the evaluator's comments were collected, evaluated, and incorporated into the system if deemed adequate. The summary of results from the final evaluation is presented next.

SAFETY FIRST EVALUATION FORM

Evaluator: ....

Affiliation: ....

Position: ....

Phone: ....

Conclusions by SAFETY FIRST

Criteria	Rating				
	Very Good	Good	Fair	Poor	Very Poor
Adequacy					
Explanation					

Adequacy: Conclusions given by the system are adequate.
Explanation: Adequacy of explanations within the conclusion.

System's Performance

Criteria	Rating				
	Very Good	Good	Fair	Poor	Very Poor
User Interface					
Questions					
Efficiency					
Applicability					
Overall Performance					

User Interface: User friendliness of system environment, including on-line help.
Questions: Clarity of questions and data required during the consultations.
Efficiency: Efficiency and ease to use consultation scheme.
Applicability: Usefulness and practicality of the system.

Figure III-6.1 System Evaluation Form

6.4. Evaluation Results

Several groups of experts and users have evaluated SAFETY FIRST. The results of their evaluation and testing of the program have been included throughout the development of the system. Their contributions have considerably enhanced the performance of SAFETY FIRST. In this section, a discussion of a formal and final evaluation of SAFETY FIRST is presented.

The final testing and evaluation took place close to the end of the project period. During this test a representative subsystem of SAFETY FIRST (i.e., floor edge component) was evaluated by nine experts/users consisting of two experts from the Bureau of Workers Compensation (BWC), two safety consultants, two persons in charge of safety programs for the Builders eXchange (BX) of Columbus, Ohio, and three potential users from different construction companies with jobs at different management levels.

The results are presented in both bar charts and pie charts. The bar charts show the number of people assessing the system for a given rating. The pie charts indicates the percentage of answers for each rating. Two-thirds of the evaluators felt that the conclusions provided by the system were adequate and had the right amount of explanations (Figures III-6.2 and III-6.3). Two evaluators considered the conclusions as very good and one them of evaluated the conclusions as fair.

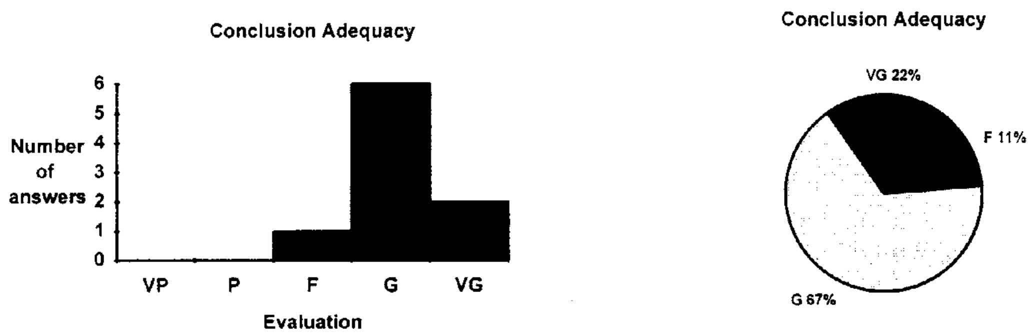


Figure III-6.2 Conclusions Adequacy (Question 1)

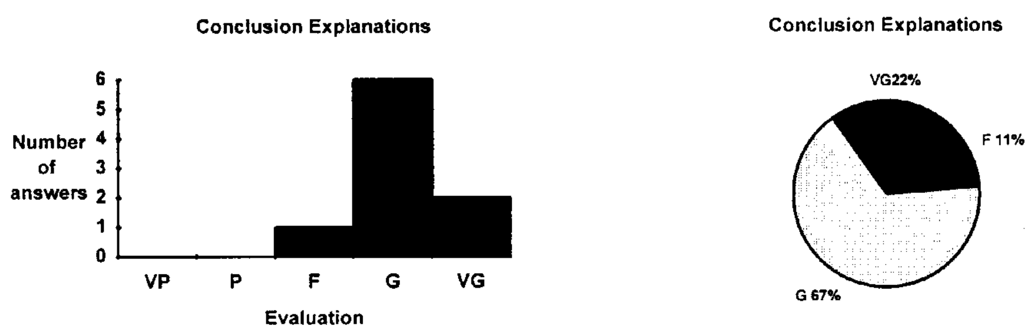


Figure III-6.3 Conclusion Explanations (Question 2)

Next, most evaluators thought that the user interface is more than adequate. Six of them rated it as very good (Figure III-6.4). The questions by the system are also rated high (between very good and good) in terms of their clarity (Figure III-6.5). Furthermore, the efficiency of the system was judged to be better than good with seven of the nine evaluators rating it as good and the other two rating it as very good (Figure III-6.6). As for the system's applicability, the evaluators also considered it as better than good (Figure III-6.7). Some of the evaluators commented that the system was good for post accident investigation (diagnosis), but could be improved for prognosis. They indicated that the system would be more widely used if the site evaluation module was a stand alone module incorporating more details.

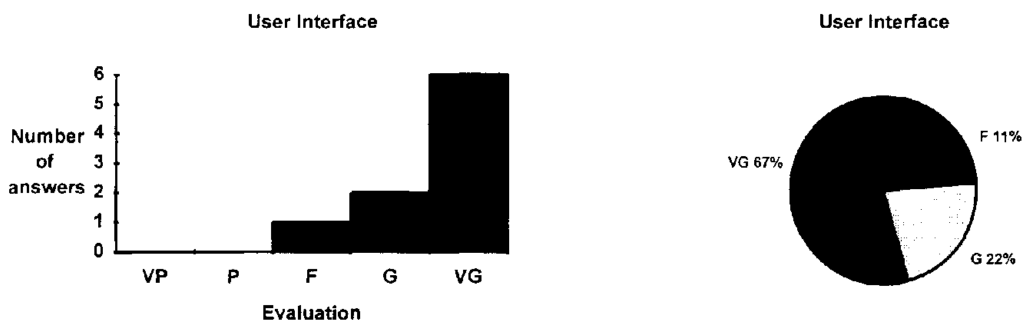


Figure III-6.4 System's User Interface (Question 3)

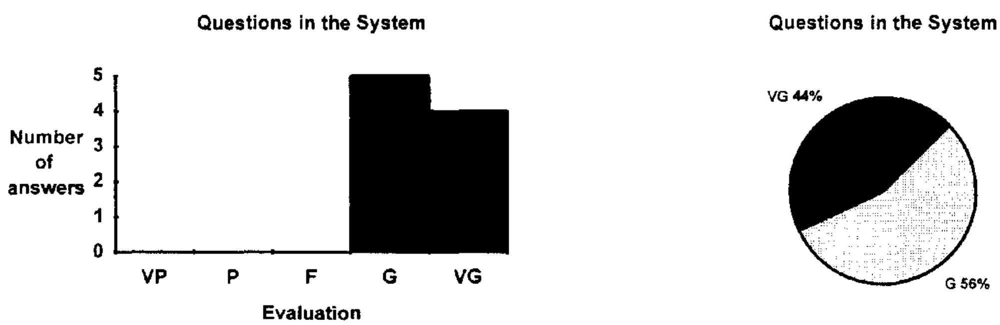


Figure III-6.5 Questions in the System (Question 4)

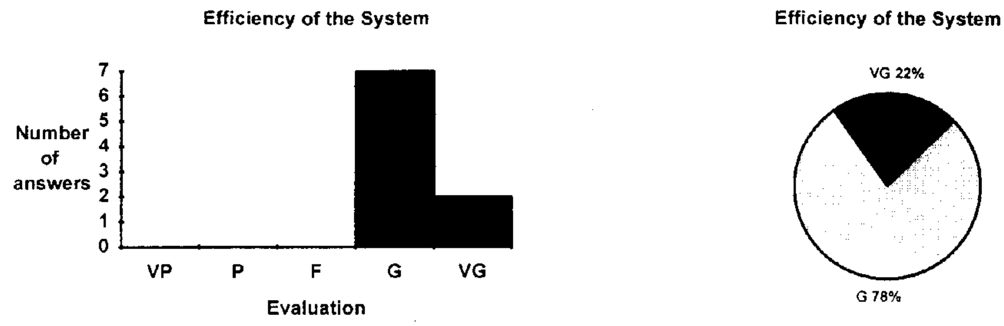


Figure III-6.6 System's Efficiency (Question 5)

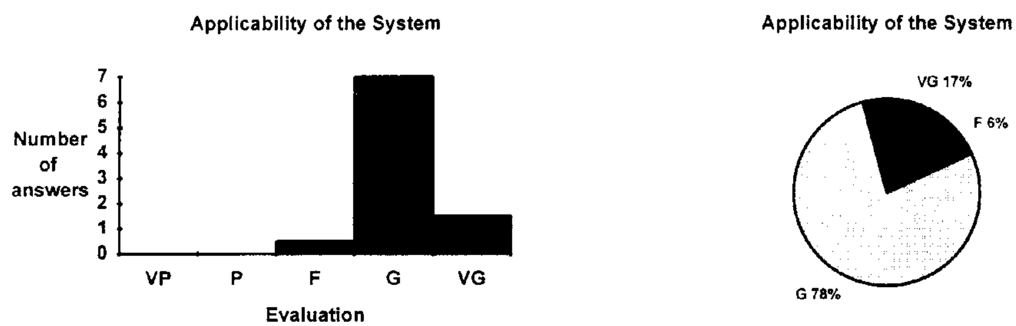


Figure III-6.7 System Applicability (Question 6)

Finally, Figure III-6.8 shows that most of the evaluators rated the system's overall performance as good or better than good (about 90 % of population).

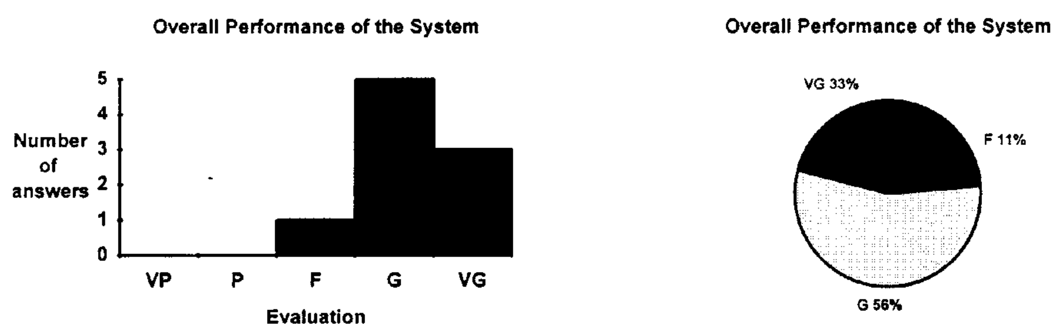


Figure III-6.8 System's Overall Performance (Question 7)

The following are some of the general comments they gave about the system and its performance:

> " I tried several times to fool the system into giving me an incorrect answer and it never did. It correctly picked up the information from the answers to the questions I gave."
>
> "This is a good system for post-accident investigation. As a training tool, this program would greatly aid in hazard recognition for novices and allow determinations to be made to insure the work site is free from fall hazards that the workers will be exposed to."

The evaluators also indicated that the system's performance was improved compared to previous validations. The following are some of the comments in this regard:

> "A definite improvement. Several reasons: 1) scenarios were more broad, 2) conclusions were more in depth. I felt the addition of the code information made a big difference on my confidence on the final conclusion."
>
> "You have done a great job of correcting some problems from our first review....
> First, here is what I really like:
> - Cross checking to OSHA code numbers
> - Expanded info in conclusions to address 'don't know' answers
> - The Stop signs to explain that your choices contradict each other
> - Having more scenarios and options covered"
>
> "The changes made have:
> - increased the speed of the operation
> - the "don't know" option helps pinpoint areas that need to be checked [further] on site
> - it asks pertinent questions"

There were also comments to improve SAFETY FIRST. While these comments are important, they are beyond the scope of this study. These comments are included in the recommendations of this study. Finally, although the goal and objectives in developing SAFETY FIRST are met, its development and evaluation processes continue. The principal investigator and his doctoral student, who participated in this research, will enhance and refine SAFETY FIRST by including multi-media and other features based on comments made by experts and users alike. We will continue working on it, so as to make it a useful tool to the industry.

CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1. Summary

While the development of SAFETY FIRST encompasses the entire process, starting from the knowledge acquisition until its testing and evaluation, this chapter is primarily concerned with the latter stages of its development, i.e., in creating the knowledge base.

SAFETY FIRST was developed in an expert system shell, with major components, such as the inference mechanism, the knowledge base, user interface, and facilities for external files interface. The inference mechanism, often called the "brain" of the system, comes with the shell. The knowledge base serves to store the body of knowledge. The knowledge acquired was first structured as fault trees, and then, restructured as decision trees. Since the way experts often diagnose a fall is similar to the pattern used in fault tree models, their knowledge was best represented by these models. While fault trees include the causality relationships of falls, decision trees include the causes and the variables/parameters involved. The development of SAFETY FIRST's knowledge base encompassed knowledge conversion from fault trees into decision trees, and from decision trees into frames, production rules, and demons.

SAFETY FIRST was also developed with its users in mind; hence, throughout its development, emphasis was also placed on user interface. Screen displays were carefully crafted so that users feel comfortable in interfacing with the system. Further, in each screen, terms that may not be too clear for first time users and novices in construction safety are furnished with detailed explanation using SAFETY FIRST's help facilities and the comment boxes provided on each display. Messages, graphics, and help statements are abundant and readily accessible to the users. In addition, the sequence of displays was designed so users can be guided in a tour of thought process, similar to the way an expert would think in solving a fall case.

7.2. Conclusion

The time and effort spent in this project has produced a prototype expert system that is capable in determining the causes of unintentional construction falls and in acting as a consulting tool to check if fall protection devices used are adequate according to construction safety experts and OSHA standards.

Prior to the development of SAFETY FIRST's knowledge base, fault tree models were used to structure the knowledge. We conclude that fault tree models play a significant role in representing the way experts think through the causes of a fall, deducing these causes to obtain the most likely cause, and establishing causal relationships among these causes. Further, our study revealed that the graphical representation of these models can be used independently as a template to guide users to the basic and conditioning causes of falls.

The study also revealed that to develop the knowledge base, decision trees are needed, since they can incorporate the variables and parameters of falls that are not available in fault trees. Although decision trees by themselves do not show causal relationships, these trees are required to convert such relationship into frames, production rules, and demons in the knowledge base of SAFETY FIRST. Hence, both fault tree and decision tree models complement each other in their use in building SAFETY FIRST's knowledge base.

While the system is primarily developed as a diagnostic tool, its design is such that, to a certain extent, it can also be used as a prognostic tool. For example, one can assess variables and information in a construction site and use them as an input for the system. The system can guide the user to the potential "weak links" that may cause the occurrence of falls and, therefore, furnish the user with a warning to avoid such an accident from occurring.

As a part of the study, testing and evaluation of SAFETY FIRST by independent experts and users have shown an overall performance of the system as rated between "good" and "very good." From comments made by our experts and users, as it stands now, SAFETY FIRST seems ready to be used as a training tool, particularly for trainees to be aware of the potential danger of operations in various construction platforms, to evaluate the adequacy of fall protection devices, and to understand the importance of safety in construction. Experts agree that tools such as SAFETY FIRST are a much needed application in the industry.

7.2. Recommendations

While the objectives of this project have been reached, like any other expert system development, continuous refinement and modification of the system is needed. As new technology in materials, erection methods, safety devices, and regulations emerge, much effort is needed to enhance and improve the system. Since an expert system also depends on computer technology, the continuing changes in this technology also calls for updates and upgrades in the system requirements. While numerous recommendations can be suggested as the result of the study, the following can be implemented immediately:

- As a diagnostic tool the system could be improved with more detailed knowledge about the enabling causes of fall from the hazardous components included in the system. The numerous variables often exist when a fall occurs may often limit the system to furnish the users with a general conclusion. This is particularly true when a user wishes to obtain a more specific cause (e.g., specific type of illness, structural strength of a safety device, etc.,) which is beyond the scope of this study. While these specific causes are important, our system requires other domains of knowledge (e.g., medical, structural engineering, etc.). This can certainly become an extension of SAFETY FIRST in the future.

- As a prognostic tool, the system could be expanded to evaluate in detail the adequacy of the fall protection devices. As it stands now, the evaluation of fall protection devices is performed as a part of the diagnostic module. The system would become a more efficient tool if these two modules were separated (i.e., fall diagnostic and safety evaluation modules). Much of the information that is significant for safety evaluation is not significant for a fall investigation and vice-versa.
- Furthermore, we estimate that the knowledge bases of SAFETY FIRST could be improved by using multimedia facilities such as hypermedia and hypertext, and video and sound files. The incorporation of these facilities would make the system more informative and easier to use.

APPENDIX III-A

LIST OF REFERENCES

ANSI (1991). "American National Standards for Construction and Demolition Operations. Requirements for Safety Belts, Harnesses, Lanyards and Lifelines for Construction and Demolition Use," *ANSI Standards*, American National Standards Institute, approved July 31, 1991.

AISC (1996). "CONXPRT AISC Software's Connection Design Program," *Modern Steel Construction*, January 1996, pp. 54.

Brule J.F. and Blount A. (1989). *Knowledge Acquisition*, McGraw-Hill Publishing Co.

Buchanan B.G. and Feigenbaum E.A. (1978). "DENDRAL and Meta-DENDRAL: Their applications dimension," *Journal of Artificial Intelligence*, Vol. 11, pp. 5-24.

Buchanan B.G. and Shortliffe E.H. (1984). *Rule-Based Expert Systems -- The MYCIN Experiment of the Stanford Heuristic Programming Project*, Addison-Wesley Publishing Company, October.

Carrico M.A., Girard J.E., and Jones J.P. (1989). *Building Knowledge Systems: Developing and Managing Rule-based Applications,* McGraw-Hill, New York.

CFR-29 (1994). "Code of Federal Regulations 29, Part 1910 and 1926", Office of the Federal Register National Archives and Records Administration.

Diaz C. (1992). *Basement Failure Diagnosis Expert System*, Dissertation Presented to The Ohio Sate University, at Columbus, Ohio, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Ellis N. (1989). *Introduction to fall protection,* American Society of Safety Engineers.

Hadipriono F.C. (1992a). "Expert System for Construction Safety. I: Fault Tree Models," *ASCE Journal of Performance of Constructed Facilities,* Vol. 6, No. 4, November 1992.

Hadipriono F.C. (1992b). "Expert System for Construction Safety. II: Knowledge Base," *ASCE Journal of Performance of Constructed Facilities,* Vol. 6, No. 4, November 1992.

Hadipriono F.C. (1988a). "Fuzzy Reasoning Expert System (FRES) for Assessing Damage of Protective structures," *Research Report Presented to Universal Energy Systems,* Subproject under the United States Air Force Office of Scientific Research, Contract No. S-760-6MG-054.

Hadipriono F.C. (1988b). "Damage Assessment Expert System," *Proceedings of the International Workshop on Fuzzy System Applications,* IFSA, Iizuka, Japan, pp. 211-212.

Hadipriono F.C. (1988c). "Damage Assessment Based on Functionality Criterion," *Proceedings of the 6th National Conference of The Application of Microcomputers in Civil Engineering*, Florida, pp. 127-131.

Hadipriono F.C. (1986). "Development of A Rule-Based Expert System for Damage Assessment of Air Force Base Structures," *Research Report Presented to Universal Energy System*, Subproject under the United States Air Force Office of Scientific Research, Contract No. F49620-85-C-0013.

Hadipriono F.C., Ward A.D., and Wu W.K., (1992c). "Knowledge Acquisition Strategies for ADAPTES," *Ohio MSEA Specific Research Activity*, No. 15, pp. 1-5.

Hadipriono F.C. and Ross J.T. (1991). "A Rule-Based Fuzzy Logic Deduction Technique for Damage Assessment of Protective Structures," *A Special Issue of Journal of Fuzzy Set and Fuzzy System*, Vol. 44, No. 3, pp. 459-468.

Hadipriono, F.C. and Ross, J.T. (1988). "Expert System for Reparability of Protective Structures," *Proceedings of the 7th Annual Meeting of the North American Fuzzy Information Processing Society*, San Francisco, pp. 76-80.

Hadipriono F.C. and Ross, J.T. (1987). "Towards A Rule-Based Expert System for Damage Assessment of Protective Structures," *Proceedings of the Second International Fuzzy Set Association Congress*, Tokyo, Japan, pp. 156-159.

Harmon P. and Sawyer B. (1990). *Creating Expert Systems for Business and Industry*, Wiley, New York.

Ignizio J.P. (1991). *Introduction to Expert Systems*, McGraw-Hill, New York, NY.

Information Builders (1993). *Level5 Object Reference Manual*, Release 3.51, Information Builders Inc., New York, NY.

Information Builders (1993a). *Level5 Object User's Manual*, Release 3.51, Information Builders Inc., New York, NY.

King R.W. and Hudson R. (1985). "Construction Hazard and Safety Handbook," Butterworth & Co., Ltd., Norfolk, England.

Levine R.I., Drang D.E., and Edelson B. (1986). *A Comprehensive Guide to AI and Expert Systems*, McGraw-Hill, New York, NY.

Martin J. and Oxman S. (1988). *Building Expert Systems: A Tutorial*, Prentice-Hall, Englewood Cliffs, NJ.

Mather M.L. and Fenves S.J. (1985). "HI-RISE: A Knowledge Based Expert System for the Preliminary Design of High Rise Buildings," *Research Report No. R-85-146*, Department of Civil Engineering, Carnegie Institute of Technology, Carnegie-Mellon University, January 1985.

OBWC (1979). *Specific Safety Requirements of the Ohio Bureau of Workers' Compensation relating to Construction*, Ohio Bureau of Workers' Compensation Division of Safety and Hygiene.

OSHA (1987). *Construction industry OSHA Safety and Health Standards (29 CFR 1926/1910),* U.S. Department of Labor Occupational Safety and Health Administration, OSHA 2207.

Parsaye K. and Chignell M. (1988). *Expert Systems for Experts,* John Wiley & Sons Inc., New York, NY.

Pople H.E. (1977). "Heuristic Methods for Imposing Structure on Ill-Structured Problems: The Structuring of Medical," *Artificial Intelligence in Medicine (AAAS Selected Symposium 51),* edited by Peter Szolovits, Boulder, CO Westview Press, 1982.

Roberts N.H., Vesely W.E., Haals D.F., and Goldberg F.F. (1981). *Fault Tree Handbook,* National Technical Information Service, January, pp. IV-2--IV-11.

Sekii K. (1992). *Knowledge Base Development for an Expert System for Selecting an Erection Method for Precast, Prestressed, Concrete Bridge Girders in Japan,* a thesis presented in partial fulfillment of the requirements for the degree of Master of Science in the graduate school of the Ohio State University, Fabian C. Hadipriono (Advisor).

Simons G.L. (1985). *Expert Systems and Micros,* NCC Publications, pp. 27.

APPENDIX III-B

GLOSSARY

ACCIDENT: An unplanned event which has a probability of causing personal injury of property damage [King and Hudson 1985].

BODY BELT (Safety Belt): A strap that both secures around the waist and attaches to a lanyard, lifeline, or deceleration device [ANSI 1991].

BODY HARNESS: Straps that are secured about an employee in a manner that distributes the arresting forces over at least the thighs, shoulders, and pelvis, with provisions for attaching a lanyard, lifeline, or deceleration device [ANSI 1991].

CATCH PLATFORM: Device erected at the outside edge of the roof and prevents the worker from falling all the way to the ground (usually, it is a scaffolding structure).

CONTROLLED ACCESS ZONE (CAZ): Area in which certain work (e.g., overhand bricklaying) may take place without the use of a guardrail system, personal fall arrest system, or safety net system. Access to the zone is limited.

COVER: It covers holes in floors, roofs, and other walking/working surfaces. If located on roadways, they have to be able to withstand the maximum axle load of the largest vehicle expected to cross the cover. Other covers should be able to support without failure at least twice the weight of employees, materials, and equipment that may be imposed on it. They should be secured to prevent accidental displacement and color coded or labeled to identify them [29 CFR 1926.502 (I)].

DECLARATIVE KNOWLEDGE: It concerns with logical or empirical relationships between two or more terms [Harmon and Sawyer 1990].

DEFINITIONAL KNOWLEDGE: "Defined by common agreement about how words are to be used" [Harmon and Sawyer 1990].

DEMONS: Functions that are not invoked explicitly, but hibernate until a pre-defined condition occurs" [Carrico et al. 1989]. They are also known as "When Changed" or "When Modified" functions.

FAULT TREE: A fault tree is a graphic model that shows parallel and sequential causes or events contributing to predetermined top undesired event [Roberts et al. 1981].

FORWARD CHAINING: This inference method focuses on the IF side of the rule rather than their conclusions. Once the condition on the IF side is true, the action on the THEN side must also be true. It is also known as antecedent driven inference.

FRAME: "A group of attributes that describes a given object. Each attribute is stored in a slot, which may contain default values, rules, procedures for changing the values attached to the attributes" [Martin and Oxman 1988].

GUARDRAIL: A temporary barrier which consists of a top rail, an intermediate rail and posts and whose main objective is to provide the worker with support. It is usually placed on unprotected edges and openings where there is a drop of more than 4 feet.

HARNESS: Component of fall arrest system which consists of straps worn by the worker around his shoulders an chess to hold him/her in case of an accident.

HAZARD: A condition with potential for an accident or ill health [King and Hudson 1985].

HEURISTIC KNOWLEDGE: Rule of thumb that allows the assignment of a value to or a judgment or a variable that would otherwise be unpredictable [Harmon and Sawyer 1990].

INFERENCE ENGINE: It is responsible for the control and execution of the reasoning strategies used by the expert system. It is considered the 'brain' of the system.

KNOWLEDGE: "An integrated collection of facts and relationships which, when exercised, produces competent performance" [Harmon and Sawyer 1990].

KNOWLEDGE BASE: It contains all the knowledge obtained from experts and literature regarding the causes of falls and the way to identify these causes.

PERSONAL FALL ARREST SYSTEM: System used to arrest an employee falling from a working level. It consists of an anchorage, connectors, a body belt or harness, and may include a lanyard, deceleration device, lifeline, or suitable combinations of these. After January 1, 1998, the use of belts for fall arrests is prohibited.

PROCEDURAL KNOWLEDGE: Composed of specific steps that can be followed to achieve a specific result [Harmon and Sawyer 1990].

PRODUCTION RULES: Statement in the form IF (condition) THEN (action). It is the most popular tool for coding knowledge into a knowledge base given that people tends to express their knowledge in the form of IF-THEN rules.

ROOF: Exterior surface on the top of a building. This does not include floors or formwork which, because a building has not been completed temporarily become the top surface of a building.

SAFE: A working environment is "provisionally deemed as safe if its risks are deemed known and in the light of that knowledge judged to be acceptable" [King and Hudson 1985].

SAFETY NET: Net erected underneath the working surface to catch workers in the case of a fall. Safety nets should be provided when the use of guardrails, catch platforms, or fall arrest devices is not practical or possible. The net should be installed as close as practicable under the walking/working surface on which employees are working, but in no case more than 30 feet below such level. Other regulations for the net erection can be found on the Code of Federal Regulations (CFR), section 1926.502 (c).

SCAFFOLD: A temporary or movable platform supported on the ground or suspended; used for working at considerable heights above the ground [McGraw-Hill, 1984].

SELF-RETRACTING LIFELINE/LANYARD: Deceleration device containing a drum-wound line which can be slowly extracted onto the drum under slight tension during normal employee movement, and which after onset of a fall automatically locks the drum and arrests the fall.

SLIP (NOT FALL): A slip results in a sliding motion when the friction between the supporting surface and the foot gear is inadequate. In this case, the accident results in the worker losing his/her balance but not falling [Ellis 1989].

USER INTERFACE: It compresses all the displays by which the system interacts with the user to either get information required to reach a conclusion or provide explanations to the user as needed.

WALL OPENING: A gap or void at least 30 inches height and 18 inches width, in a wall or partition and through which employees can fall to a lower level.

APPENDIX III-C
LIST OF ABBREVIATIONS

BX: Builder's eXchange

BAFDES: Basement Failure Diagnosis Expert System

CAZ: Controlled Access Zone

Cond: Conditioning Causes

CP: Catch Platform

DT: Decision Table

EXPERECT: Expert Erection (Expert System)

FEBas: Floor Edge Basic Cause

FOBas: Floor Opening Basic Cause

FSBas: Form Scaffold Basic Cause

FTES-FALL: Fault Tree Expert System for Construction Falls

LISP: List Processing

OSHA: Occupational Safety and Health Administration

PLBas: Portable Ladder Basic Cause

Prob: Conditioning Problem

PROLOG: Programming Logic Language

RoBas: Roof Basic Cause

SBBas: Steel Beam Basic Cause

SLBas: Same Level Basic Cause

SliBas: Slip Basic Cause

TWBas: Top of Wall Basic Cause

WOBas: Wall Opening Basic Cause

APPENDIX III-D
DECISION STRUCTURES

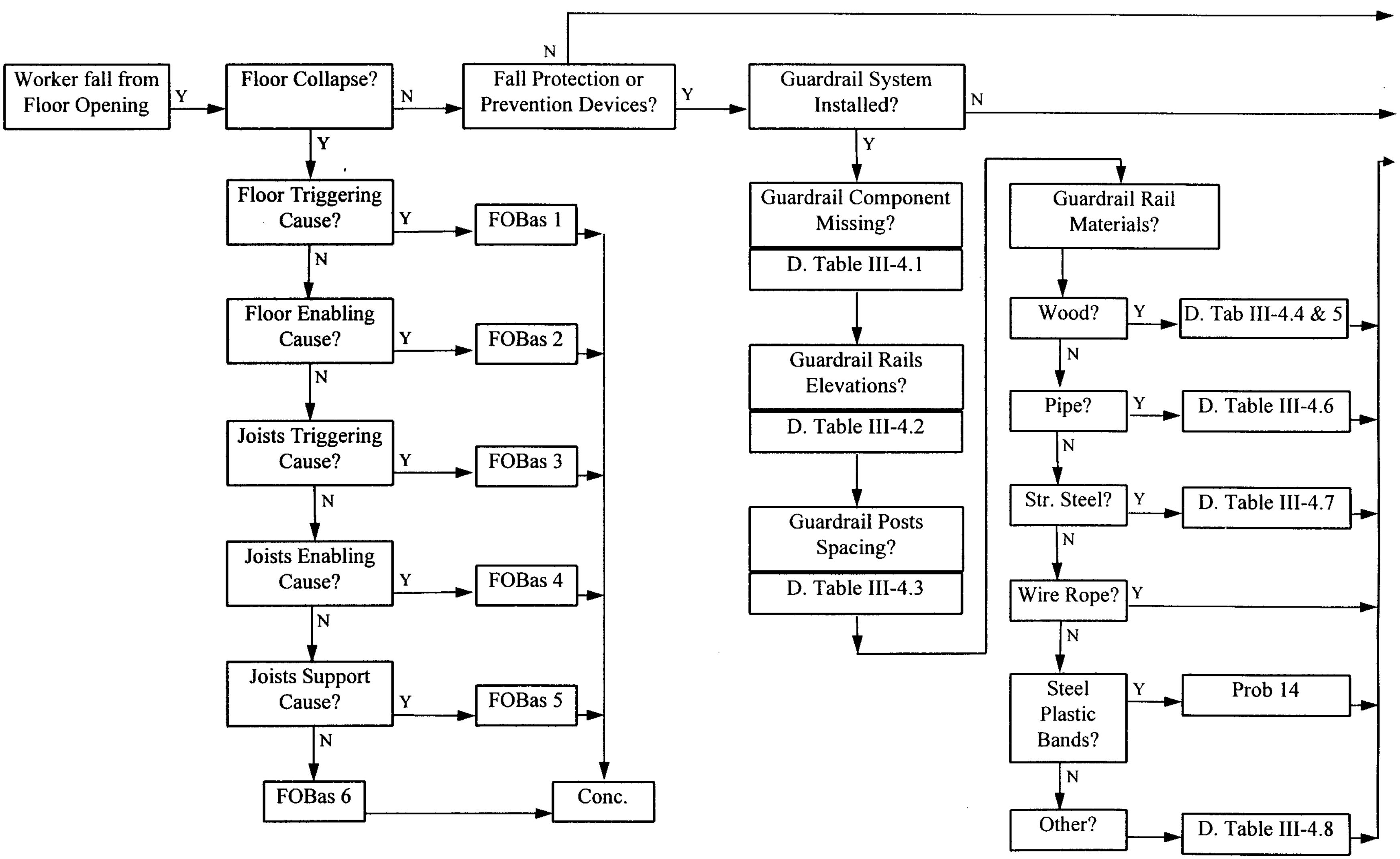
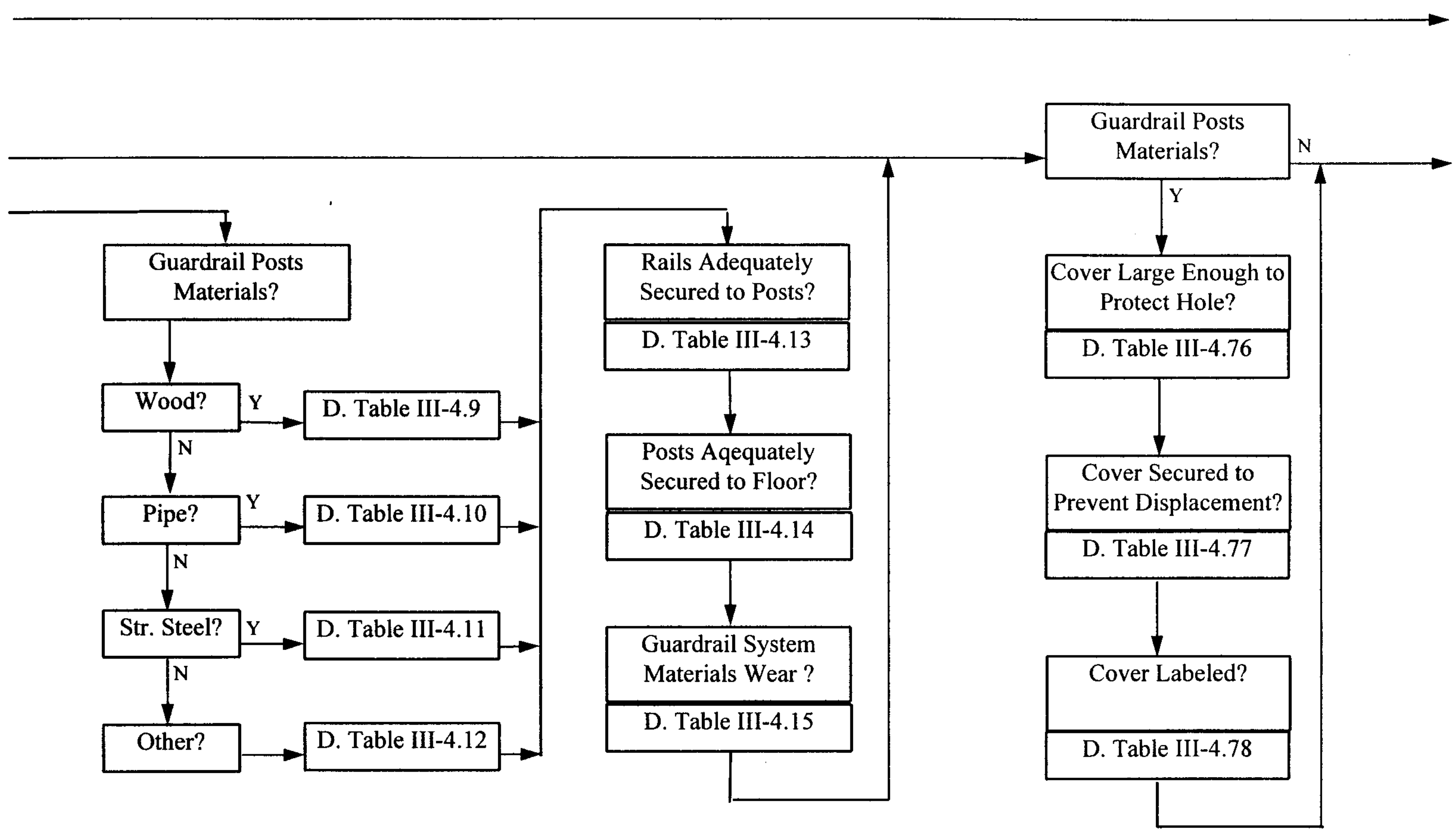


Figure III-D.1 Decision Structure for Worker Fall from Floor Opening



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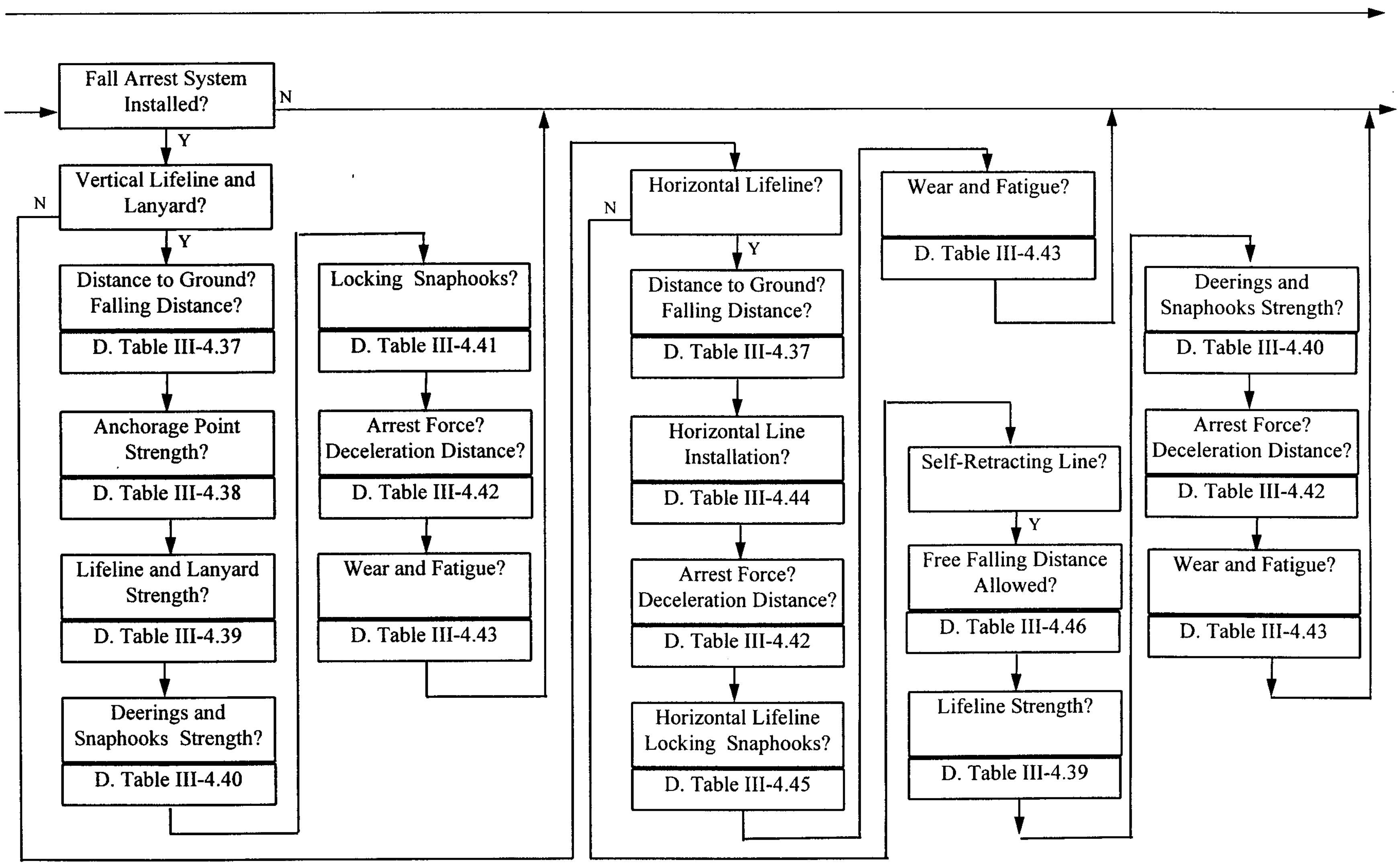

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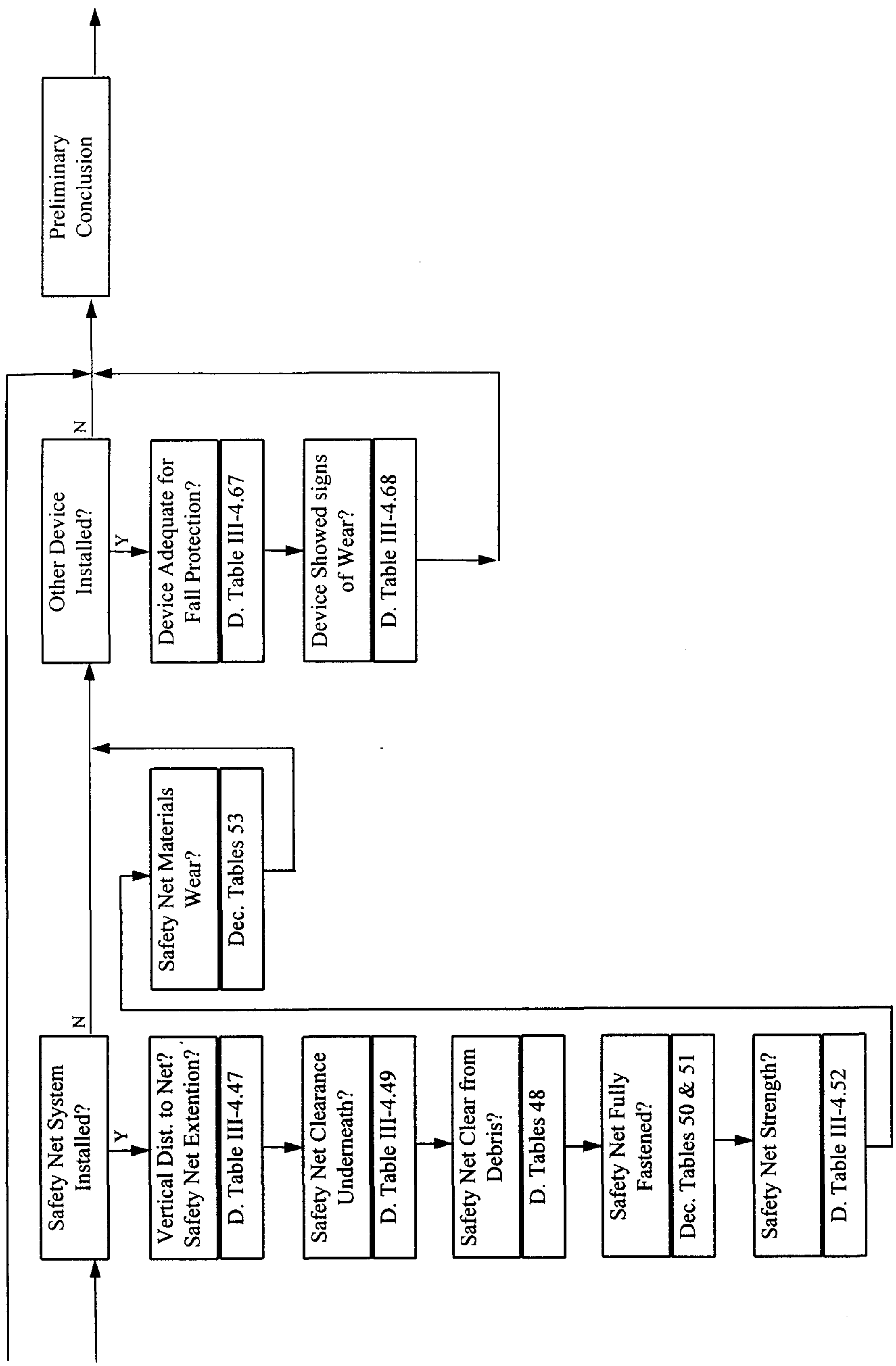

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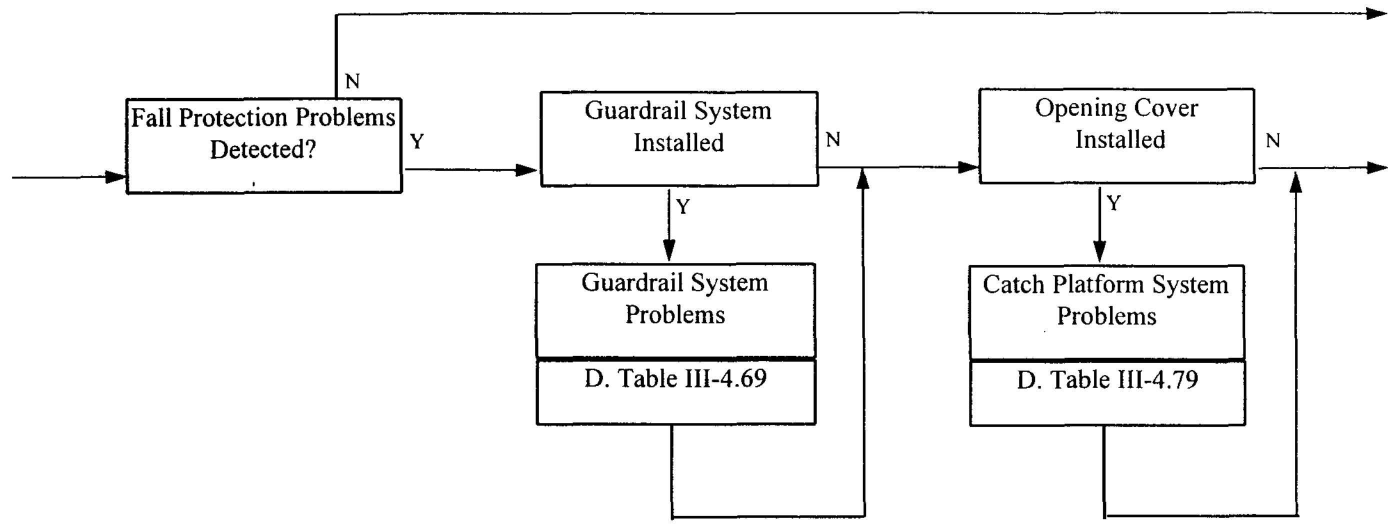

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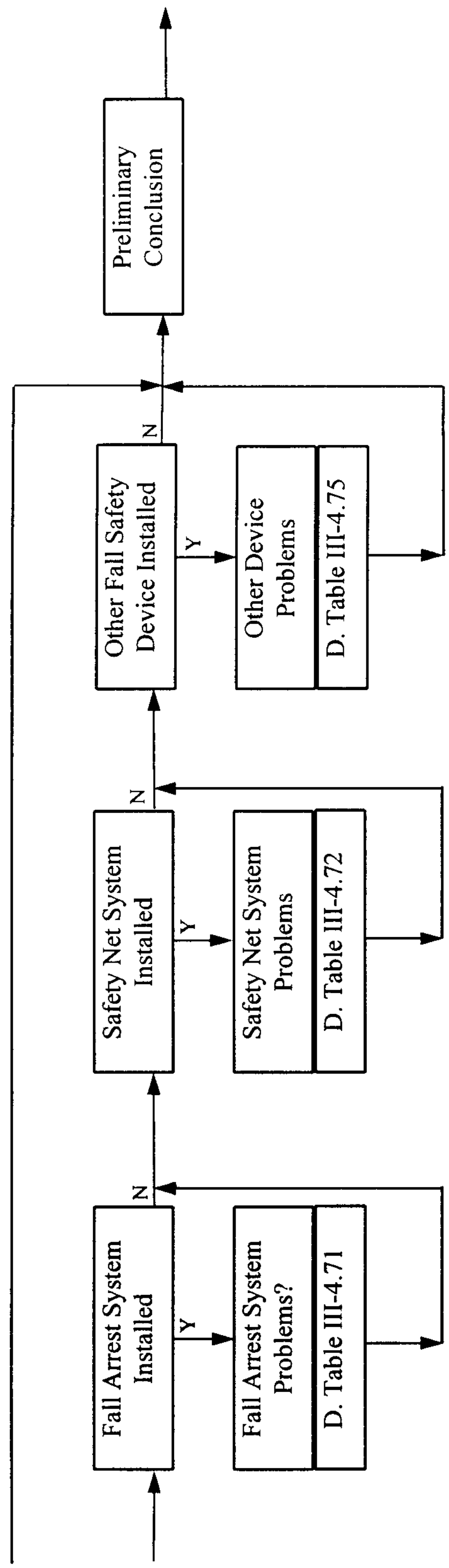

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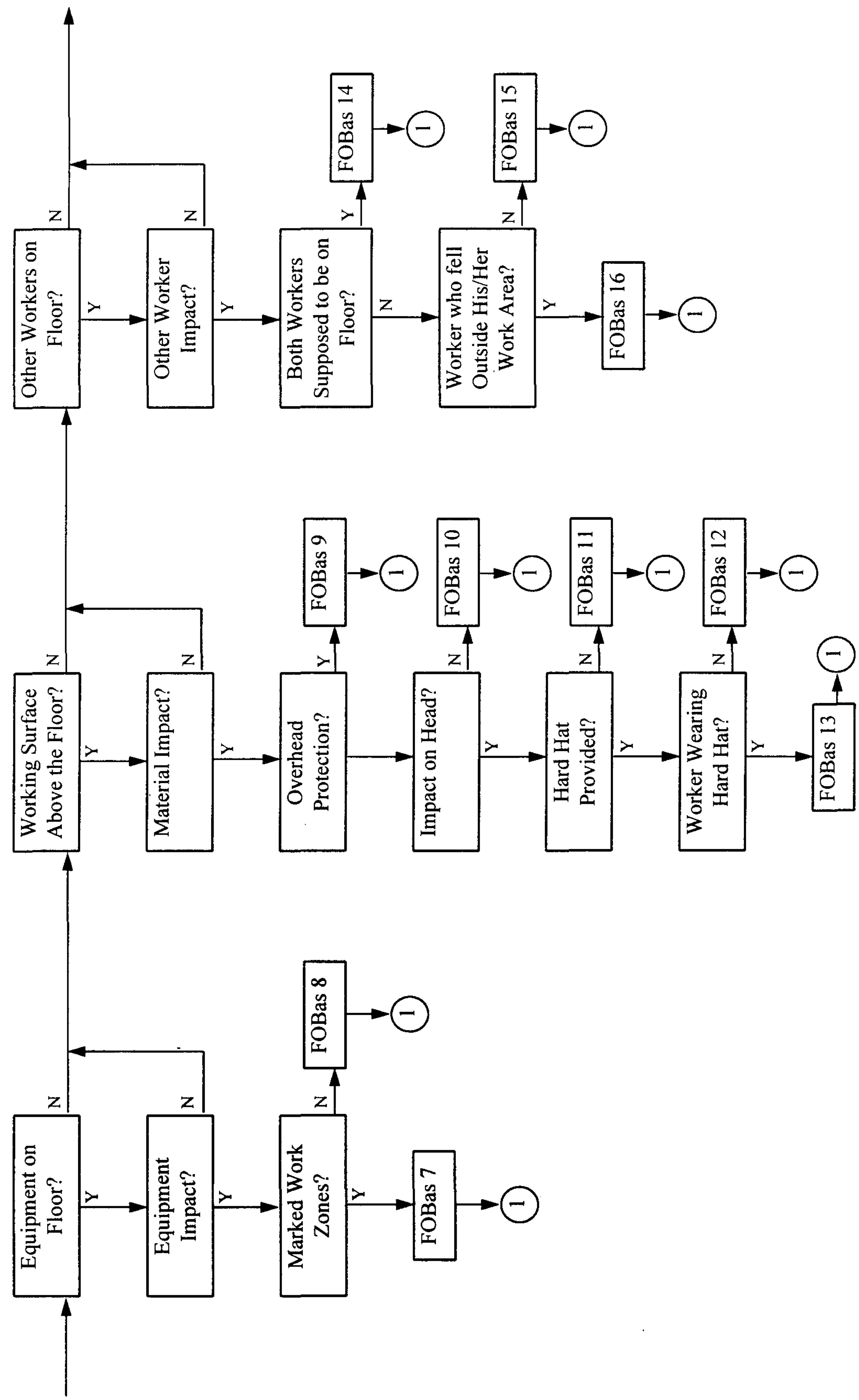

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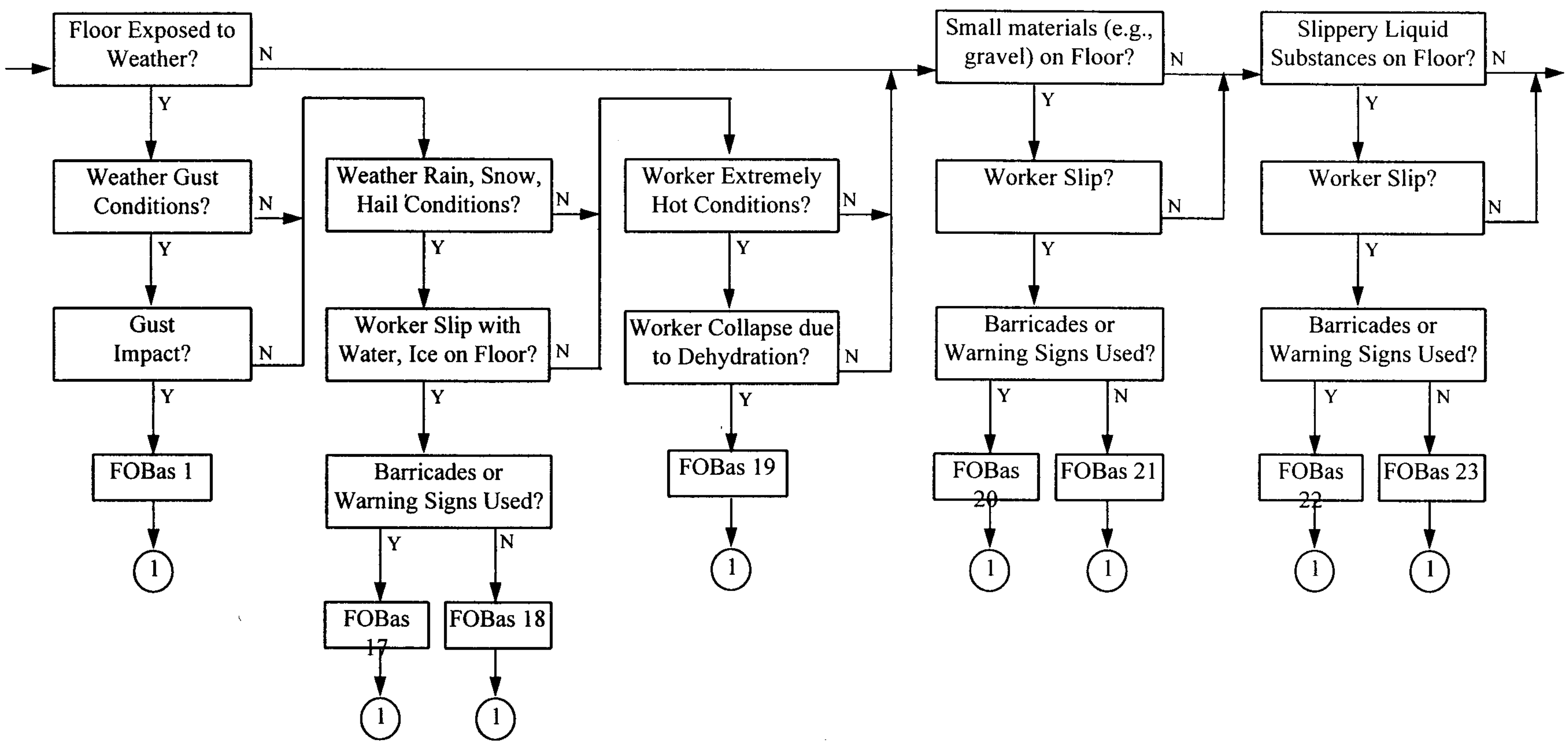

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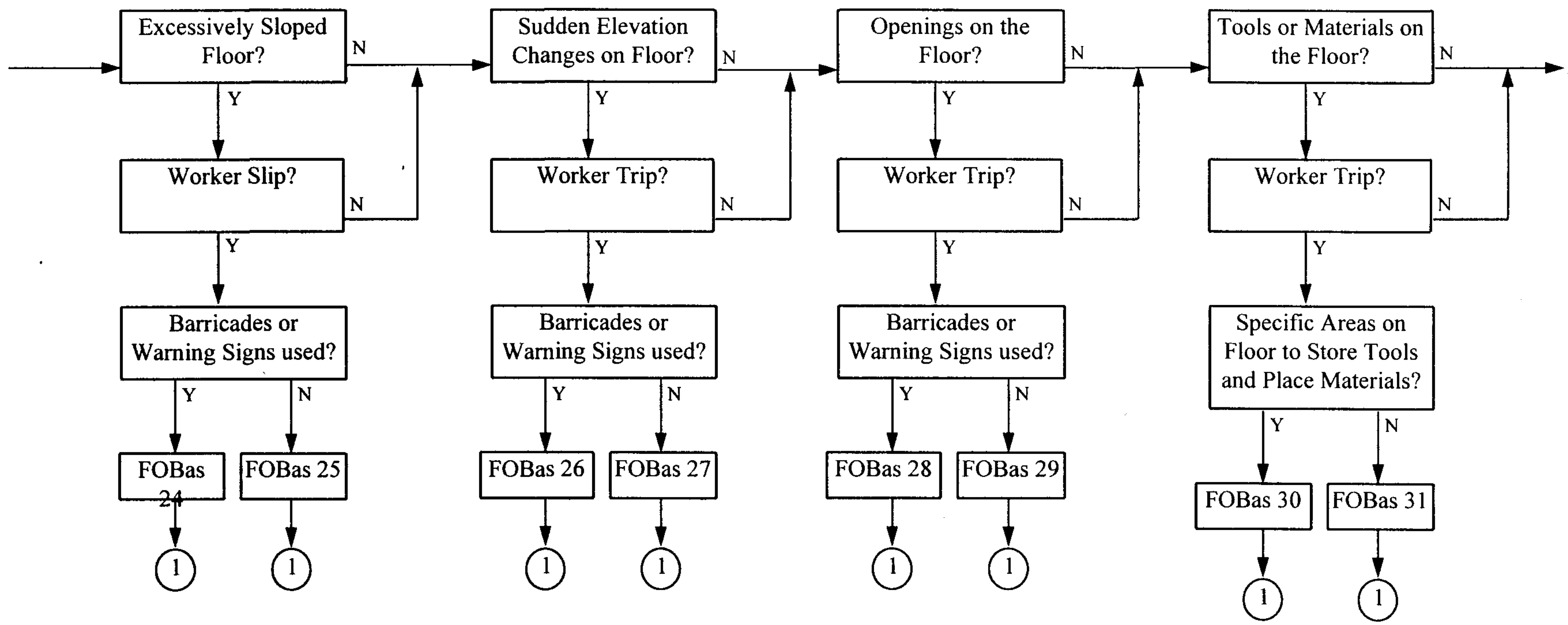

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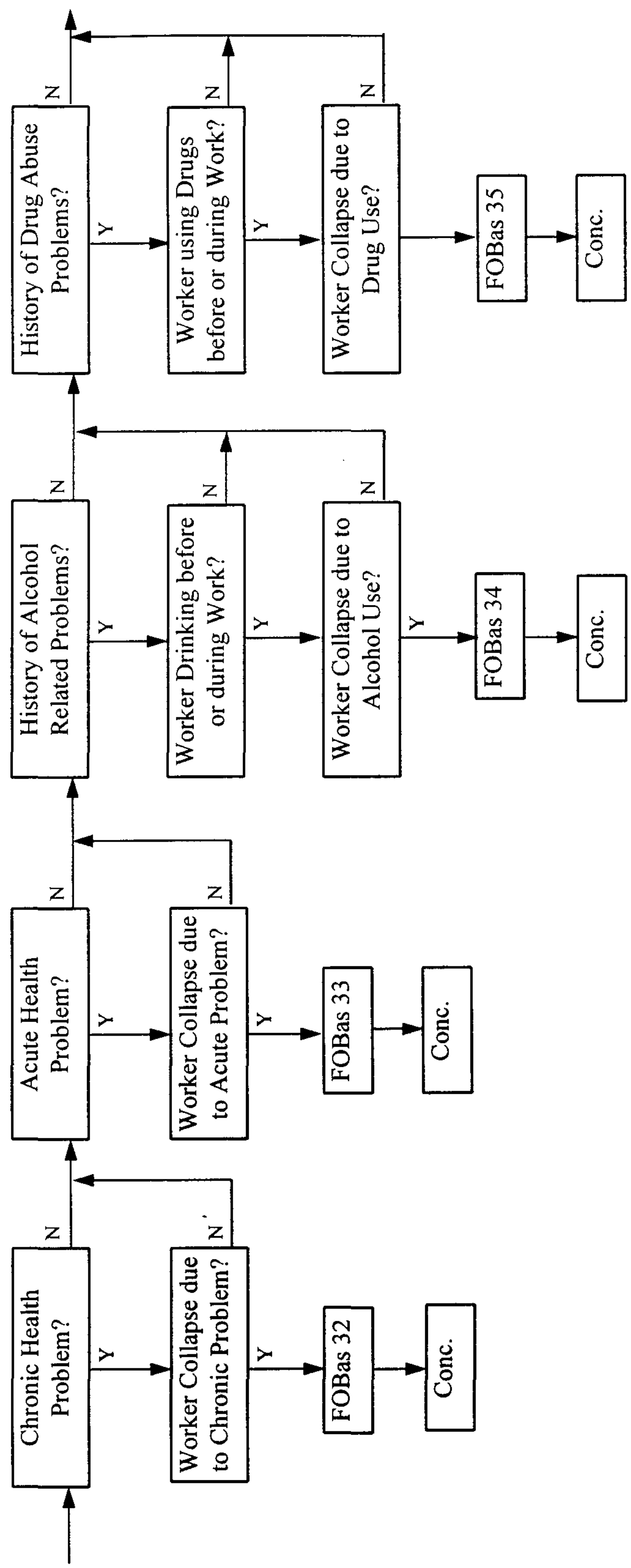

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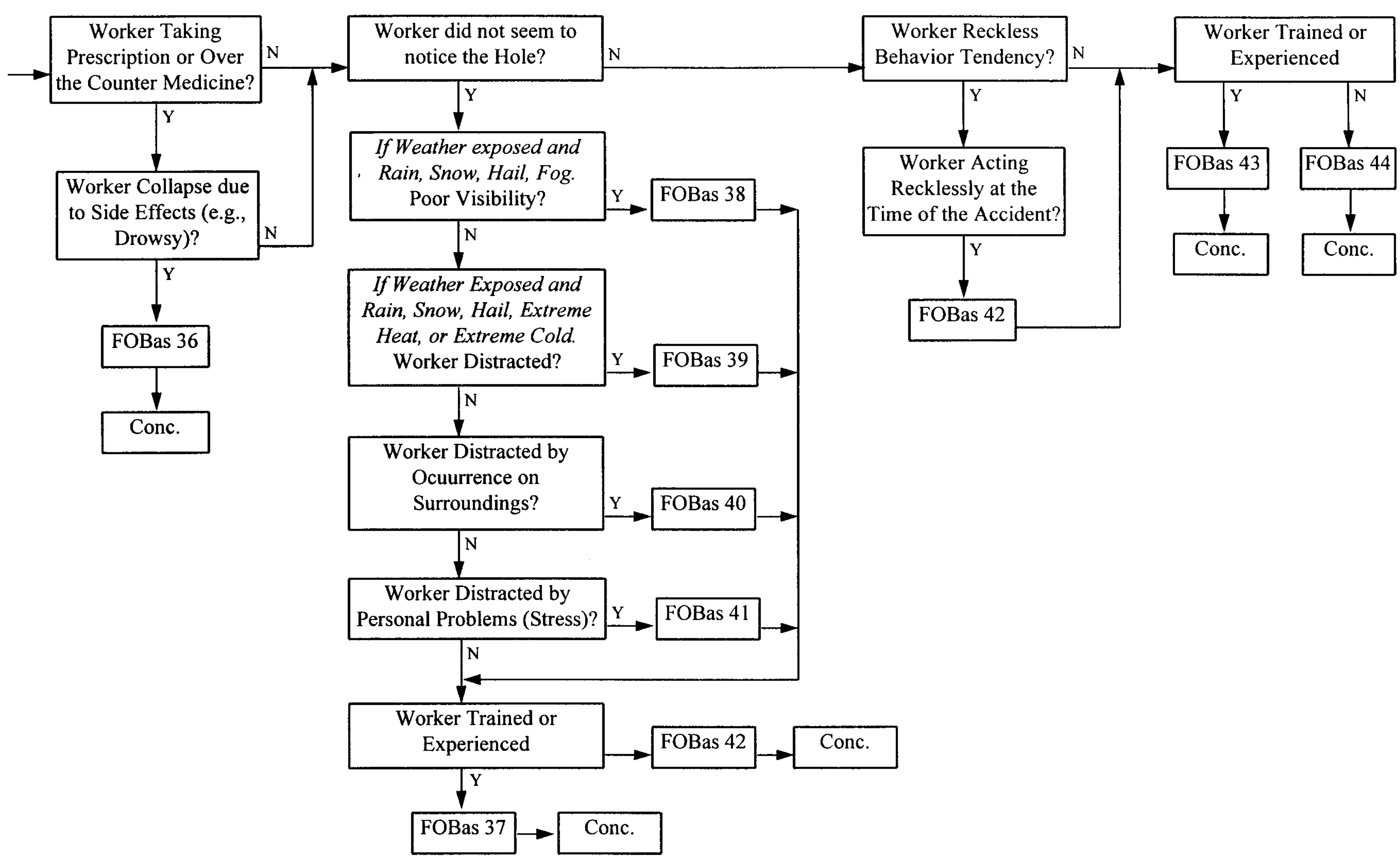

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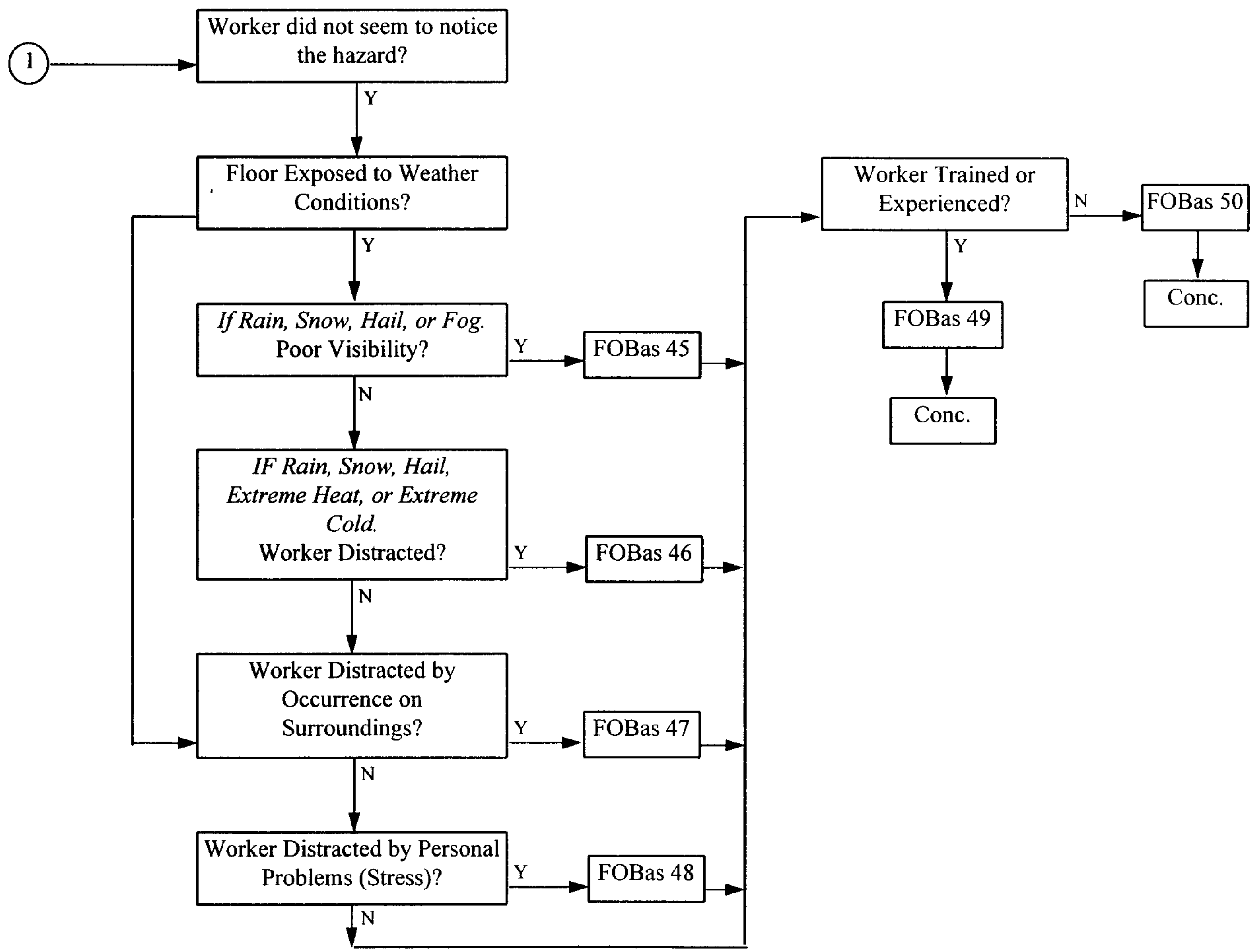

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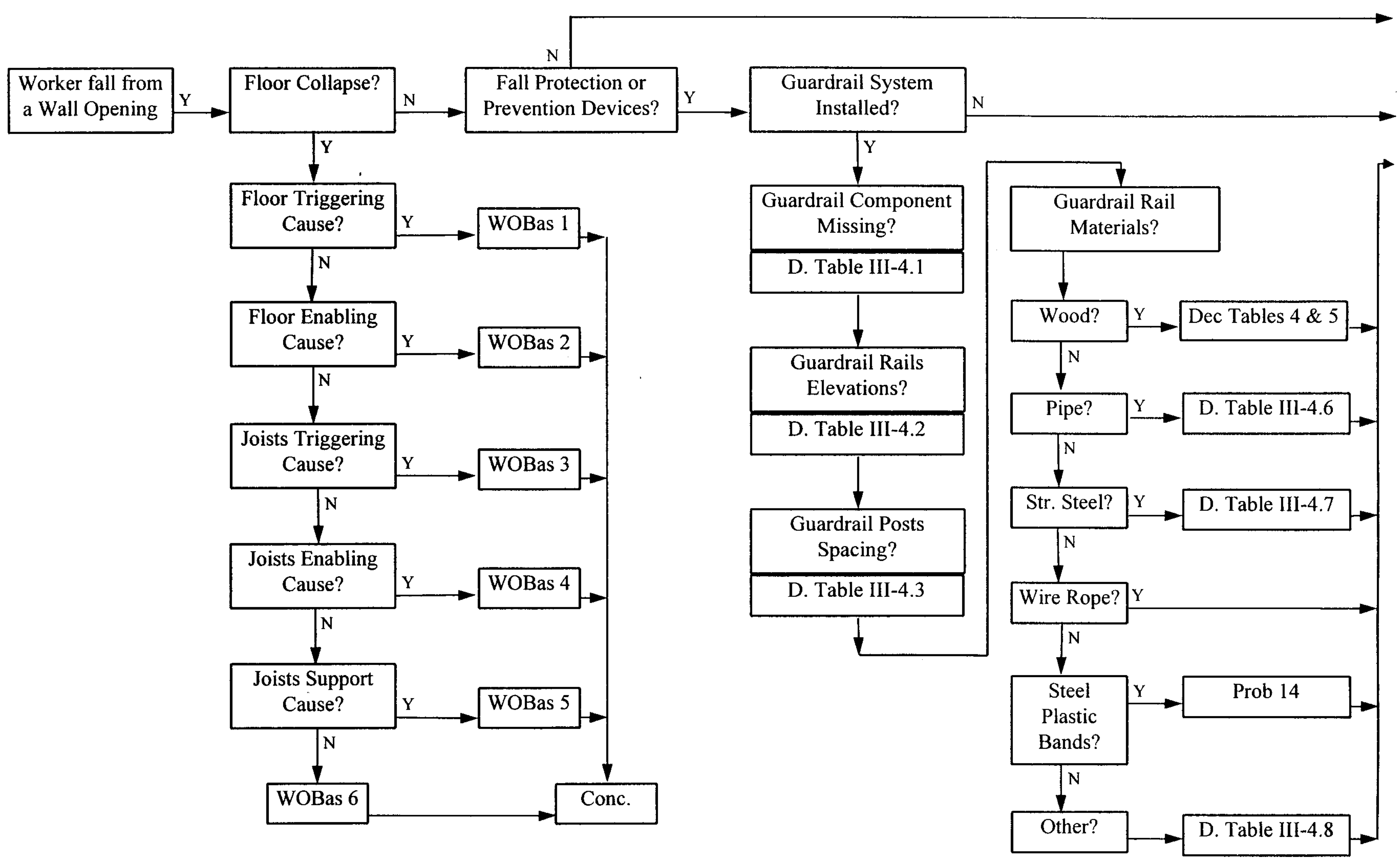

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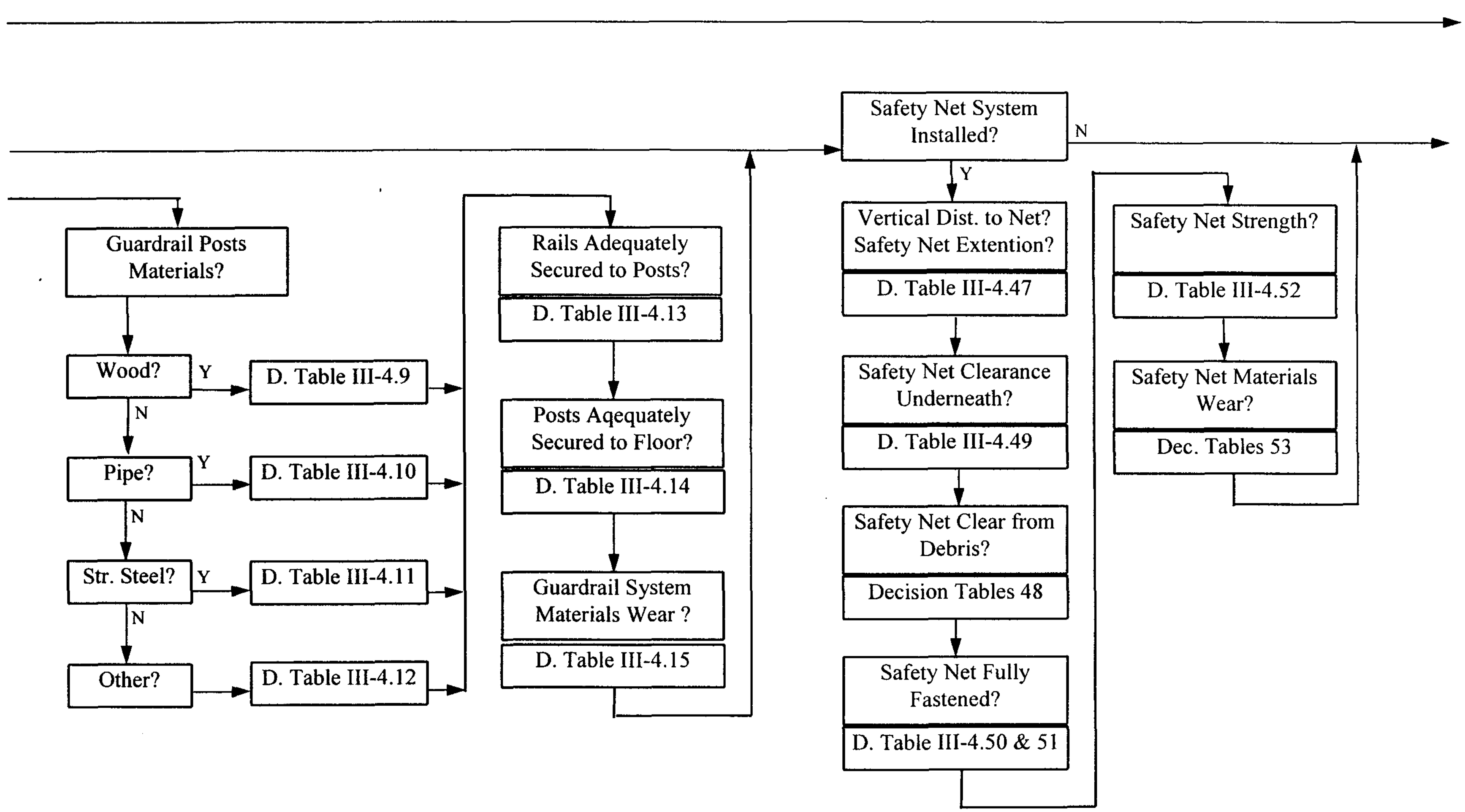

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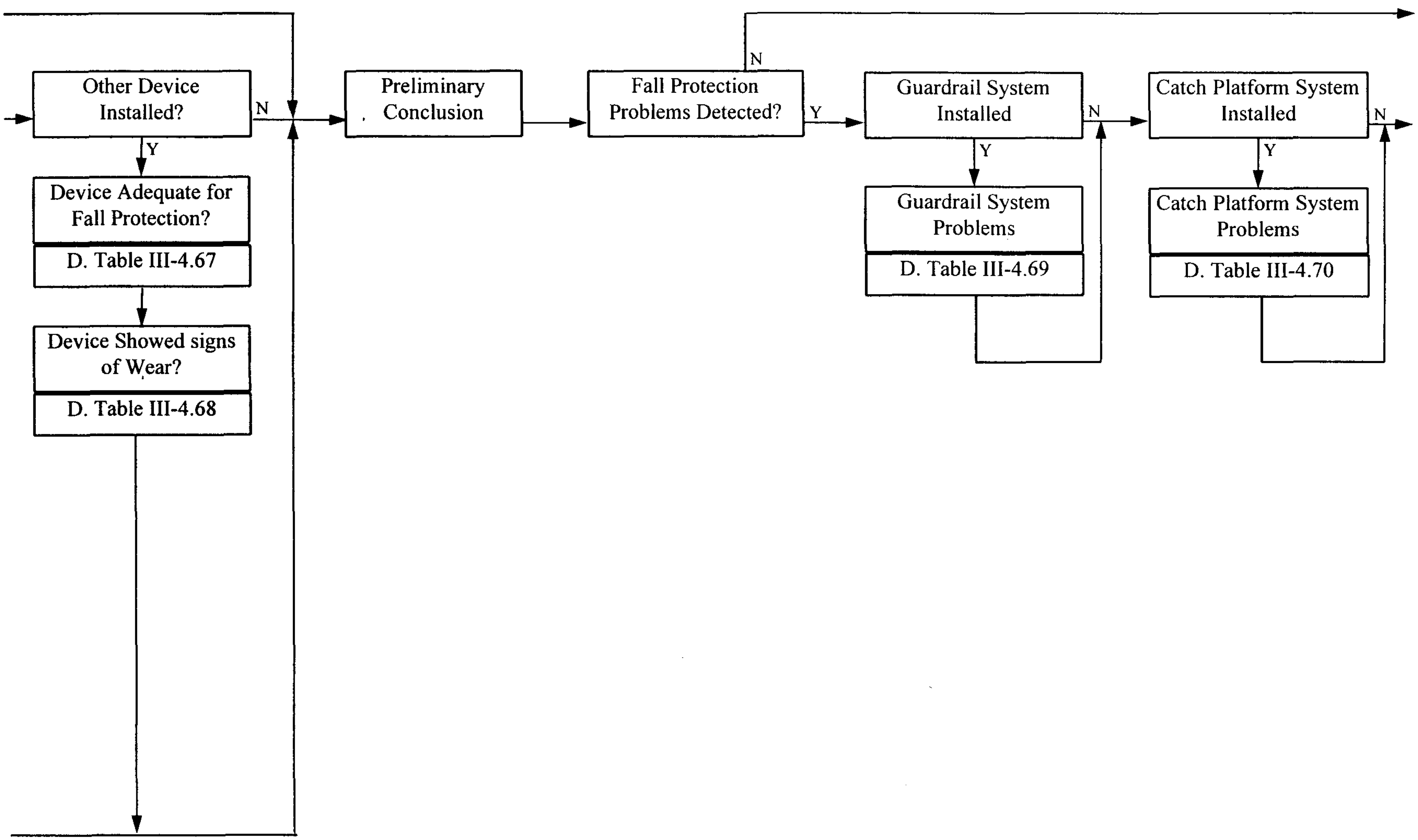

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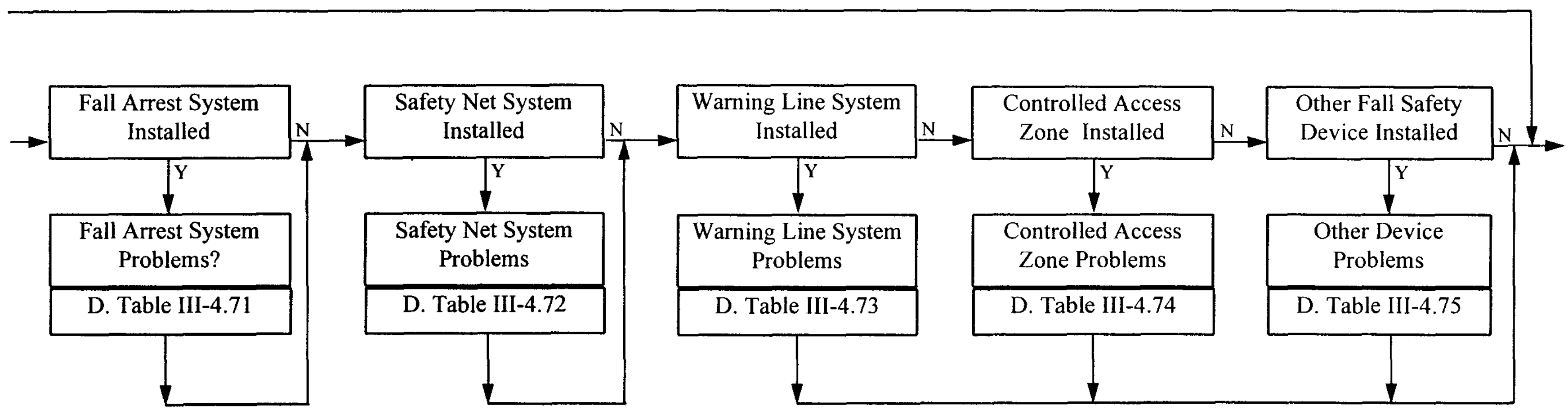

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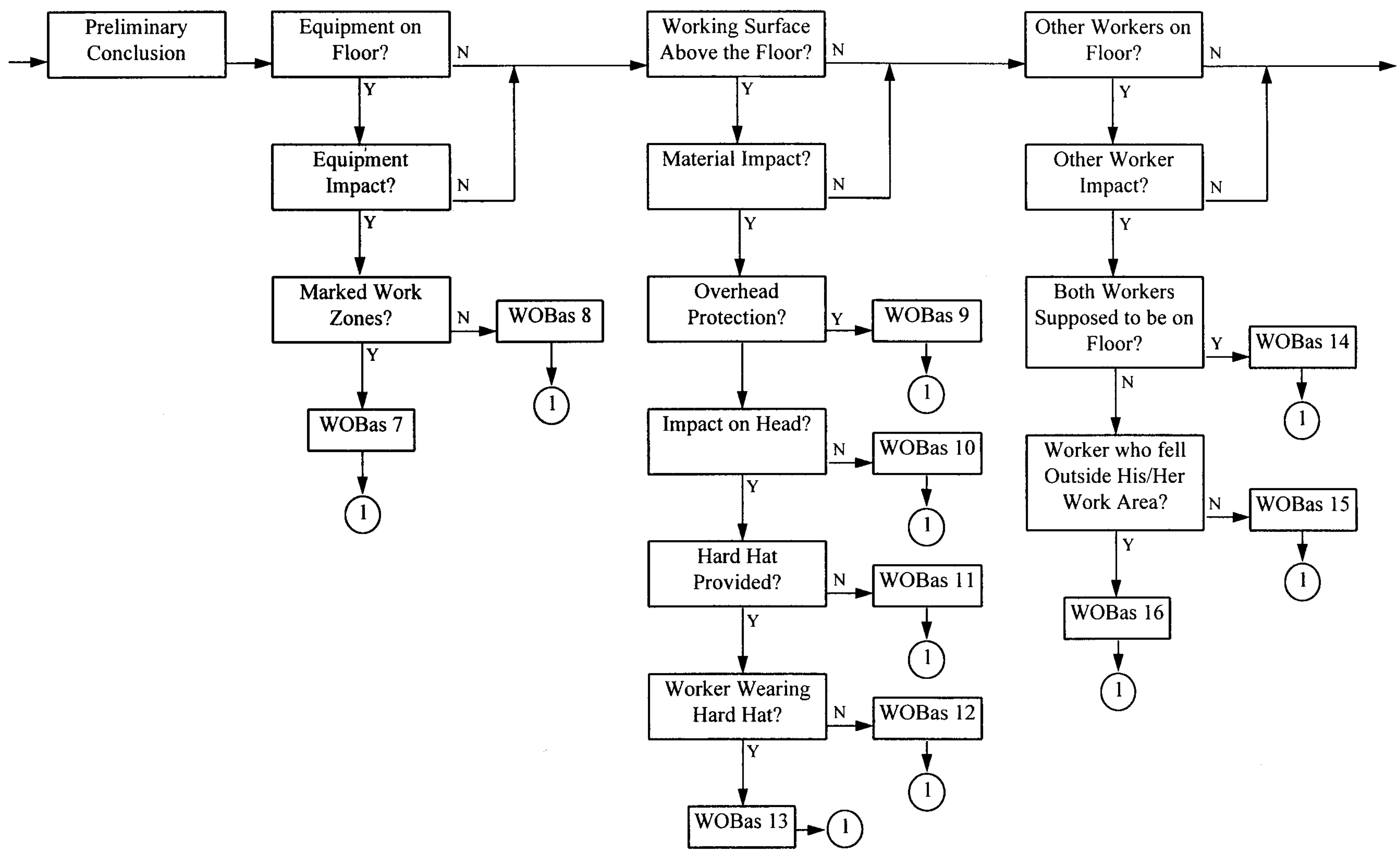

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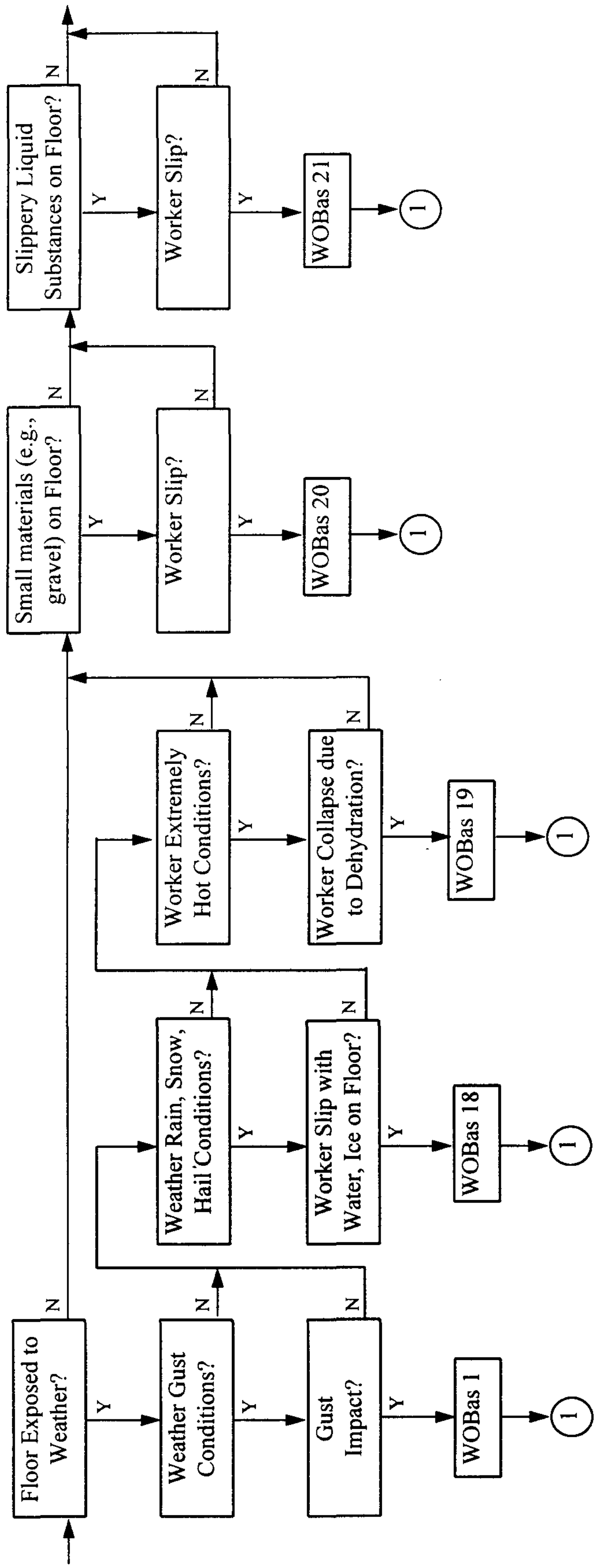

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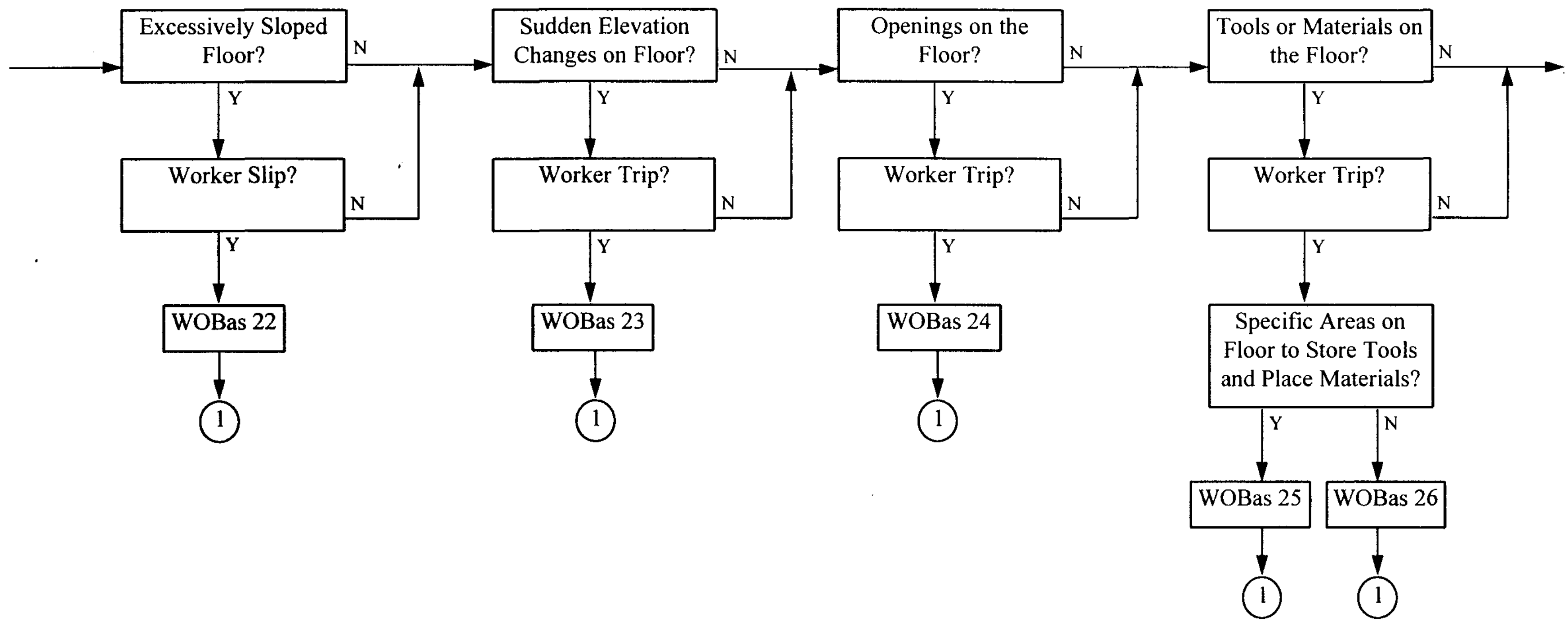

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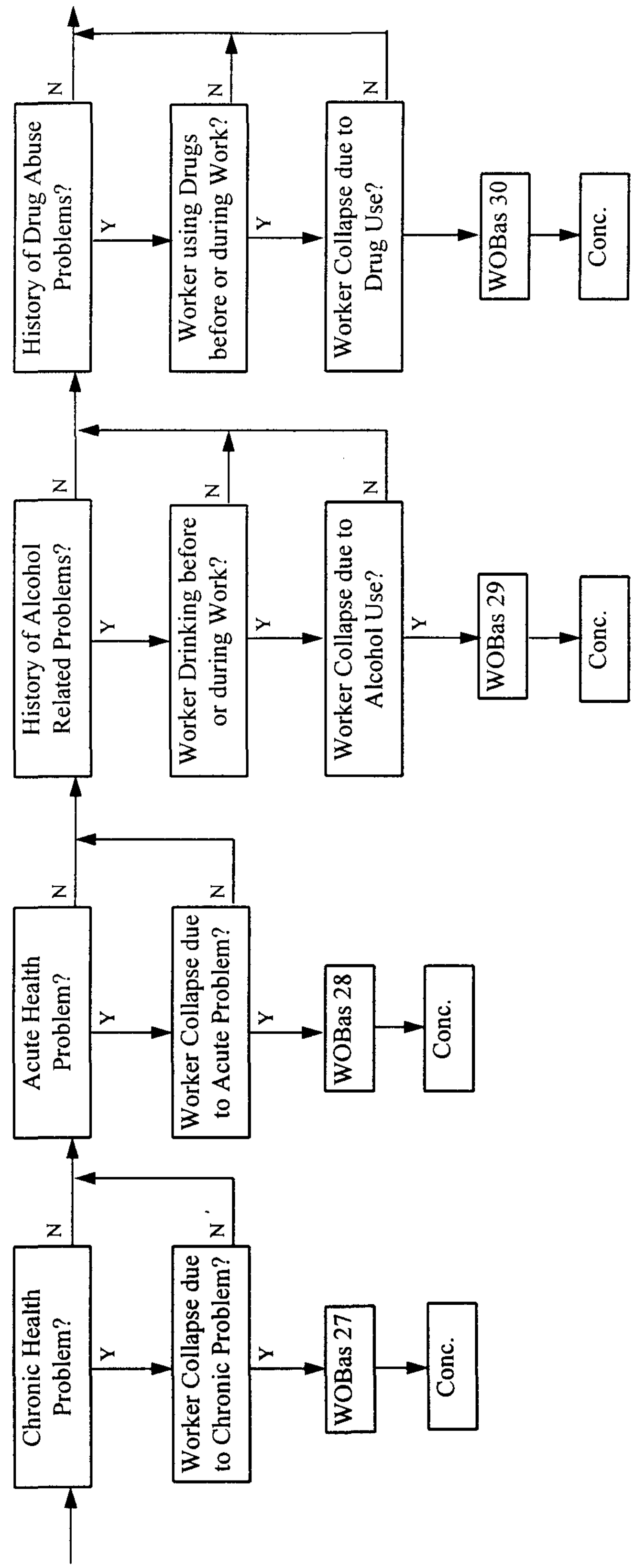

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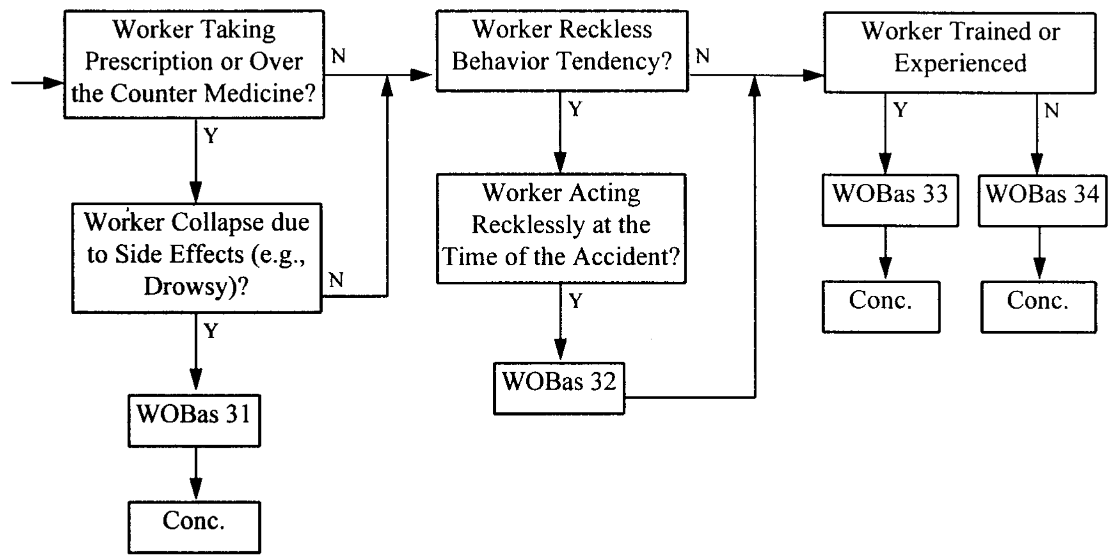

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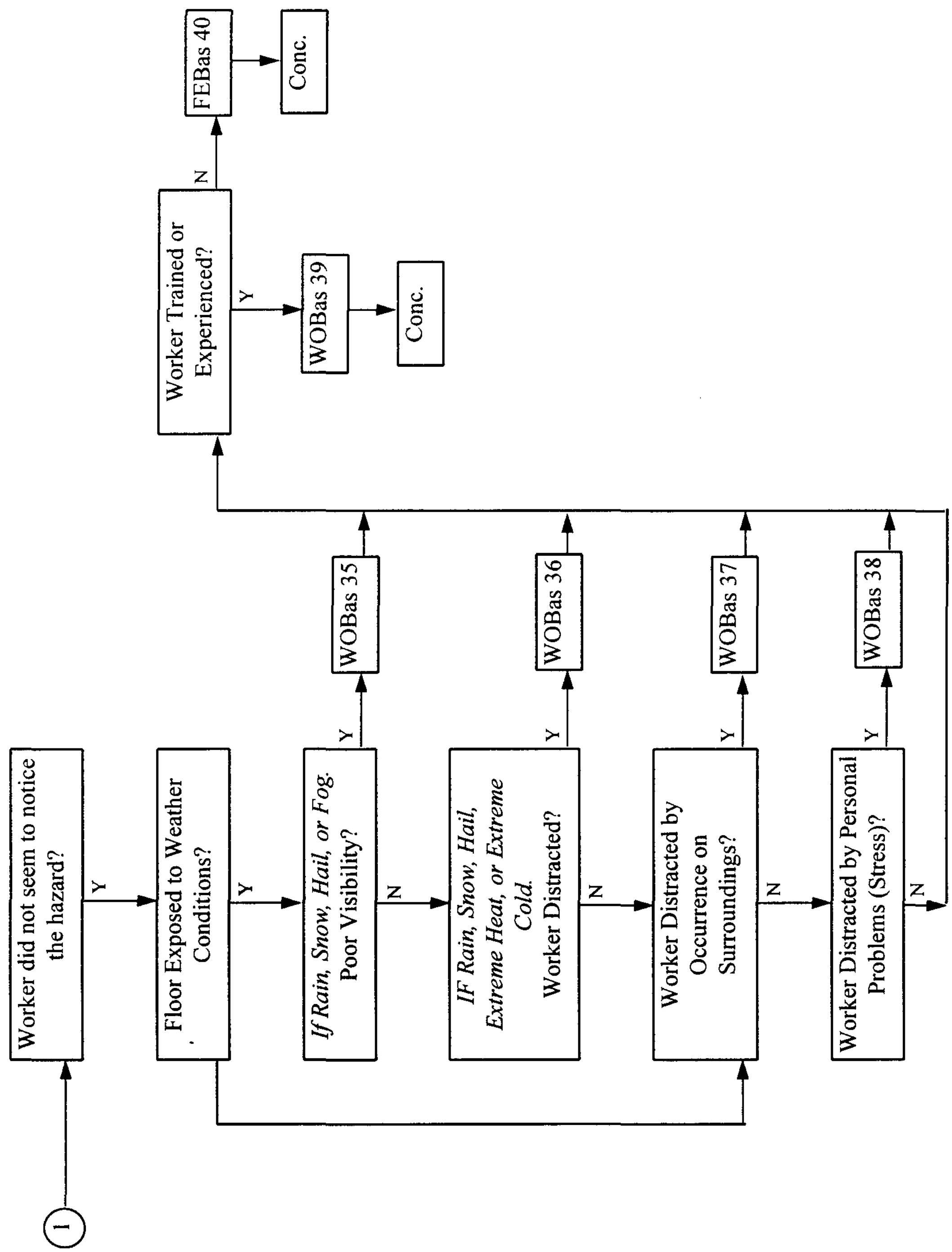

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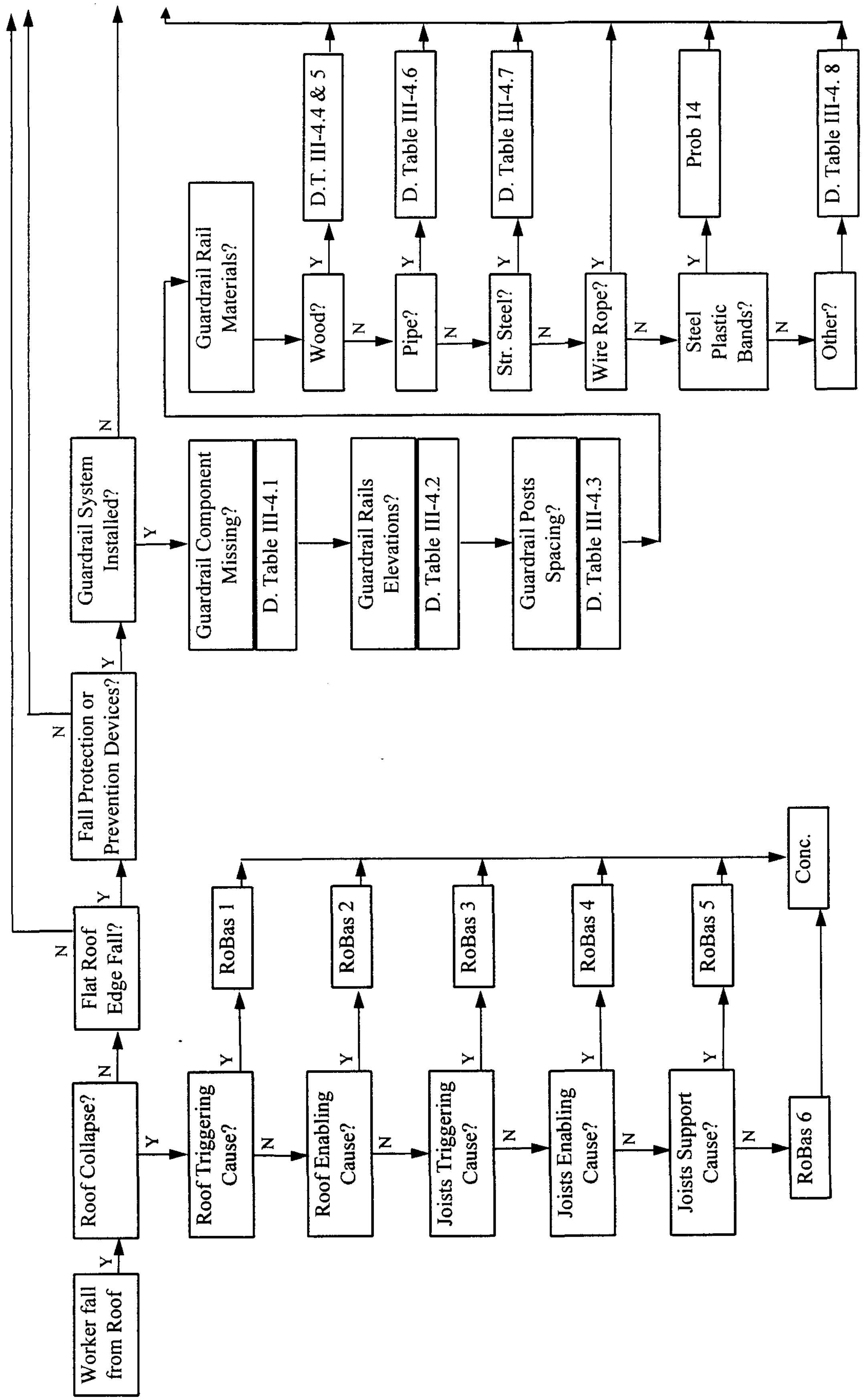
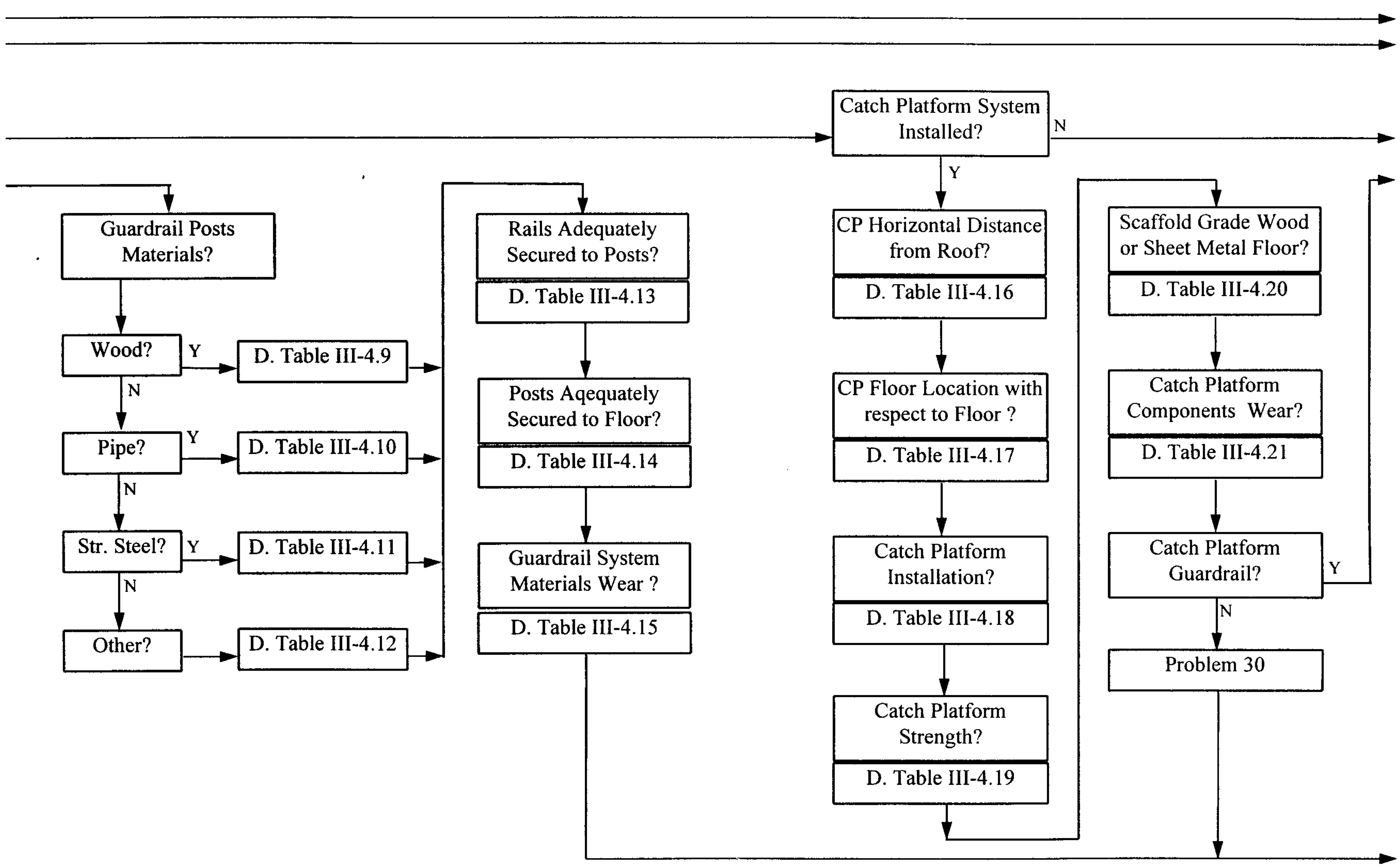


Figure III-D.3 Decision Structure for Worker Fall from Roof



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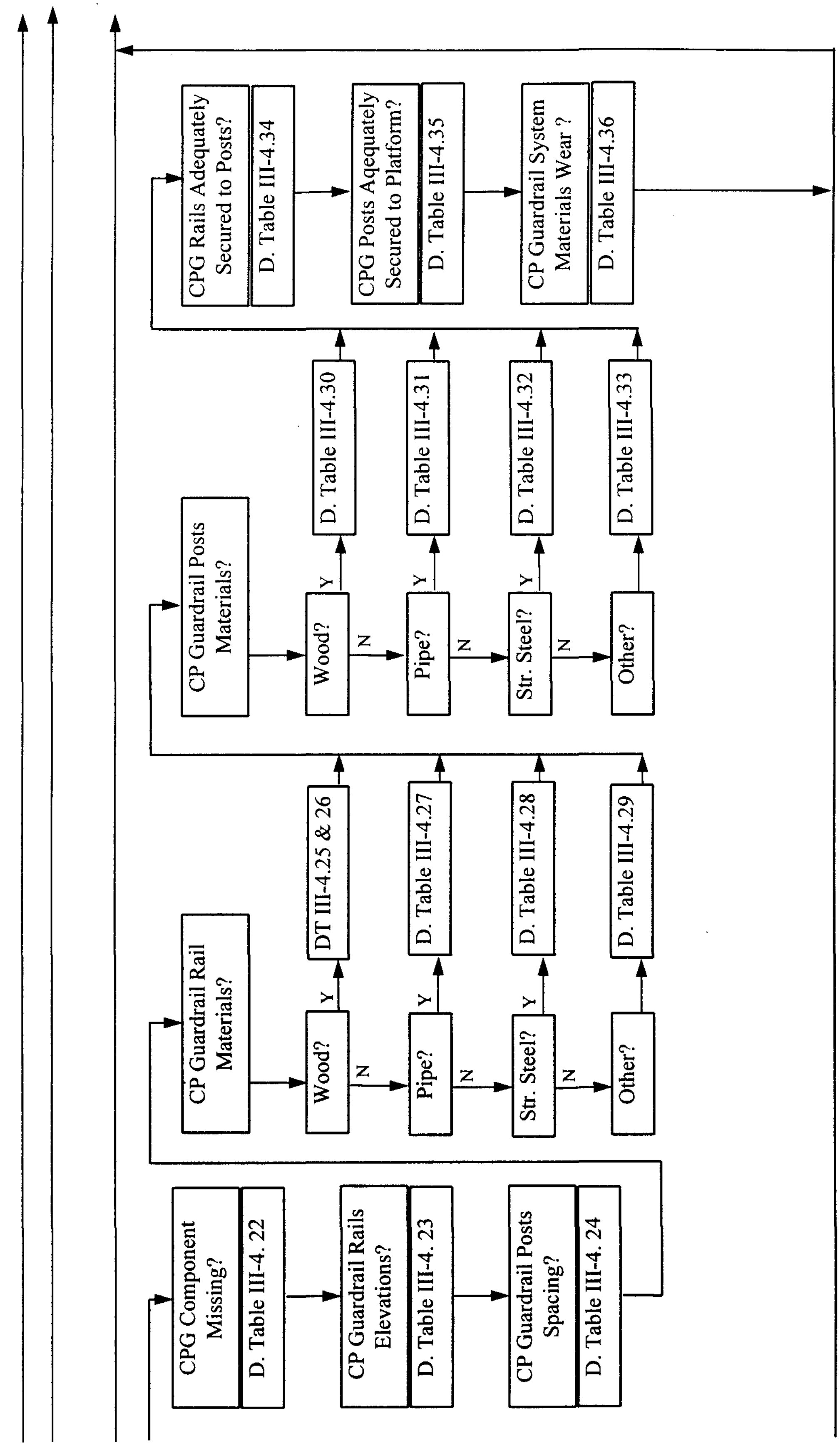

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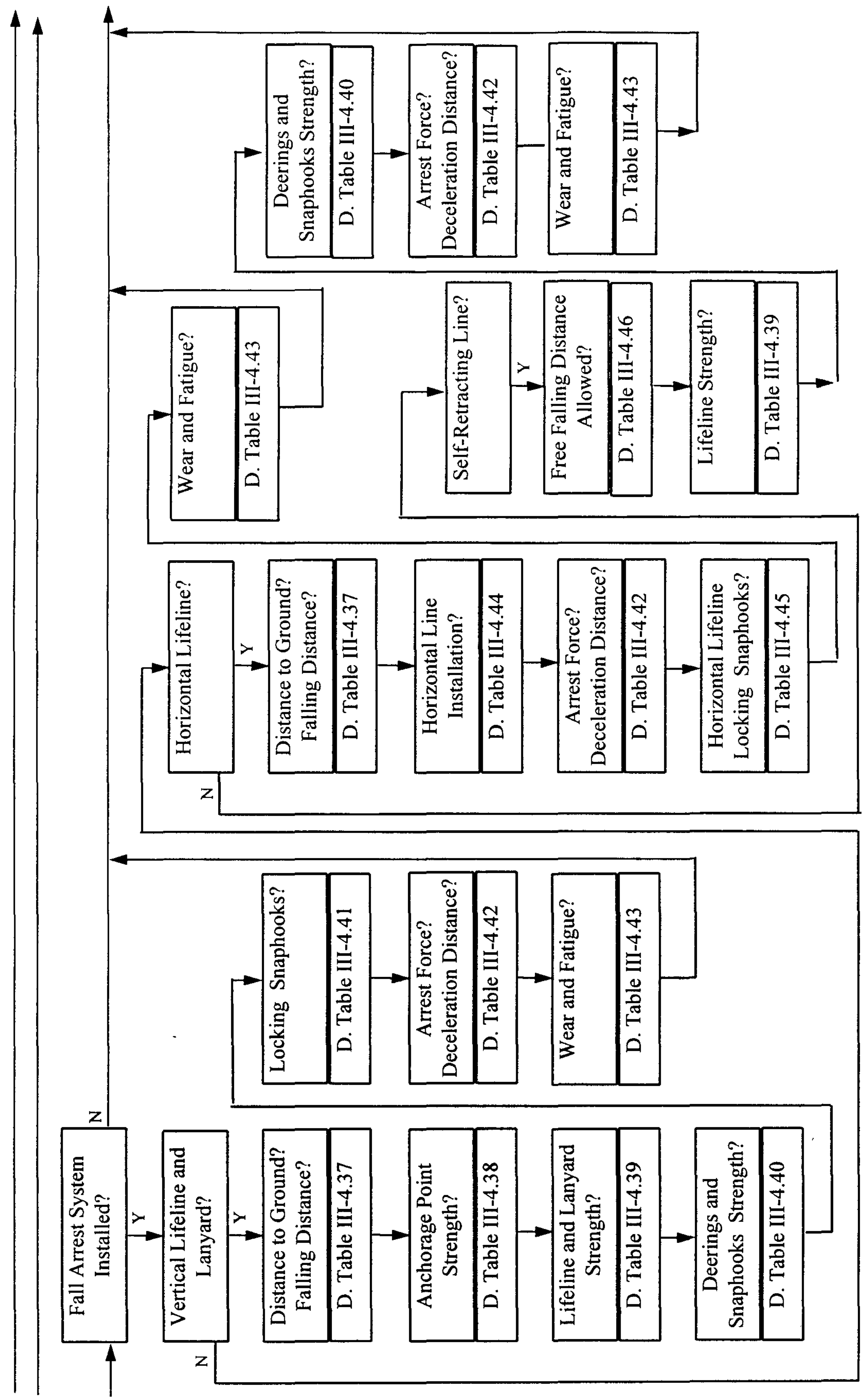

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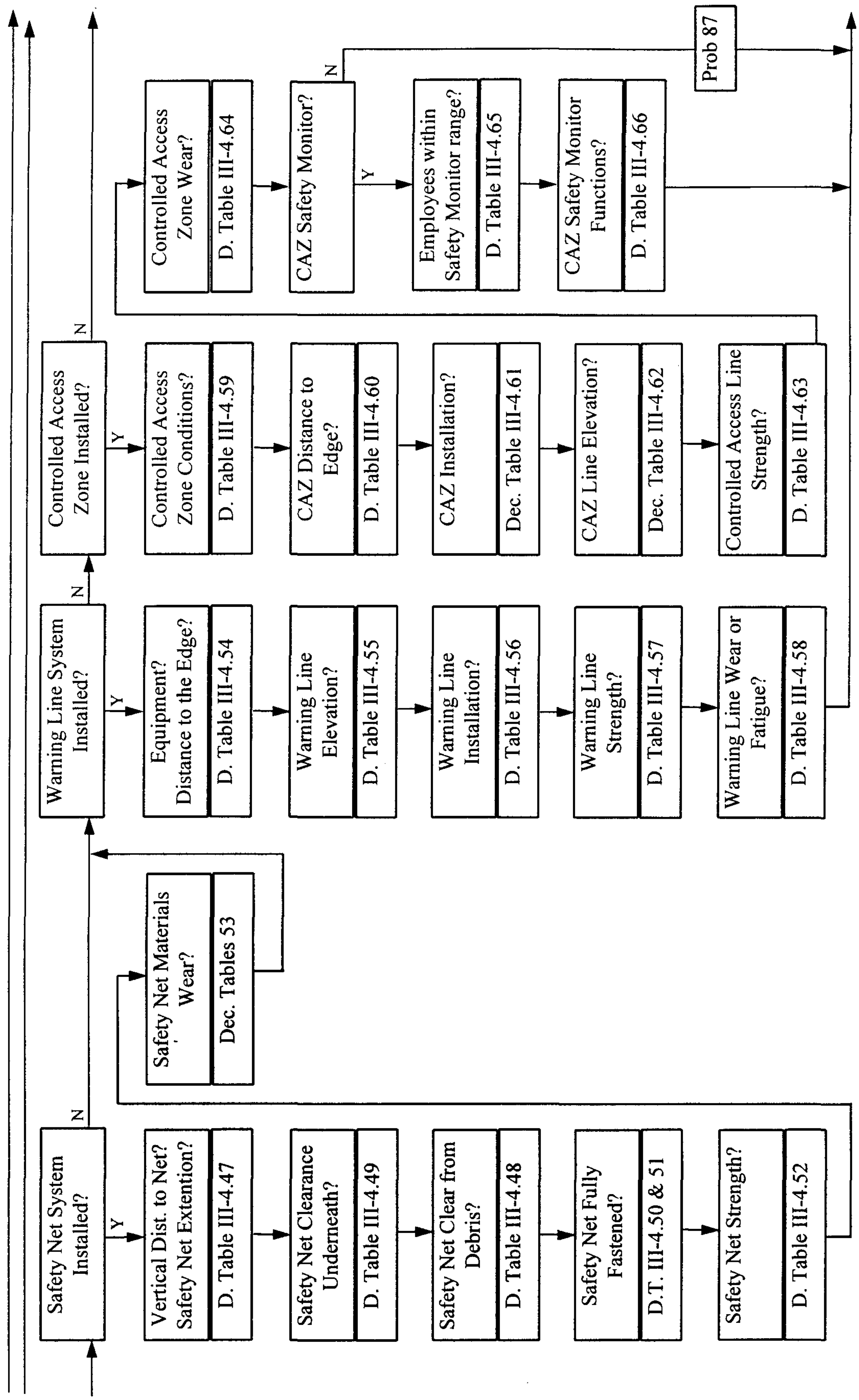

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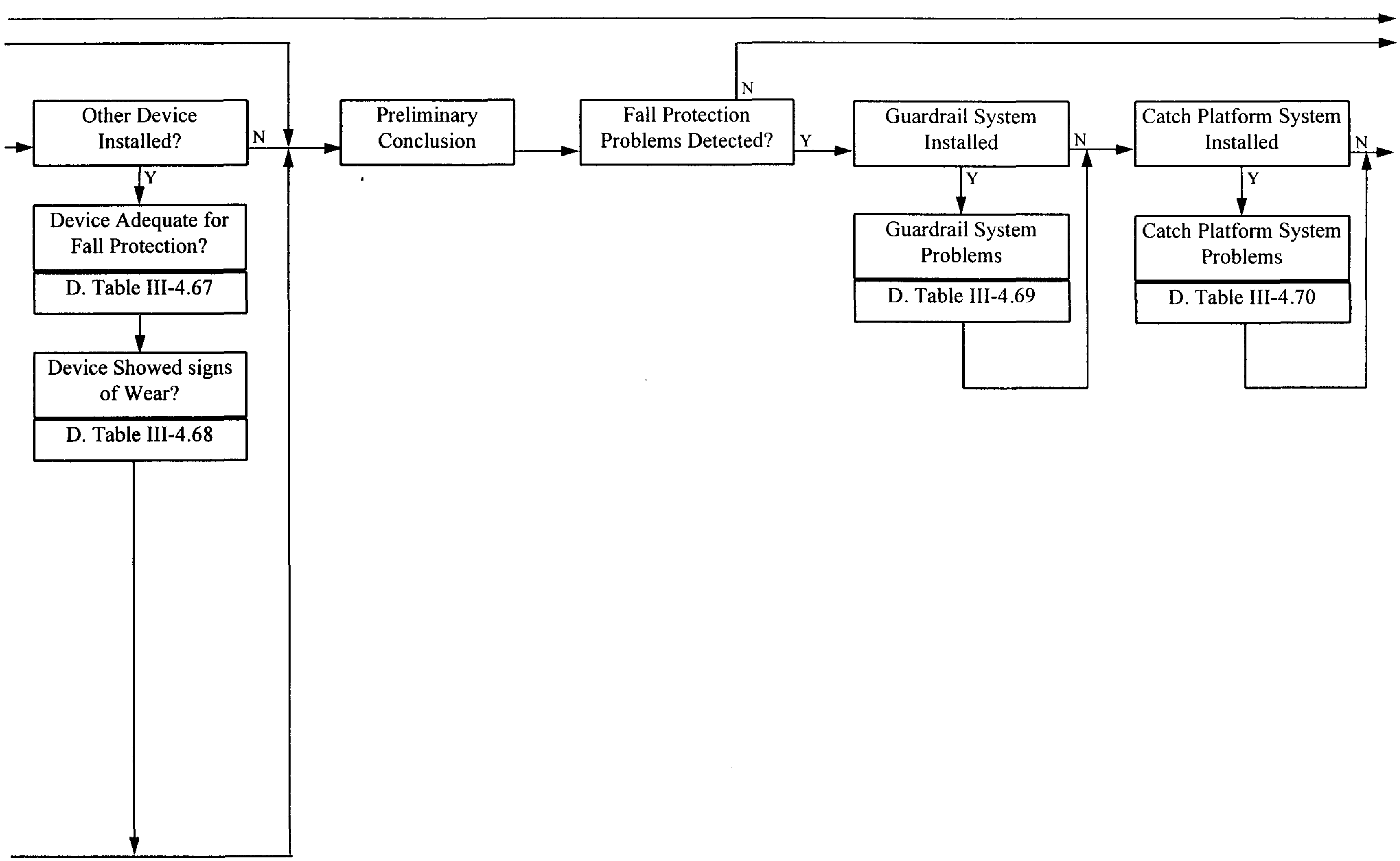

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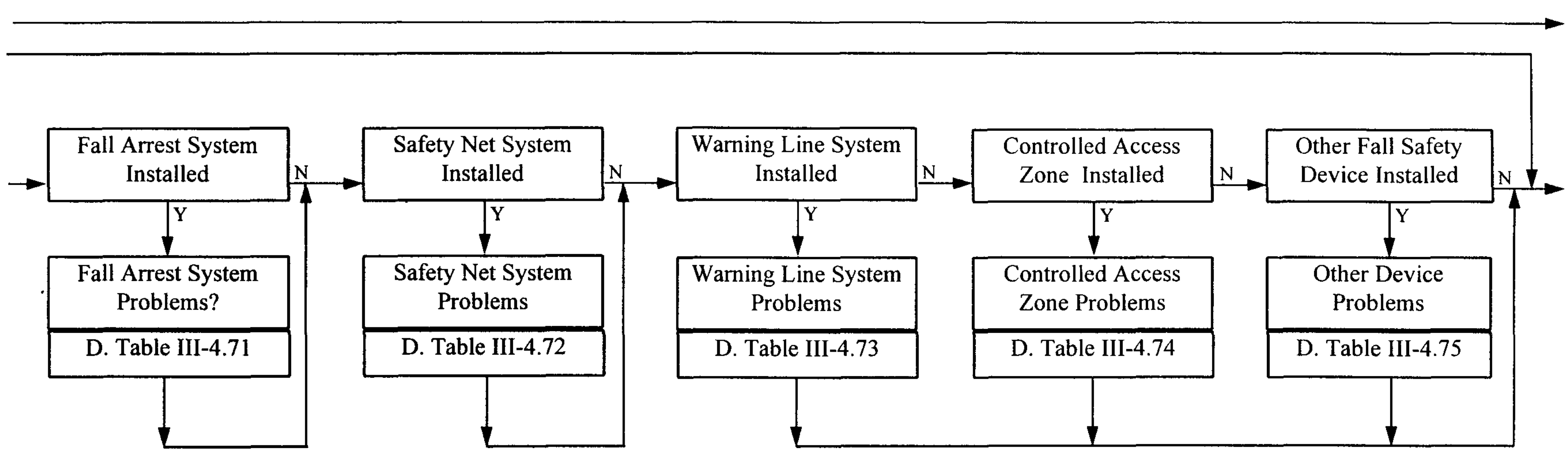

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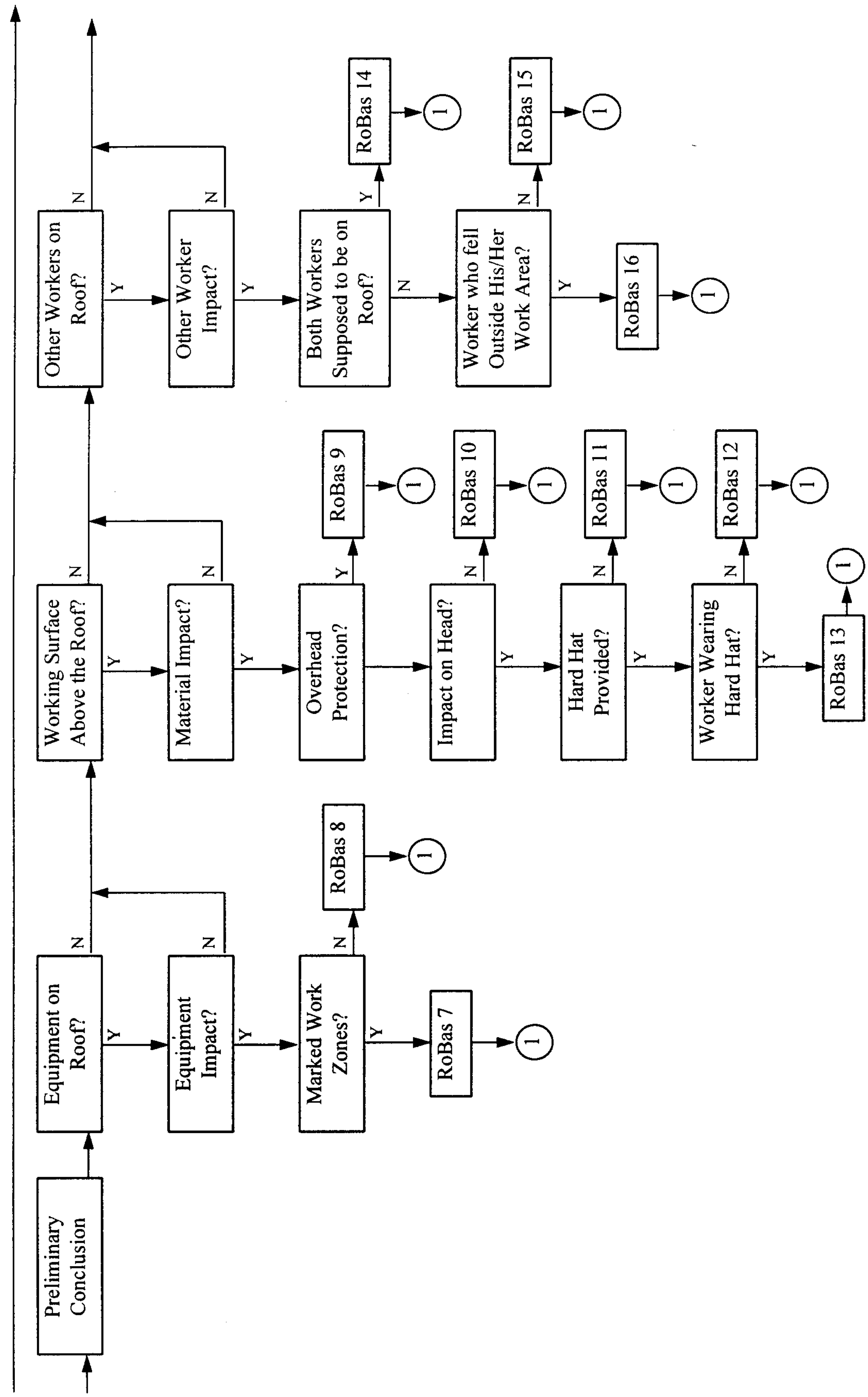

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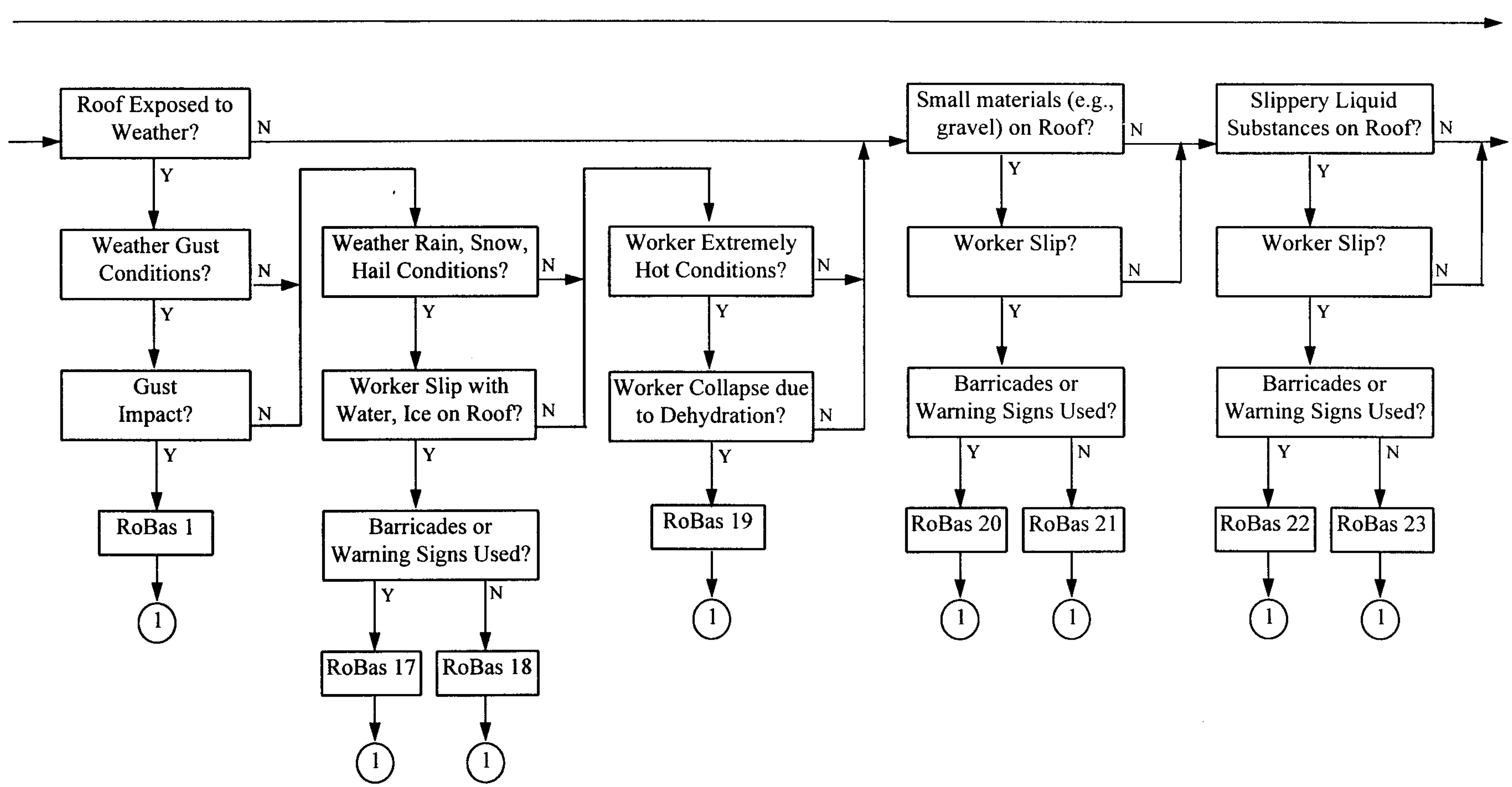

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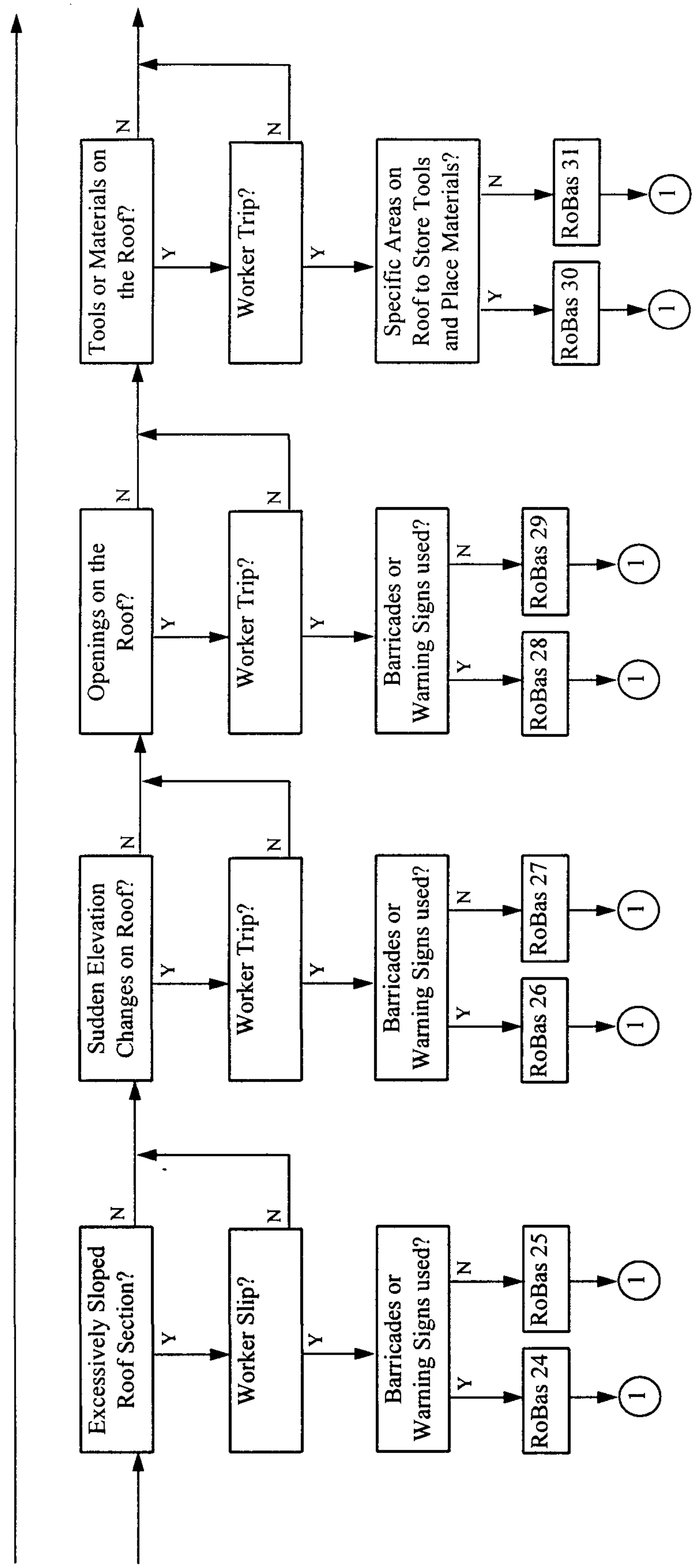

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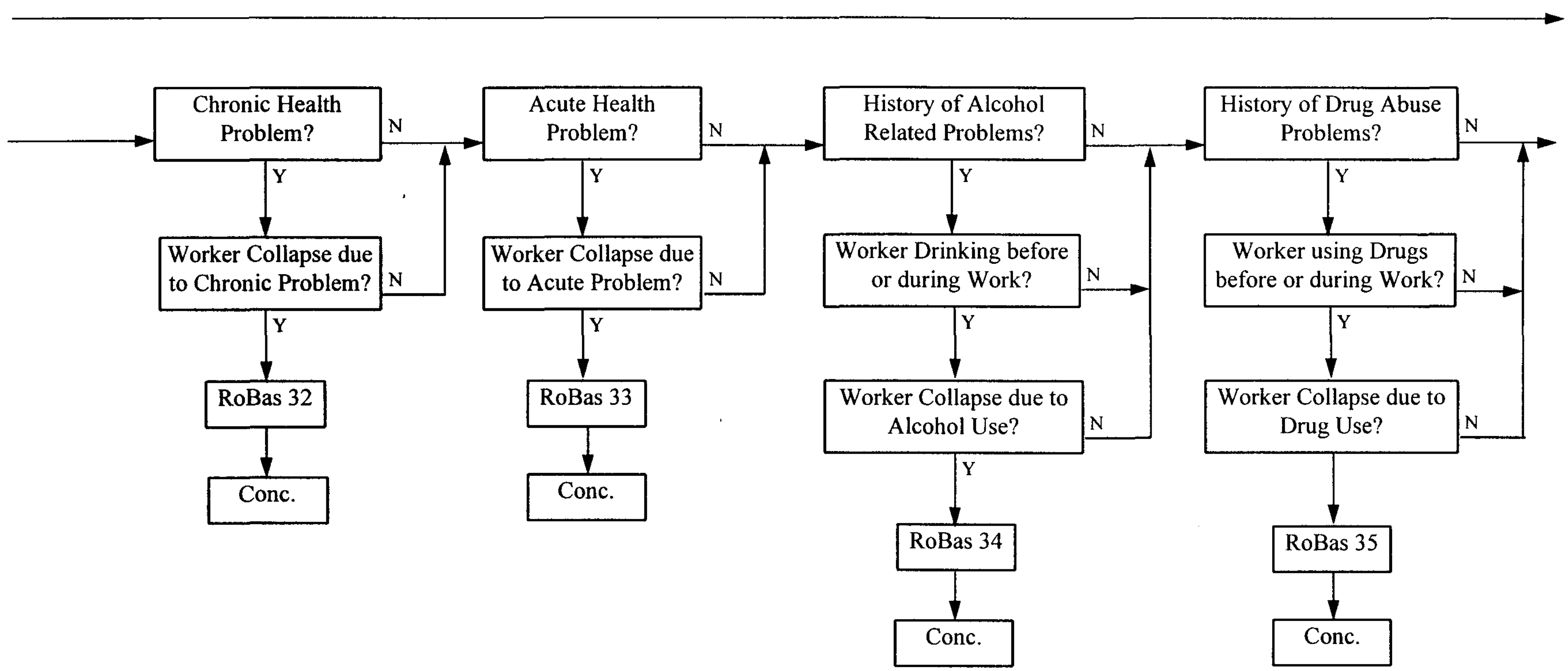

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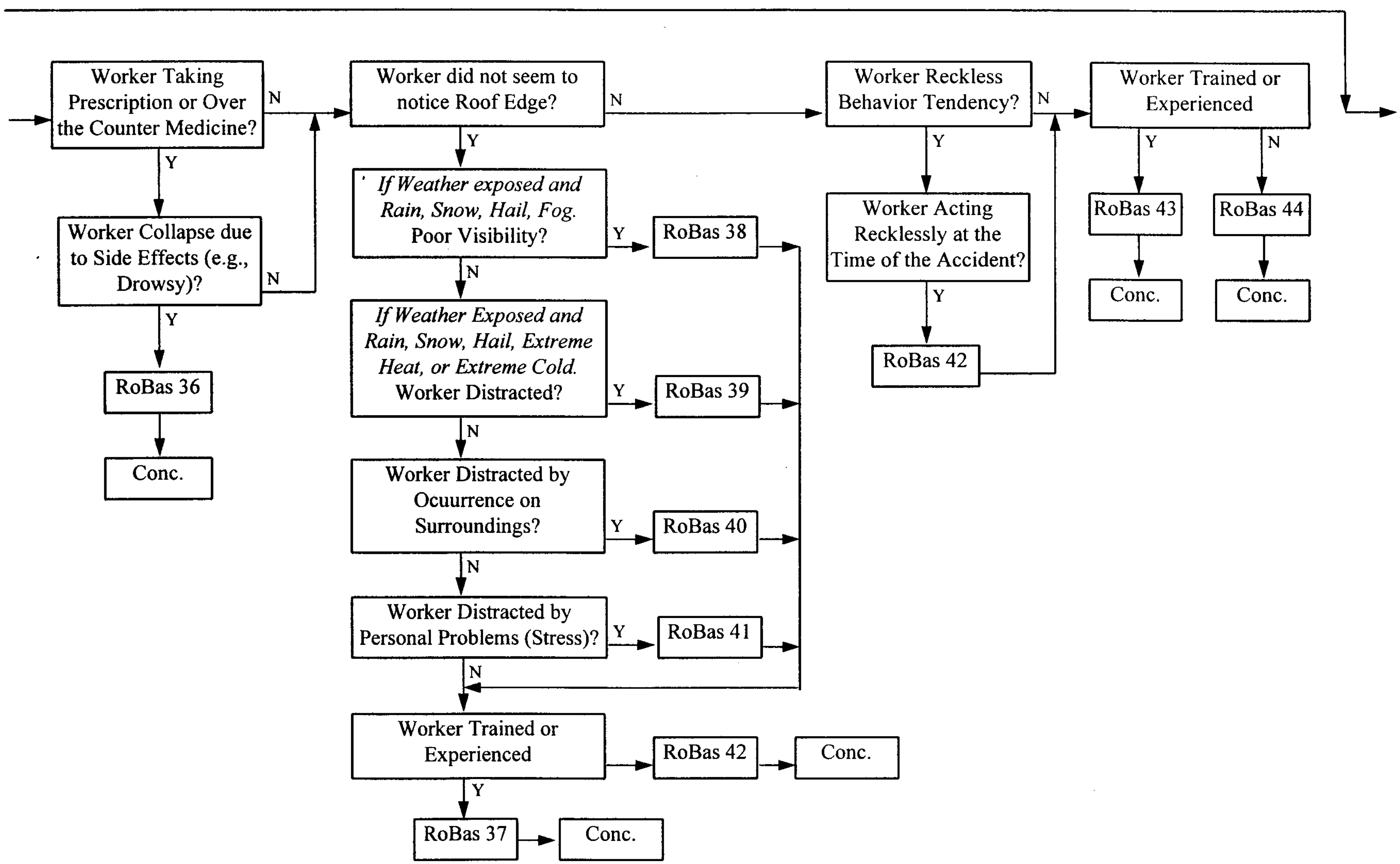

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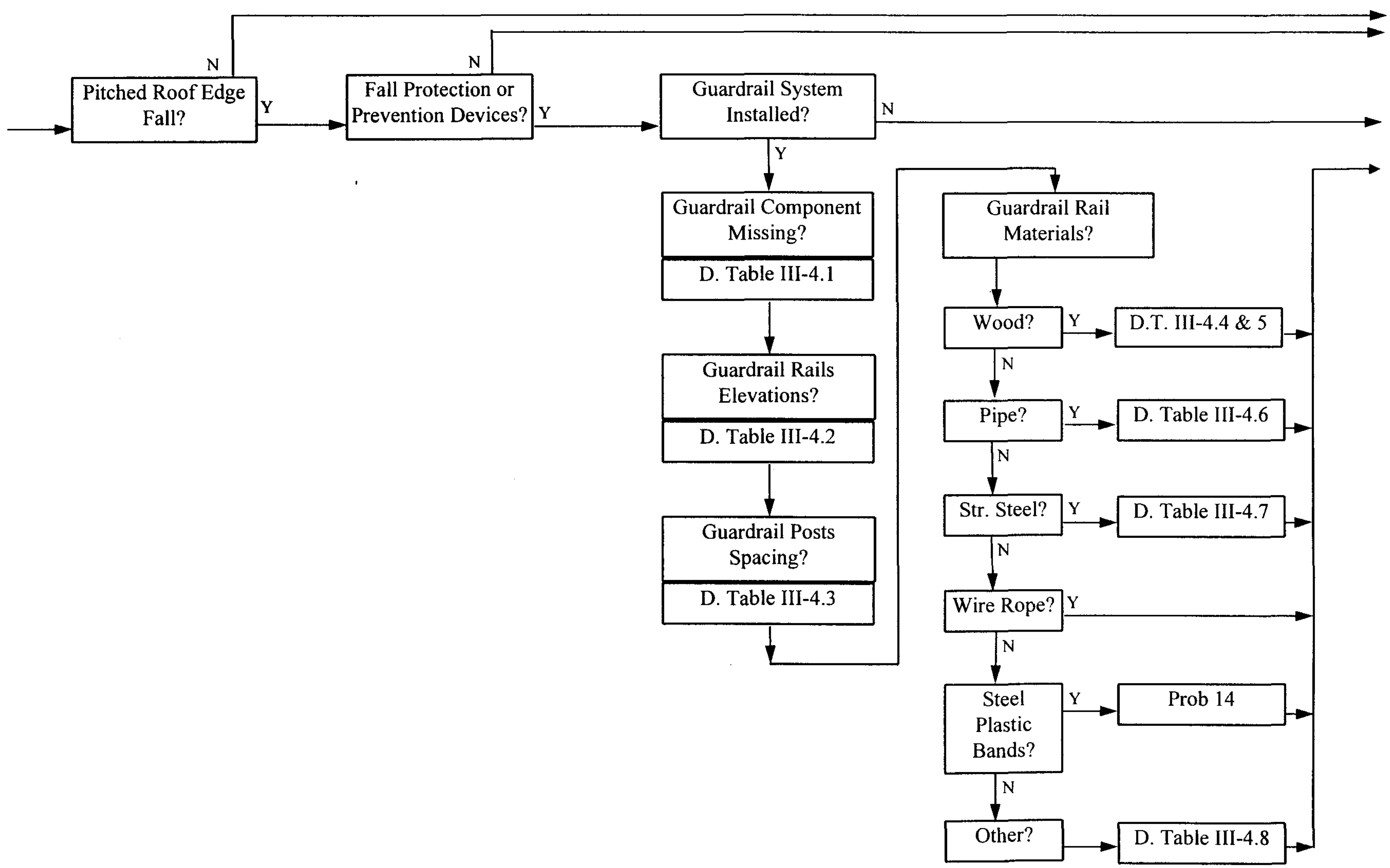

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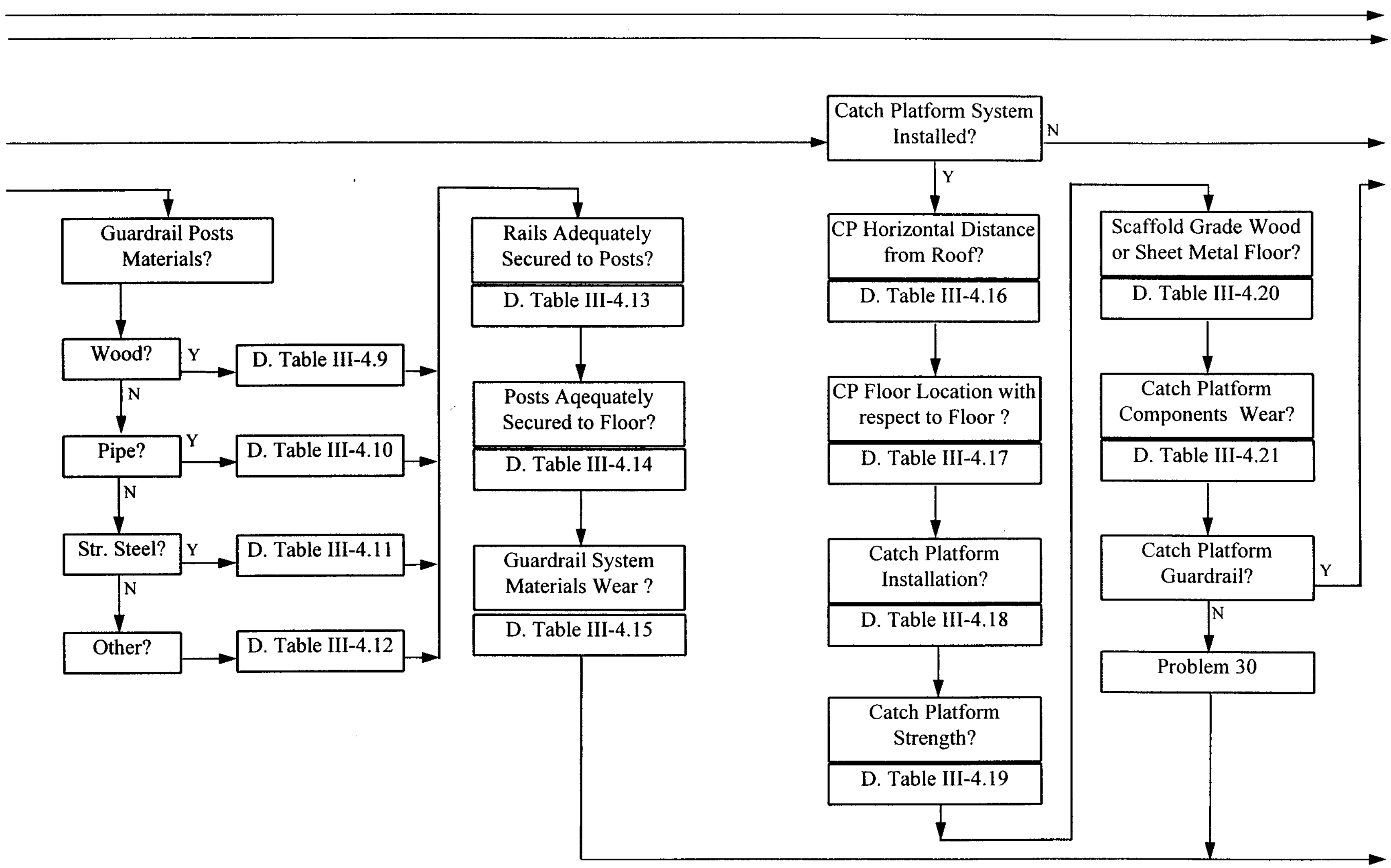

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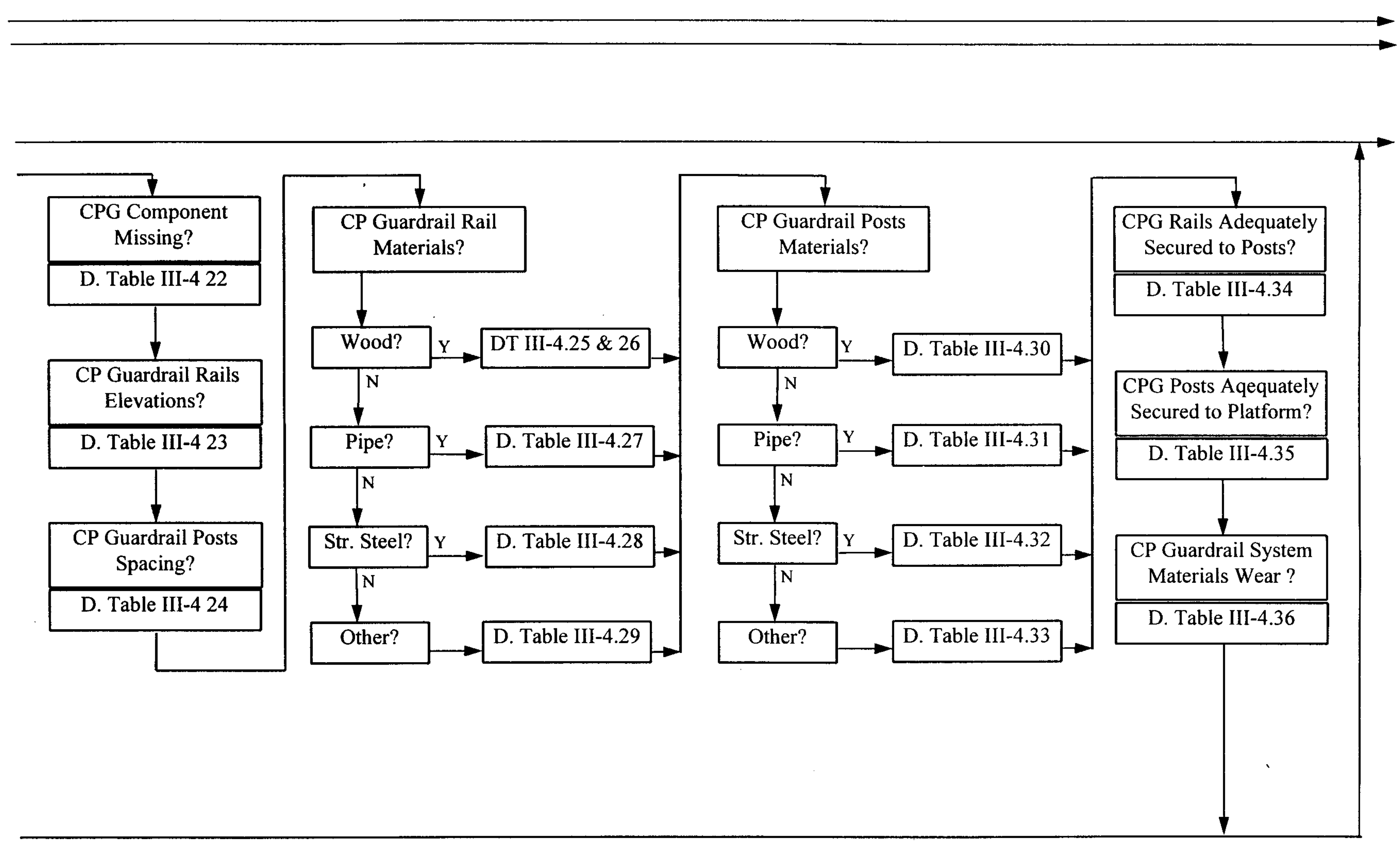

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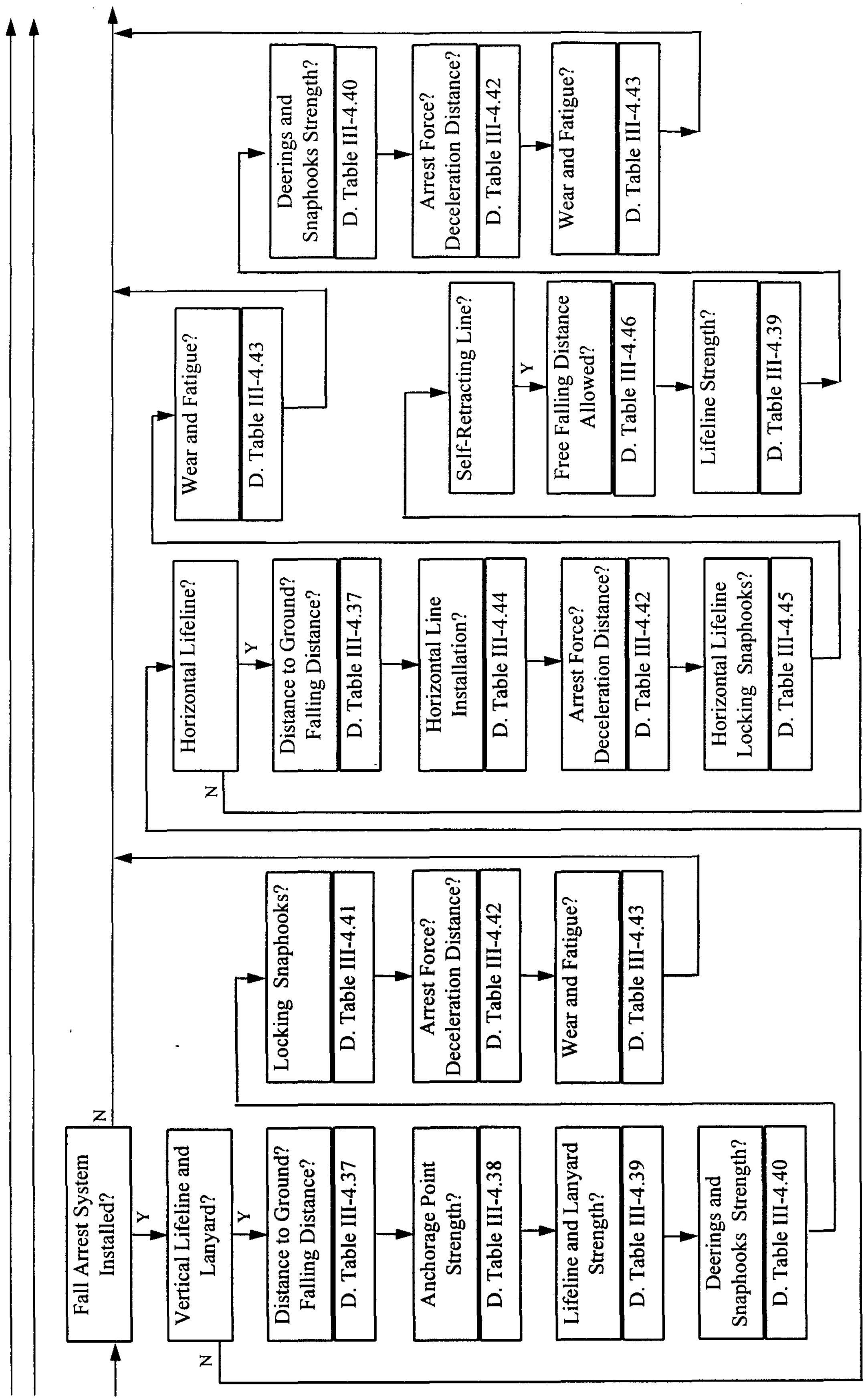

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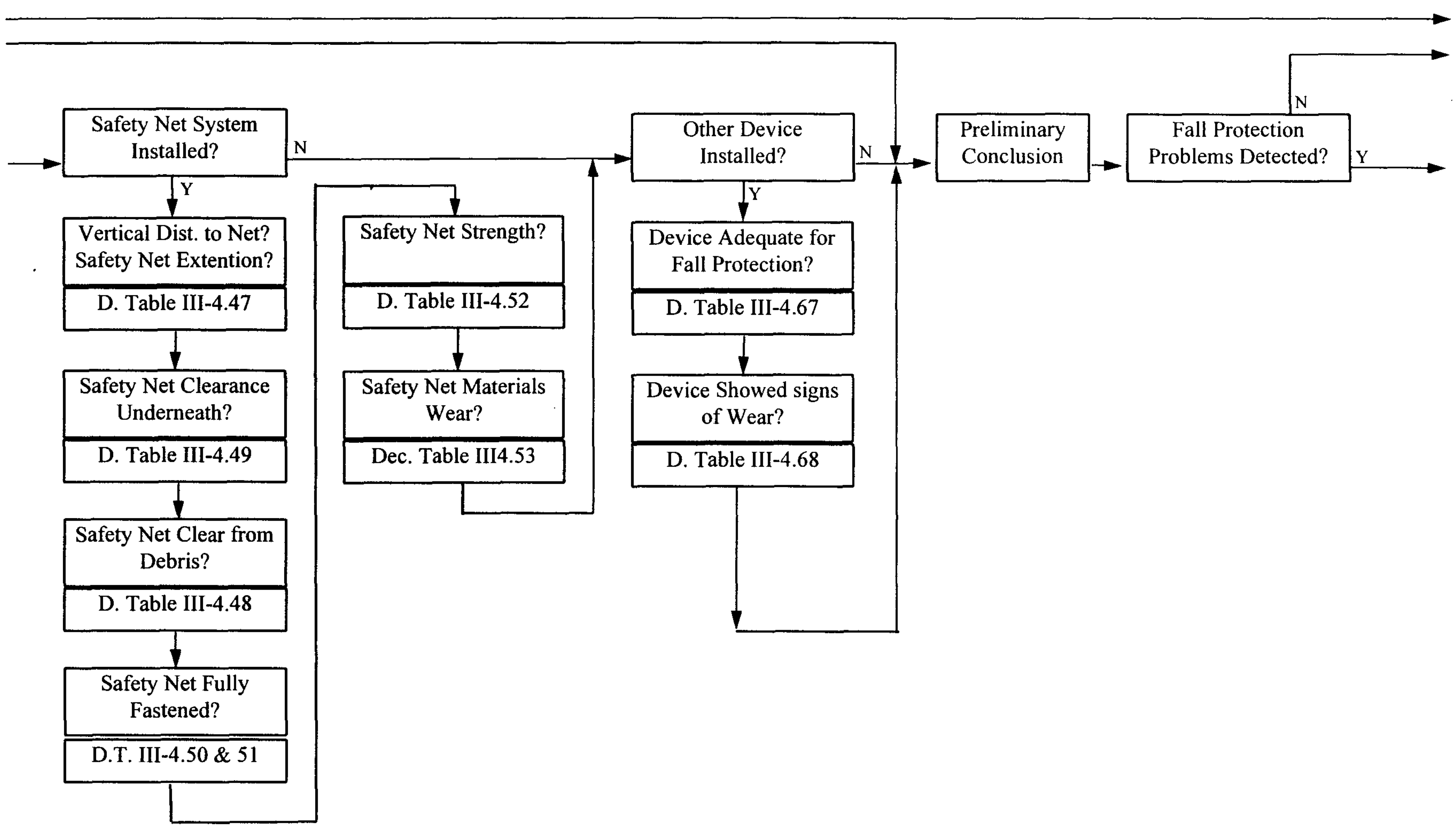

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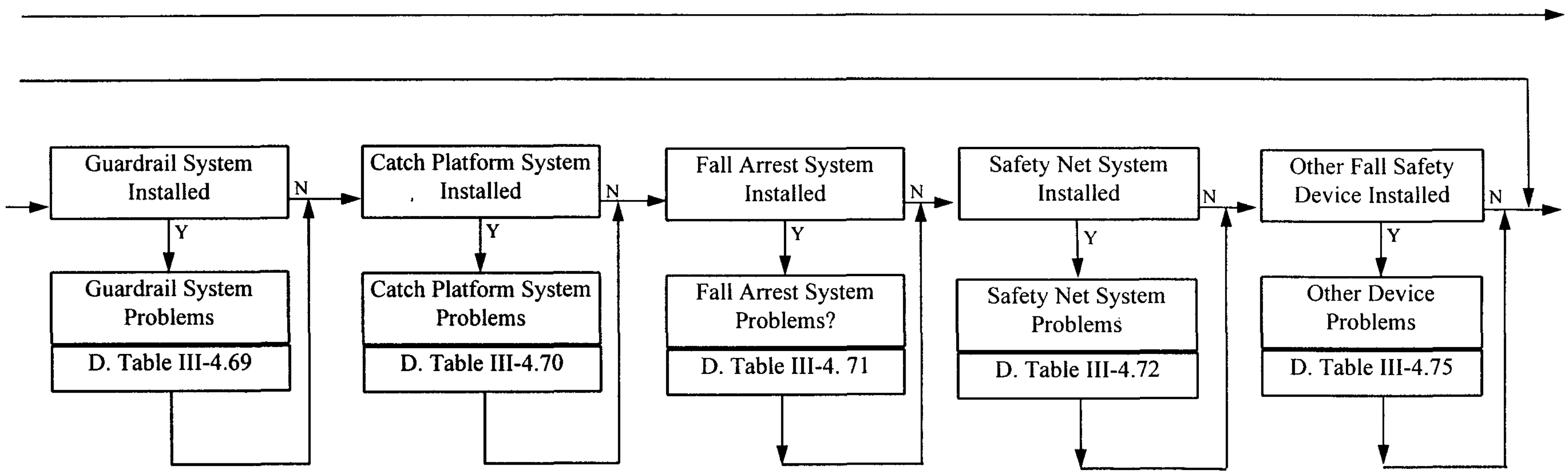

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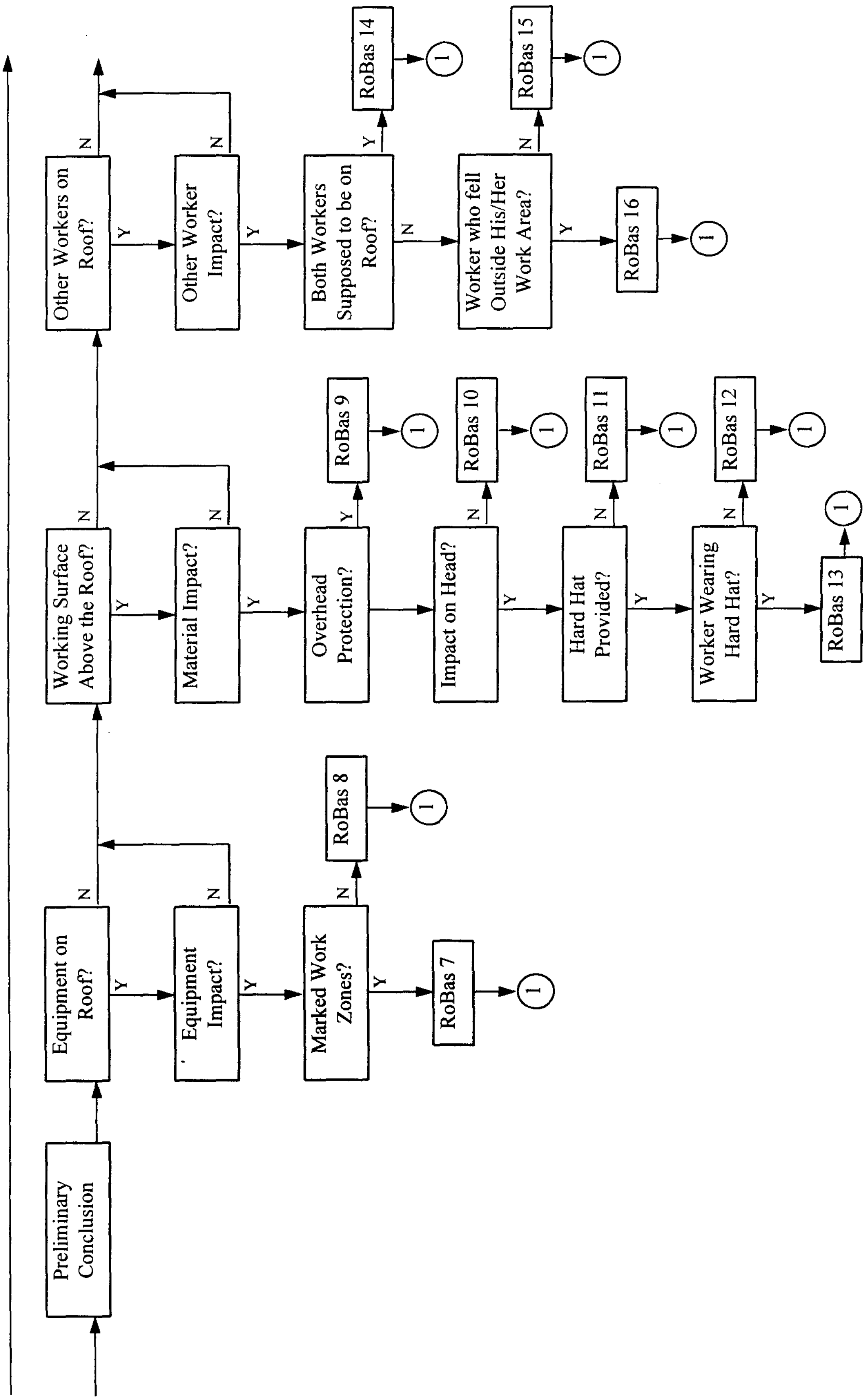

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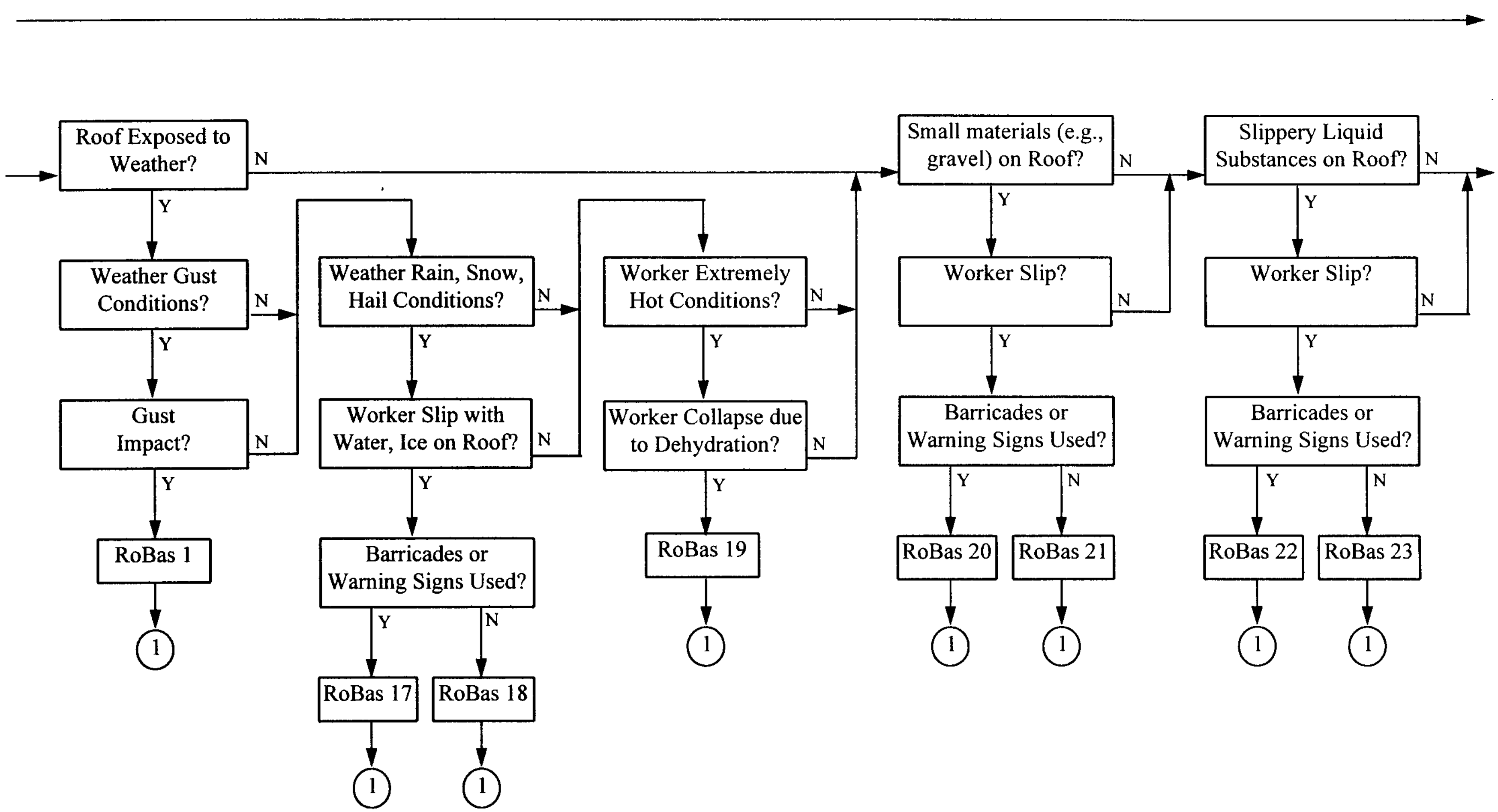

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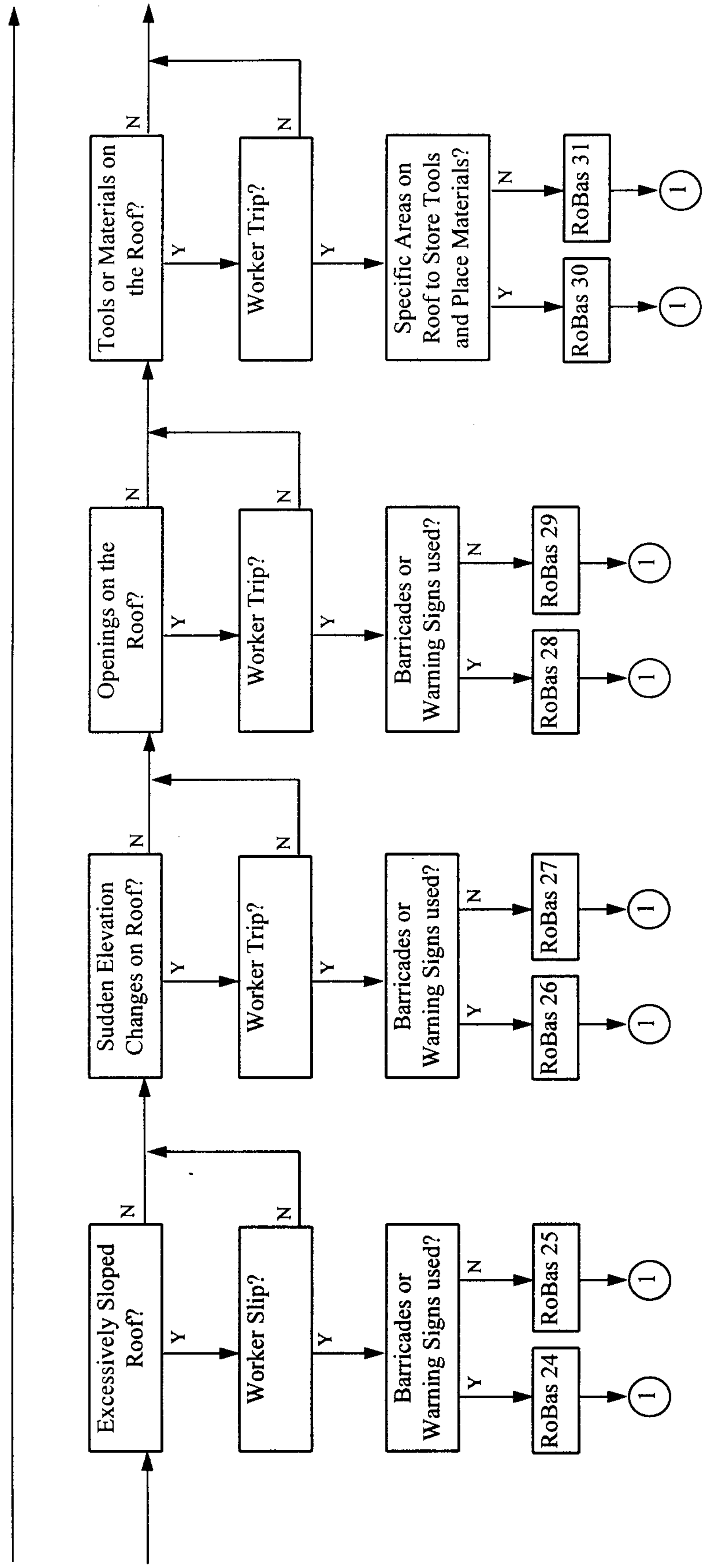

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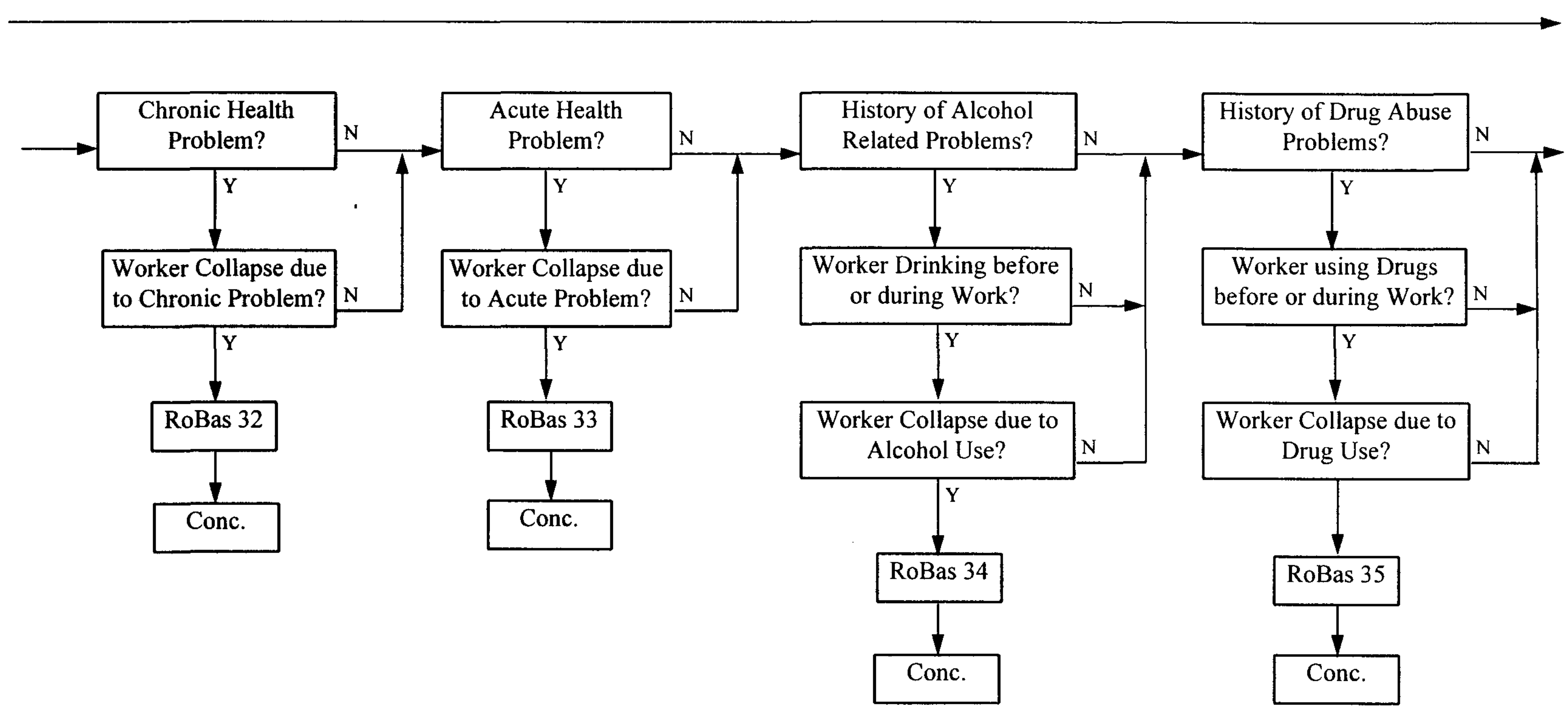

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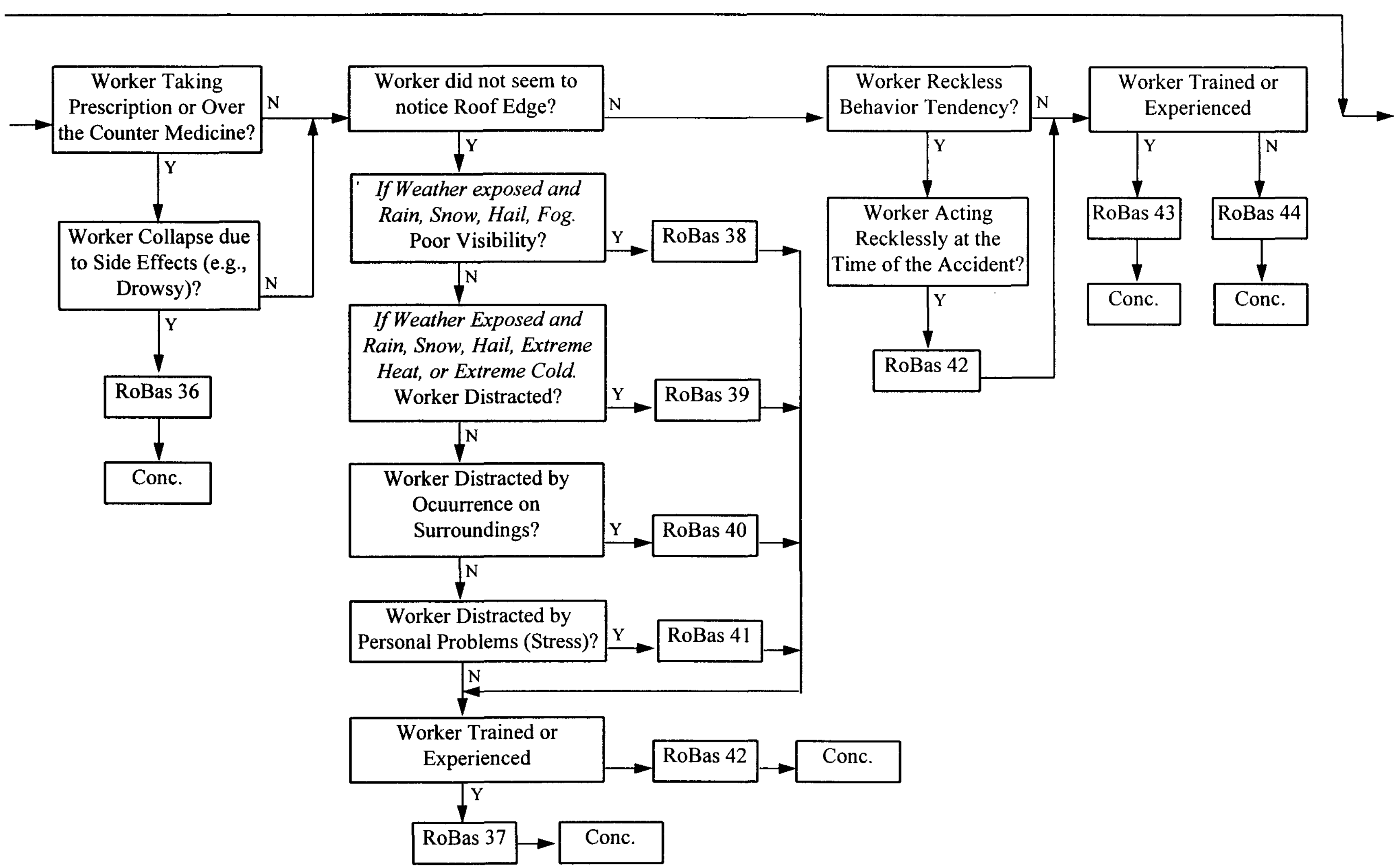

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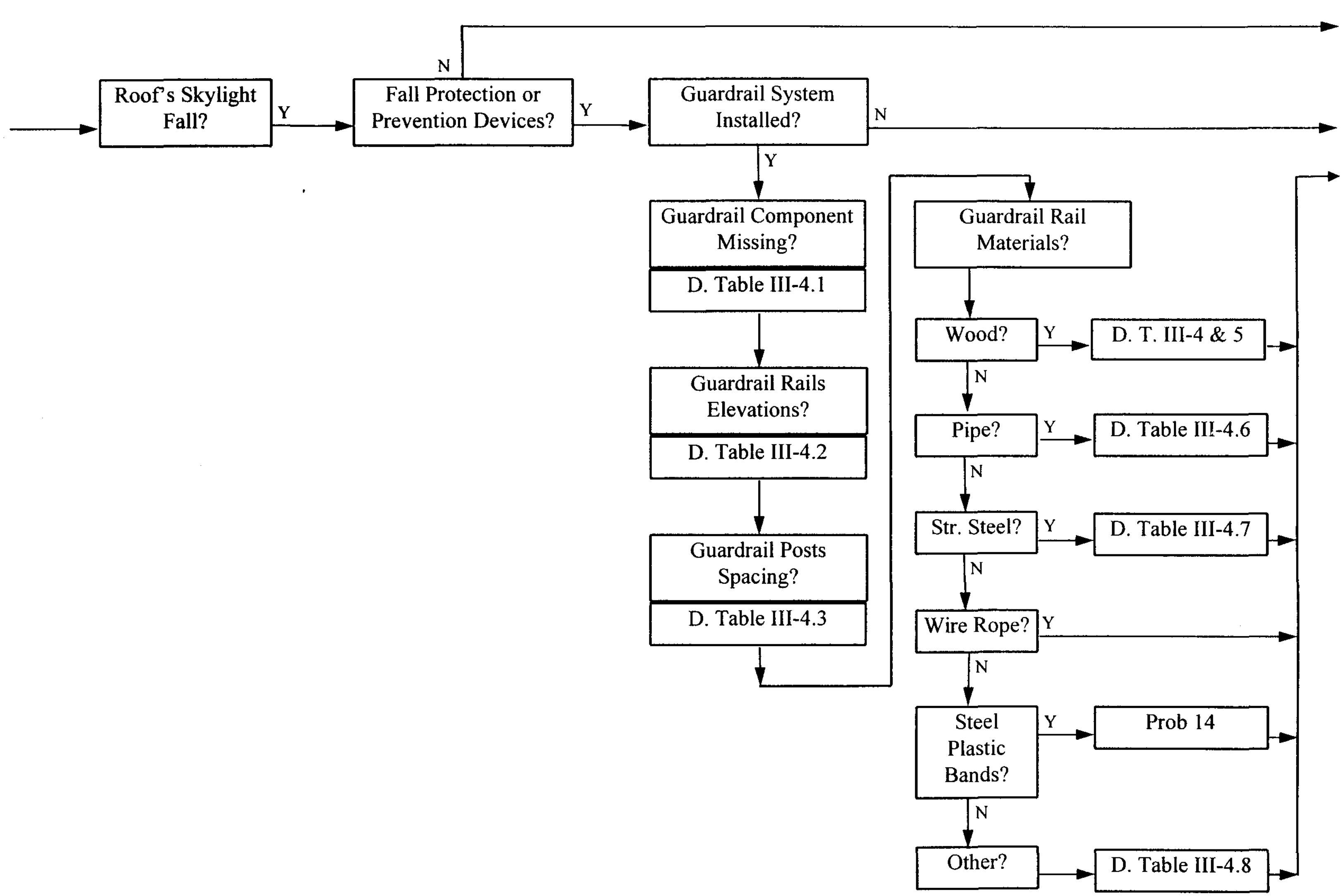

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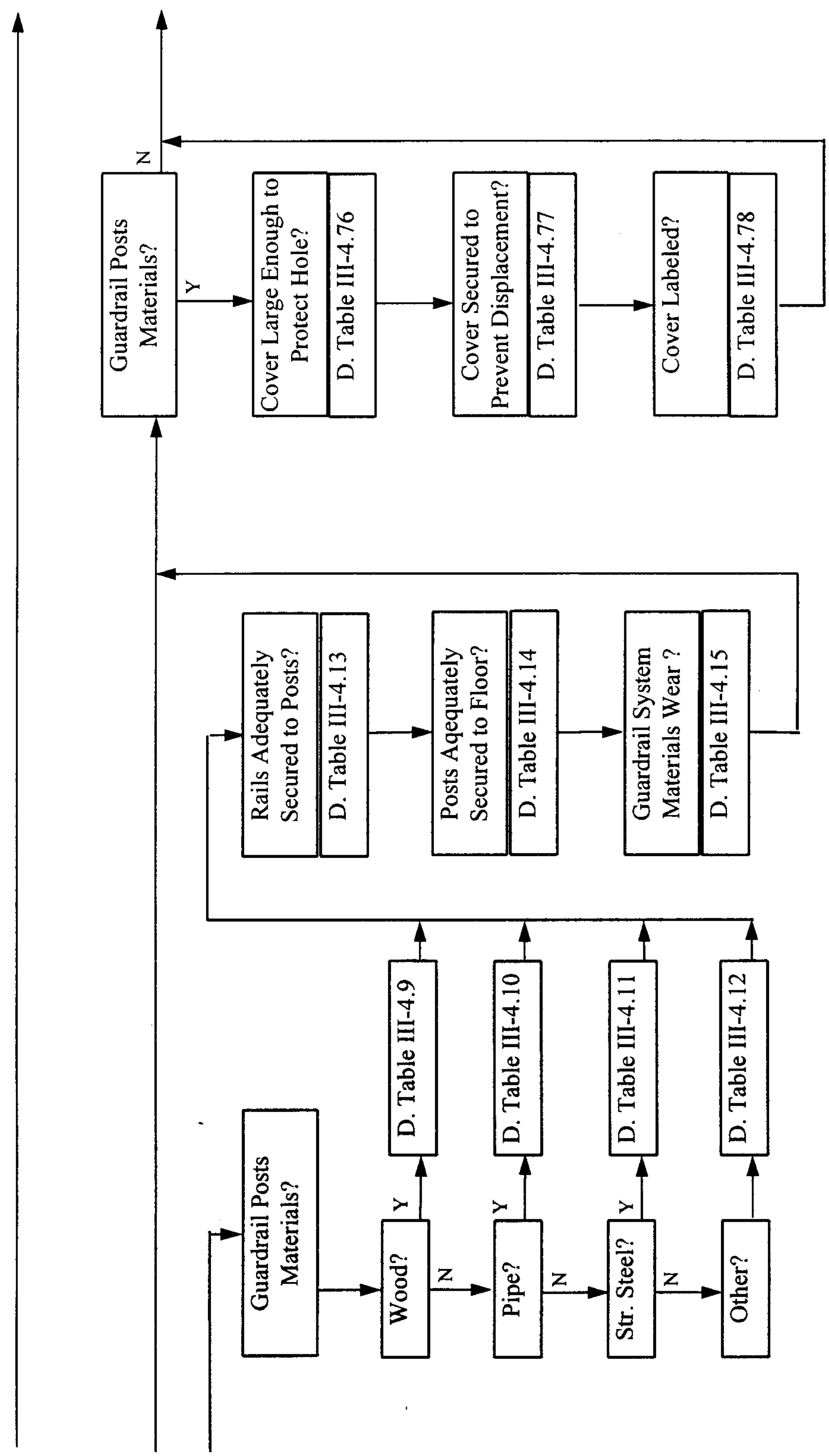

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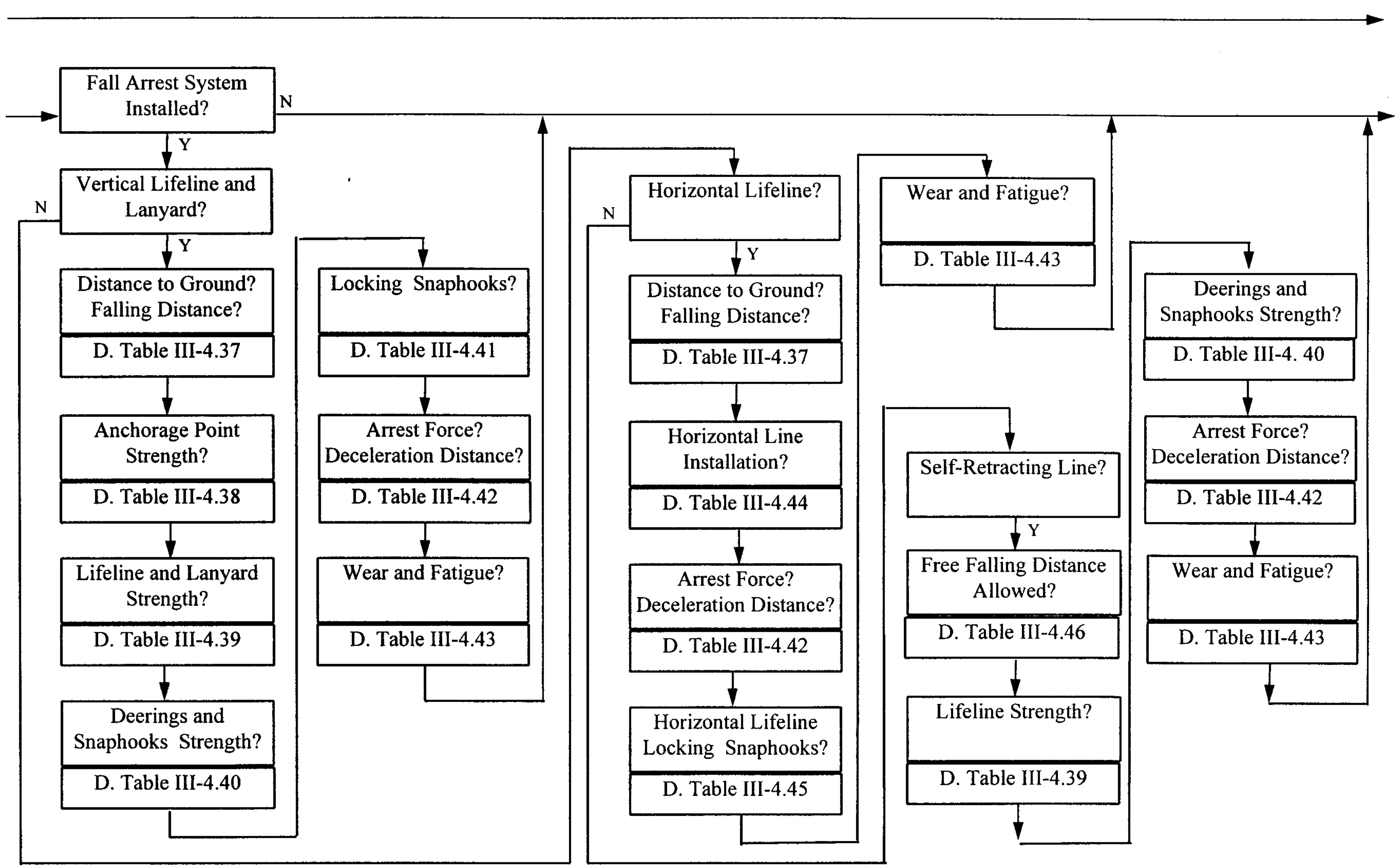

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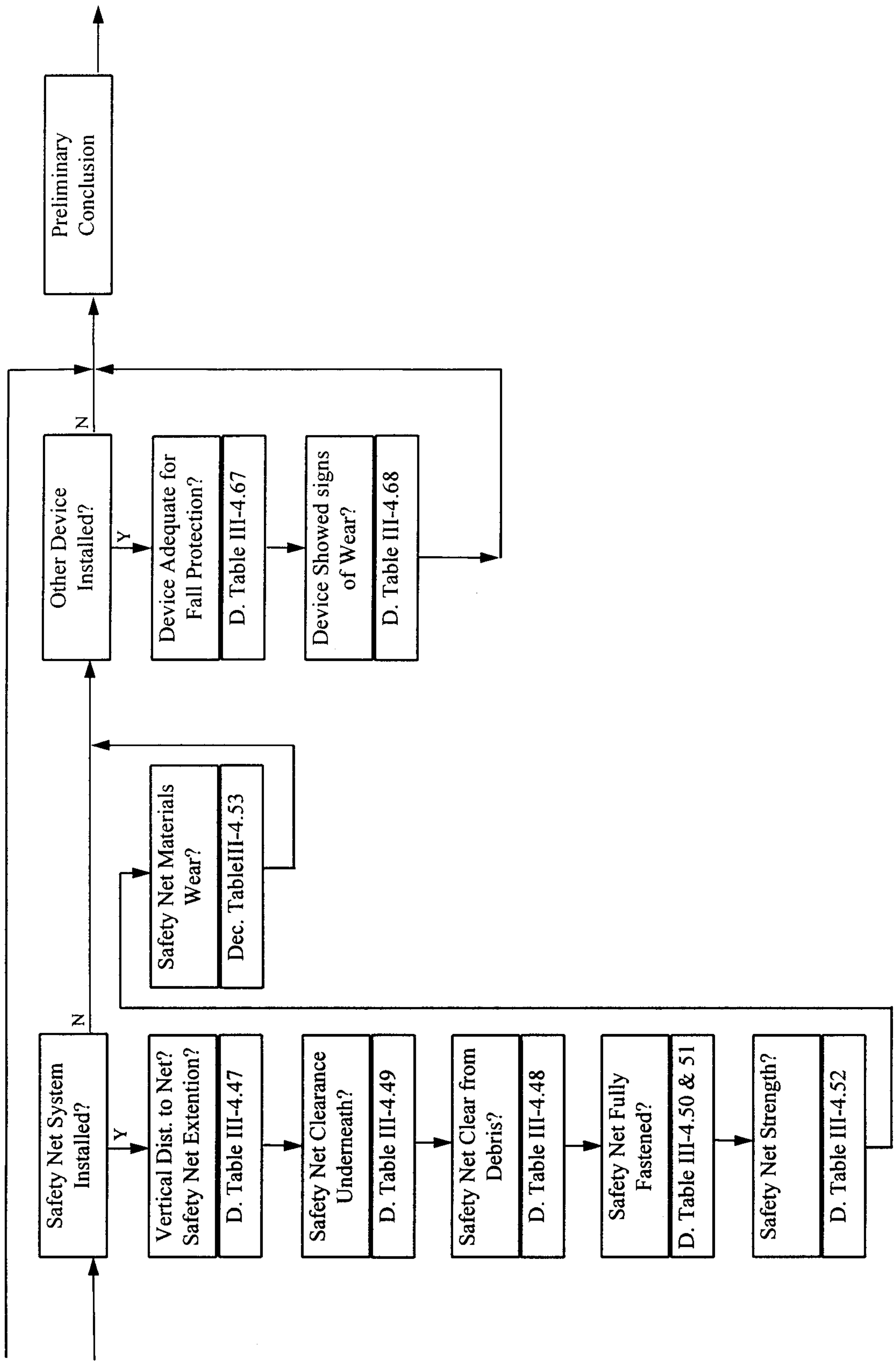

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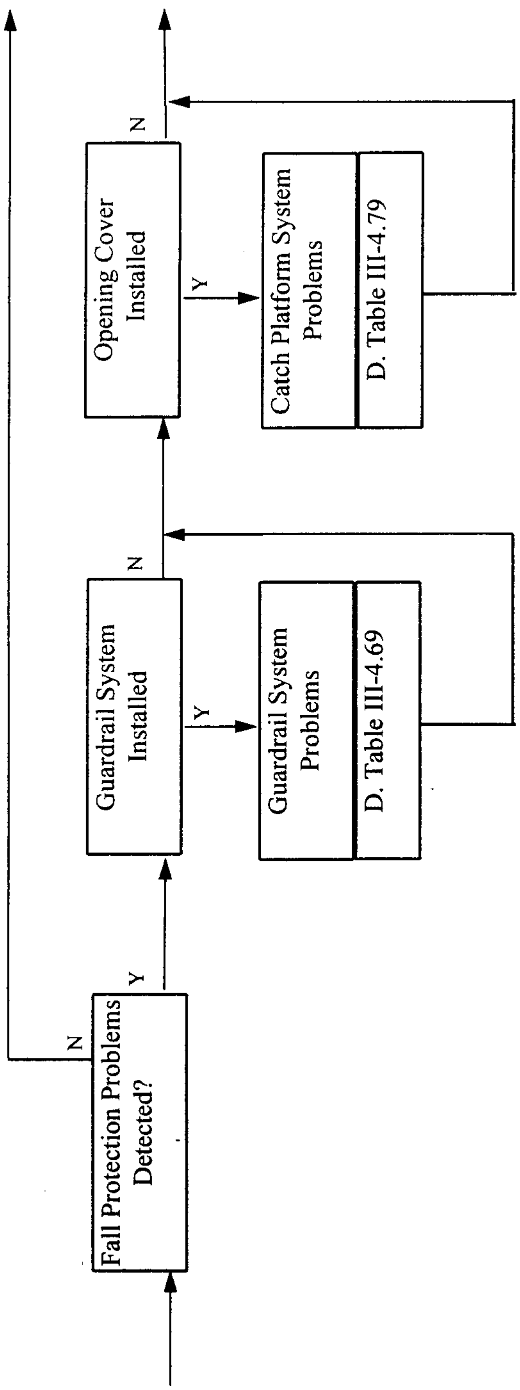

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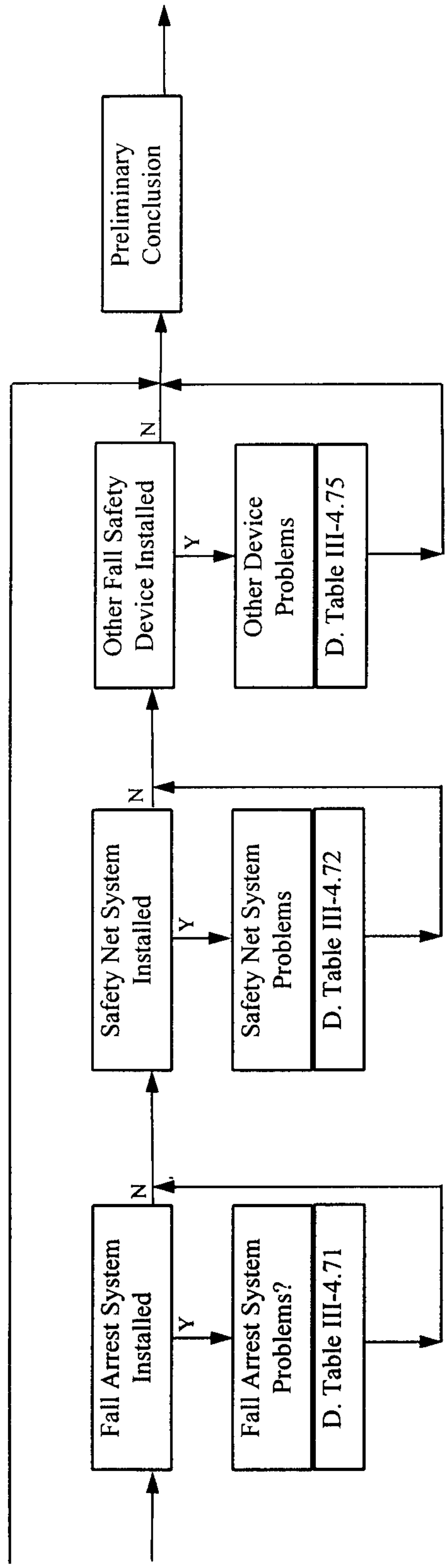

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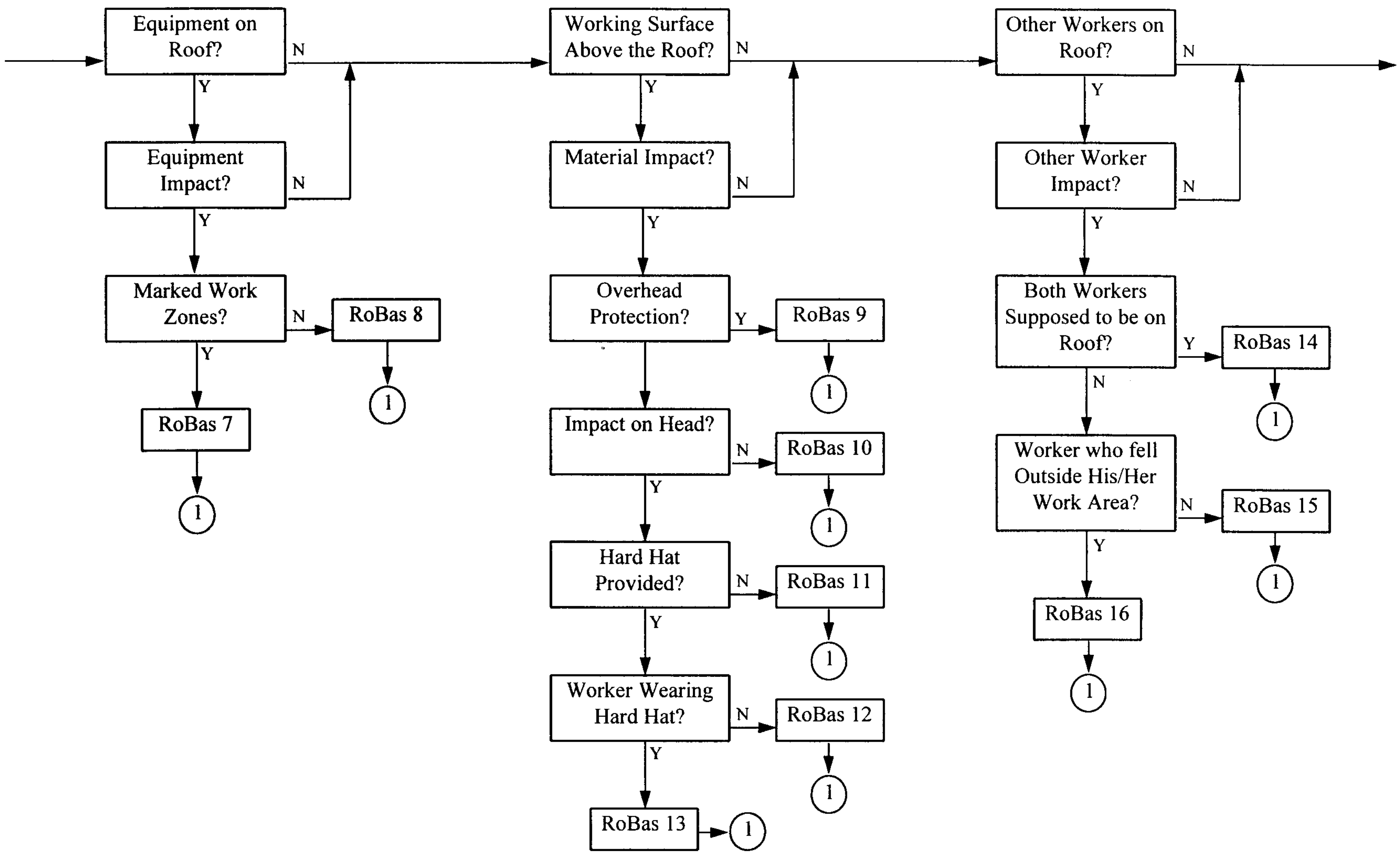

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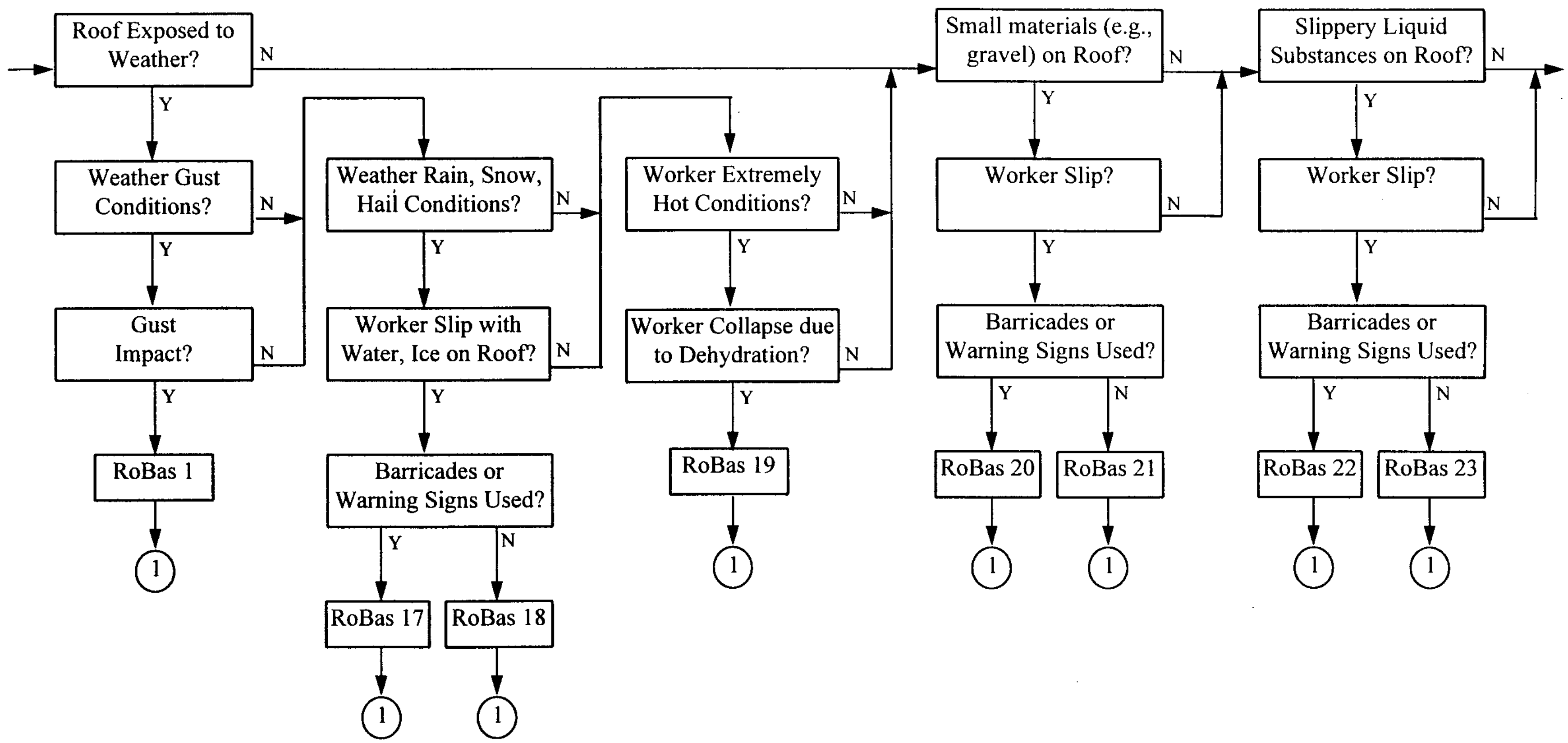

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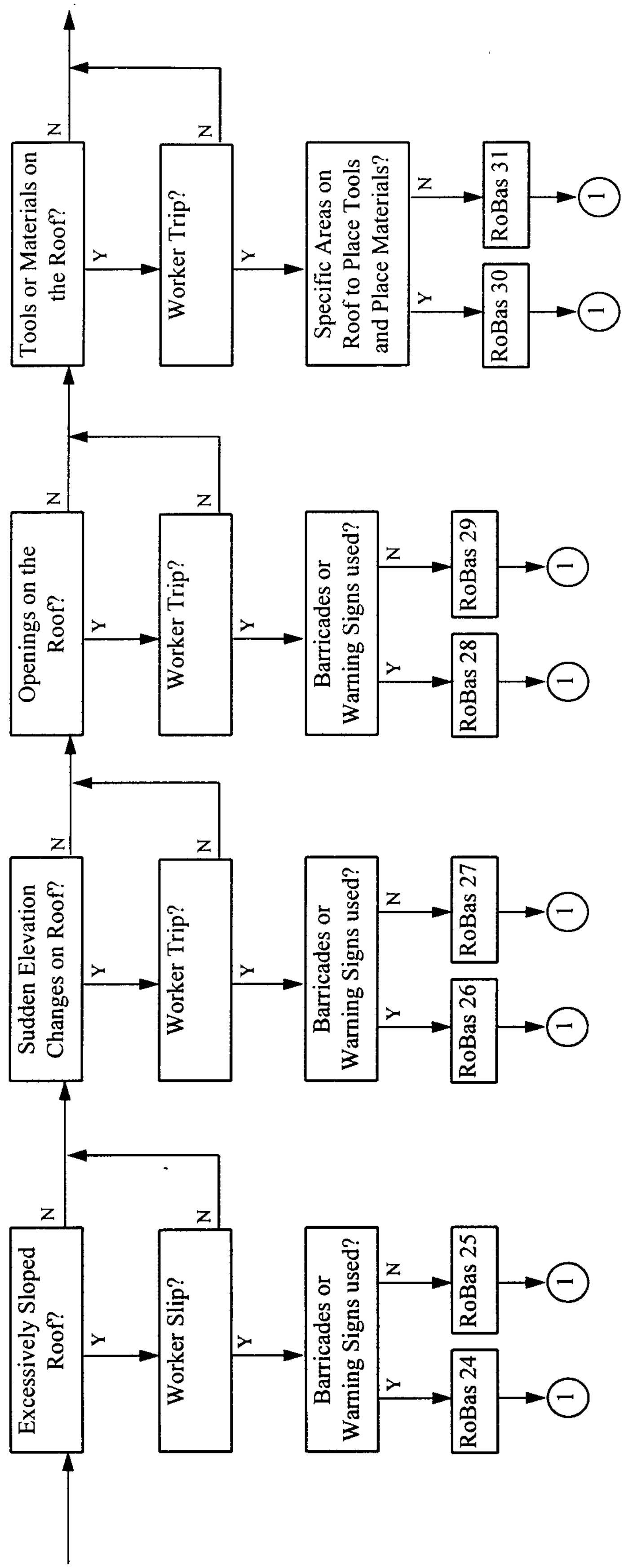

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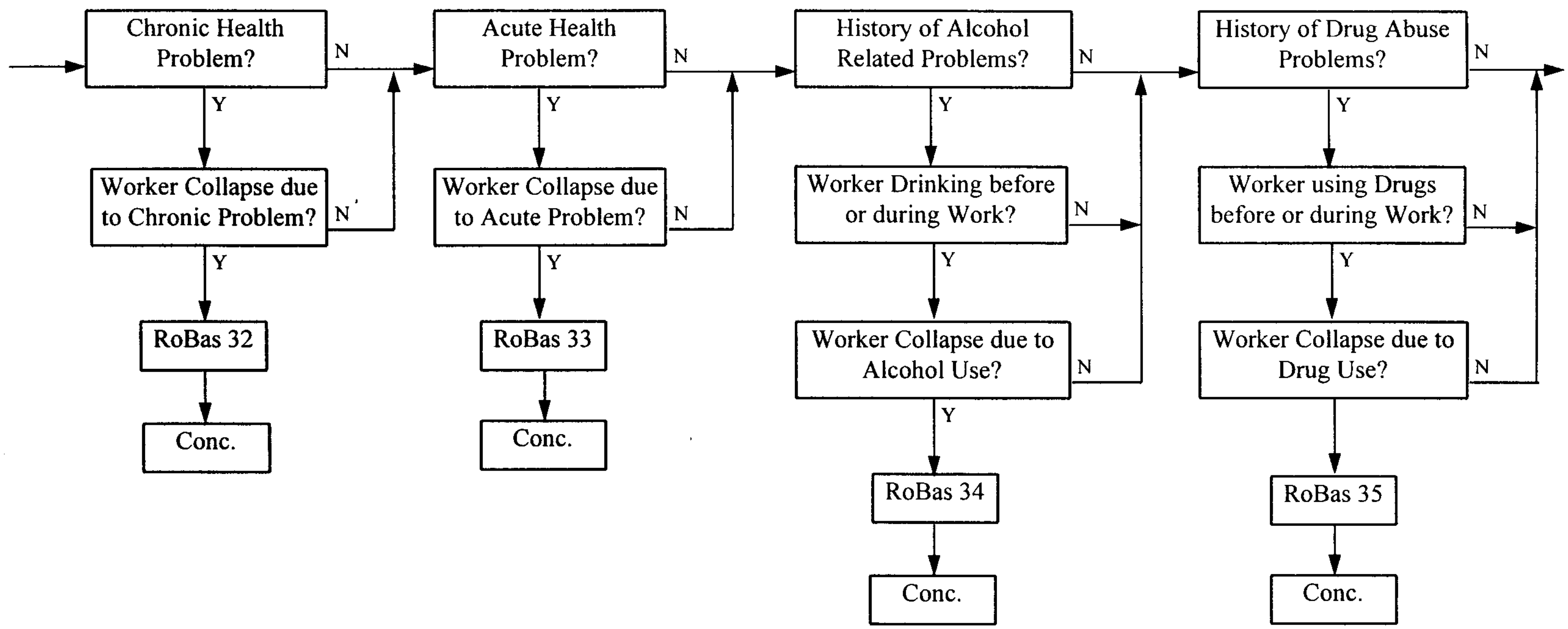

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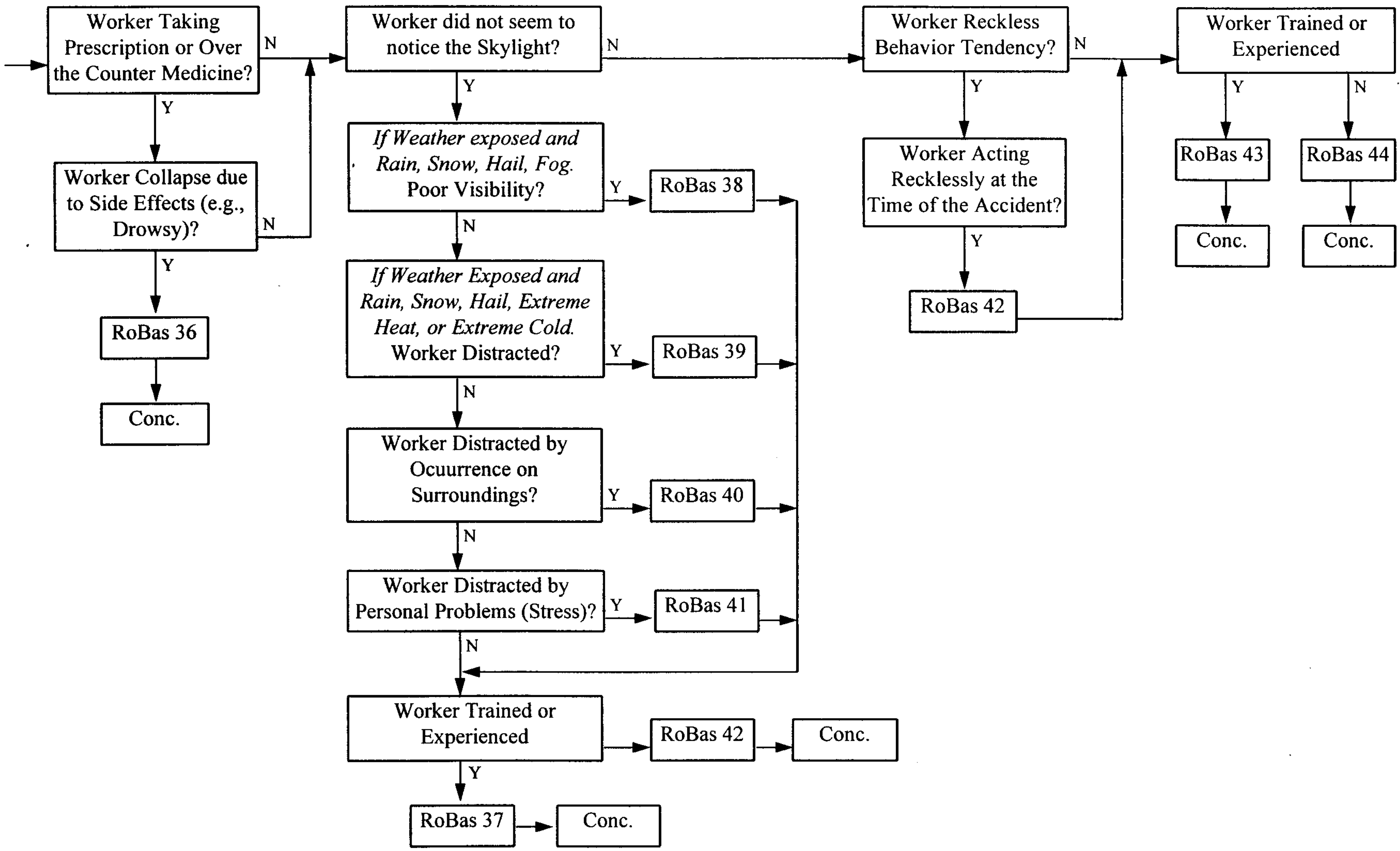

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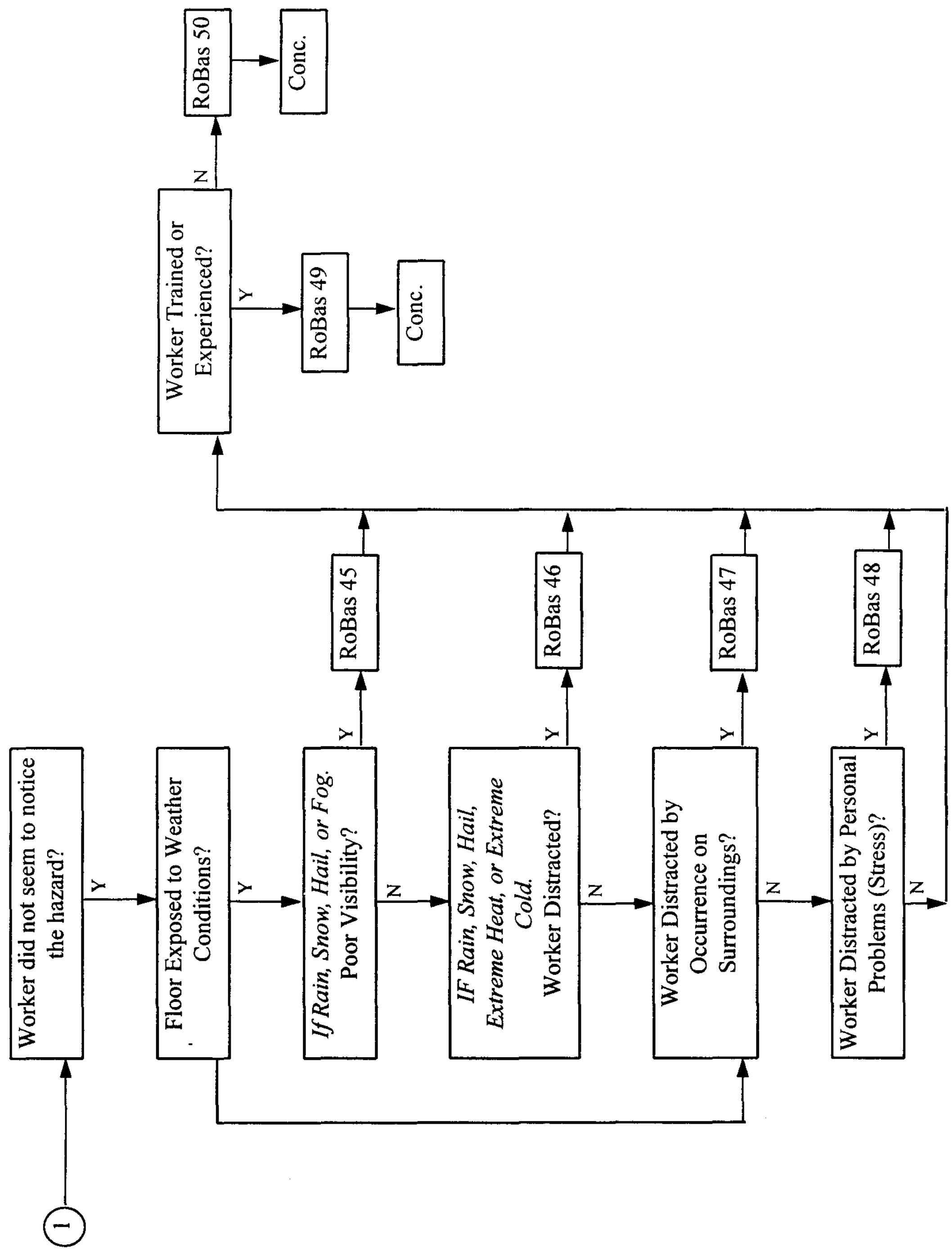

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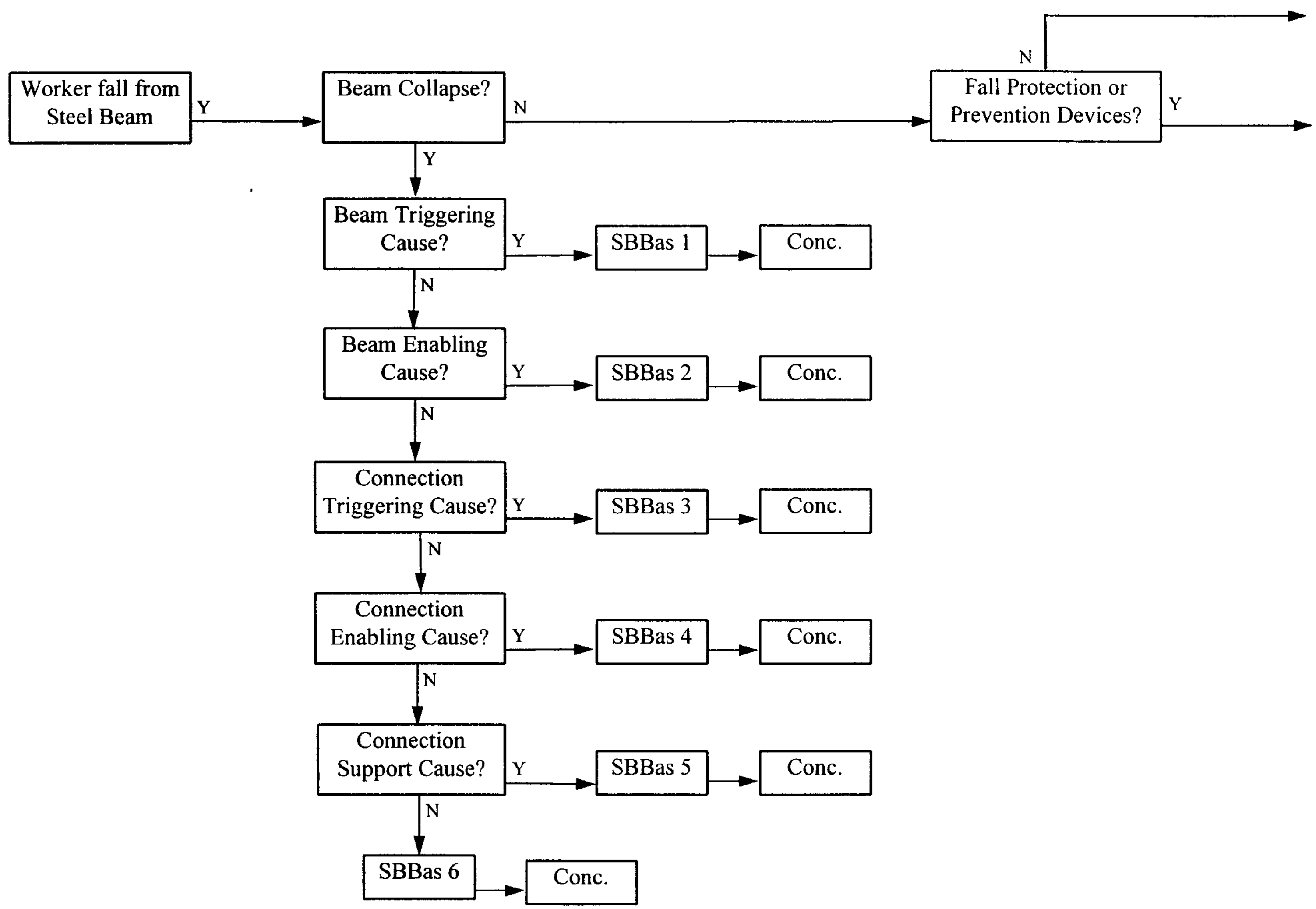
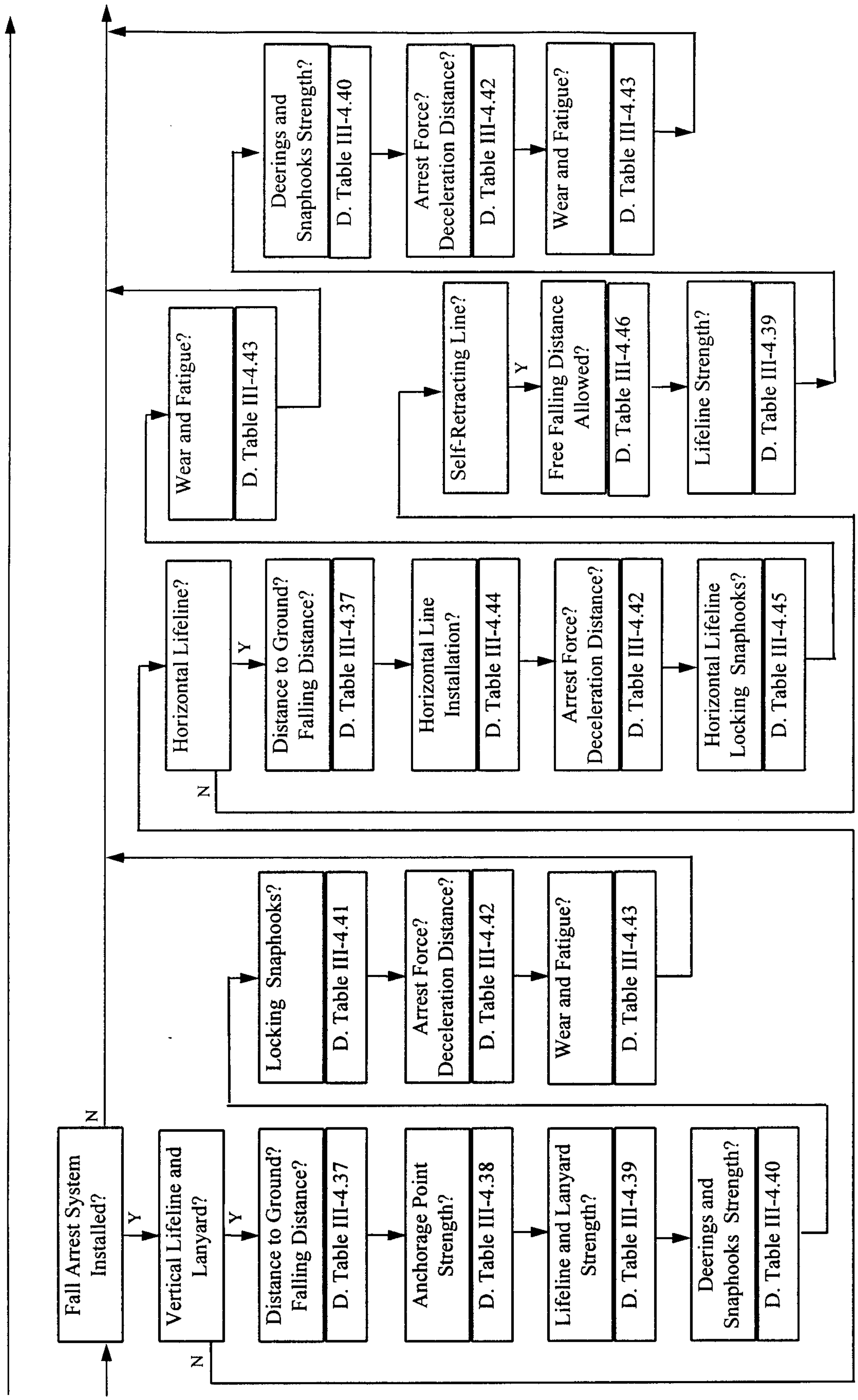


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam



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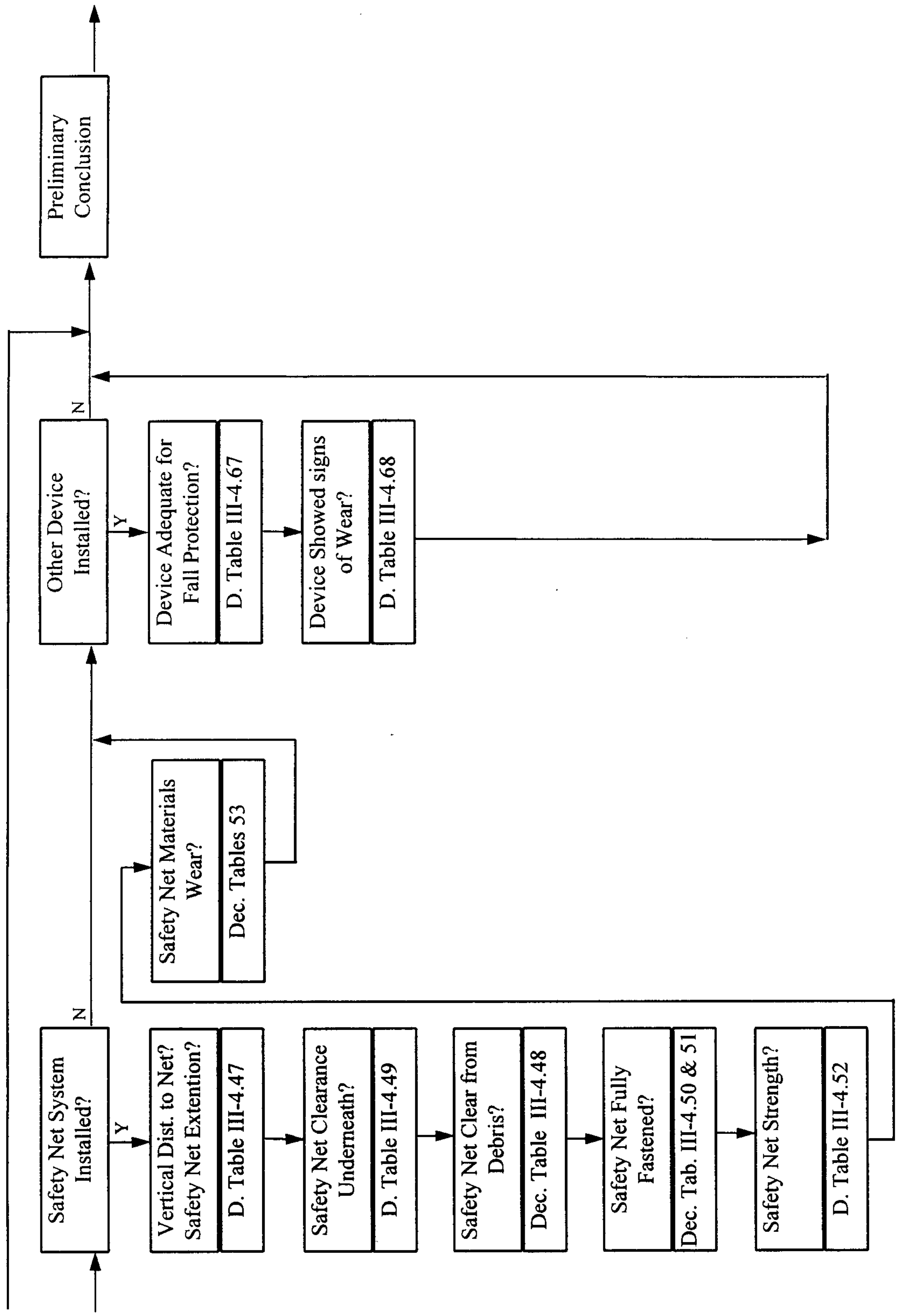


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

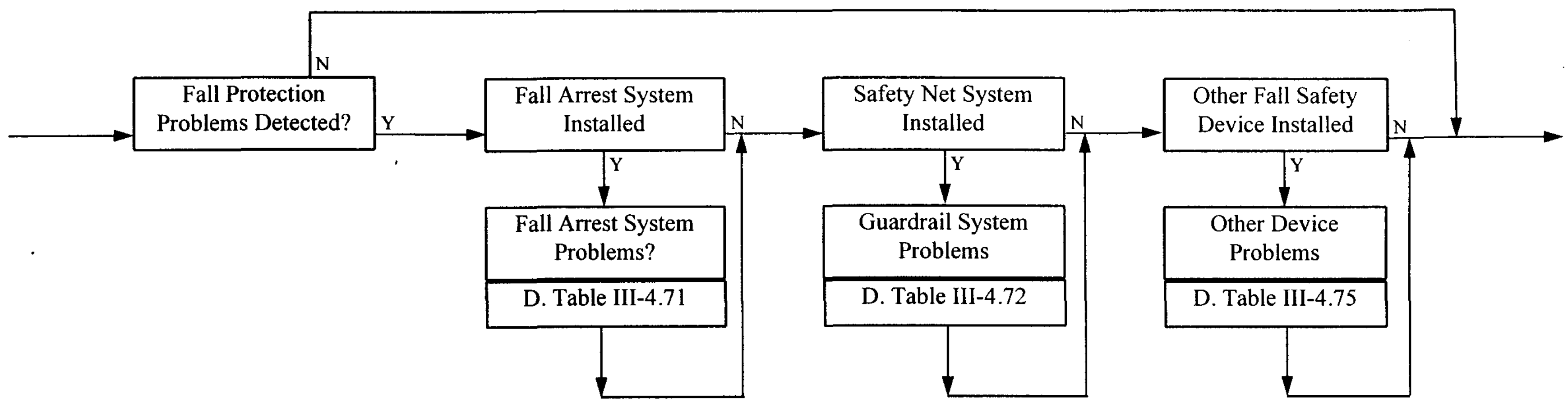


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

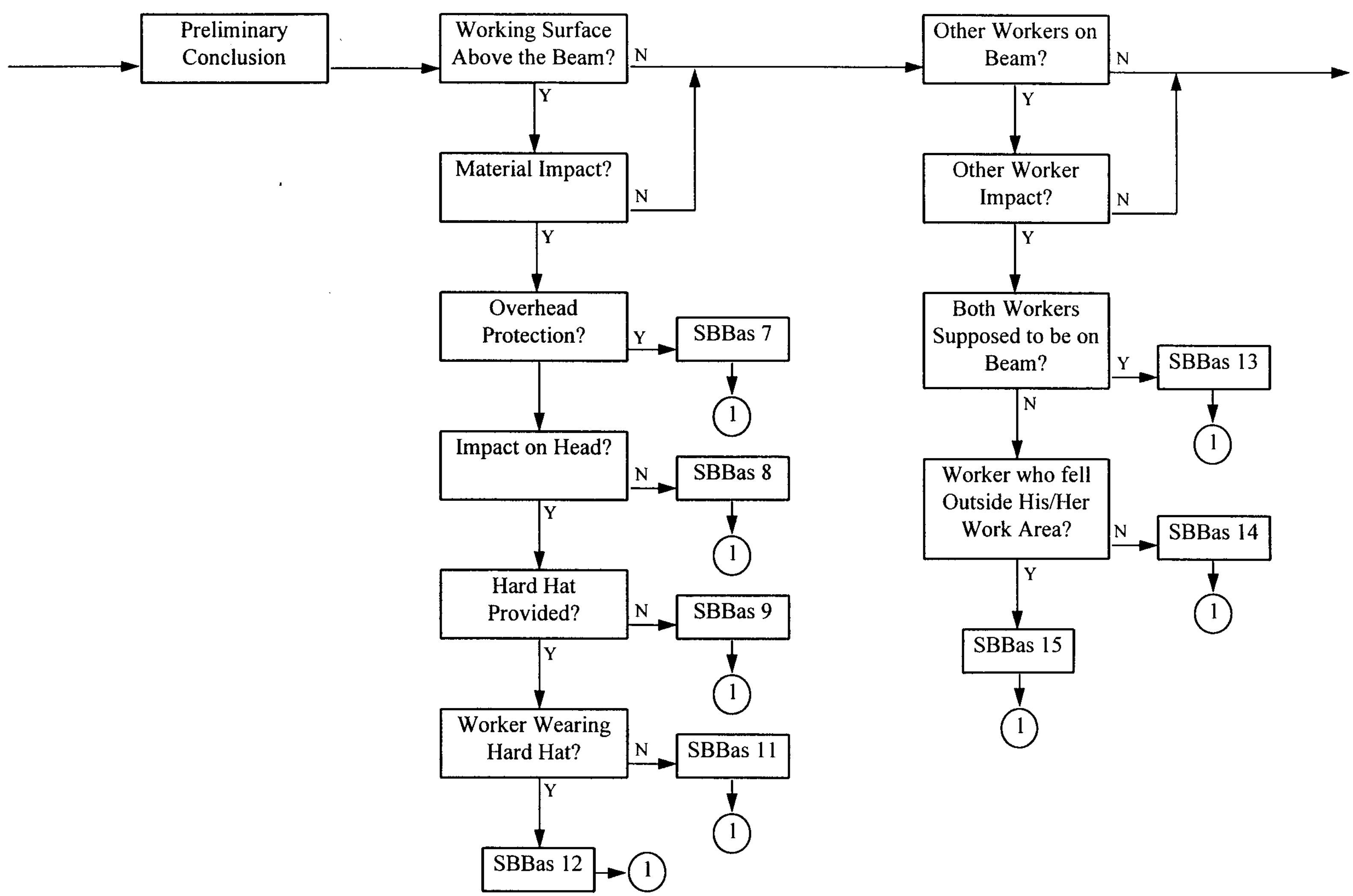


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

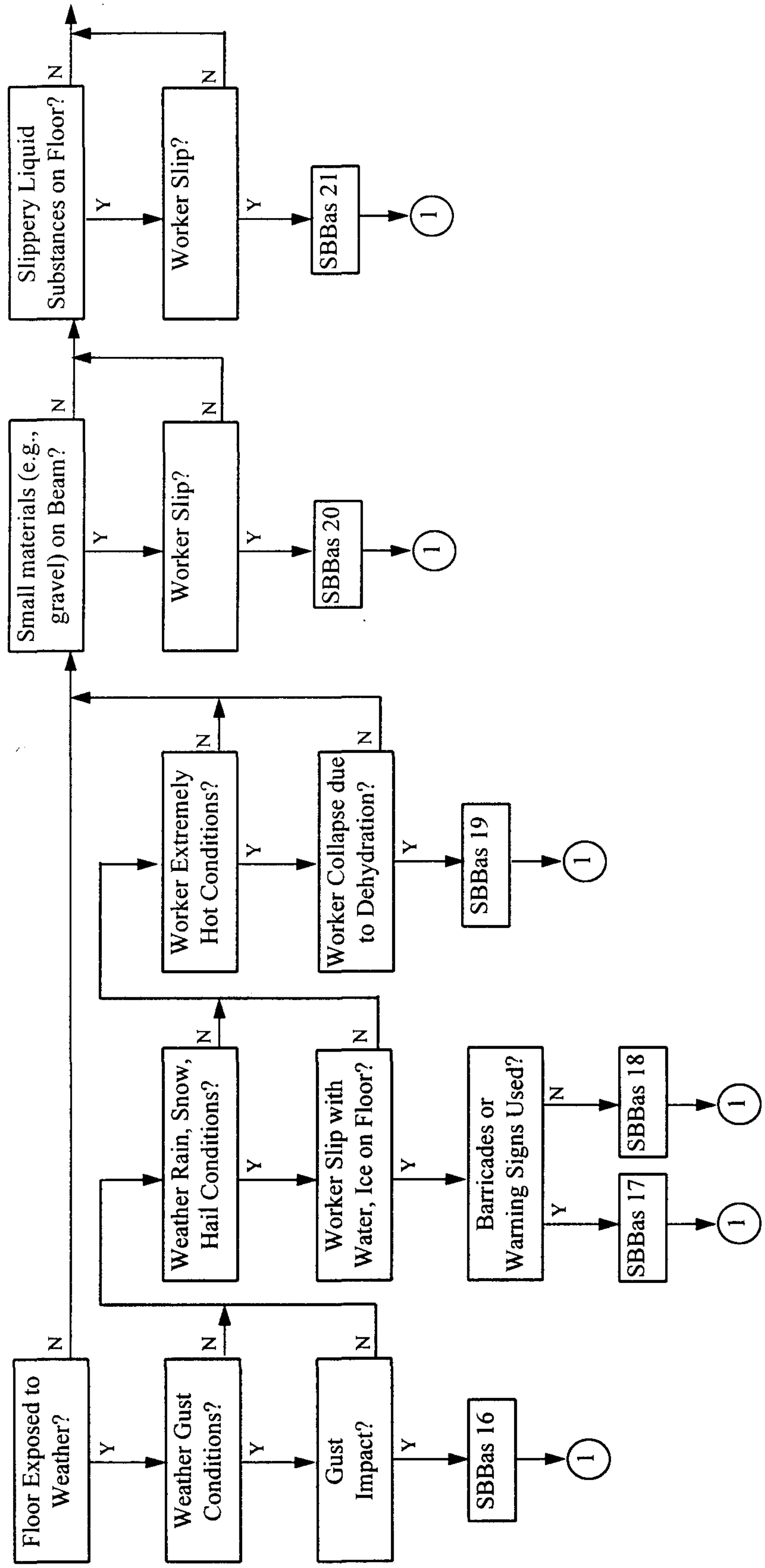


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

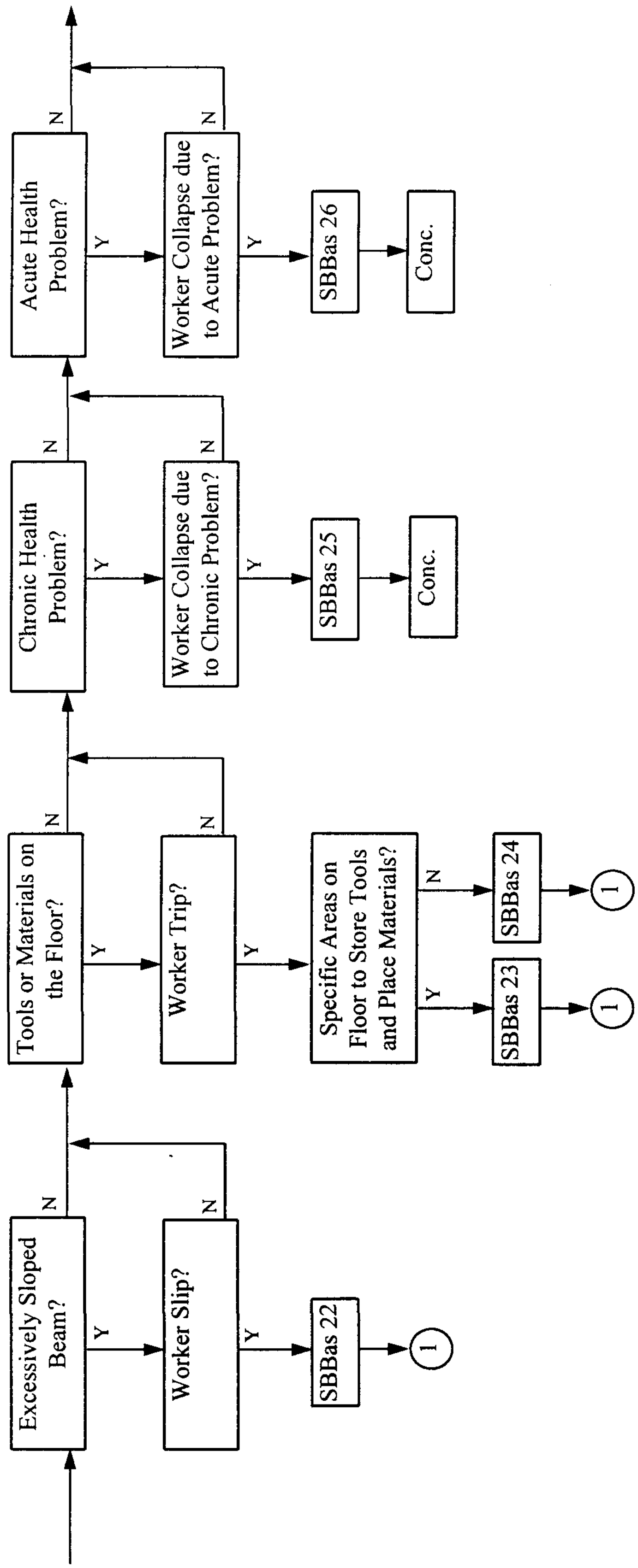


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

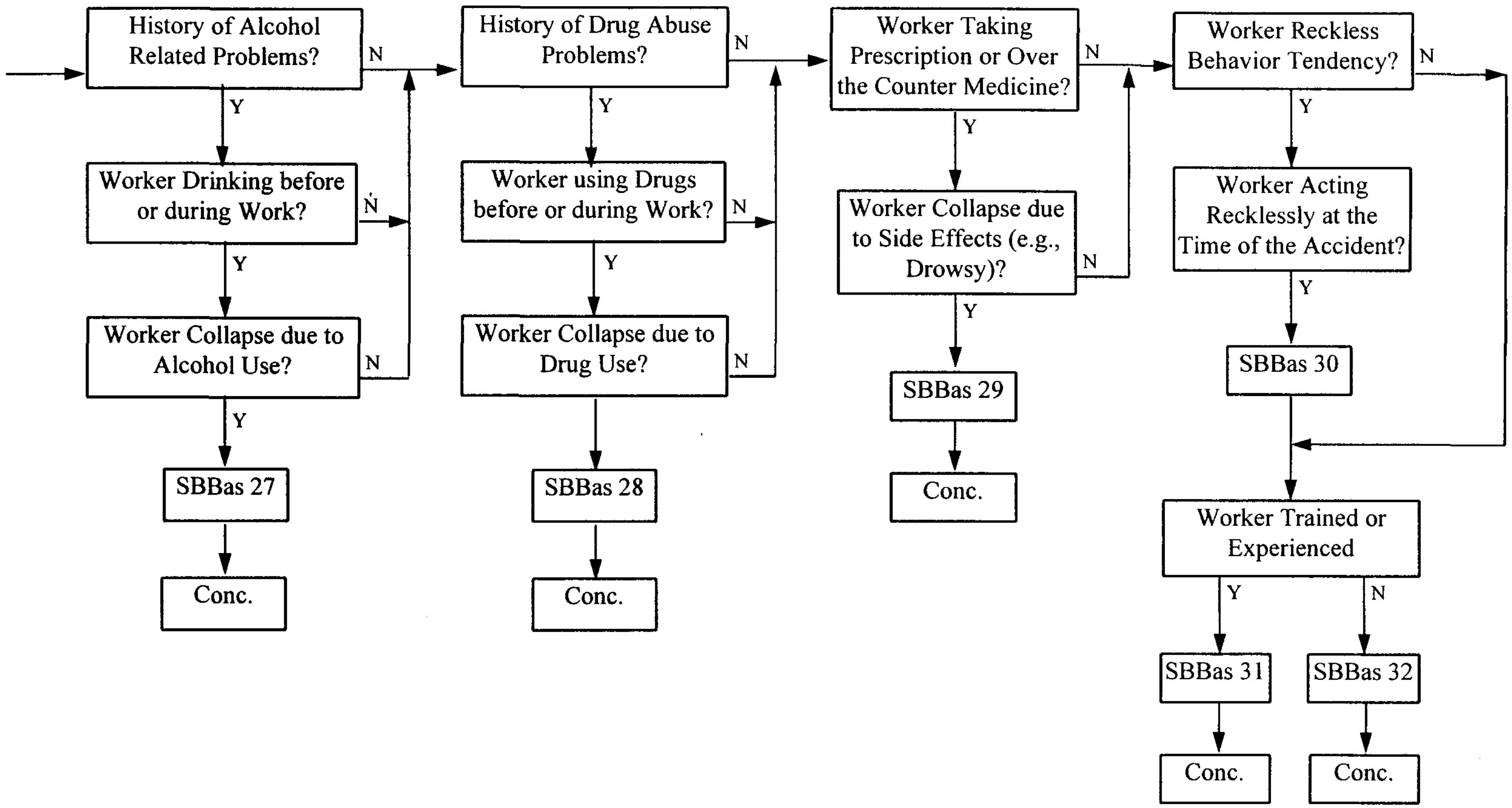


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

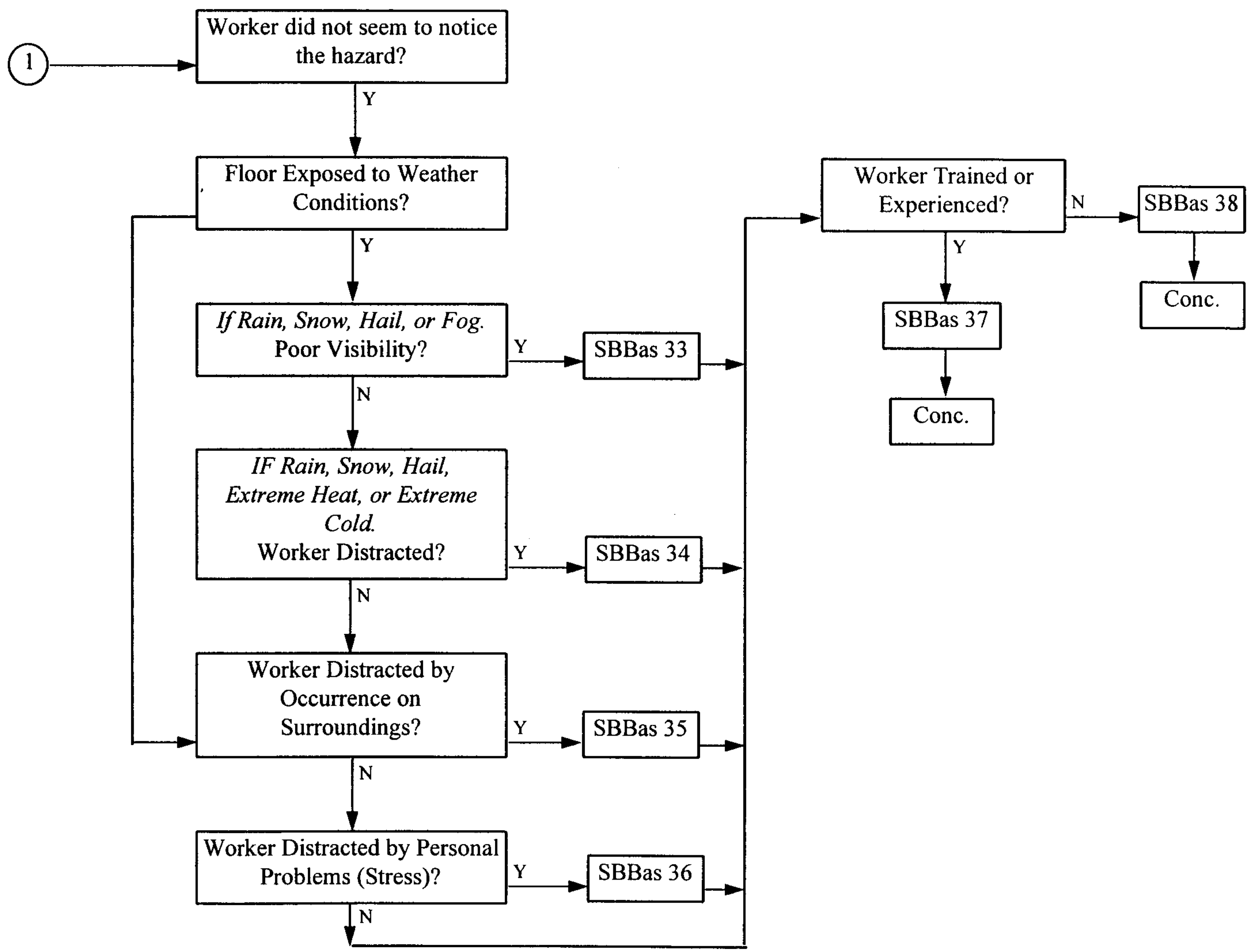


Figure III-D.4 Decision Structure for Worker Fall from Steel Beam (Cont'd)

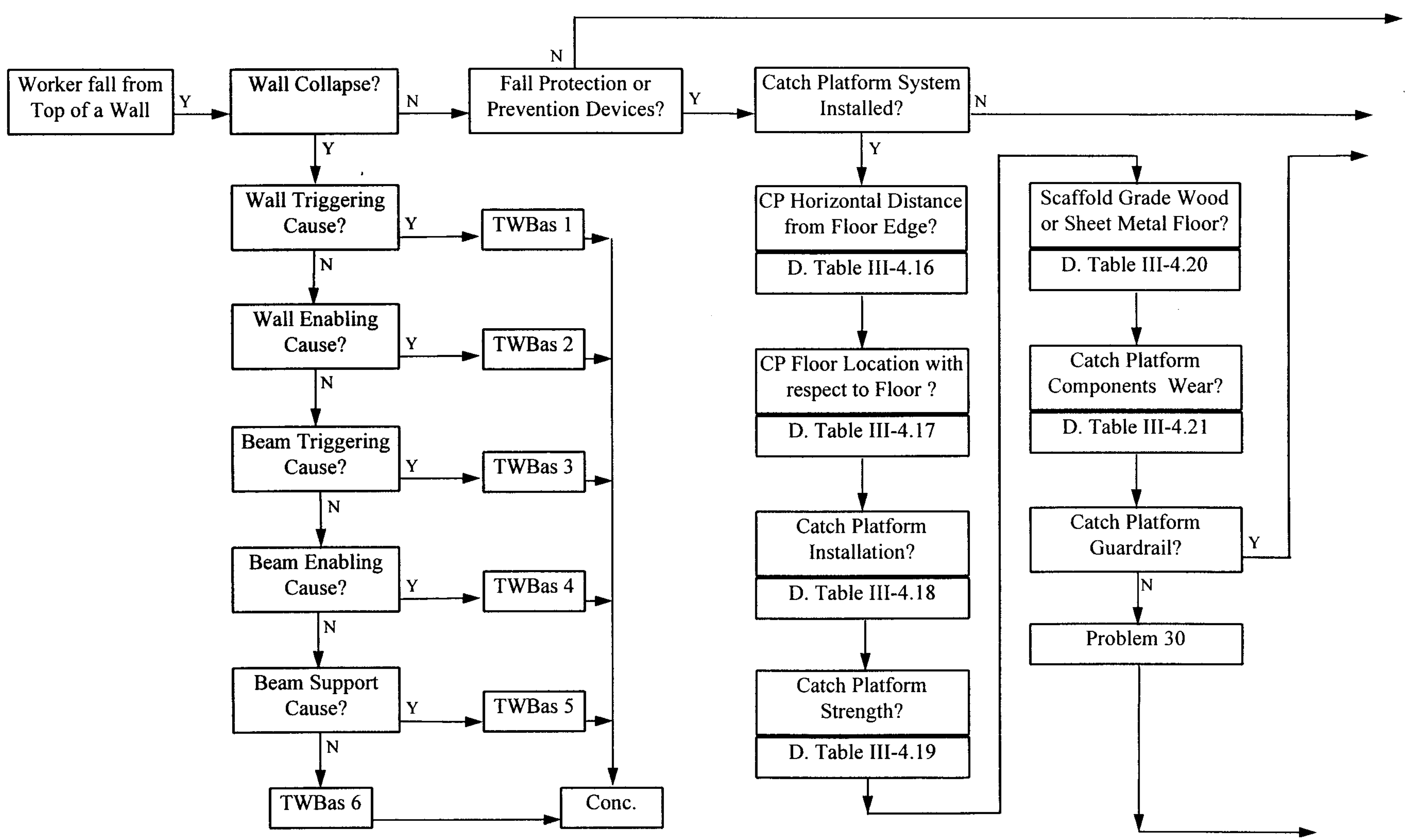


Figure III-D.5 Decision Structure for Worker Fall from Top of Wall

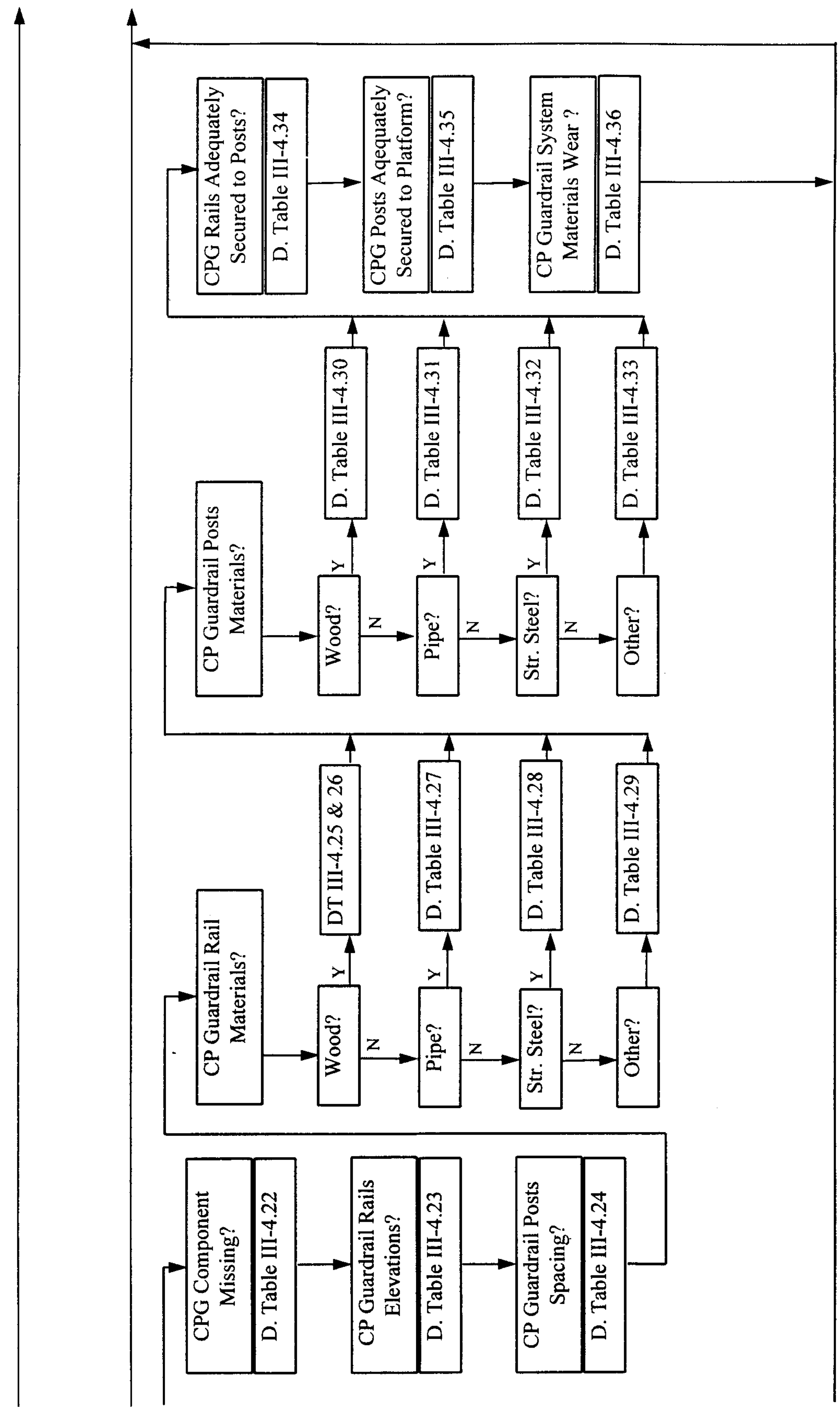


Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

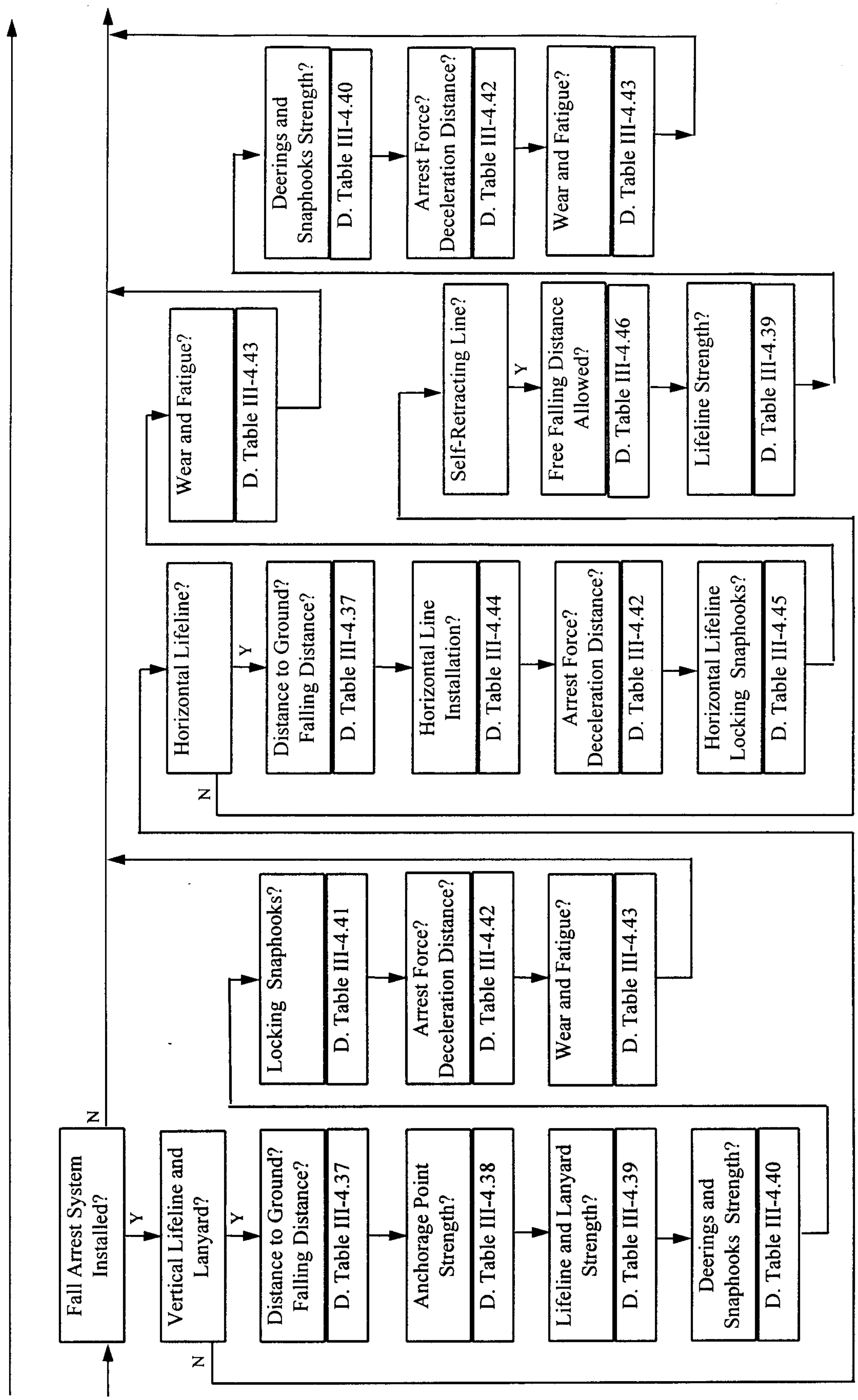


Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

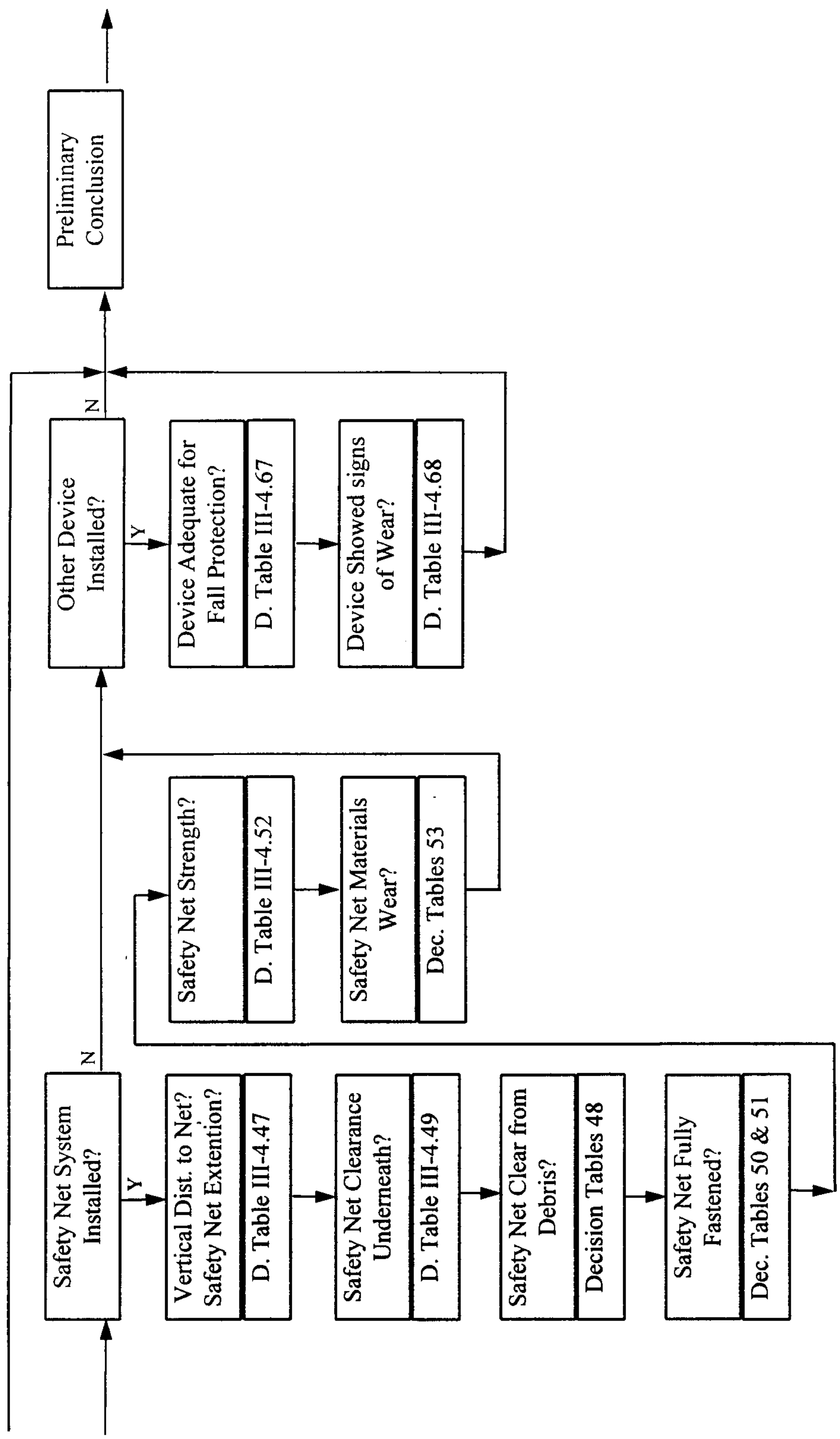
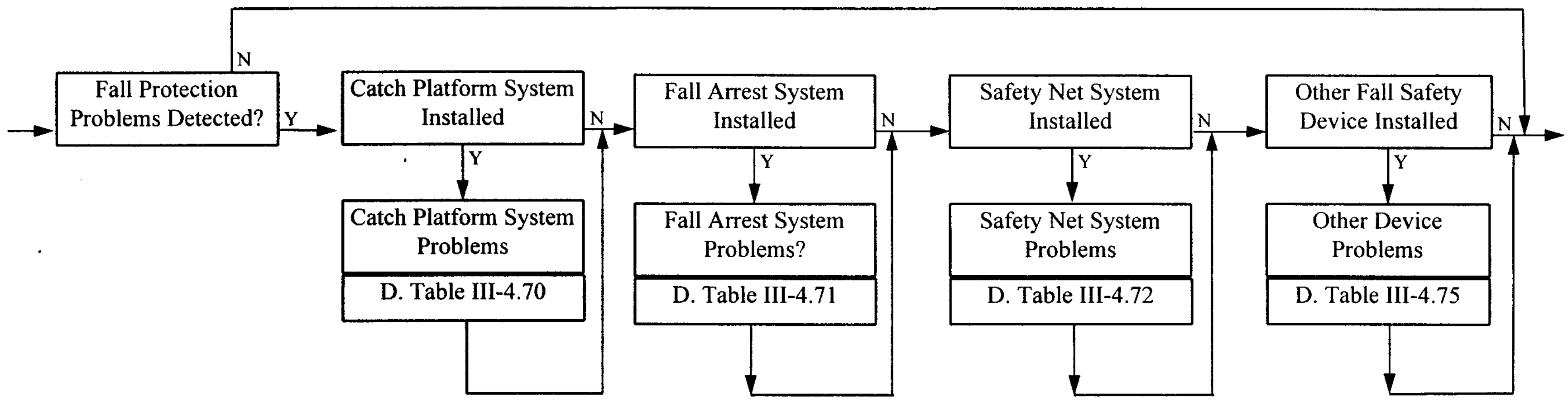


Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)



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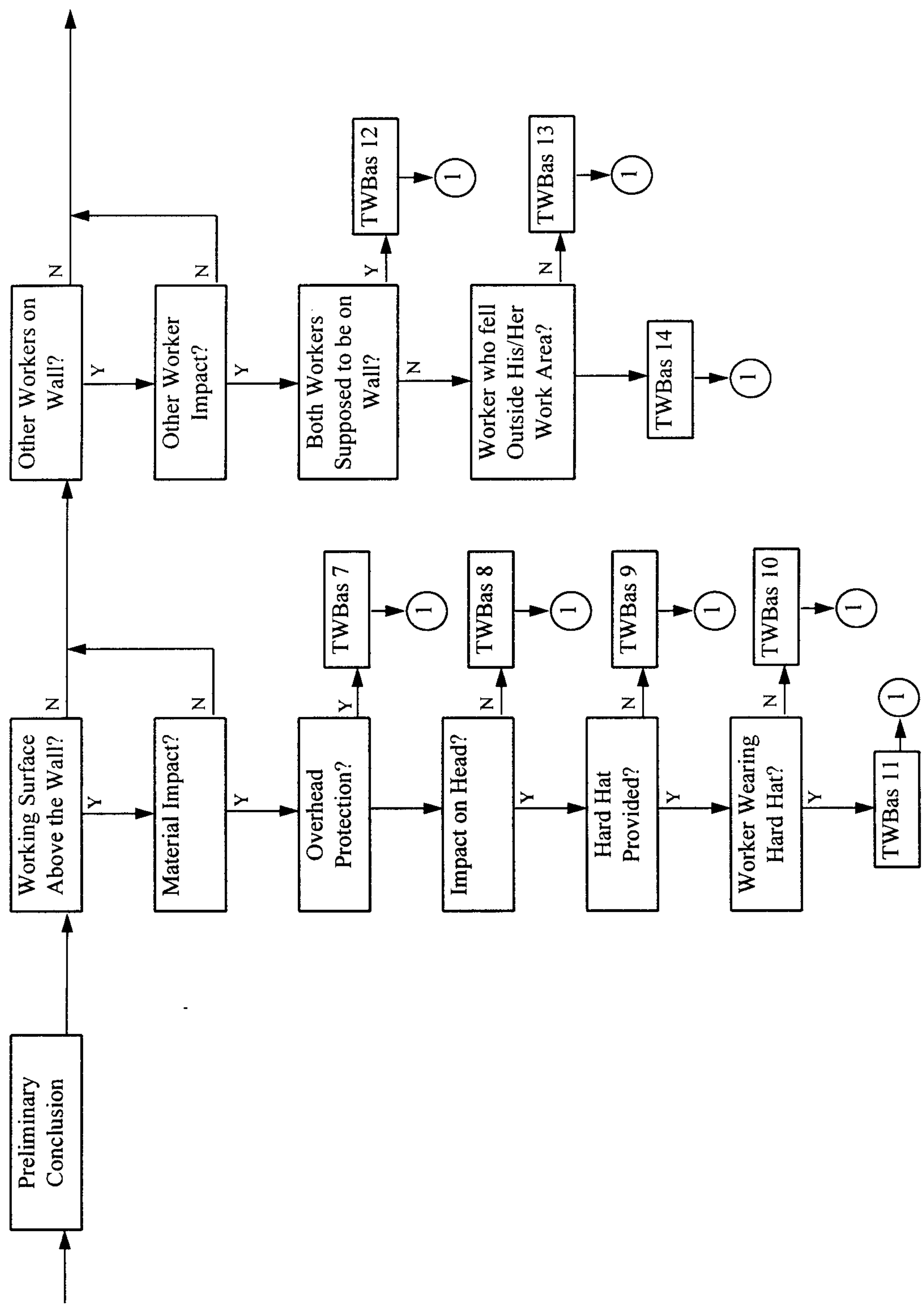

Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

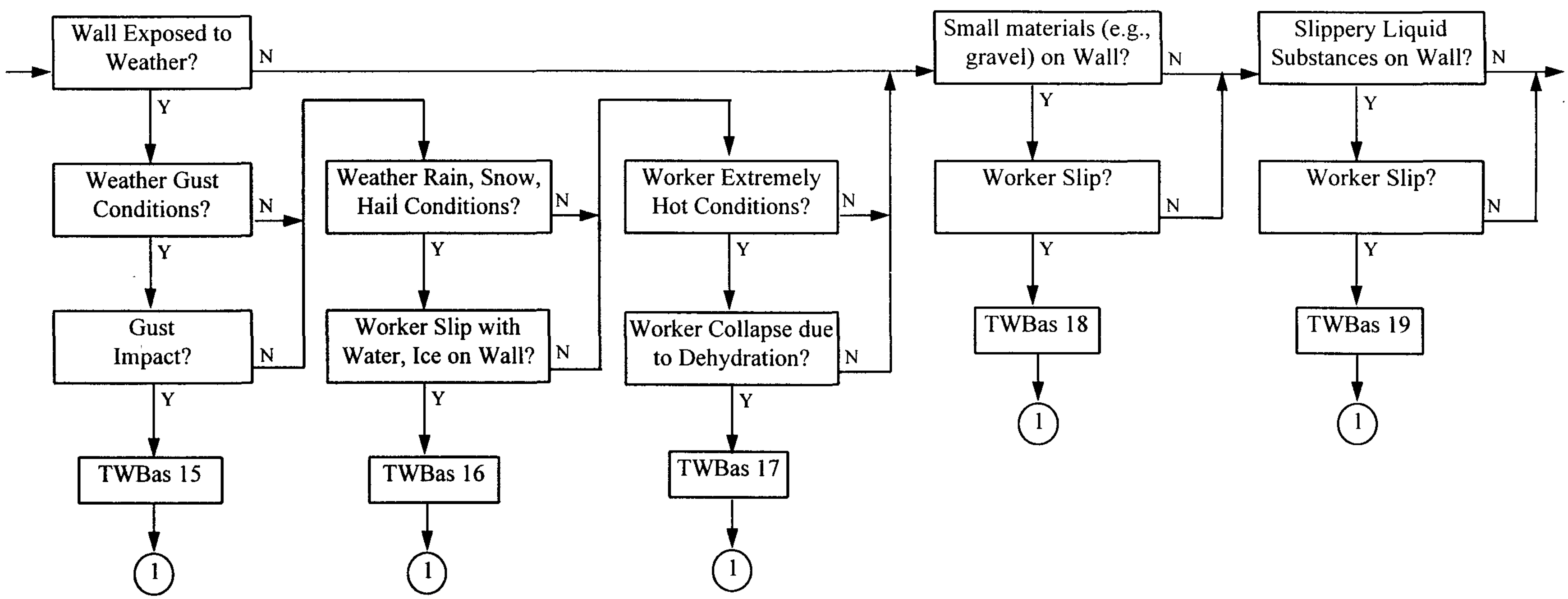

Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

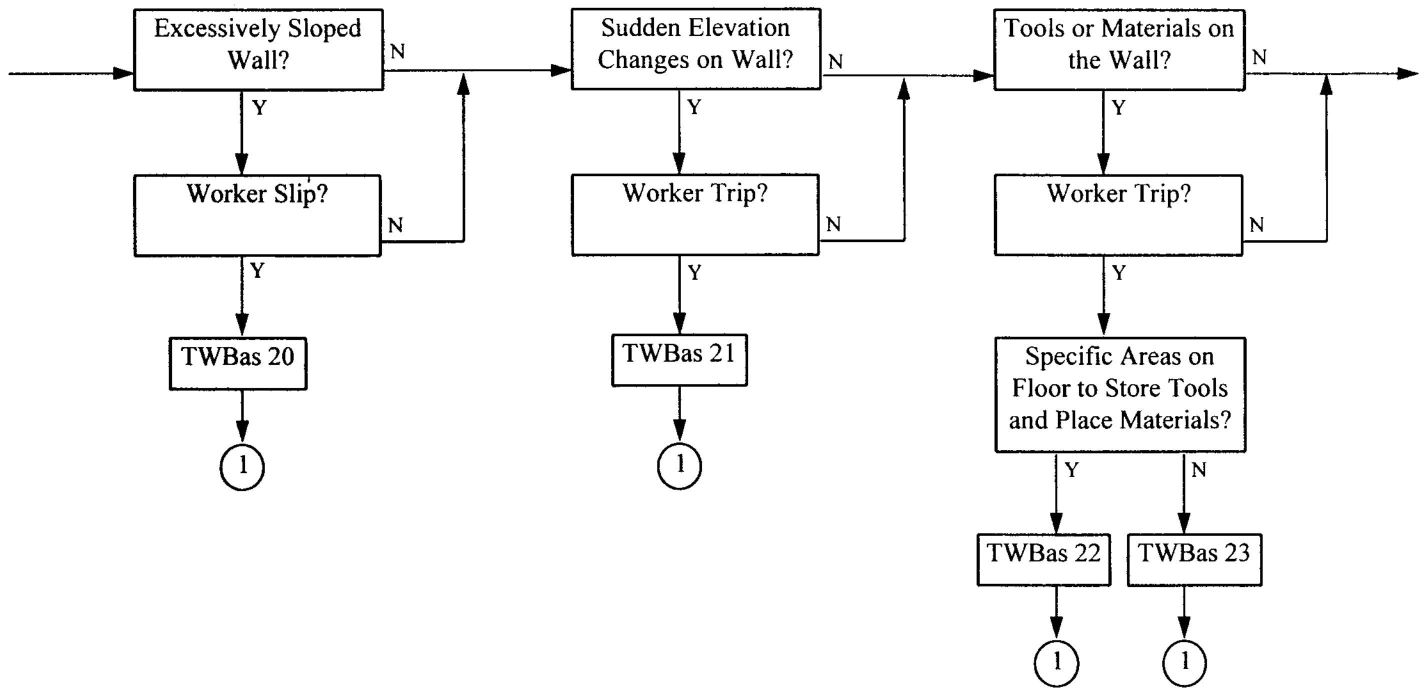

Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

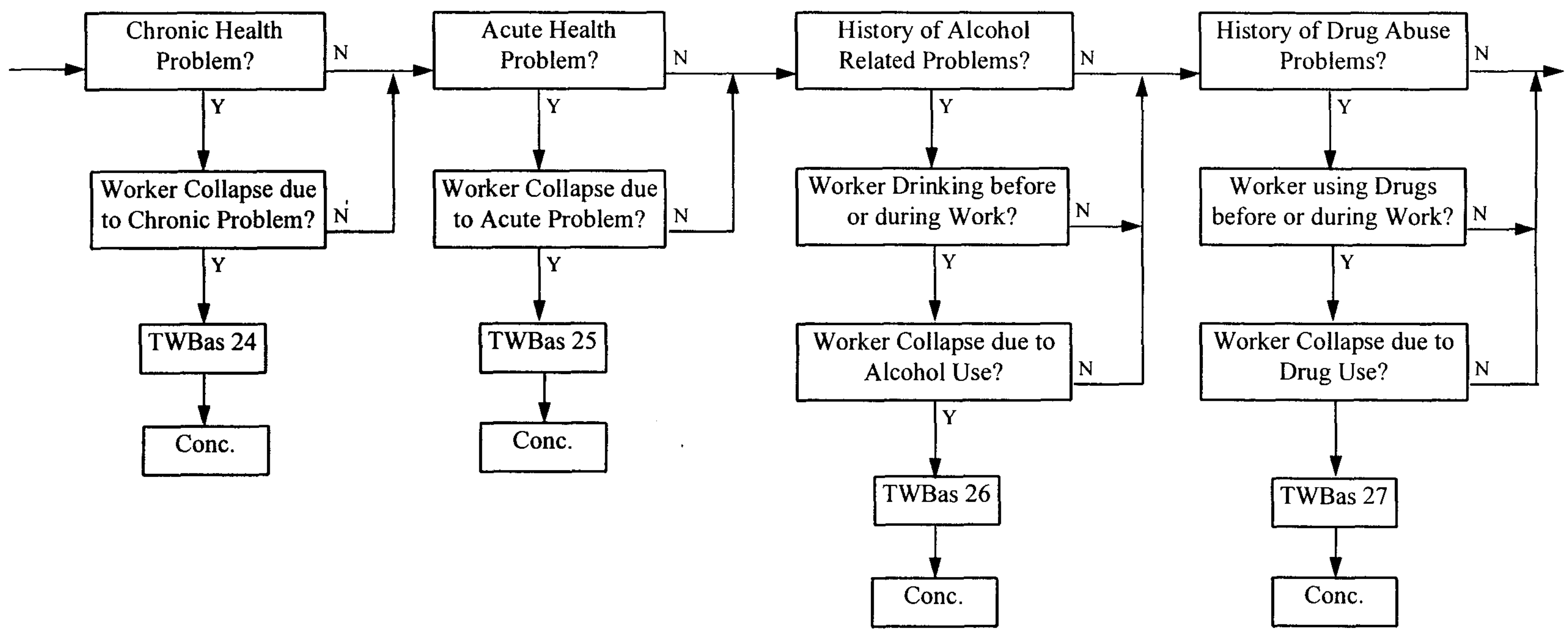

Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

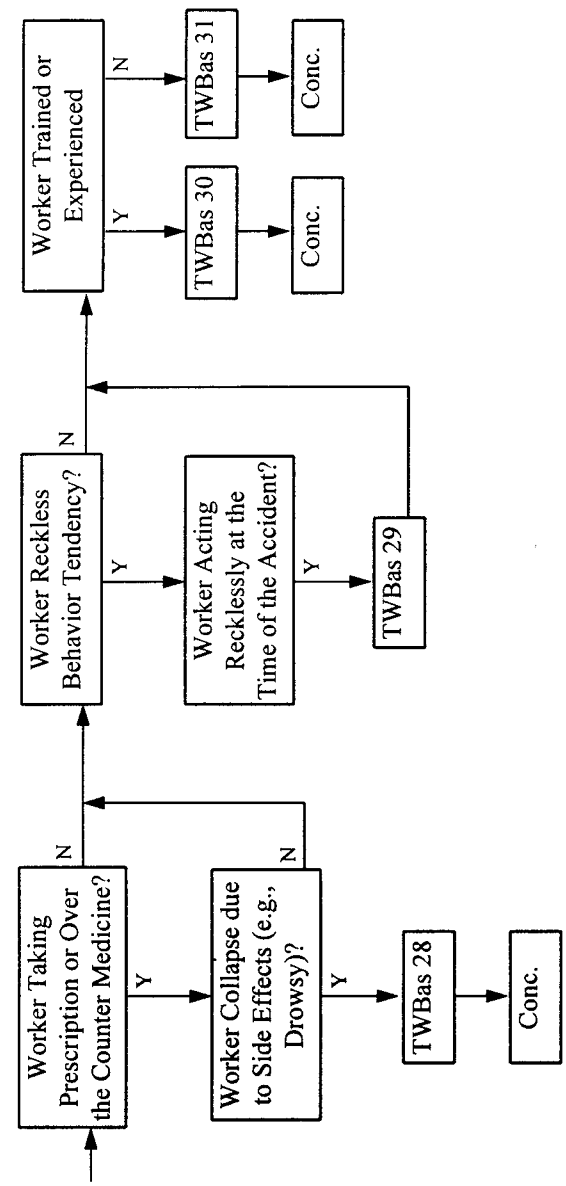

Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

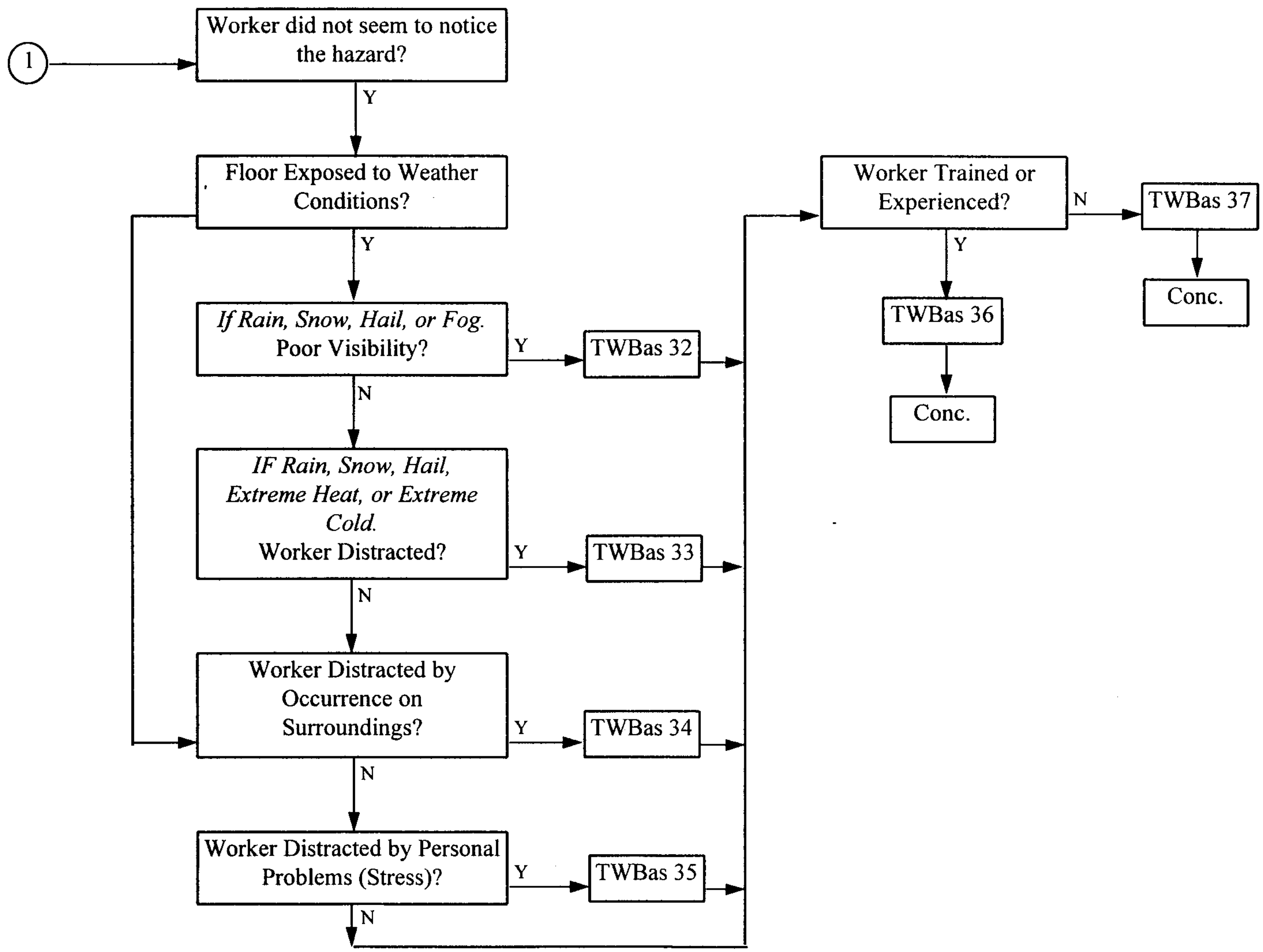

Figure III-D.5 Decision Structure for Worker Fall from Top of Wall (Cont'd)

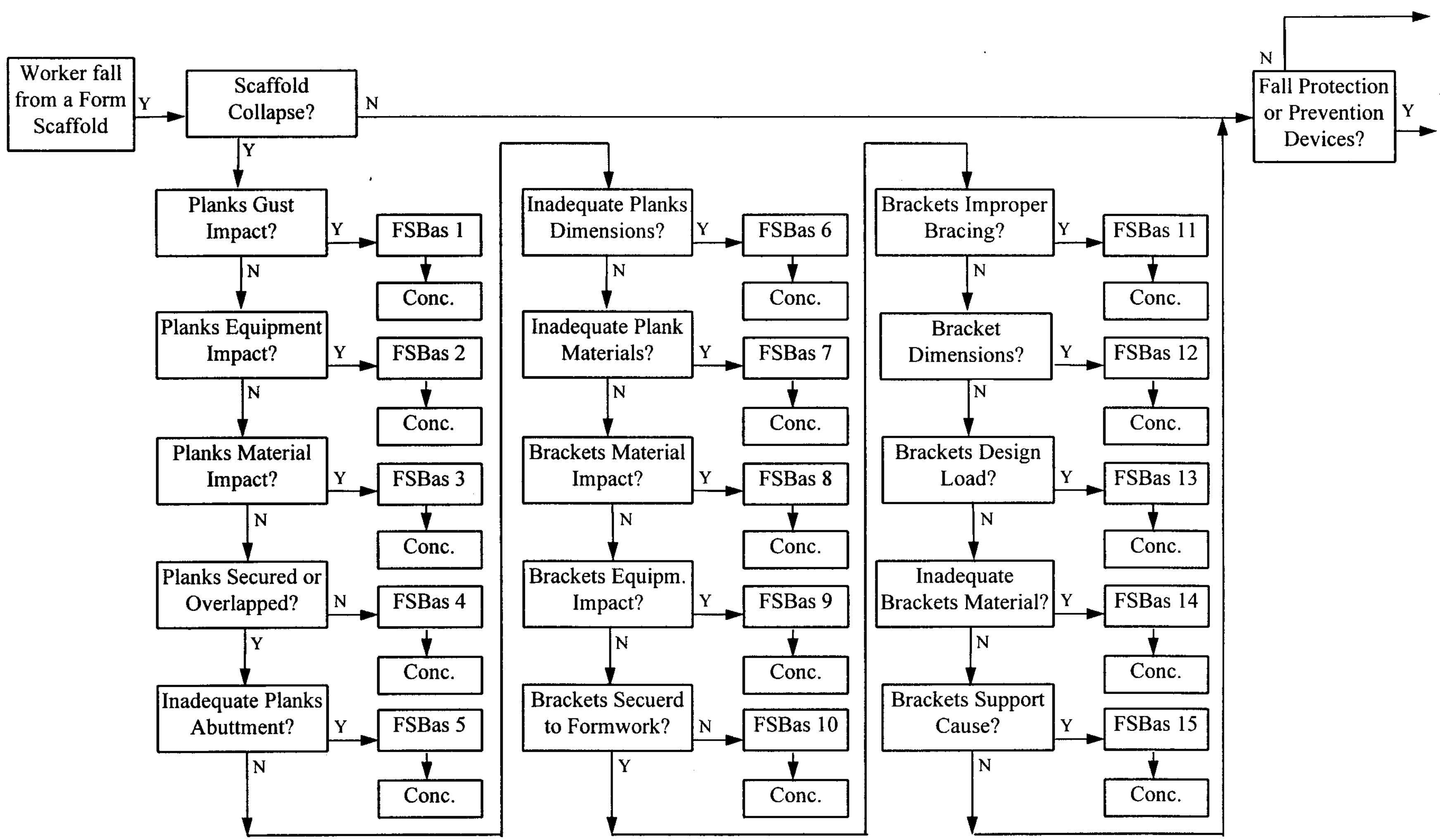

Figure III-D.6 Decision Structure for Worker Fall from a Form Scaffolding

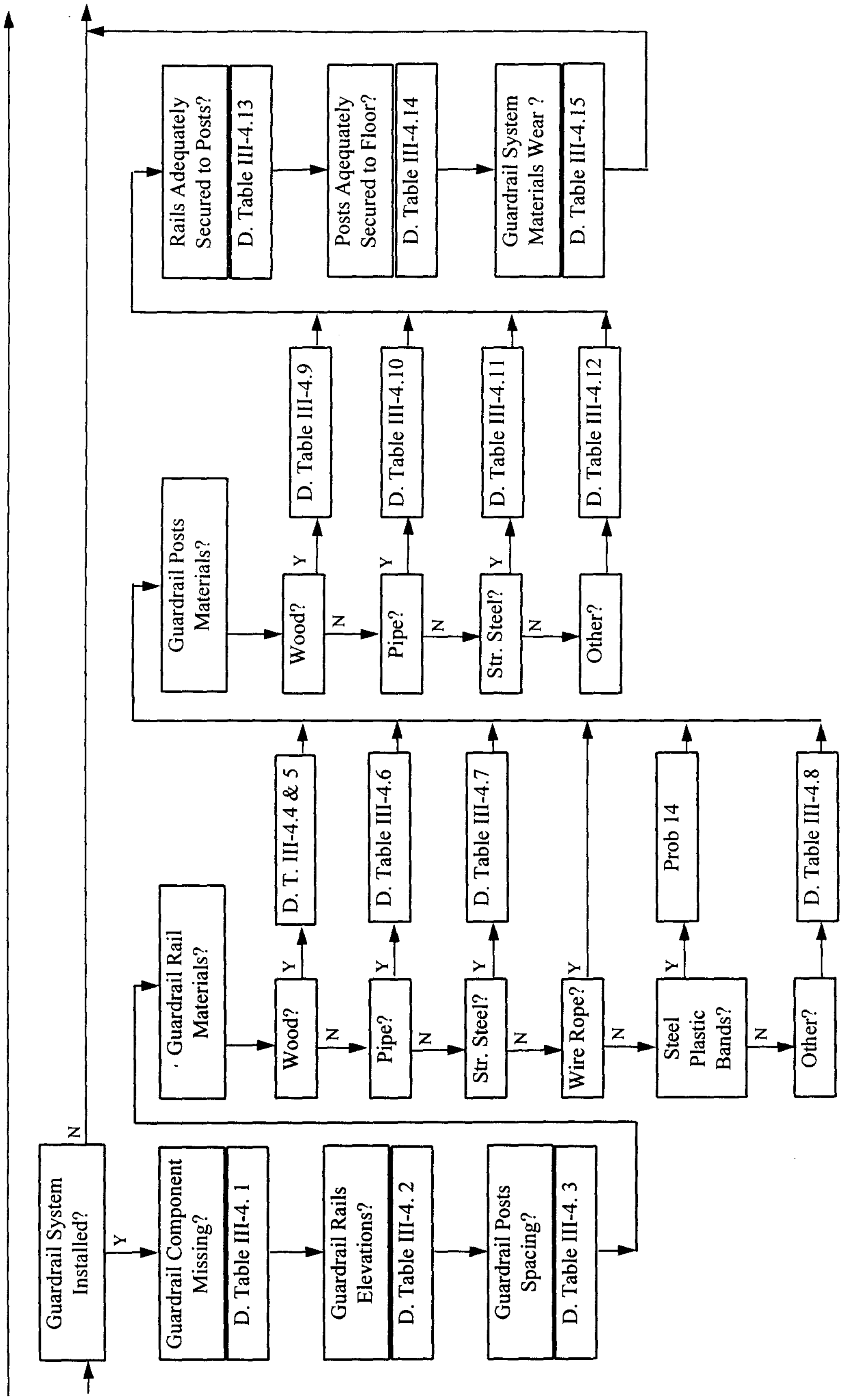

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

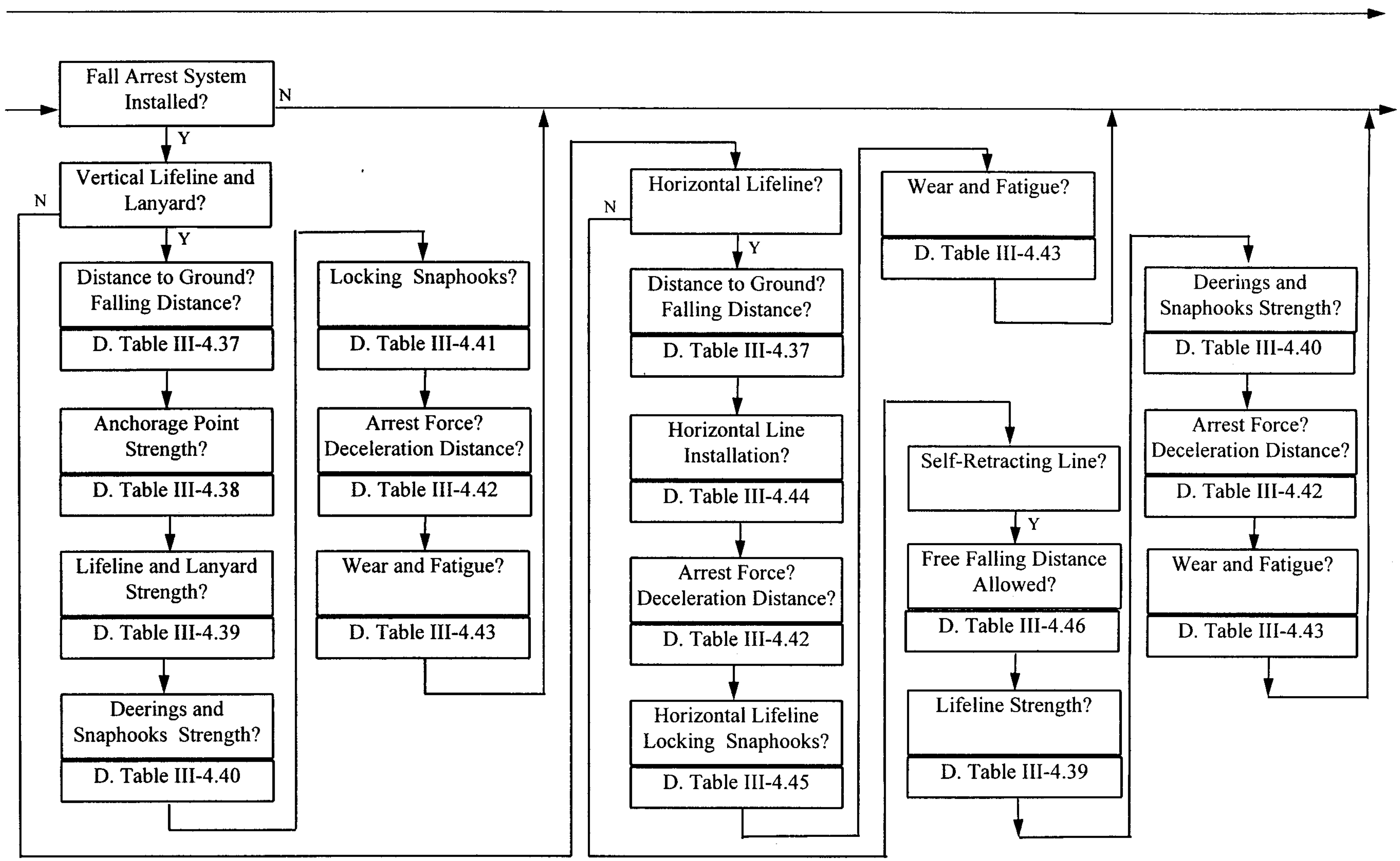

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

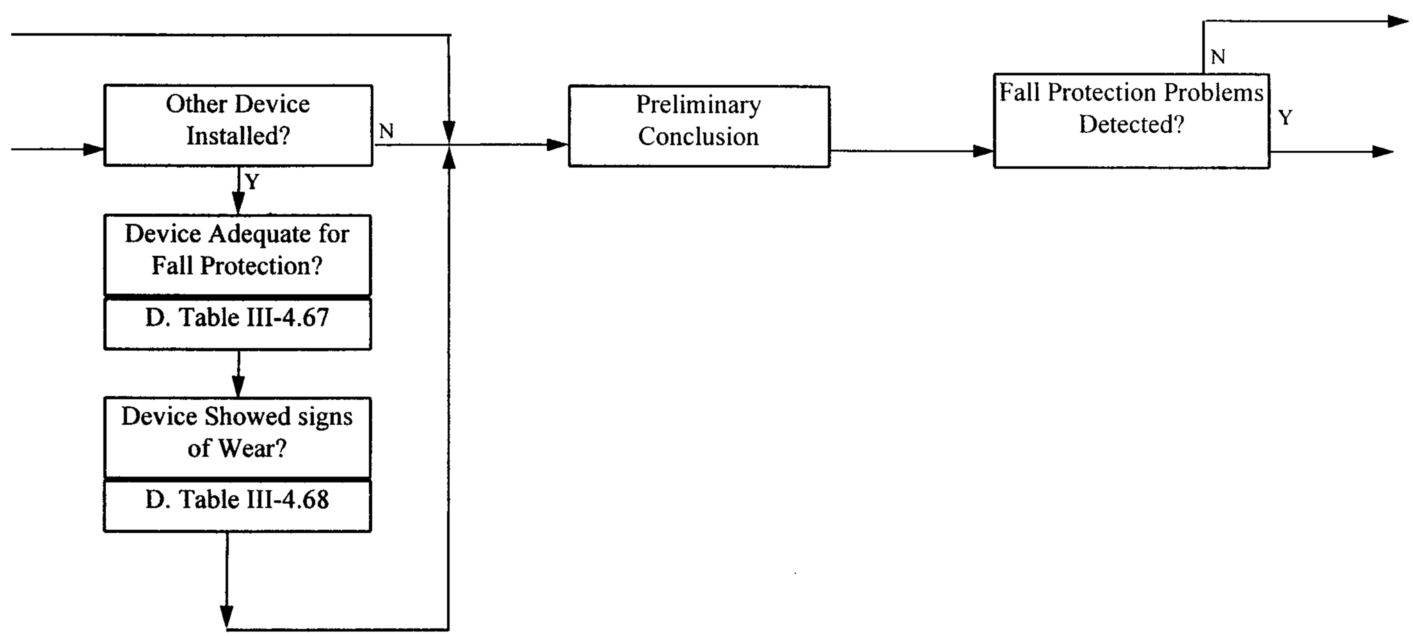

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

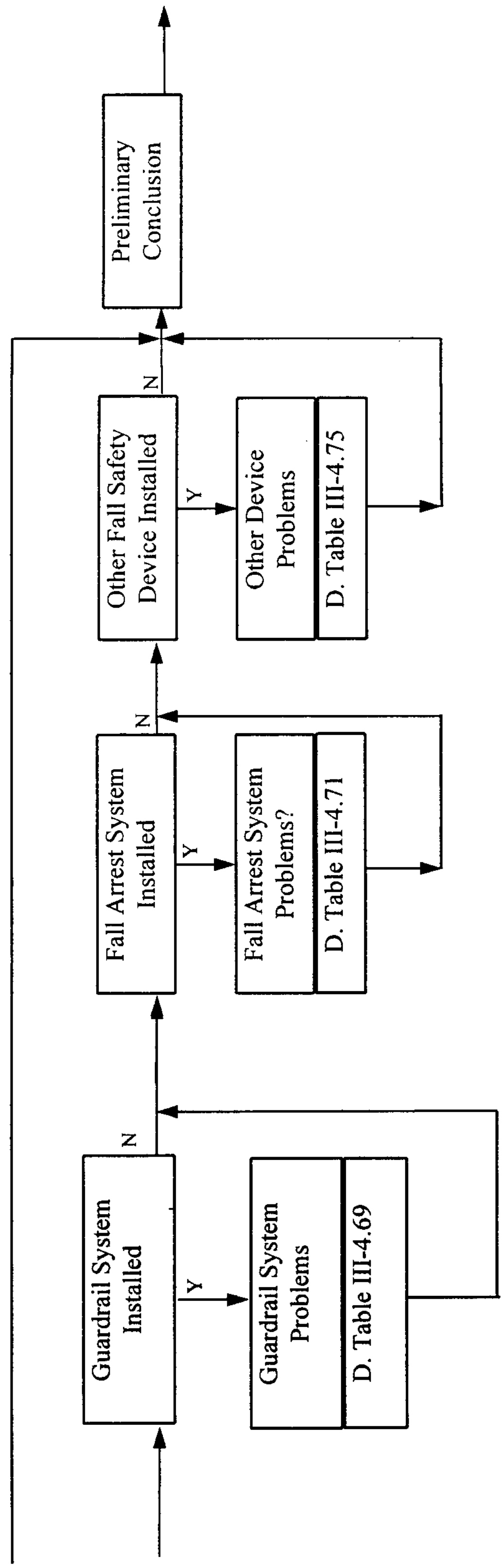

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

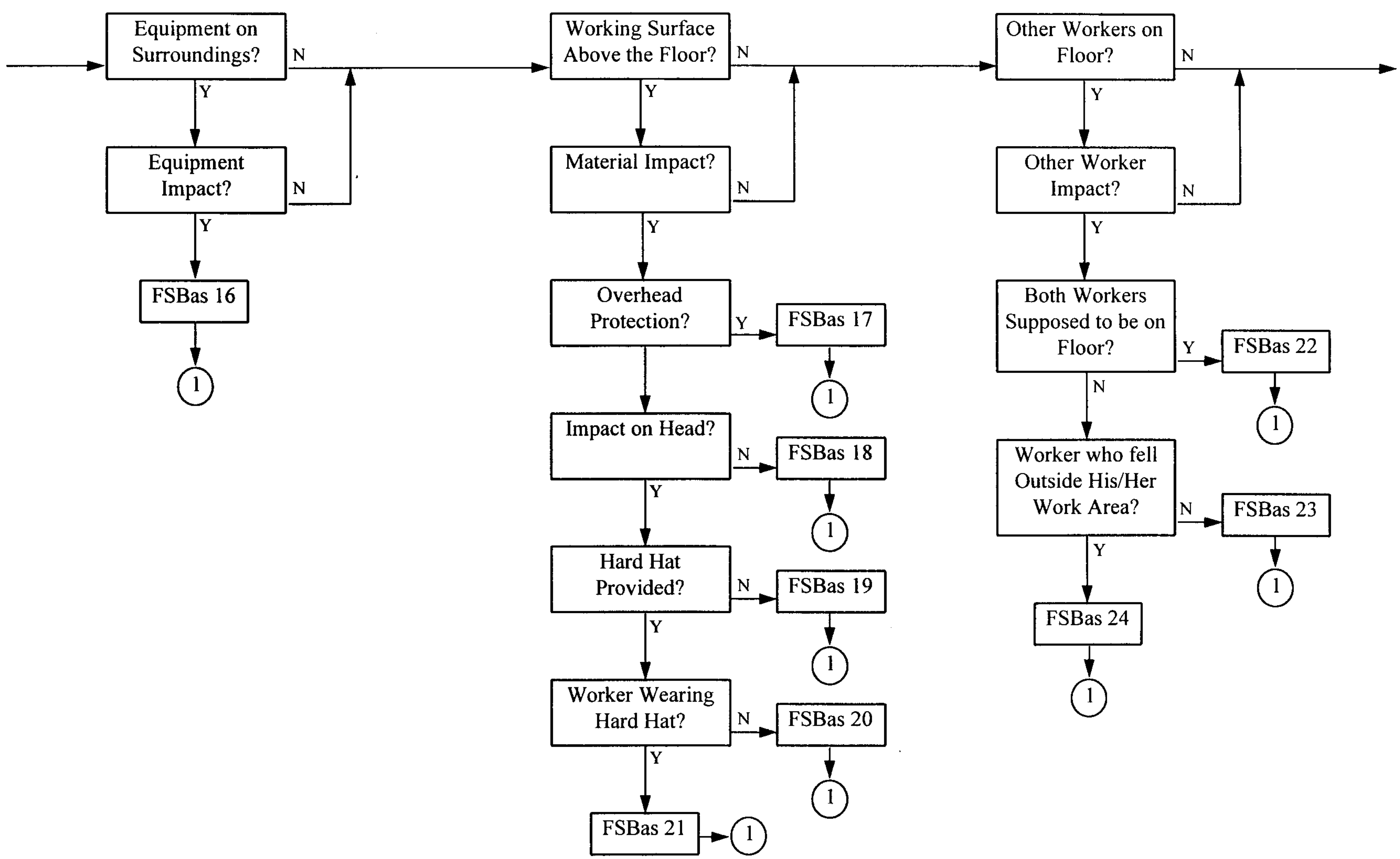

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

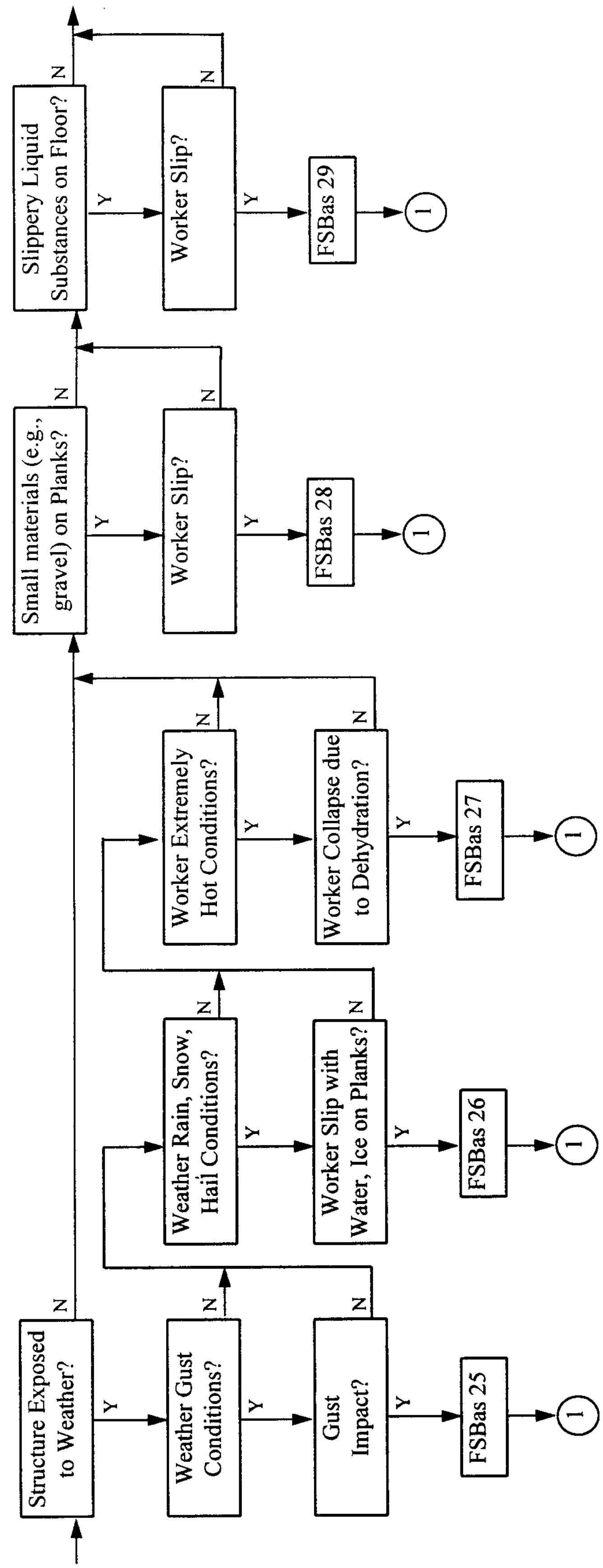

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

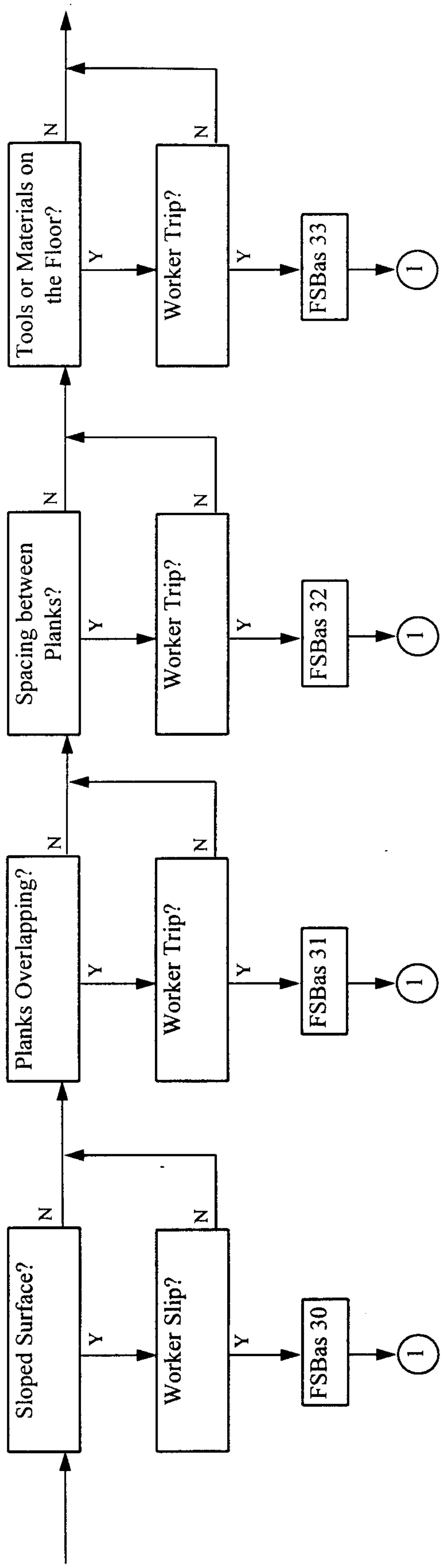

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

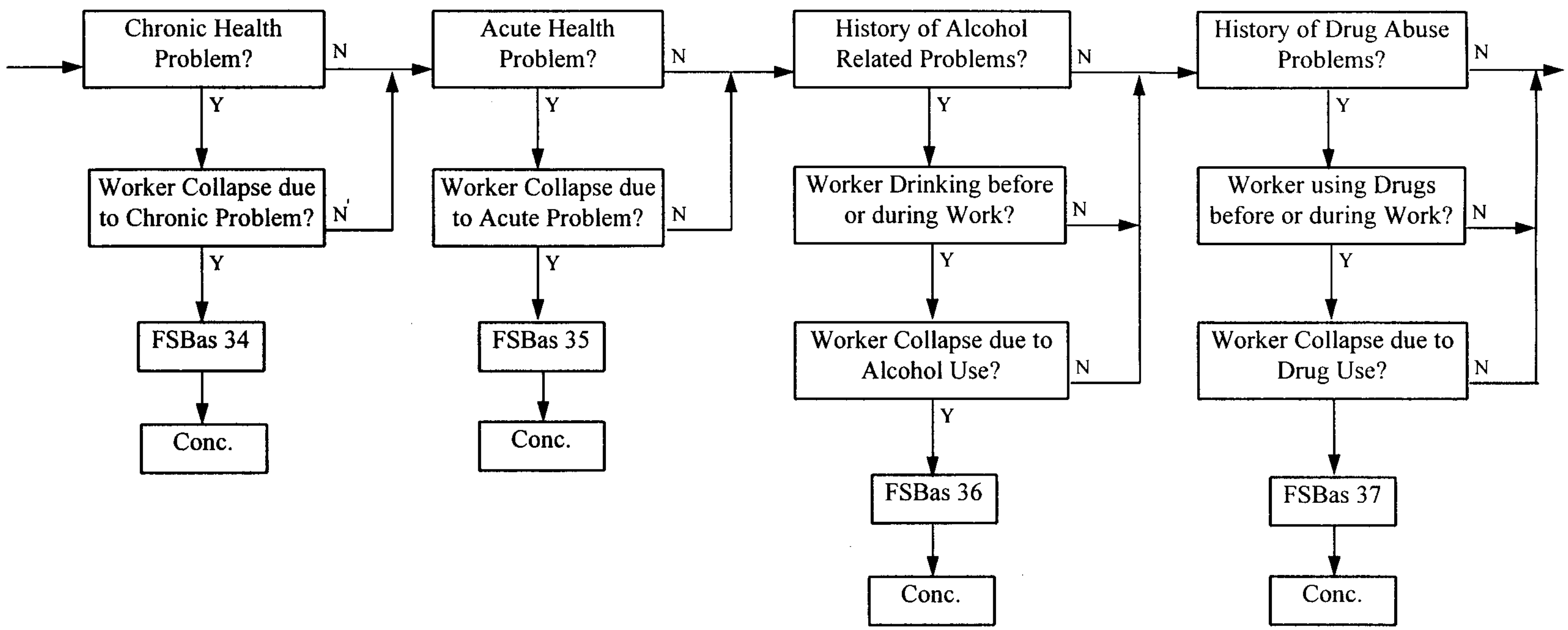

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

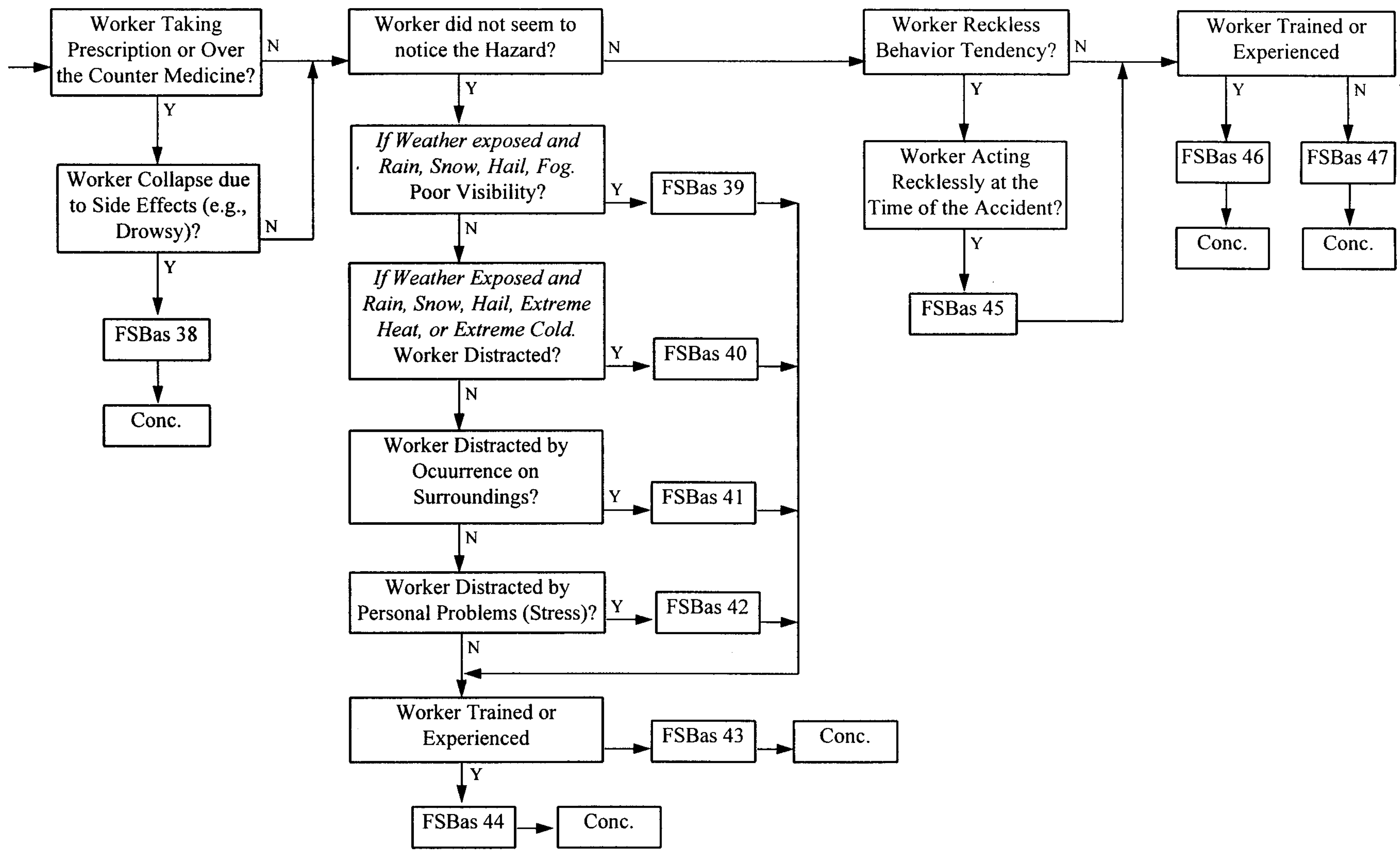

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

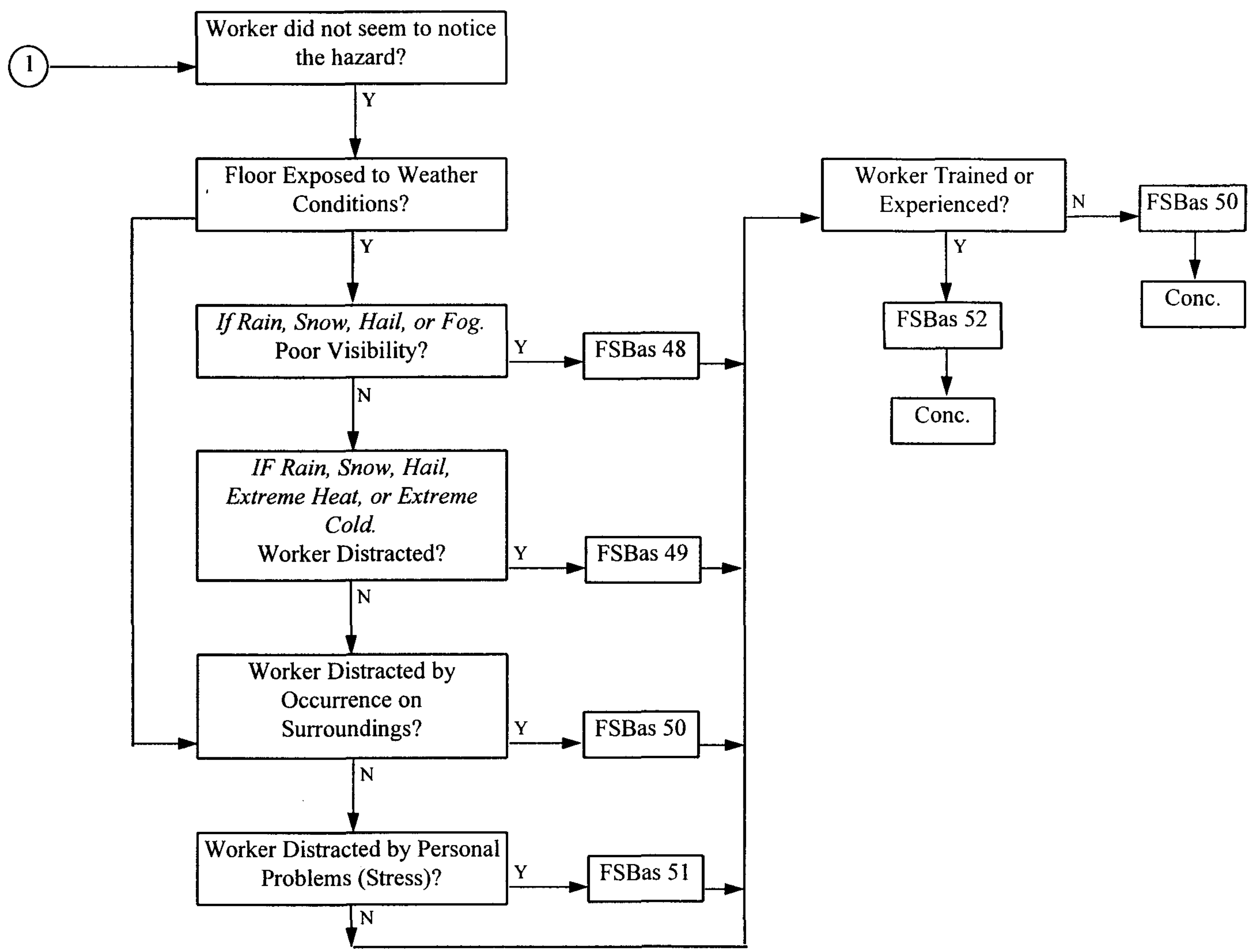

Figure III-D.6 Decision Structure for Worker Fall from a Form Scafolding (Cont'd)

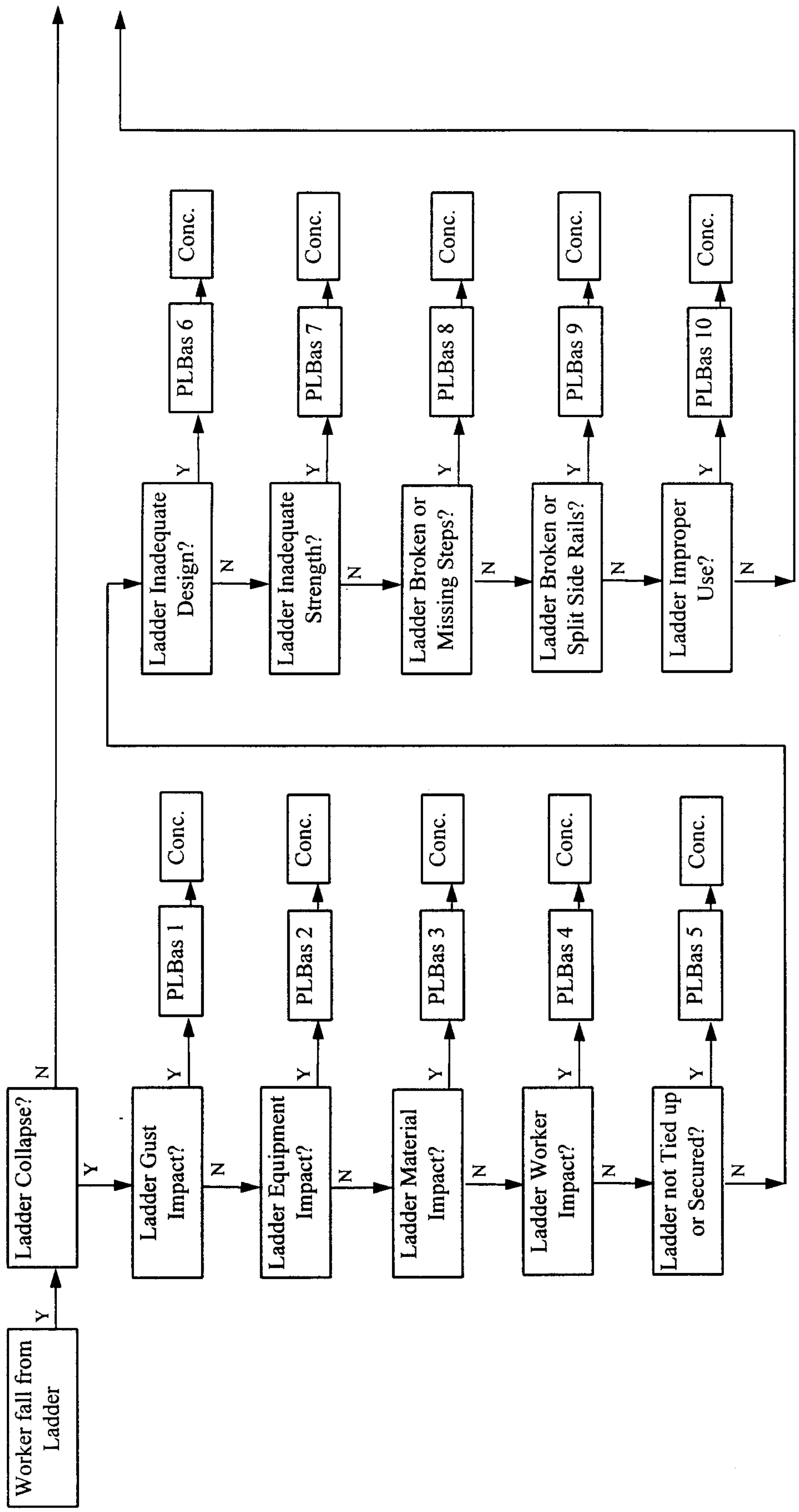

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder

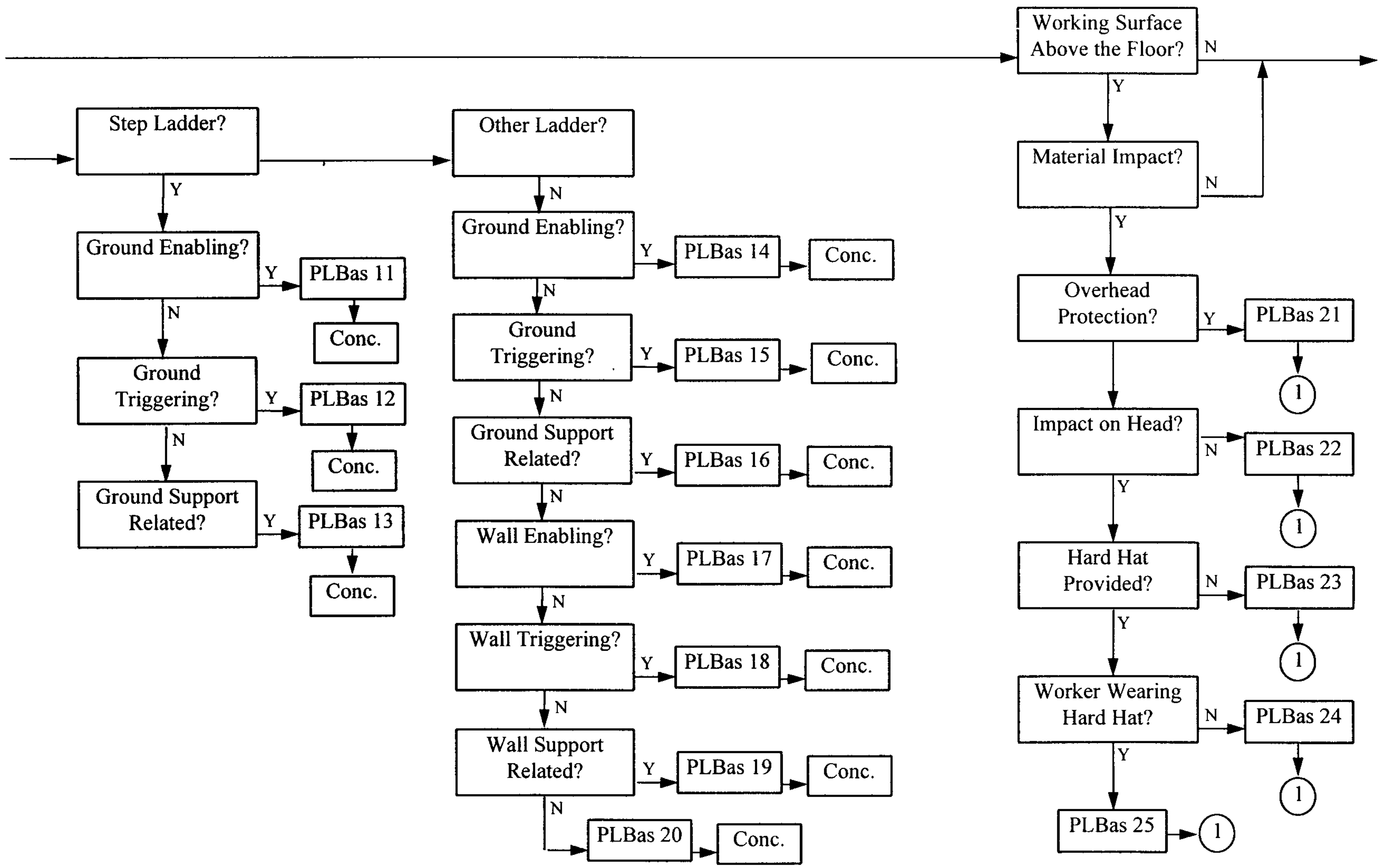

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder (Cont'd)

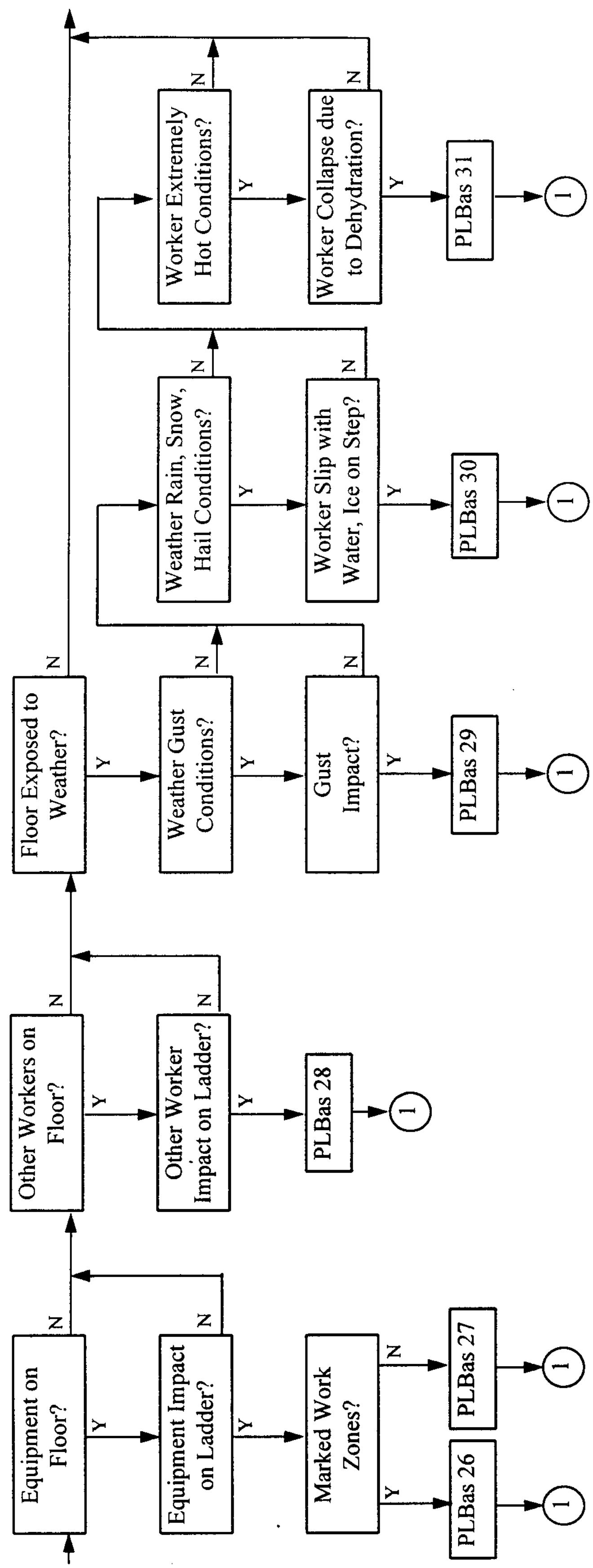

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder (Cont'd)

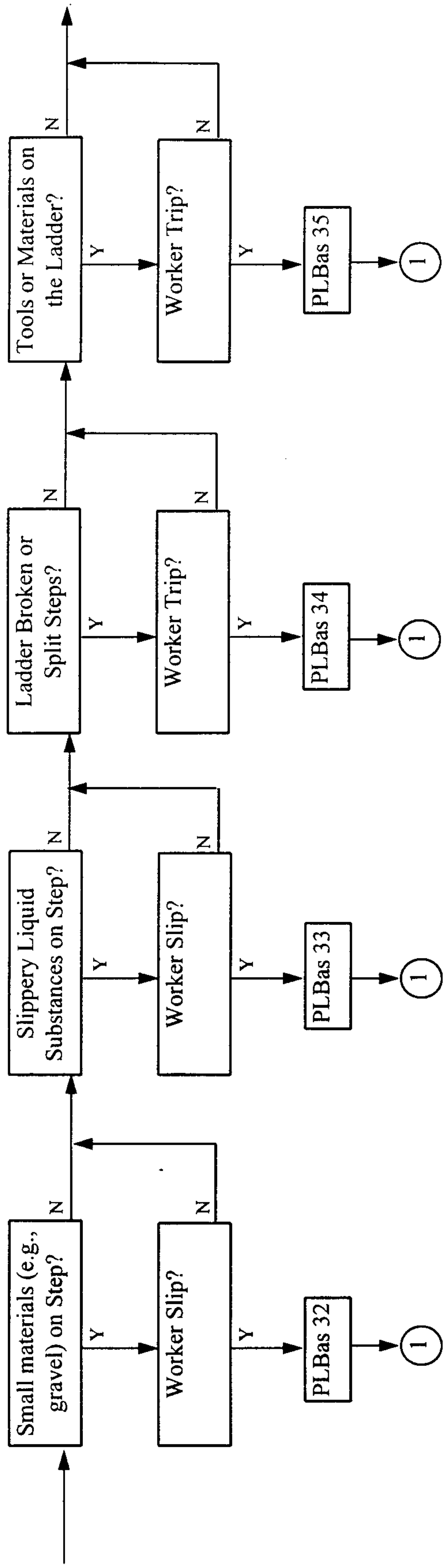

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder (Cont'd)

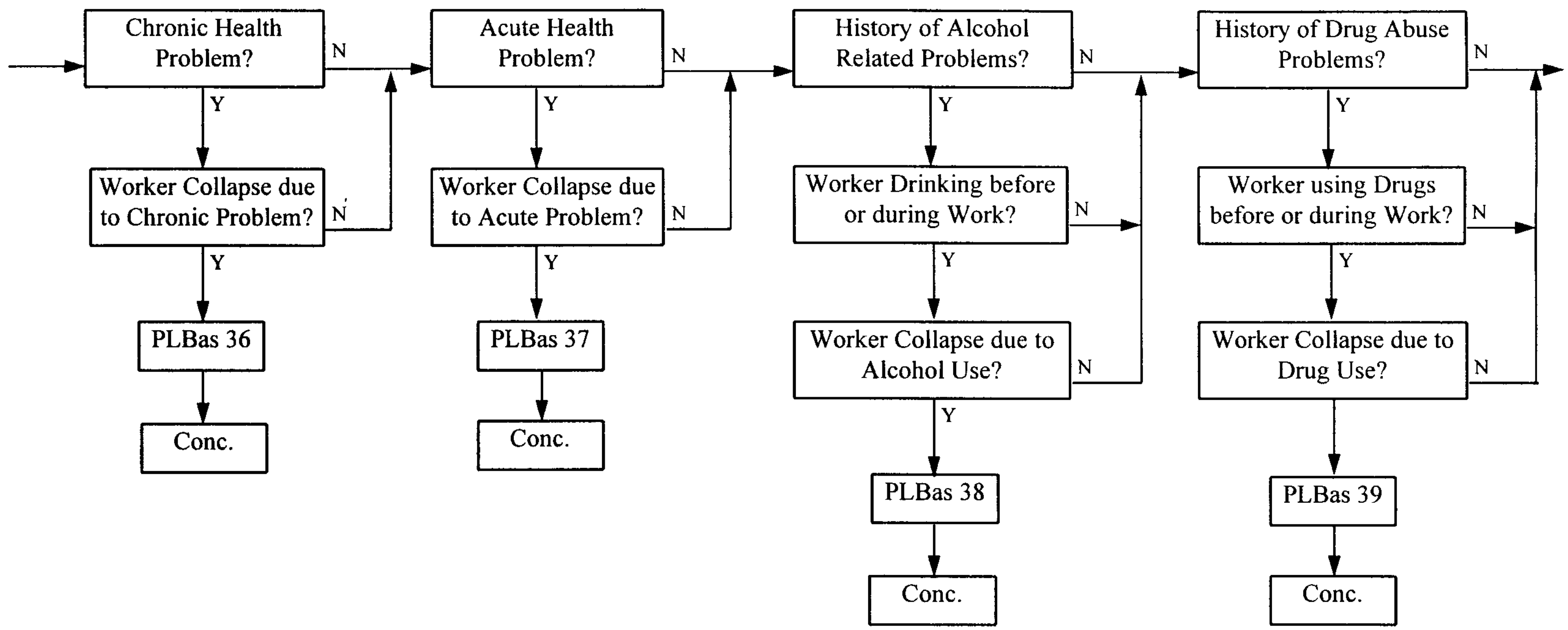

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder (Cont'd)

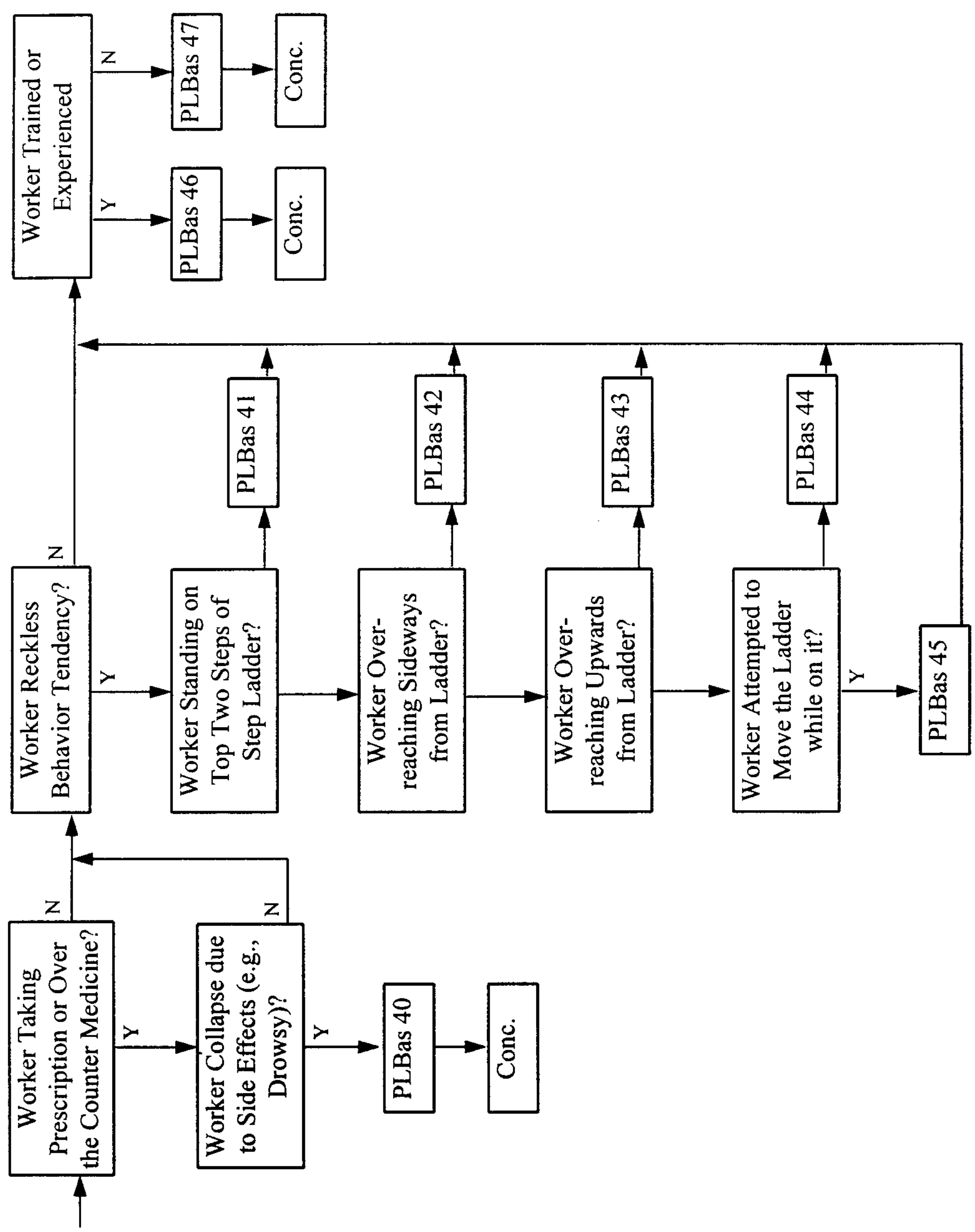

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder (Cont'd)

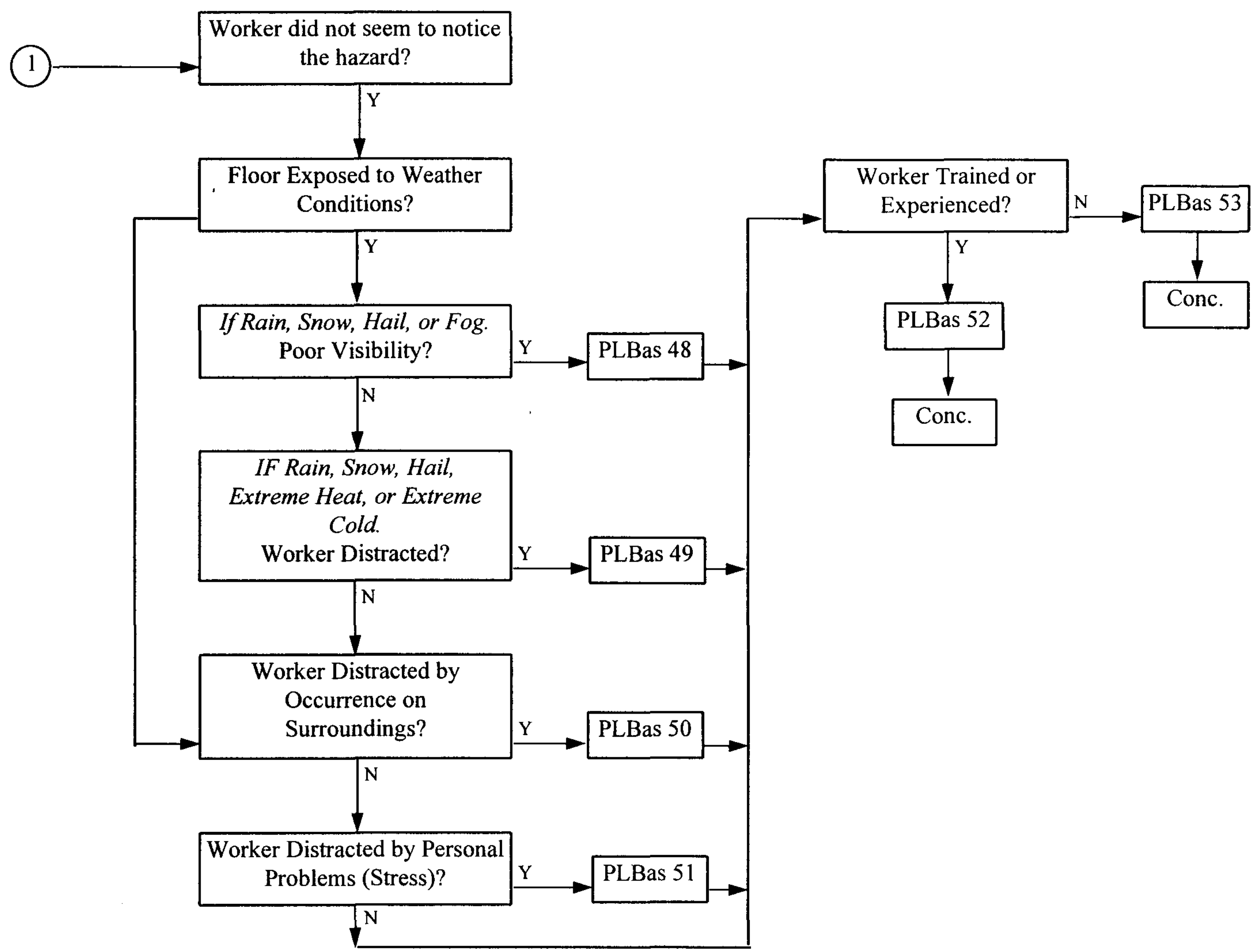

Figure III-D.7 Decision Structure for Worker Fall from a Portable Ladder (Cont'd)

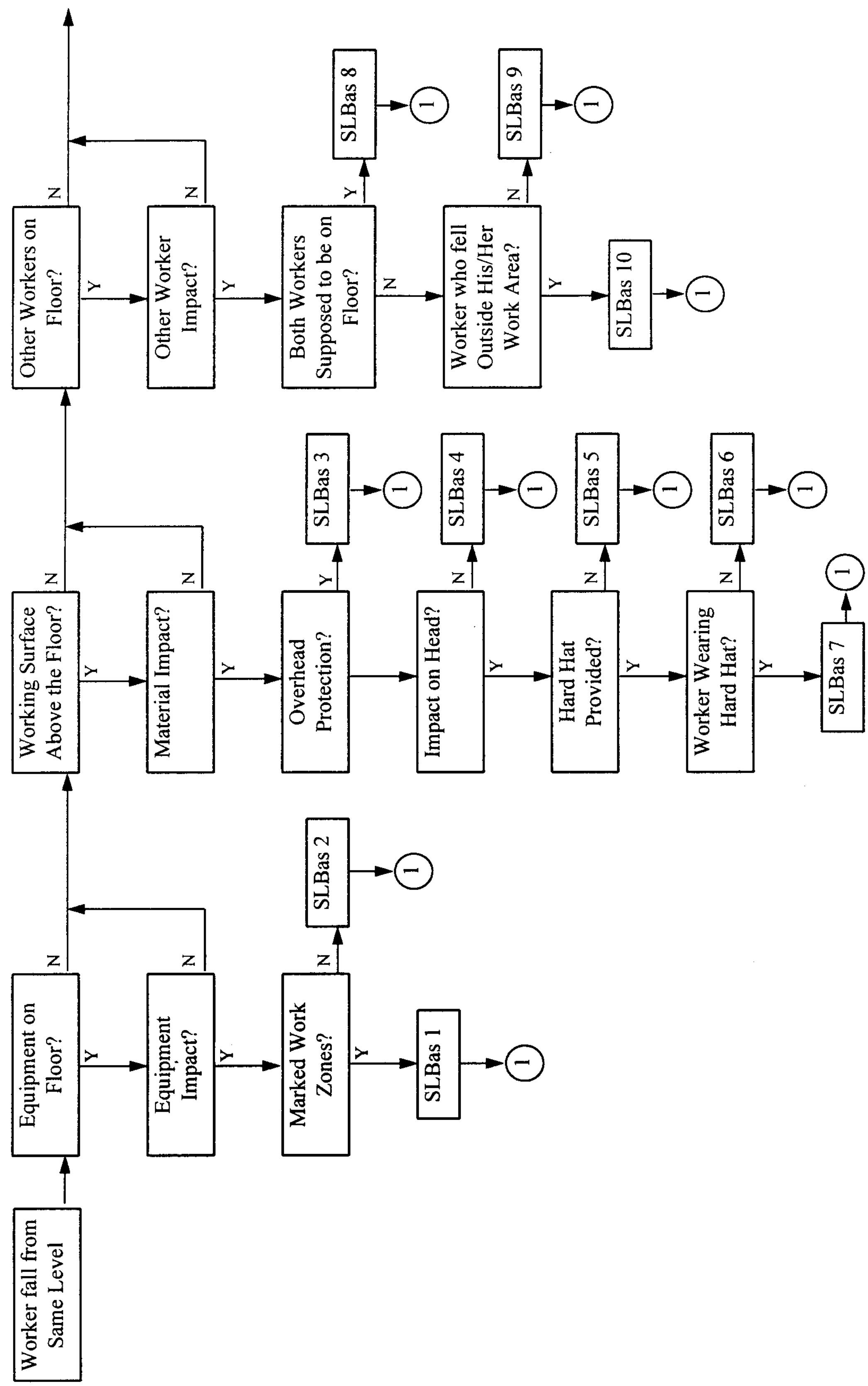

Figure III-D.8 Decision Structure for Worker Fall from Same Level

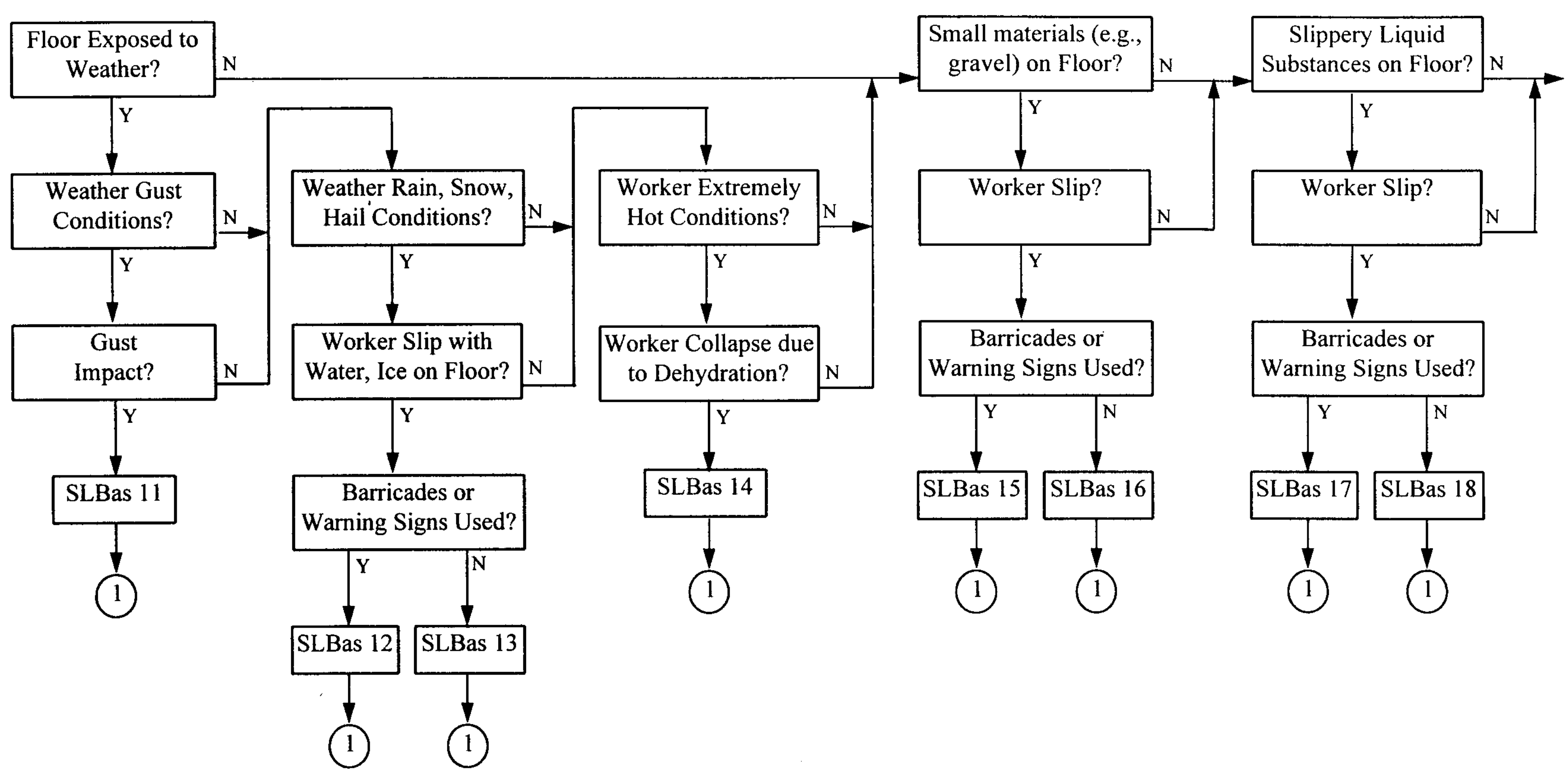

Figure III-D.8 Decision Structure for Worker Fall from Same Level (Cont'd)

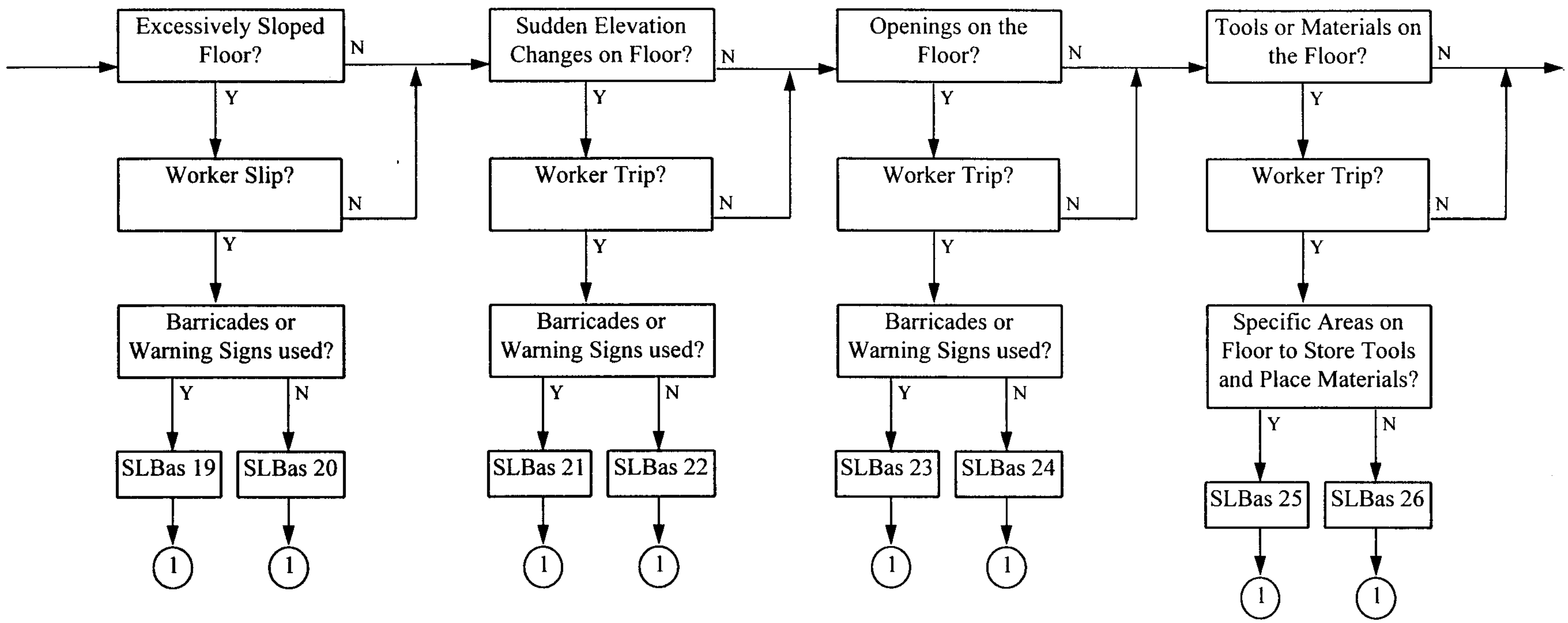

Figure III-D.8 Decision Structure for Worker Fall from Same Level (Cont'd)

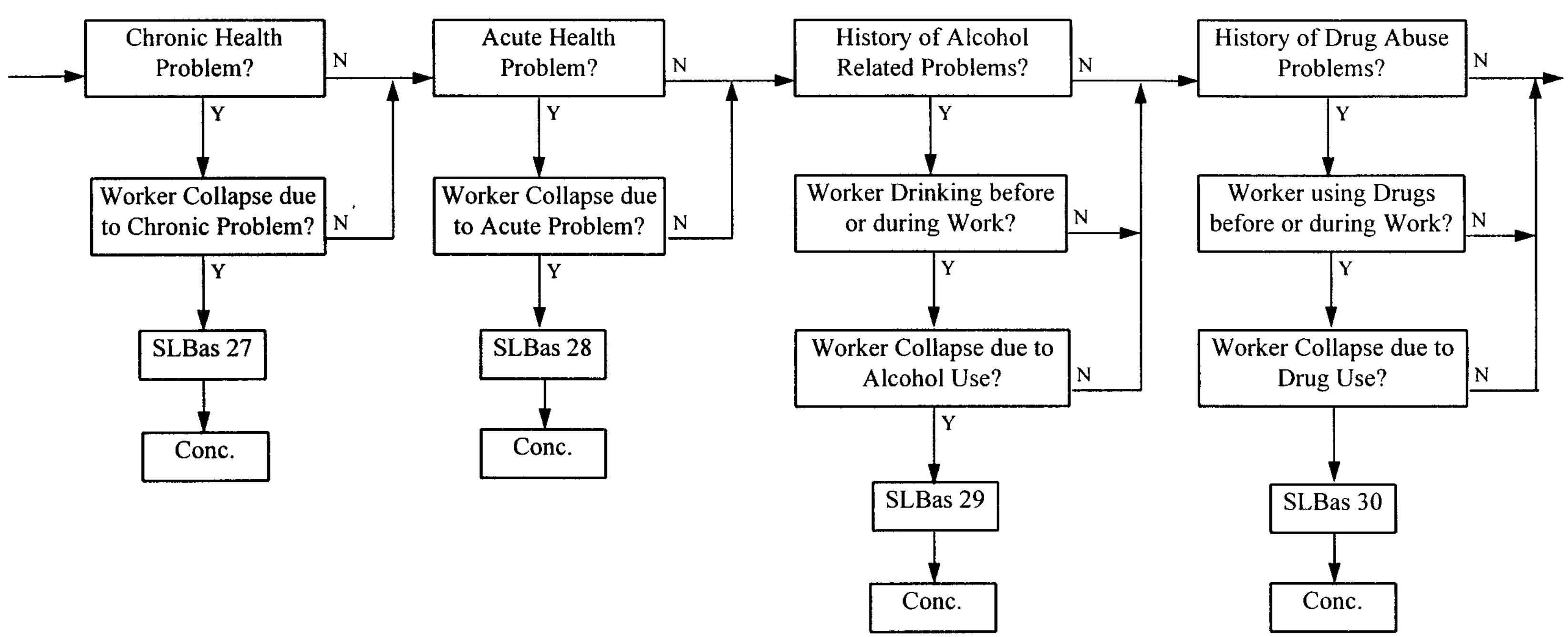

Figure III-D.8 Decision Structure for Worker Fall from Same Level (Cont'd)

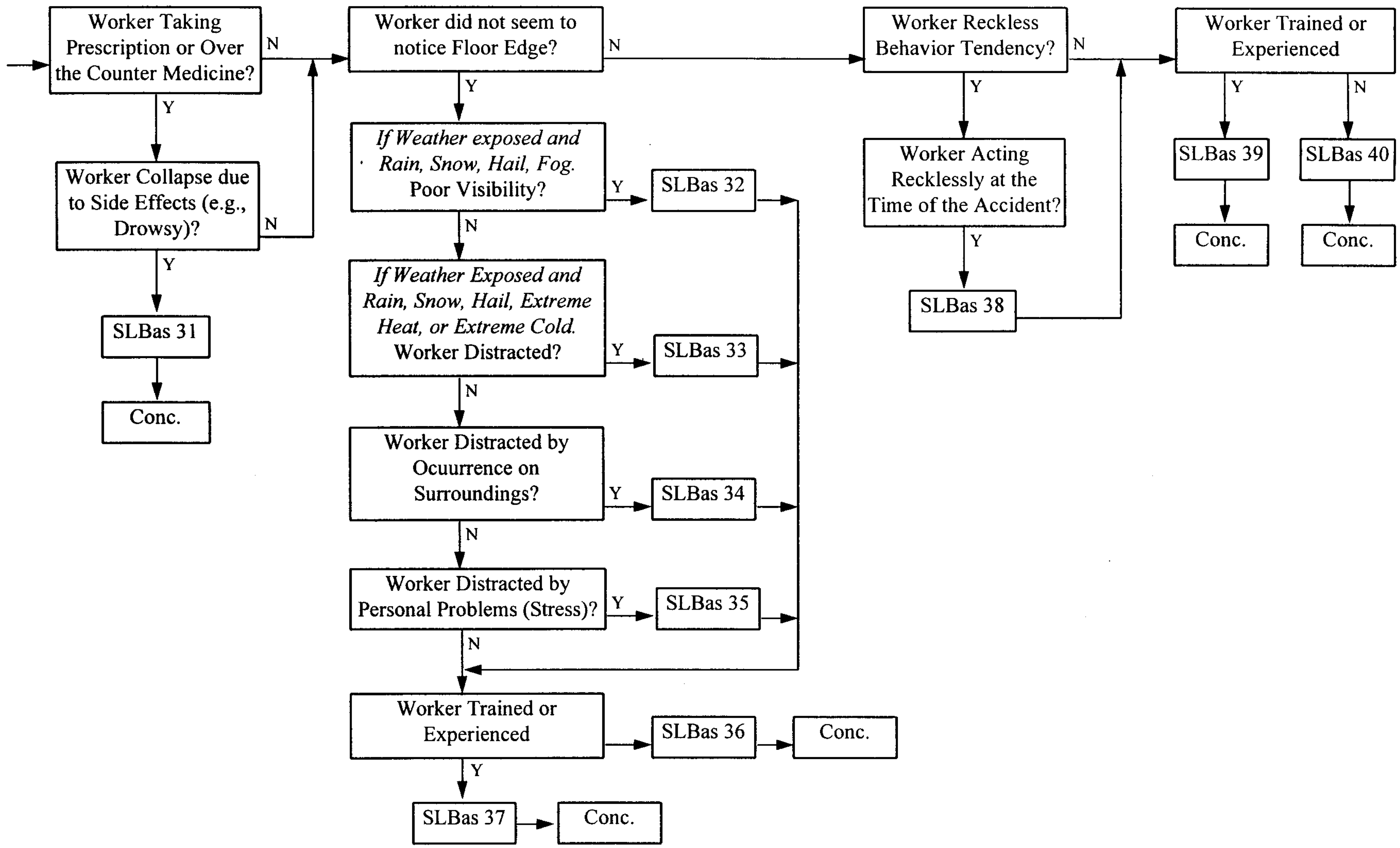

Figure III-D.8 Decision Structure for Worker Fall from Same Level (Cont'd)

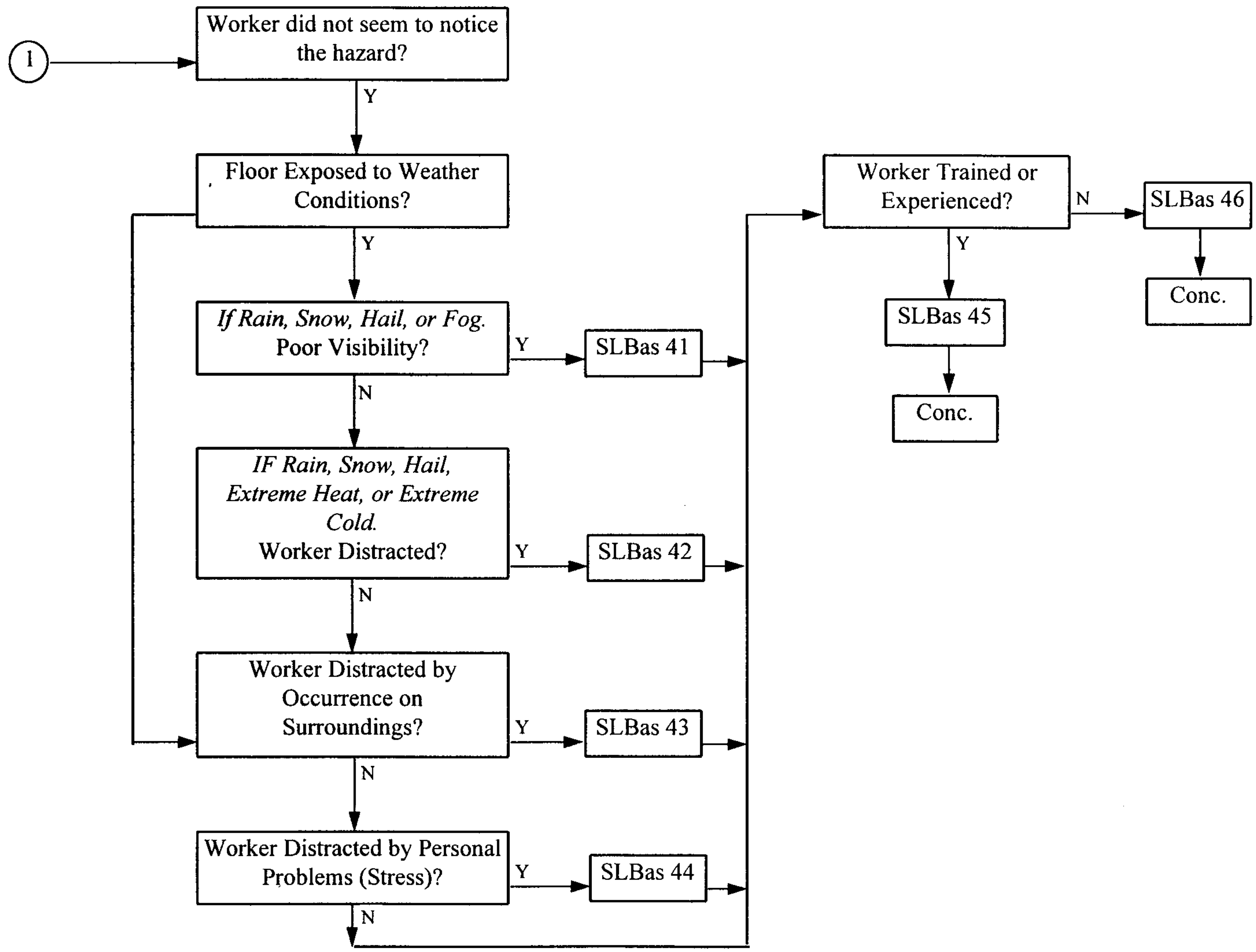

Figure III-D.8 Decision Structure for Worker Fall from Same Level (Cont'd)

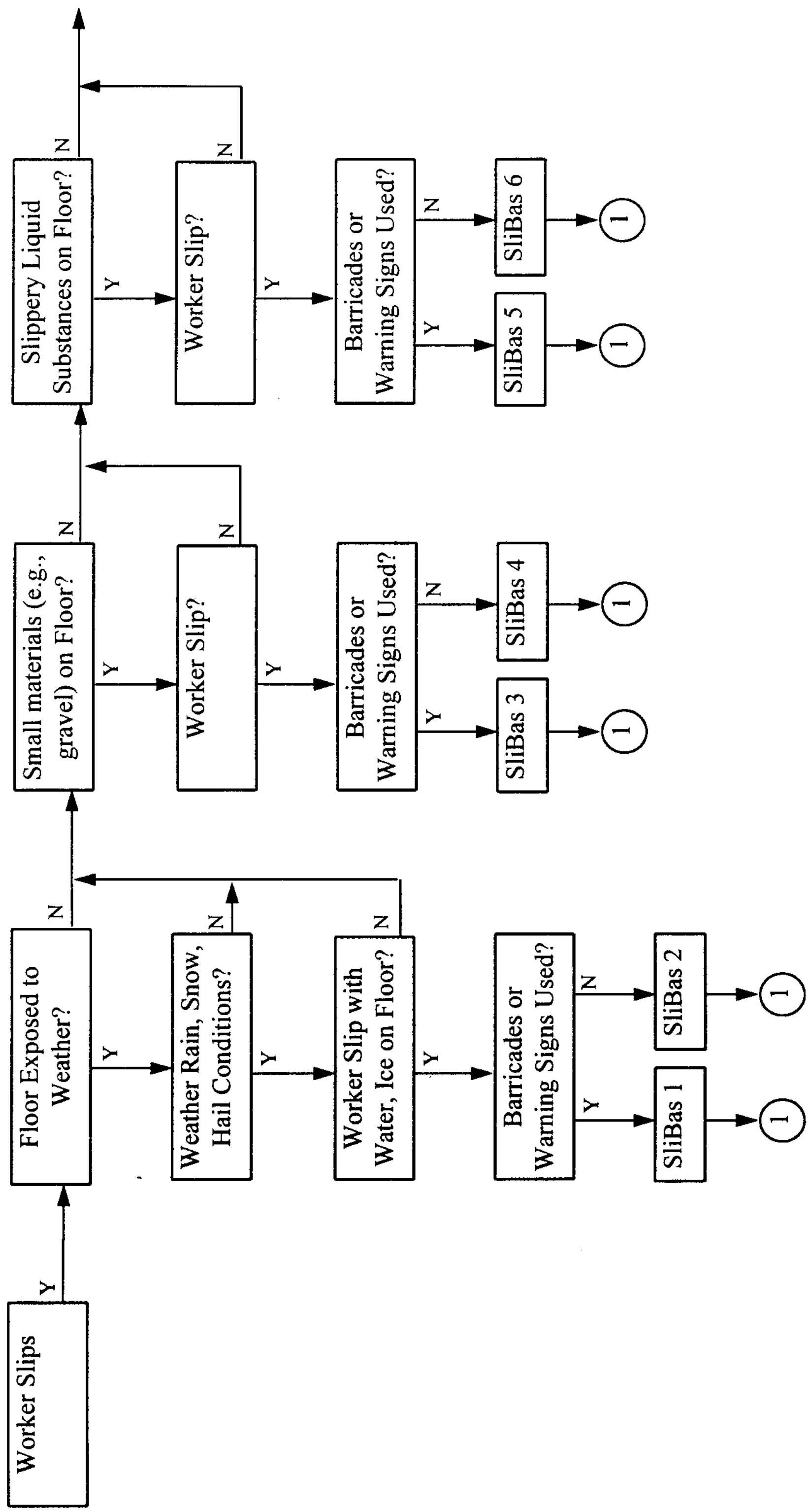

Figure III-D.9 Decision Structure for Worker Slips

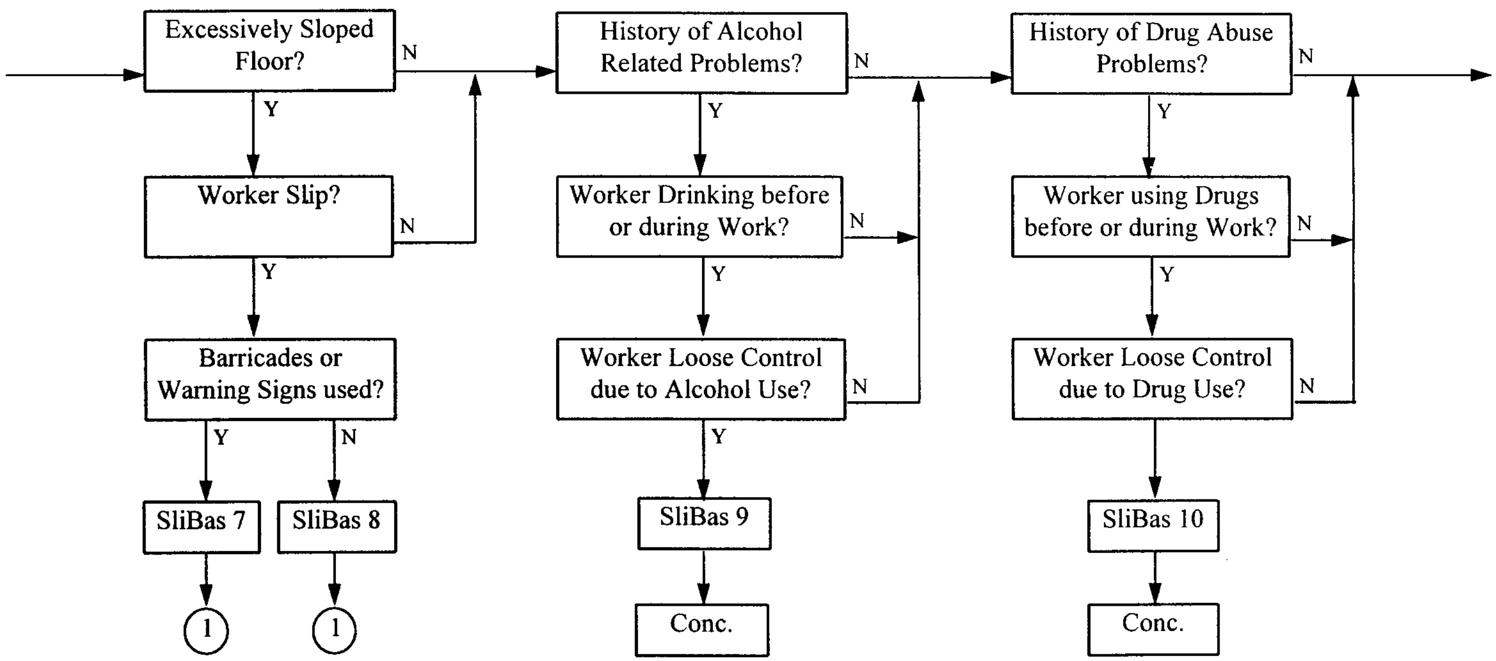

Figure III-D.9 Decision Structure for Worker Slips (Cont'd)

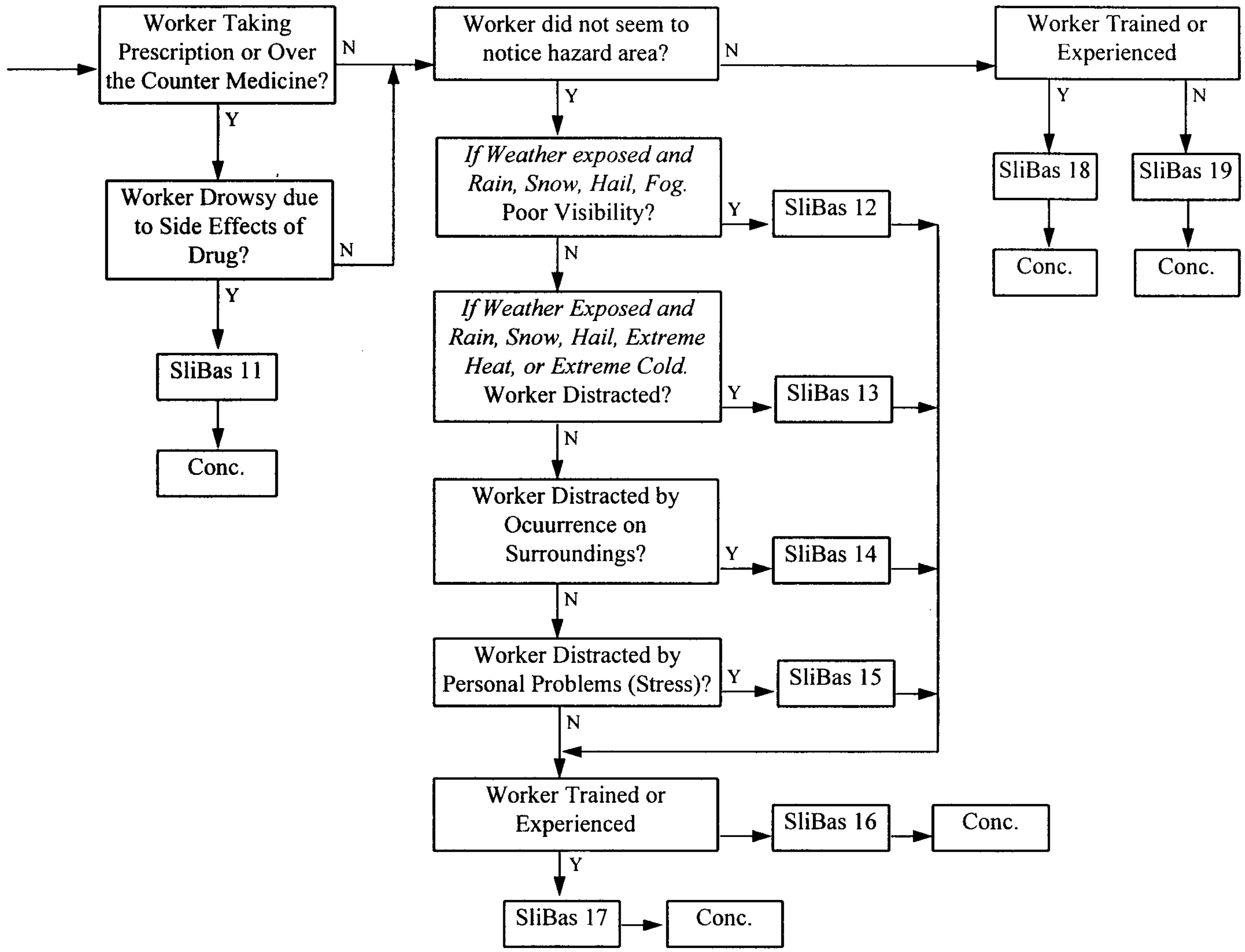

Figure III-D.9 Decision Structure for Worker Slips (Cont'd)

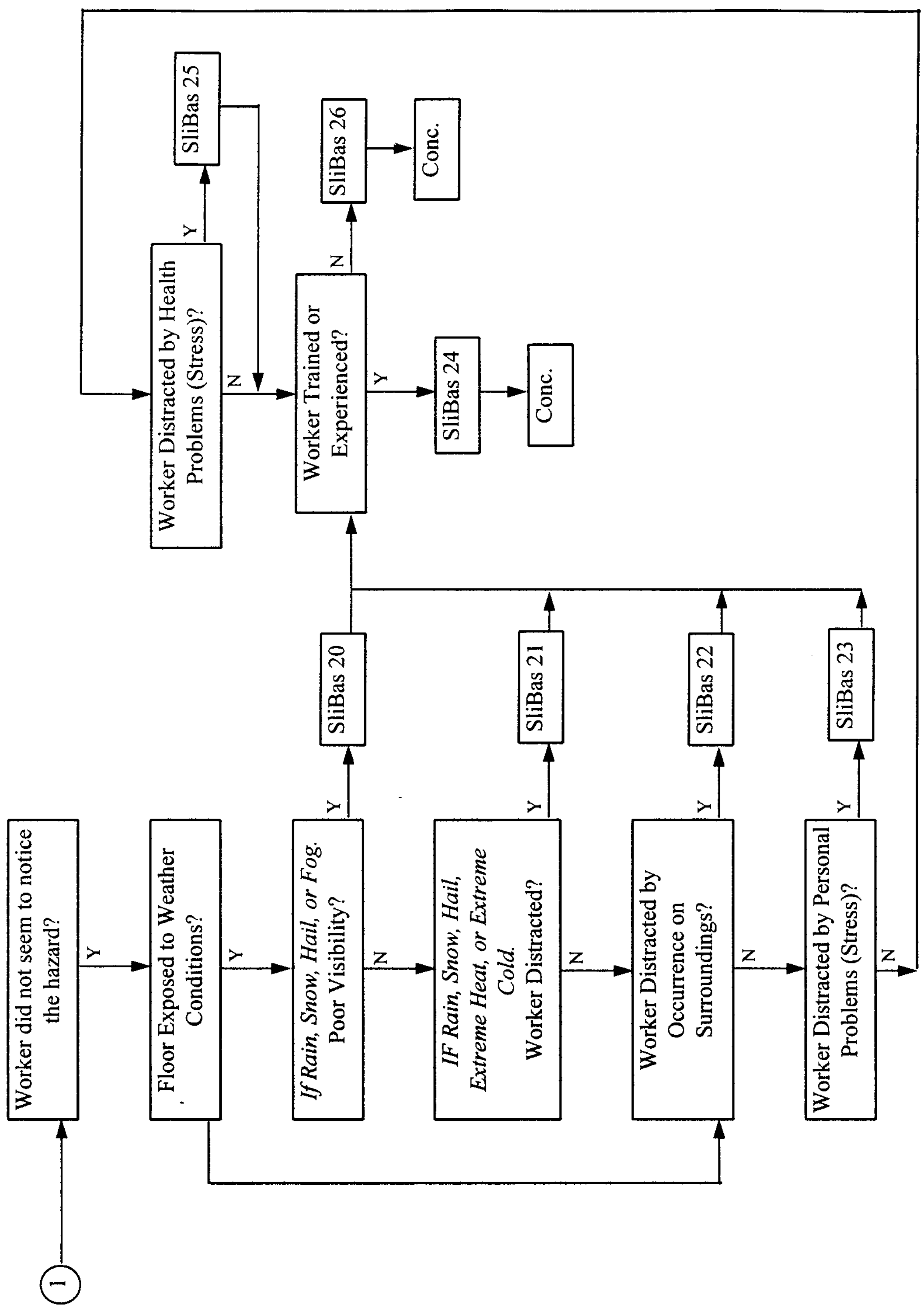

Figure III-D.9 Decision Structure for Worker Slips (Cont'd)

APPENDIX III-E

NAME AND AFFILIATION OF SAFETY FIRST'S EVALUATORS

APPENDIX III-E
NAME AND AFFILIATION OF SAFETY FIRST'S EVALUATORS

Table III-E.1 lists all the non-participating experts and other professionals who agreed to test the SAFETY FIRST program and provided their valuable comments for the development and improvement of the system.

Table III-E.1 Name and affiliation of evaluators

Name	Discipline and Affiliation	Expertise
Mr. Richard L. Burns	Occupational Safety and Health Administration (OSHA)	Safety and Health Specialist
Mrs. Meg Conlon	Builders eXchange (BX)	Safety Programs in BX
Mrs. Stacy McAllister	Builders eXchange (BX)	Safety Programs in BX
Mr. J. Bruce Mounts	Complete Carpentry Inc.	President of Company
Mr. Martin D. Mostin	Turner Construction Co.	Operations and Safety
Mr. Matt Ogle	Stephen J. Ogle & Associates, Inc.	Safety Consultant
Mr. Scott Parker	Edwards Steel Erectors	General Manager
Mr. Terence Siemer	Ohio Bureau of Workers Compensation (OBWC)	Safety Consultant
Mr. Robert W. Tullet	EXXCEL Contract Management	Vice-president of Operations

APPENDIX III-F
LIST OF PUBLICATIONS

APPENDIX III-F

LIST OF PUBLICATIONS

The following publications are related to the topic of this volume. Other publications are listed on their pertinent volumes.

III-F.1 Future Publications

More papers will be published in the future; however, the following are those that can be anticipated to be published immediately:

Larew R.E., Hadipriono F.C., Barsoum A.S., Soedarmono D., and Vargas C.A., "A Vision: International Collaboration for the Prevention of Construction Accidents," abstract submitted for presentation in the *International Conference on Implementation of Safety and Health on Construction Sites*, Lisbon, Portugal, September, 1996.

Vargas C.A. and Hadipriono F.C. "Knowledge Base Development for the SAFETY FIRST Expert System," a paper to be submitted to the *ASCE Journal of Performance of Constructed Facilities*.