WARNINGS

VOLUME I

FUNDAMENTALS, DESIGN, AND EVALUATION METHODOLOGIES

FIRST EDITION

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PREFACE

This volume is the first from a series that focuses on warning labels and other product- and situation-related characteristics that serve or are intended to serve warning purposes. The development of these volumes was inspired by the increased importance of warning-related issues to both human factors and product design engineering, not to mention the limited degree to which these issues have been formally addressed within any discipline. This lack of formal structuring has, during recent warnings litigation, resulted in a large number of unsupported allegations by those who claim expertise in the area. As a consequence, judicial decisions are often based on only a "common sense" rationale which has resulted in some alarmingly inconsistent decisions. Subsequently, the warning precedence is currently being established by both the engineering and legal professions with little underlying scientific foundation. In their defense, resource material, as provided here, that reveals the true level of complexity involved in the warnings issues, has not previously been available. We who think we do have some higher level of expertise have been slow in making available those theories, methodologies and structures which can support more scientifically justifiable positions. The authors hope that this series will partially fill this void, allowing a more rational perspective on the warning issues to emerge.

The second volume in this series, (Warnings: Volume II - An Annotated Bibliography) by Miller and Lehto, concisely summarizes some 400 references that are directly relevant to many different warning issues. The references were obtained from international sources over the past three years. The citations vary in length from 100 to 500 words, depending upon their complexity and relevance to important warning-related issues. These references obviously represent a part of the research upon which the current volume is based. Accordingly, many of these same references are cited in this first volume.

The third volume in this series, (Warnings: Volume III - Formalized Design Standards and Design Methods For Compliance) will be available by mid 1988. Mr. David Clark joins us in the authorship of Volume III. Topics in that volume will include discussions and summaries of Federal government promulgated warnings requirements, including the required characteristics of warning and labelling standards, the specific products or types of products covered, requirements unique to particular agencies,; identification of which products are required to have warnings; and the specific warnings designs that must be provided for those products. It is also planned for Volume III to include an illustrative intelligent expert graphics system for assisting in the design/layout of warning labels for specific types of products or applications Finally, the topic of creating operator and instructions manuals will be addressed in relation to how warnings should be incorporated.

The current volume addresses what these authors have arbitrarily called the "warnings issue" to suggest a broad concern. An initial appreciation for the breadth of this global problem can be gained by considering the following types of questions, which make up only a part of what is at issue:

How should the hazards associated with particular products and tasks be isolated and analyzed?

Which characteristics of the product, user, and environment influence the potential hazards found within particular products and tasks?

Does the analysis of a given task suggest that these potential hazards justify further design consideration?

Are there circumstances which suggest that some type of a "warning" be included in that additional design consideration?

What types of warnings are feasible alternatives under these particular circumstances, and how should they be described?

For each feasible type of warning, which specific design configurations are candidates for this application?

How can one apply existing knowledge about human behavior or perform research to determine the likelihood that a particular warning design will be effective in achieving its purpose?

The addressing of such questions required a significant synthesis of many different approaches used in human factors and safety engineering, along with the development of several new methodologies. These methodologies served to structure some general human factors problems, thereby providing the scientific foundation needed during the evaluation of either the general effectiveness of warnings or the desirability of specific designs. The approach we took is conceptually simple, as it consists of decomposing the global "warnings issue" into smaller, more well-defined, problems. Solutions to these smaller, well-defined, problems can then potentially be developed by applying existing knowledge or by performing a reasonable amount of research. To describe and organize these subproblems, we have, of course, drawn from some of the established areas of psychology including communications theory, sensory psychology, behavioral psychology, and human information processing. Ideas from the newer areas of artificial intelligence and knowledge engineering have also been utilized when structuring these problems, with our ultimate goal being the implementation of the approaches within one or several different computerized expert systems.

The book itself is intended to be of interest to a varied group of professionals. As such, its considerable breadth, varying levels of complexity, and wide span between theory and application will cause the value of specific sections to depend on the particular interests of the professional using it.

The contents will generally assist lawyers and their engineering experts in: formulating opinions as to whether or not warnings should be or were provided on a product; evaluating how the warnings, if necessary, should have been designed; determining the extent to which such warnings, if present, might foreseeably have been effective in modifying the behavior of a particular accident victim; and in establishing the likelihood that such a change of behavior would have prevented a particular accident or would have changed the amount of damages or injury.

The plaintiff lawyer may discover from the contents that he and his "expert" have overlooked some of the relevant human engineering aspects of "failure to warn" theories. Such oversight will not be easy to overcome against a competent defense expert's analysis.

The defense lawyer will find useful material for determining if one has selected a knowledgeable warnings expert to examine the merit of the plaintiff's allegations and to develop countering defenses. The contents can also assist in the preparation of questions to be asked in interrogatories and during testimony, to determine if the plaintiff's expert has considered all the facets of product warnings before arriving at opinions which condemn a particular product or its warnings.

The product designer can use the contents to provide a structured way of making rational decisions about the application of warnings to products. The described approach emphasizes practical criteria that are directly concerned with effectiveness, instead of emphasizing the threat of negligence for failing to warn.

The book also emphasizes to the designer the necessity of conducting research to determine those situations in which warnings are likely to be effective in reminding consumers of desirable or undesirable behavior. These approaches are intended to help the designer make design-related decisions that can be strongly justified.

The safety ergonomics and human factors professionals claiming expertise in warnings will find much of the included contents mandatory. Additionally, the background and advanced methodologies provide a deeper and more organized approach to several other general human factors and safety applications than has previously been available.

The members of governmental or consensus standard-making organizations will find data and methods for justifying various warning-related provisions within standards. There has been a minimum amount of useful research applicable to either the promulgation of standards or to the determination of the relative "goodness" of detailed provisions within them. Although many organizations have been able to rely on people with vast experience to provide expert consultation and consensus, the issues are becoming more technical both because of the increased application of standards in widely divergent consumer settings and because of the critical attention which standards have received during litigation. As a consequence, the requirements for justifying standards are continually leaning away from consensus opinions and towards a more research- and science-based rationale.

The theorist, human behavior researcher, and academician will discover, herein, several innovative knowledge-based and knowledge-engineered structures which decompose the complex warnings problem into definable subproblems. The general models provide a source from which to draw future modeling efforts, academic discussions, and a family of safety ergonomics research topics. As a consequence, the contents have applications which extend far beyond the warnings focus which was the catalyst for their development.

This volume was not designed as a single textbook for undergraduate courses in either psychology or engineering programs. However, it will serve well as a source of references, research topics, or selected readings. The discipline areas include primarily: cognitive psychology, human information processing, safety ergonomics, human factors, knowledge engineering and product design. The authors are currently using portions of both Volume I and Volume II in their respective teaching of graduate level courses at Purdue University and the University of Michigan.

The title may appear to suggest the contents to be more specialized than they are. Certain chapters have reviews and applications of human cognition topics. [Chapter 2: "modeling techniques;" Chapter 4: "eliciting attention;" Chapter 5: "eliciting comprehension;" Chapter 6: "memory, decisions, and responses;" Chapter 9: "conspicuity related design criteria;" and Chapter 10: "flow of information and critical information transfers"].

Parts of other chapters provide an introduction to methodologies which may prove to be useful in other applied areas of safety ergonomics. [Chapter 7: "taxonomical classification systems;" and Chapter 8: "methods of risk assessment"].

Section IV (Advanced Topics) is intended to challenge the more sophisticated safety ergonomics and computer science researcher with the introduction of "knowledge based approaches to human performance." The researcher will find the book to be innovative in its application of production systems; network models of human performance and safety related activity; and a general warning tree model. The latter comes close to being an overall model for relating many of the more important safety aspects to human performance.

As suggested above, some of the presented methodologies have already been incorporated by the authors within operating expert systems. We have chosen not to include those efforts as a part of this volume to avoid overshadowing our presentation of the underlying new theories, evaluation methodologies, and example applications which should advance the state of the art.

We sincerely hope that we have adequately responded to this challenge of being the first to bring together such a diversity of information and approaches regarding such a controversial topic. Many questions have been answered, but it seems clear that the number of relevant research topics and issues will continue to expand. With these points in mind, we heartily welcome dialogue with those who desire to share with us their viewpoints and suggestions.

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SECTION I.

WARNINGS: THEIR COMPLEXITY AND RELATIONSHIP TO INFORMATION PROCESSING

This section consists of Chapter 1: Important Issues Related to Warnings; and Chapter 2: Definitions and Modeling Techniques. Together, they indicate the complexity of the warning issue and explore its relationship to human information processing. Chapter 1, after introducing the "warning issue," provides an overview of the book's contents. Chapter 2 begins with some needed definitions and then reviews traditional modeling techniques based on communication theory and human information processing theory. The Chapter 2 discussion of modeling techniques provides an organized description of the warning issue which guides the analysis in the remainder of the book. It is in these later sections that the theories and methodologies dealing with effectiveness, adequacy, design, and application of warnings are evolved.

CHAPTER 1

IMPORTANT ISSUES RELATED TO WARNINGS

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IMPORTANT ISSUES RELATED TO WARNINGS

It may be difficult, impossible, or undesirable to design products that function independently of a human user. As a consequence, the safe and effective use of many products is predominately determined by the decisions and actions people make. In most cases, the decisions and actions made during the use of a product are appropriate and result in safe use, but sometimes mistakes are made that lead to accidents. To help prevent the types of behavior that lead to accidents, people are often provided detailed information along with the product. Such information can specify the intended functions of the product, recommend operating and maintenance procedures, or denote product hazards.

Recently, much attention has been focused on warning labels, often without realizing that there are many other forms of safety information. Warning labels on many newly developed products list the hazards associated with the use of a product, the results or consequences of ignoring the warning, and the countermeasures to the hazard. There are those who justify the presence of such labels, on the basis of "common sense" and the premise that people will heed such information when it is given so explicitly. Accordingly, explicit warning labels are commonly perceived as one desirable method for conveying safety information (Philo, 1983; Peters, 1984; Kolb and Ross, 1981).

THE SHORTCOMINGS OF COMMON SENSE

On the basis of this "common sense," the potential benefits of placing warning labels on products have been treated as intuitively obvious. However, little rigorous analysis of warning labels has been performed that either considers the complexity of human behavior or takes advantage of the existing behavioral research. Consequently, much uncertainty exists in regard to issues such as: defining the term "warning," determining the effectiveness of warnings, deciding when to apply warnings. and determining how to design a warning. These overall areas of confusion are hereafter collectively referred to as the "warning issue;" the resolution of which will require the application of approaches much more sophisticated than common sense alone.

The complexity of the warning issue arises from the combinatorial explosion of possible users, products, environments, and their interactions. Each combination influences or is associated with the human's processing of information, upon which the ultimate consequences of a warning depend. In other words, for a particular product, the information processing activity of each potential user, within each environment and task phase may differ in ways that depend upon that particular combination of task, user, product, and environmental factors. Given the widely based failure to perceive the complexity of the warning issue, it is not surprising that the term "warning" is frequently confused with other terms used for describing different ways of transferring safety information to product users, namely: "educating," "persuading," and "informing."

Since the warning issue is so poorly understood that even the basic term "warning" is imprecisely used, it is obvious that there will also be confusion regarding the more complex topics such as "warning effectiveness," "warning adequacy," "warning design," and "warning application." Isolated areas of existing behavioral research address topics related to these issues, but the overall "warning issue" has not received attention from professionals in the areas of safety science, human factors engineering, or psychology. In particular, no researchers have ever attempted to synthesize the existing base of research and knowledge which can be related to warnings in a scientific way. In contrast, the area has been subject to significant legal attention in advance of any scientific foundations upon which to justify such attention.

CONTEMPORARY FACTIONS

The issue that the current book is about, warnings and labeling, is in the center of a societal struggle over product liability that involves several factions.

1. The safety engineer struggles on the behalf of consumers and employees to reduce hazards. As such, the safety engineer practices where the hazards that can cause damage or injury exist, in the environment where products are used, at home or at work.

2. The manufacturer struggles to make the whole of society better through improved growth, ample jobs, profitability, and an increased standard of living.

3. The court systems struggle in their attempt to fairly manage, within "common law" guidelines, the change which societal and political pressures seem to be advocating. This process requires that the courts evaluate the fairness of the new theories proposed as the foundations for such change; as becomes especially necessary in the area of product liability, where many new theories have evolved over the past ten years.

4. The legal advocates struggle with the mission of bringing pressure on the court systems and society on behalf of their client's interests or their own motives. The courts often look to these advocates to propose the new theories upon which judicial or societal change can be justified.

5. The legislative and administrative branches of government struggle to use their legislated powers to formalize "standards of conduct" perceived by them as desirable in assuring that the humanitarian benefits resulting from change can be shared uniformly by all.

6. The insurance industry struggles to spread the risks by providing a broad based collection, administration and redistribution of financial resources. In accordance with what the industry has contracted to do, insurance may be oriented toward spreading the cost of liability. As often reported in the press, the cost of insuring against liability is mounting and might be viewed as an indicator of the economic changes spurring a general societal concern regarding court assessed liability.

This book was not intended to support or criticize any of these factions in the warnings issue struggle. Instead, the position is taken that none of the factions seem to have adequate background knowledge to support the warning-related viewpoints they advocate. Because of a lack of substantive factual data, they have generally had to base their positions on the belief that if the "truth" about warnings and labeling effectiveness were known, their positions would be supported. One role of this book is to present the knowledge and methodologies which will provide the "truths" which the different factions need to consider in arriving at their respective legal and social positions.

The Emphasis on Litigation

Although the warnings problem is not well understood, its surface simplicity has led to a heavy emphasis on warnings in product liability and other litigation. The courts seem to have little hesitation in judging whether or not a warning should have been applied after the fact. To summarize the legal situation, if uninformed consumers incur damages caused by a product, the manufacturer of the product may be liable for the damages under the theories of negligence (Noel, 1969) or strict liability (Sales, 1982). It has been suggested that suits based upon the criteria of inadequate warnings have proliferated because of the relative ease of initiating tort actions based upon inadequate warnings, the difficulty in defending against such actions, and the argument of an "apparently" low cost of placing warnings on products (Twerski, et al., 1976).

The Problems Induced by Litigation

It has been recognized that warnings related legal decisions are frequently based upon an intuitive rather than a scientific approach. Little consideration is given to the true complexity of the warnings issue (Kantowitz and Sorkin, 1983). Consequently, these decisions may have long-term implications that are counterproductive to safety (Twerski, et al., 1976; Schwartz and Driver, 1983).

One of the more serious problems associated with the legalistic emphasis on warnings is that other approaches to product safety tend to be ignored. In particular, effective design and training are not given adequate attention or recognition as a means of promoting safety. Also, warnings may be mandated in scenarios where they have little or no effectiveness, perhaps resulting in their over-application. Such over-application of warnings might eventually cause all warnings to lose their effectiveness (Weinstein et al., 1978). It might also lead to significant social costs by causing consumers to avoid using beneficial products (McGuire, 1980).

The dependence upon an intuitive, rather than a scientific, evaluation of the warning issue also results in inconsistent conclusions by the various courts. For example, current legal doctrine does not seem to require warnings for the so-called patent, obvious dangers, but may require warnings for latent, non-obvious, dangers that are much less likely to cause damages. As another illustrative example, in determining whether a warning is necessary, certain courts will only accept evidence of the injured party's actual knowledge about the hazard as an acceptable substitute for an explicit warning label. (It is particularly difficult to determine actual knowledge when the accident victim is deceased, making the latter legal test a virtual requirement for explicit warning labels under these conditions.) Other courts are willing to accept evidence that describes the expected knowledge of the population as being relevant to the determination of whether a warning was needed. Still other courts place the burden on the plaintiff to prove that it was the lack of a warning which actually caused the accident.

The Research Need

There is an obvious need for basic and applied research which emphasizes methods of measuring a warning's effectiveness and adequacy, as well as the development of guidelines that specify when to apply and how to design a warning. Although some methods for measuring elemental aspects of a warning's effectiveness and adequacy are available, additional research efforts might provide for the developing of more comprehensive and multidimensional measures. This book has attempted to directly contribute to these objectives.

In another area of need, several safety standards recommend warning design configurations, but do not support their recommendations with persuasive and/or substantive research. Also, several recent warning-related standards and publications seem to purposely ignore the question of when a warning is necessary, possibly in an attempt to avoid legal liability. Given the lack of research that has been directed toward answering this question, knowledgeable individuals may also have perceived the state-of-the-art as being inadequate to justify blanket statements as to when warnings are needed. While current practice in regard to standards and litigation are important areas, it has been the decision in the current book that they not be heavily emphasized. Emphasis is instead placed on the development of a technically sound scientific approach to the "warning issue;" a contribution that has not come forth from other authors.

SCOPE OF BOOK

One basic function of this book is to survey and organize the available literature regarding warnings. In so doing, emphasis has been placed on defining and evaluating critical research issues. Both traditional and model based methodologies are used. The traditional approach has consisted of extensive reviews of the existing literature relating to the warning issue. As an outcome of that research, a second volume has been concurrently published by these authors consisting of an annotated bibliography of selected articles and books [*Warnings: Volume II – Annotated Bibliography, by Miller and Lehto*]. The model based approach, on the other hand, emphasizes methods of organizing the existing findings from the literature into a useful form and has led to the identification of numerous research topics during the writing of this book.

The book is organized into four major sections. Section I. (Warnings: Their Complexity and Relationship to Information Processing) consists of Chapters 1 and 2. Chapter 2 introduces some pertinent definitions and then summarizes traditional modeling techniques based on communication theory and information processing theory. The latter portions of the chapter are at an advanced level, as the goal here is to define the warning issue well enough so that the important questions regarding effectiveness, adequacy, design, and application of warnings can at last be formulated. In other words, before one can even determine the intelligent questions to address, the warning issue has to be adequately defined.

Section II. (The Effectiveness of Warnings) consists of Chapters 3 through 6. These chapters will be of great interest and significant benefit to many professionals, including lawyers, psychologists, and engineers. Chapter 3 discusses the difficulties in evaluating effectiveness and provides a general approach to such evaluation. The next three chapters then consider particular aspects of warning effectiveness, with Chapter 4 addressing the ability of warnings to attract attention. Chapter 5 dealing with the comprehension of warnings, and Chapter 6 exploring the effects of warnings on memory, decisions, and actual behavior.

Section III. (Types of Warnings, Their Applications and Design) consists of Chapters 7 through 10, and specifically addresses a number of design-related issues. As such, this chapter is of interest to those people who apply, design, and recommend ways of providing warnings. Chapter 7 provides an initial structure to the design problem by classifying the different types of warnings and their applications. Many of the principles and much of the terminology used in this chapter is based on the more theoretical material given in Chapter 2. Chapter 8 introduces an approach for initially selecting warning applications. The approach is based on risk and effectiveness-related criteria derived from the second section of this book. In Chapter 9, the approaches recommended in safety standards and the criteria found within human factors handbooks are summarized and critiqued. Chapter 10 then presents a multistage description of the warning design process. This material emphasizes the application of task analysis, criticality analysis, and other evaluation methodologies especially applicable during warning design.

Finally, Section IV. (Advanced Topics) consists of Chapters 11 and 12, and addresses the potential application of knowledge based approaches during warning design and evaluation. A primary goal in these chapters is to represent the human, task, and product with consistent knowledge structures. The two chapters are at an advanced level, reflecting the complexity of the topic. The modeling techniques themselves are not easily applied using traditional approaches; instead they may best be applied using recently developed computer tools, such as object-oriented computer programs, as used in Artificial Intelligence (AI). Chapter 11 specifically considers a knowledge-based approach to the modeling of human performance, as illustrated by the development of a production system-based model of elemental tasks. The chapter also considers adaptations of traditional techniques such as Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA). Chapter 12 takes an even more fundamental approach toward modeling tasks and products with knowledge-based techniques.

This book has other goals that are in no way subsidiary. In particular, it will become clear throughout this book that the formal modeling approach to organizing the warning literature has resulted in the definition of many relevant research issues. For example, in the section on effectiveness alone, at least fifty topics requiring investigation can be found, many of which are explicitly noted. It is anticipated that by laying out such areas of deficiency, research into the warnings issue will be stimulated.

It is also hoped that by placing the needed research into a larger framework, significant interest will be encouraged toward extending model-based schemes for organizing warning-related information. Such a framework also leads to the possibility that a knowledge-based computer program can be used to incorporate these ideas, and also provide guidance in the actual design of warnings. The authors are developing such expert assisting computer systems which should be available shortly after publication of the present book.

CHAPTER 2

DEFINITIONS AND MODELING TECHNIQUES

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DEFINITIONS AND MODELING TECHNIQUES

To organize the ill-defined warning problem or issue, a set of definitions and an overall structure will first be developed. This requires that the general process of information transfer (within which warnings may play a significant role) must be defined. A precise definition must also be determined for that system consisting of the human, product, task, and environment within which this information is transferred.

The process of information transfer consists of several transient stages, while the system within which information is transferred is composed of static or structural components. This chapter considers both the transient and structural aspects by focusing on the general topic of information processing within tasks. A large number of modeling approaches become relevant when such an approach is taken. Many of these approaches have the potential to organize the analysis of warnings into a more manageable form, and are further developed and applied in later chapters.

The chapter begins with an initial survey of warning definitions, thereby providing insight into the current status of the warning issue. After completing this introductory discussion, attention is given to describing applicable modeling techniques. As the discussion progresses, a more detailed and formal view emerges. This progression should clearly indicate the great complexity involved in the formal analysis of warnings, and should also remedy existing misconceptions regarding the simplicity of the warning issue. Most importantly, this discussion of modeling techniques provides an organized description which can guide further analysis.

DEFINITIONS OF THE TERM "WARNING"

Commonly available definitions of the term "warning" can be subdivided into those arising from the profession of human factors engineering (HFE), and those arising from the functions of the so-called "warnings" used on products. Of primary concern is that human factors specialists have not placed a major or formal emphasis on the so-called "product warnings," but have instead emphasized warnings as used in complex displays found in aircraft, nuclear power plants, or process control. These definitions used in human factors engineering will be summarized before considering some of the more ambiguous meanings and definitions given to the term.

Traditional Definitions

The traditional definitions of the term "warning," as used in established human factors engineering textbooks, exhibit great consistency in their emphasis on alerting functions. For example, De Greene (1970, page 313) uses the word warning as a synonym for alerting, while Murrell (1969, page 156) notes that "it is a characteristic of many warning displays that some urgent action is required to avoid disaster." Murrell, (1969, page 208) also states that "warning devices are required to call the attention of the operator to some action which he has to take in relation to the equipment." He goes on to say "this can be done in many ways." McCormick (1970, page 189) discusses some of the ways audio warning signals may serve alerting functions. Specifically, he cites a study of warning signals in the context of a specific, complex Air Force weapons system, where it was claimed that warning signals should embody three components, as follows:

. "A" (for attention and alert). To attract attention and, if necessary, hold the operator's attention.

. "G" (for general category). To designate the general category of exigency (or type of emergency).

. "S" (for specific condition or suggestion). To identify the condition and/or to suggest appropriate action.

In a slightly different approach, that emphasizes the role of memory cues, Robinson (1977) says, "A warning signal captures the operator's attention, freeing up his central processor to use its decision and short-term memory capabilities to retrieve appropriate safety responses from long-term memory and subsequently produce the necessary responses." Robinson also emphasizes that warnings generally contain little explicit information, but instead rely on the user's skill and experience.

It seems obvious that the standard warning definitions used in human factors engineering emphasize three components: the alerting function of warnings, the presence of a hazard, and the roles of human behavior and attention. Note that none of these definitions describe an instructional role for warnings. It is important to emphasize that any stimulus serving an alerting function is likely to act as a memory cue which triggers the retrieval of more detailed information or the search for additional information; this point will be further emphasized during the detailed analysis and definition of warnings. Also, these standard definitions do not place a special emphasis on defining warning signals in terms of written or verbal messages. Consequently, warnings, as defined by these researchers, can encompass a wide variety of formats that use many different senses of the human, as will be extensively considered in later chapters (Chapter 7 in particular).

In accordance with these definitions, the position taken here is that, while information-bearing stimuli can serve many different functions, warnings are those stimuli that alert people to hazardous conditions. In other words, warning stimuli have very particular forms of meaning. However, the stimuli themselves can vary extensively, depending upon the sensors of the human they activate. Such stimuli can be received by the visual, auditory, tactile, olfactory, gustatory, kinesthetic, or vestibular senses.

Recognize that an unambiguous, clear definition, unanimously accepted by human factors experts, does not exist. Outside of human factors engineering, the uncertainty becomes much worse. In an attempt to show why this uncertainty exists, the following discussion briefly outlines some of the less scientific ways the term "warning" has been used.

The Popular Meanings

There is much uncertainty, especially within the legal system, regarding the meaning of the term "warning" when applied to products and their use. Among the reasons for this uncertainty are 1) the sloppy usage of the term, 2) the many functions information-bearing stimuli serve in addition to warning, and 3) the failure to recognize that warnings other than explicit warning labels exist.

Perhaps the major reason for the existing uncertainty is that warnings are commonly viewed as being synonymous with the very explicit "warning labels" which are occasionally placed on products. Such labels often list many forms of information including that which is educational, instructional, persuasive, or descriptive. When warnings are viewed as being synonymous with these very explicit warning labels (actually such labels are highly redundant information displays), a curious conclusion regarding warnings arises: Sources of information that do not explicitly (in words) describe the hazard, specify its intensity, strongly persuade accordance, and provide instructive countermeasures are held not to be warnings. That this definition conflicts with those given above is obvious.

A second major reason for the existing uncertainty is associated with the multiple functions that society expects the so-called warnings to perform. These will be discussed below.

Functional Definitions

Products often come with a wide variety of literature. Such literature is expected to perform several functions that are commonly viewed as being warning-related. Different sectors of society place varying emphasis on these functions, resulting in many different perspectives on warnings. These perspectives can simplistically be divided into the views of society as a whole and the views of the directly affected parties, which include manufacturers, suppliers, employers, insurers, consumers, and consumer representatives.

From a general, societal viewpoint, the primary reason to provide warning-related information is to reduce accidents by informing people of the risk associated with products. In other words, warnings should supplement the safety-related design features of the product by indicating how to avoid damages from the hazards which could not be feasibly designed out of the product (Weinstein et al, 1978). Theoretically, this can be done by conveying the magnitude of the potential damages and the probability of incurring the damages in a given situation or activity.

Providing such information will theoretically reduce risk by altering people's behavior when they use a particular product, or by causing people to avoid using a product. Some of these desired behavioral changes include increased alertness, performance of specific actions that consumers might not realize are important, and avoidance of specific actions consumers might not perceive as being dangerous. These changes in behavior are induced by alerting, educating, persuading, and/or reminding the consumer. The avoidance of certain products is assumed to be a function of the consumer's informed choices. The rationale behind this view is that informed consumers may choose not to buy hazardous products or may select similar but safer products.

From the more narrow views of the parties involved in litigation, warnings perform functions that have little to do with either safety or the transfer of safety-related information to the human. For example, when inspired by past experience with litigation, a manufacturer or product supplier may view warnings as a defense against litigation. It does appear that the popular decision of late is to extensively "paper" products with "warning labels." Such use of warnings might result in a situation where warnings that do not increase safety are placed upon products, (Schwartz and Driver, 1983). Another, even more troublesome, possibility is that manufacturers may use warnings as a replacement for careful design, because of the present tendency to litigate on the grounds of inadequate warnings (Schwartz and Driver, 1983) rather than design defects.

The warnings issue also gives employers and the insurers who provide worker's compensation insurance an opportunity to shift the costs of accidents to manufacturers (Schwartz and Driver, 1983). Similarly, from the view of consumers who are plaintiffs, the warnings issue provides easier and less expensive grounds for litigation than do design defects (Twerski, et al., 1976). This book will attempt to show why this latter view is completely contrary to reality; the warnings issue is probably much more complex than any of the other design issues, as also implied by Twerski et al.

These aspects of warnings or their application that are unrelated to the transfer of safety-related information are beyond the intended scope of this book, and will not be further addressed. Instead, emphasis is placed on developing a solid, more formal outlook on the warning issue that can be built upon and developed into a scientific approach.

Distinguishing Warnings from Instructions

The commonly perceived purpose of warnings is succinctly summarized in an often cited definition given by Dorris and Purswell (1978). They state that a warning is "...a message intended to reduce the risk of personal or property damage by inducing certain patterns of behavior and discouraging or prohibiting certain other patterns of behavior." There are many ways of attaining broad goals of this type; some common approaches are to instruct, persuade, inform, or warn. (As an aside, instead of dwelling on the duty to warn, perhaps litigation will eventually be centered on the duty to instruct, persuade, or inform.) These concepts must be disentangled in order to scientifically evaluate warnings.

Individuals outside of human factors engineering have realized the multiple role of the term "warnings," and have attempted to distinguish between warnings and instructions. For example, Weinstein et al. (1978) state that instructions "...tell the consumer how to use the product effectively..." while "...warnings inform the consumers of the dangers of improper use and tell how to guard against these dangers if possible." This distinction, however, is incomplete and arbitrary. For example, the second part of Weinstein's definition of a warning, "...tell how to guard against these dangers...," could be viewed as an instruction. Consequently, there is significant overlapping between the so-called "instructions" and "warnings."

Perhaps the best way to initially distinguish between warnings and other forms of safety-related information is to state that warnings are specific stimuli which alert a user to the presence of a hazard, thereby triggering the processing of additional information regarding the nature, probability, and magnitude of the hazard. This additional information may be within the user's memory or may be provided by other sources external to the user. Much of the current controversy regarding warnings is actually related to the need for this additional information.

Instructions and other forms of safety-related information might define the safe and unsafe responses to the hazard or provide detailed information regarding the hazard. Following this approach, most existing warning labels and instructions for use are combinations of warnings, instructions, and other forms of safety information (these other forms include that information which is persuasive or simply informative). This distinction between warnings and the more general concept of safety-related information will continue to be emphasized throughout this book. The distinction becomes particularly important during the evaluation of effectiveness. There, it becomes clear that true warning stimuli can be expected to have stronger effects on behavior than do educational, informative, or persuasive messages that are related to safety.

THE NEED FOR APPROPRIATE MODELING

A primary goal of this book is to define a general context for analysis of the warning issue. In other words, there are many more basic issues that must be understood and considered if one is to intelligently apply, evaluate, or design a warning. An underlying assumption is that warnings are a specific form of safety-related information. To go from this basic assumption to a detailed description of the warning issue first requires that the basic elements of the larger question of how safety information is transferred be isolated and defined. Methods for analyzing these basic elements must then be specified and, lastly, the basic elements and methods of analysis need to be organized within a conceptual model. Completion of the first two steps requires a substantial review of the commonly available principles of information processing theory. The third step, the development of a conceptual model, requires a substantial synthesis of existing modeling approaches.

The following discussion initiates this overall process of formally describing the warning issue. As such, much of this discussion is a level of detail rarely associated with the analysis of this issue. It will quickly become apparent that there are many potentially applicable techniques, and that their application requires substantial expertise. The discussion will consequently be quite difficult for those individuals who have not been exposed to communications theory or human information processing theory. Many of those individuals may desire to skim rather than read the following discussion before moving on to Sections II and III which address more applied issues.

The discussion itself is broken down into four sections: 1) Describing the Structural Components, 2) Describing the Procedural Components 3) Modeling the Procedural Components, and 4) Organizing the Structural and Procedural Components. The first section heavily emphasizes communications theory, while the next two sections emphasize human information processing theory. The last section is more closely associated with modeling techniques used in computer science and systems safety.

DESCRIBING THE STRUCTURAL COMPONENTS

It is proposed that two distinct forms of components comprise the warning process: 1) structural components and 2) procedural components. Structural components are actual and hypothetical physical elements within humans, products, and environments. Most structural components have several different states, the values of which are frequently determined by procedural components. Procedural components are elemental activities that take place within the human, product, task, and environment. It should be noted that a given task defines the process in which the human interacts with the product and environment. Such interaction can be precisely defined only in terms of the involved components of the human, product, or environment.

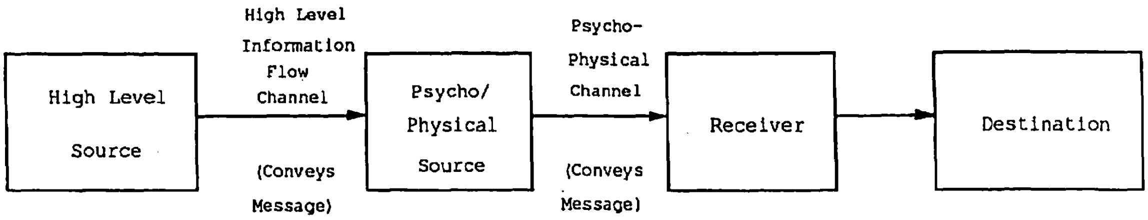

Figure 2 – 1 A General Description of the Communication Task That Occurs When Safety-Related Information is Transmitted.

This section will describe the structural components of the warning process primarily in terms of communication theory. However, the discussion will occasionally be supplemented with related ideas from information processing psychology and other areas. The next section will describe the procedural elements of this process using human information processing theory.

Communication Theory

Communication theory provides a very general and descriptive definition of the overall process in which information related to safety is transferred. Communication theory has been used by McGuire (1980) to analyze the value of "risk labels," which he defines as "persuasive communications used to influence behavior toward a product." (Note that McGuire uses the term "risk label" rather than "warning label." He also emphasizes persuasion rather than warning.) The theory has also been emphasized by Schwartz and Driver (1983) in their extensive evaluation of the warning issue.

When warnings are viewed as a special type of communication, new insights are gained, and the complexity of the warning process immediately becomes apparent. More importantly, however, communication theory provides an initial framework for independently analyzing each component of the warning process, and it can also be used to define structural elements. These structural elements are similar to the static elements defined in Chapter 12 that are incorporated within a general modeling approach applicable to tasks in general.

More specifically, communication theory assumes that there are five basic structural components within a communication task: the source, message, channel, receiver, and destination (see Figure 2 – 1). The communication task or process, then, consists of transmitting a message over a channel from a source to a receiver. The message is designed to attain an effect on the receiver; this effect is called the message's destination. Each of these complex components is influenced by several variables and can be viewed at several different levels of detail, as shown in Figure 2 – 2 and discussed below.

The Source

The source of the transmitted information is an important component of the communication process, and is simply where the information first originated. A source can be viewed at several levels of abstraction. At one extreme, there are highly aggregated sources such as regulatory agencies, consumer groups, educational institutions, standard-making organizations, commerce-

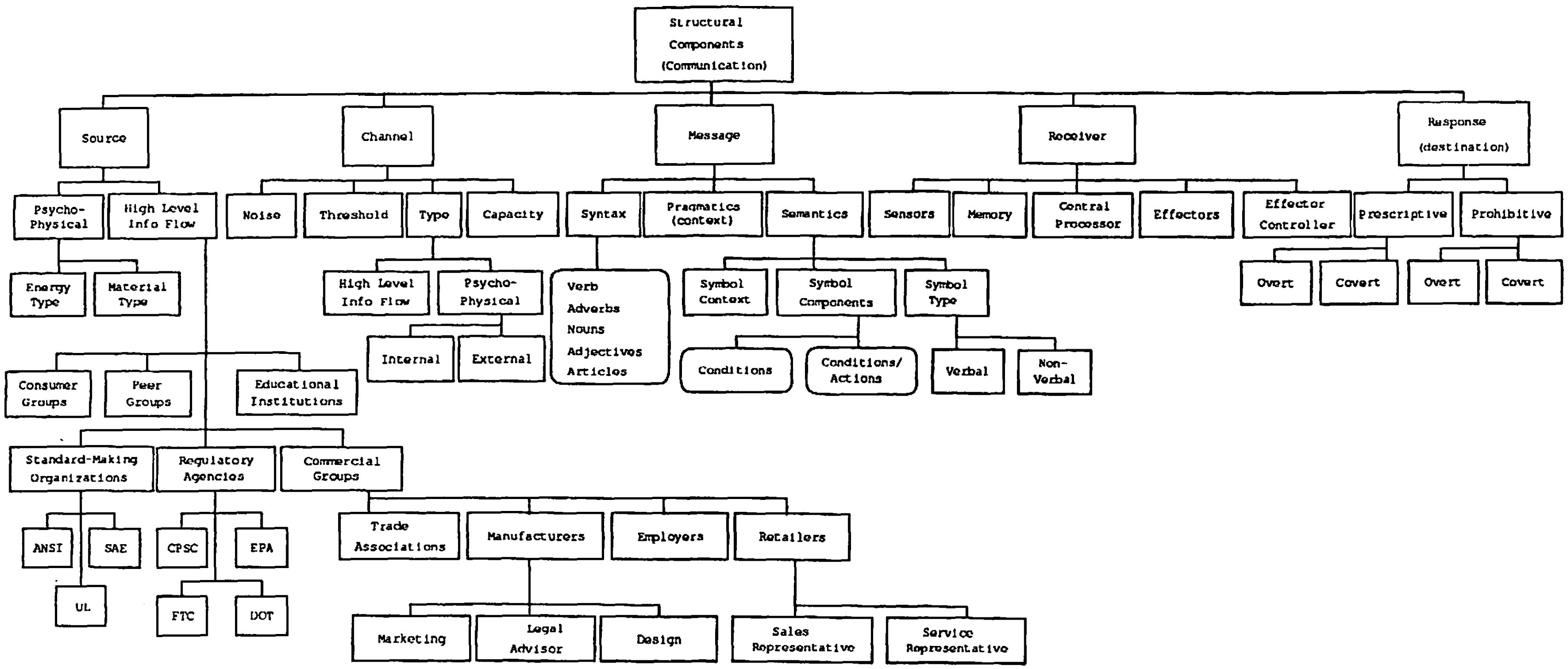

Figure 2–2 An Organized Set of Structural Components that Partially Define Communication Tasks in Which Safety-Related Information Is Transmitted.

related organizations, and peer groups. Highly aggregated sources are associated with high level flows of information (Figure 2−2), since there are many transfers of information which can be separately defined within such flow. Consequently, for each aggregate source, there are many other, more specific, sources. At the most specific level of abstraction, there are psycho-physical sources.

Psycho-physical Sources In terms of psycho-physics, the source is a physical object which emits information-bearing energy or matter. Such sources can be classified by the energy or matter, as well as the information emit. This definition of the term "source" is emphasized throughout this book, and is applied extensively, in the modeling approaches developed in Chapters 11 and 12, to the human, product, and environment alike.

When a source is ultimately broken down into psycho-physical components, it can become equivalent to what is loosely defined in social psychology as media. Media (for example, television, radio, or print) are also frequently referred to as examples of communication channels (McGuire, 1980). A vast variety of other psycho-physical sources are, however, present for products. Nearly every component of a product emits energy or material that bears information. The product itself organizes these components in a maplike fashion, wherein sources of energy and material are matched to particular information. Such sources must be considered during a detailed and complete examination of the communication process associated with a particular product.

It must be emphasized that the function-related components of product are primary sources of alerting information, as conveyed by warnings. Consequently, this book will emphasize the evaluation of sources in psycho-physical terms, as has been the case in human factors engineering and information processing psychology. When this approach is taken, the communication process can be defined in a very precise, formal way during the design of the product, which is where emphasis belongs. This is not the case when one is evaluating the influences of high level sources.

Aggregate Sources For aggregated sources of high level information, the source's credibility has a major influence on the impact of persuasive messages (McGuire, 1980; Craig and McCann, 1978). (More credible sources have greater impact.) The aggregated source also can influence legal liability, if the message is found to be inadequate by the courts. For example, if the source is the marketing division of a company, the company is likely to be liable for an inadequate message; on the other hand, liability becomes less likely if the source is a government agency. Most aggregated sources provide persuasive or educational forms of safety-related information that are conveyed by media rather than directly by function-related components of the product. The flow of information from aggregated sources to the ultimate receiver can be problematic (Page and Spicer, 1981), but since such flow does not fit within the warning definition used here, it is not of major concern in this book.

The Channel

In communication theory, the channel is the structure over which information (the message) is transmitted to the receiver from a source. This means that a channel is always connected between a source and a receiver when information is transferred. The general concept of a channel is also applicable to modeling many aspects of products which are not directly related to information flow. Therefore, channels will be extensively considered throughout this book. There are several generic types of channels, each of which has a threshold, noise level, and capacity (Figure 2−2).

The "threshold" associated with a channel may be defined as the minimum input of energy or material from the source for which the channel will transmit information to the receiver. In the simplest case, the value of the threshold is the sensitivity of the receiver divided by an attenuation factor, where the attenuation factor is a function of the channel and the distance the energy or material is transmitted. "Noise" is defined as information in the outputs of a channel which was not present in its inputs. "Capacity" is the maximum rate at which information can be transferred when the channel is noise free. The noise and capacity of a channel together define the maximum rate at which information can be transmitted, where the maximum rate is simply the capacity minus the noise.

Psycho-physical Channel The psycho-physical channel (Figure 2−1) can be broken down into very detailed elements when descriptions of the human and task are developed. Such channels are extensively developed in many information modeling approaches; the desirability of particular channels is very dependent on the task and the receiver. A psycho-physical channel exists when the receiver or source is a human, and can be either internal or external. Internal channels are present between sensors, memory, and other human components. External channels are present between the human's sensors and external sources of information. (Note that the sources connected to psycho-physical channels are always defined in terms of psychophysics.) Warning signs and instruction books are examples of sources that reflect structured patterns of radiant energy that are transmitted by external channels to visual sensors, while movement control exemplifies the use of internal channels to connect kinesthetic sensors to the cerebellum.

High Level Channel A more abstract type of channel transmits high level information from aggregated sources to the ultimate psycho-physical source found within the product. Examples of such channels can be found within any organization, and are illustrated by organizational charts. This book places little emphasis on evaluating such channels, but it should be noted that such channels are equivalent to aggregrated sequences of communications, where each communication can ultimately be broken down into psycho-physical components. It also should be noted that the equivalents of energy thresholds, channel capacity, and channel noise can theoretically be applied to high level channels. It is, however, difficult to precisely apply these measures at such an aggregate level.

The Message

The message is a transient element (other transient elements are considered in Chapter 12) of the communication process, and is conveyed over a channel. Several generic approaches to describing messages are available. Two of these approaches will be considered in this section. One approach is based on the ideas of information processing theory; the other approach is based on knowledge processing theory. Both approaches will be expanded upon below, and after doing so, some general types of messages will be considered.

A Message as Information Information, as defined in information processing theory, is an abstract concept used to mathematically model messages which are transmitted over a channel. Perhaps the most commonly used measure of information is "bits," which are the number of binary decisions needed to specify a particular datum from the set of possible data. The definition of information in terms of bits explicitly neglects the meaning of data (Shannon and Weaver, 1948). (Bits are actually a measure of stimulus uncertainty rather than meaning.) When used in computer applications, bits are an unambiguous measure of information. However, in regard to human information processing, great disparities in apparent information processing rates are often found for stimuli that possess equivalent information when measured in bits (Morgan et al., 1963).

These disparities can be explained in terms of a hierarchy, where the information contained in the stimulus's energy appears at the bottom of the hierarchy, and the ultimately perceived information appears at the top. Figure 2−3 illustrates how the structure of stimuli in a reading task can be hierarchically defined. At the lowest level, the continuous energy patterns of the light waves reflecting off the reading surface contain a nearly infinite number of bits of information. At the next level, the approximately 130 million cells of the retina convey a vast amount of information with their discrete activation patterns. At a slightly higher level, an immense number of bits is still required to specify the perceptual features (lines, edges, curves) or primitive shapes from which alphabetical symbols are formed. The alphabetical symbols on the page correspond to hundreds of bits of information, while the individual words correspond to tens of bits. The single sentences convey far fewer bits of information; the page may convey a single message.

The hierarchical nature of information, when measured in bits, is a direct consequence of the interaction between the human's knowledge and the stimulus's internal structure. In other words, the human's knowledge is used to discard immense amounts of structural information not directly related to the high level information within the stimulus. This effect is shown by the right-most line in Figure 2−3 where the level of processing (or, equivalently the external structure of the stimulus) is inversely related to the raw measure of information in bits.

Accordingly, information might be considered as being equivalent to "stimulus structure" (Garner, 1974), where the structure internal to the stimulus is distinguished from the external structure imposed by the human. Such a definition recognizes that the term "information," when used in regard to human information processing, cannot neglect the interaction between the human's knowledge and the stimulus's structure. Such a definition is also similar to the knowledge based definition soon to be discussed.

The Coding of Information A message must be encoded in an understandable format if it is to be successfully transmitted. The information code defines this encoding, and represents the set of primitive attributes (or features) that a stimulus or concept contains (Atkinson, et al. 1974). Recall from the previous section that channels can be either internal or external to the human. Different codes are used depending upon whether the channel is internal or external. The following discussion emphasizes the codes used within external channels. However, since external codes are very much related to those used in internal channels, where certain codes reflect more processing by the human, internal codes are simultaneously considered.

Information codes can be roughly subdivided into intensity, temporal, spatial, and verbal codes. Within an internal channel, intensity and temporal codes are the most primitive and correspond to the basic response of sensors, as elicited by energy or material inputs. In other words, sensory firing patterns can directly correspond to either intensity or temporal coding. Within an external channel, intensity codes encode information by varying the level of stimulus energy or the concentration of materials in either discrete or continuous steps. As such, an intensity code correspnds to Amplitude Modulation. Temporal codes encode information in external channels by varying the time that elapses between differing levels of stimulus energy or concentrations of material. As such, a frequency code corresponds to Frequency Modulation. Combinations of intensity and temporal codes are very common; feasible combinations can be specified for nearly every one of the human's senses.

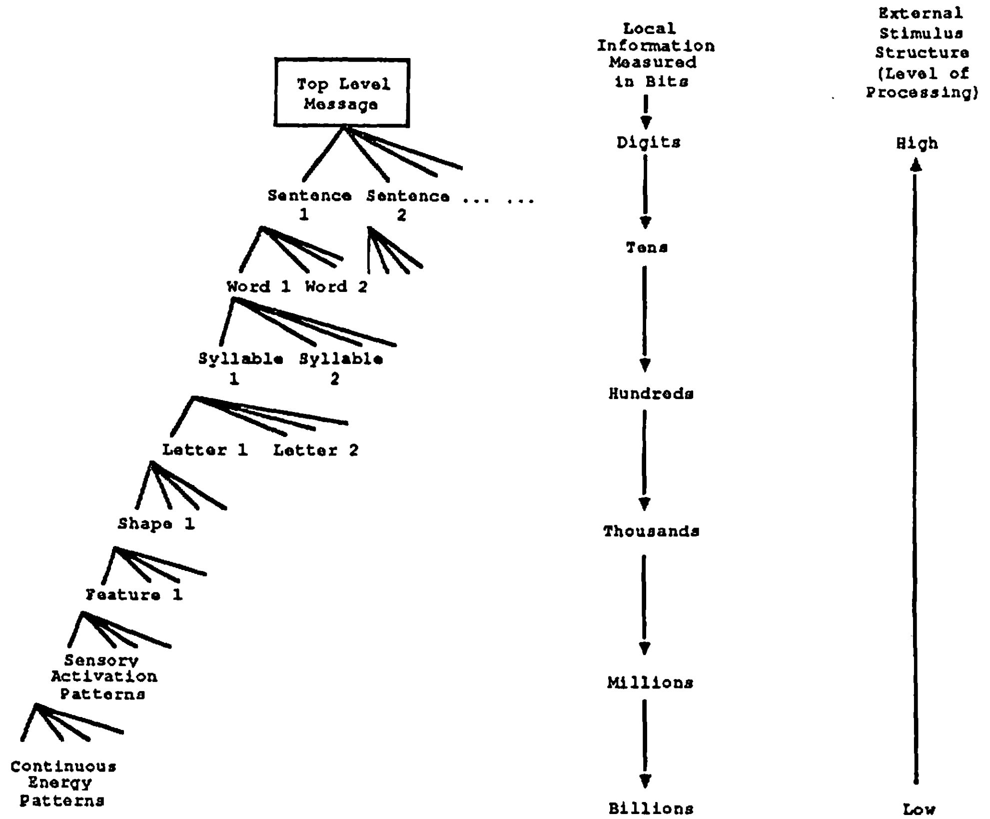

Figure 2−3 The Hierarchical Structure of Stimulus Information, when Measured in Bits, and within a Reading Task.

Many spatial and all verbal codes correspond to more processing by the human than do the simple temporal and intensity codes, and are therefore more closely related to the external structure of a stimulus. (Note that the external structure of a stimulus is closely related to the code used within the human.) Within an external channel, spatial codes encode information in terms of the location of particular levels of energy or the concentrations of materials. Spatial codes can also be viewed at a higher level where they correspond to patterns that describe arrangements of the primitive features of a stimulus. Such patterns are composed of lower level elements that are encoded by temporal, intensity, and spatial codes. Although patterns must be described by the external structure of a stimulus if they are to be perceived, they are also imbedded within the internal structure of a stimulus.

The locations of stimulus features can directly correspond to activated sensors. Consequently, certain spatial codes have direct sensory analogs, as do intensity and temporal codes. Verbal codes, on the other hand, exclusively reflect the external structure (or meaning) of a stimulus and are generally either visual or auditory. In other words, although verbal codes can be specified by patterns of lower level elements that are imbedded within the internal structure of a stimulus, verbal codes do not have direct sensory analogs. Verbal codes are always defined at the most primitive level by combinations of intensity, temporal, and spatial coding.

A Message as Knowledge The meaning of the message has received much attention during litigation regarding warnings, particularly when determining their adequacy (Sales, 1982). For a message to be meaningful, the symbols used to convey the message must be meaningful to the receiver, as must their arrangement in the setting within which the message is given. These important factors which define the meaning of a message fall into the categories of semantics, syntactics, and context.

Semantic factors determine the meaning the symbols themselves have for particular receivers. Symbols themselves can be broken down into verbal and nonverbal symbols, and each of these categories can be further subdivided. Verbal symbols can be broken down into various languages, within which vast sets of meanings exist. Verbal symbols can also be distinguished as being either written or spoken. Nonverbal symbols can be broken down into abstract symbols and pictographs, which can also be broken down further into vast sets of meaning. (Dreyfuss, (1972) has collected a large set of nonverbal symbols and their meanings.) While written verbal symbols are abstract symbols, generally the term "abstract symbols" refers to nonverbal symbols which do not have an immediate, unlearned association with physical objects. In contrast, pictographs are symbols which explicitly resemble specific physical objects. Of interest is that certain pictographs can be generalized to become ideographs, or actually abstract symbols.

The term "syntax" refers to the way an arrangement of symbols, as opposed to the symbols themselves, conveys meaning. The study of syntax considers how symbols can be arranged into particular patterns, each of which might have a different meaning. The dependence on syntax to convey meaning is directly proportional to the ratio of desired messages to the number of defined symbols. In other words, if a large number of messages are to be conveyed with a relatively small number of symbols, syntax becomes more important, or vice versa.

Messages conveyed by verbal symbols are therefore highly dependent upon syntax, because a vast set of meanings can be conveyed by a relatively small set of words when they are combined into sentences. Importantly, the syntax of a given language follows standardized rules most receivers understand, provided they understand the language. This is not as true in general for nonverbal symbols.

Abstract nonverbal symbols are also frequently dependent upon syntax, as in mathematics or other instances where the order of symbols conveys a particular meaning. Pictographs and very specifically designed abstract symbols are the least dependent upon syntax because they are generally intended to convey very particular meanings independently of other symbols (i.e. there are nearly as many symbols as possible meanings, and usually exactly as many symbols as intended meanings). If abstract symbols or pictographs are combined to convey other than the most simple semantic information, syntax becomes important. This form of syntax might not follow a set of standarized rules understood by most receivers, but might be easily learned.

The study of the context-specific meanings of symbols is frequently referred to as pragmatics. In other words, the meaning of individual symbols or strings may depend upon the exact environment within which they are introduced, upon a particular receiver, or even upon events which took place earlier. Such dependence occurs because most verbal symbols and many nonverbal symbols have multiple semantic meanings. The intended meaning of an isolated symbol with multiple meanings must be inferred from the context within which it appears. (For example the word "fire" might mean one thing to someone working in an oil refinery, and something entirely different to someone on a shooting range.) While syntactic processing of

Table 2 − 1
A Matrix of Message Types Defined Using Components of Message Meaning. (The different types of messages fall within the cells of the matrix. The x-axis corresponds to the type of symbol, while the y-axis corresponds to the type of meaning.)

	VERBAL SYMBOLS	ABSTRACT SYMBOLS	PICTOGRAPHIC SYMBOLS
SEMANTICS (nominal)	words numbers	numerals letters mathematical operators logical operators hazard alert symbols	descriptive marks
SYNTAX (relation between symbols)	logical statements theories	formulas strings	diagrams, charts graphs
CONTEXT (current situation or values of symbols)	descriptions	measurements values	maps blueprints drawings photographs models

strings of symbols reduces the set of possible meanings, a syntactically correct string may still have multiple meanings, depending on the context within which it appears.

Much more attention to the knowledge-related aspects of messages is required, before the communication process can be modeled in detail. These details, however, require further background knowledge regarding human information processing, and consequently will be considered in relation to information theory in Chapter 11.

Types of Messages Doblin (1980) provides an interesting approach toward distinguishing between different forms of messages. In this approach, he distinguishes between orthographical and iconographical messages, each of which can convey nominal, noumenal, and phenomenal information. These factors are arranged into a matrix to define a wide variety of messages. Rather than use his somewhat confusing terminology, a similar matrix using the terminology of the previous section is given in Table 2 − 1.

In Table 2 − 1, verbal, abstract, and pictographic symbols are listed on the x-axis, and semantic, syntactic, and contextual components of meaning are listed on the y-axis. The cells of the matrix define particular types of messages. The table is quite self-explanatory and will not be discussed in detail. It should be noted, however, that the example messages are in a hierarchical arrangement. For example, a word (a verbal message with a nominal meaning) is composed of letters (abstract symbols with nominal meanings). Also, the word can be used within a description (a verbal message that conveys contextual meaning).

The effects of this hierarchical arrangement are more confusing in regard to pictographic symbols. In particular, drawings and photographs can provide semantic, syntactic, or contextual meanings. This occurs because of the wide variation in the possible types of drawings and photographs. In other words, a descriptive mark could be a drawing or a photograph.

The Receiver

The characteristics of receivers (which can be people who receive messages, or components of products) also constitute an important element of the communication process. People vary in personality, age, sex, knowledge, education, attitudes, abilities, moods, and other ways. Differences between individuals can influence the effectiveness of a specific source, message, or channel used to communicate information. At this initial, definitional stage, no attempt will be made to exhaustively analyze these differences. Instead, attention will be given to outlining the basic components considered in information processing psychology.

As shown in Figure 2−2, the human receiver consists of several basic components; these include sensors, memory, central information processor, effectors, and effector controllers. The sensors can be divided into internal and external sensors. External sensors are sensitive to radiant energy, temperature, pressure, acceleration, and certain types of chemicals. Internal sensors can detect forces, positions, and chemicals within the body. Two general types of memory are present within the human receiver: long term and short term. The term "effectors" refers to the musculo-skeletal components of the body; some of the more commonly used effectors include the upper and lower limbs, the hands, and the oculomotor system. The central processor processes information within short term memory which arrives from sensors or from long term memory. The term "effector controller," refers to other components of the lower brain or cerebellum that refine the responses selected by the central processor.

These structural components will be considered more extensively when the general processes that comprise information processing tasks are addressed. A similar breakdown is also applied to the product in Chapter 12.

The Destination

The "destination" of the communication refers to the desired behavior the message is expected to elicit. Actual attainment of the destination requires a successful communication, and is also influenced greatly by receiver-related factors. For people, such factors include their existing behavior patterns, their ability to understand or perform the desired behavior, and their willingness to perform the desired behavior. Such factors affecting behavior will be further considered throughout the remainder of this book, and particularly so in Section II regarding the effectiveness of warnings.

DESCRIBING THE PROCEDURAL COMPONENTS

A task is simply a group of activities performed by the human in order to attain some goal. These activities along with those that take place within the product or environment comprise the procedural elements of the warning problem. Emphasis in this section is exclusively on defining those activities that take place within the human. Chapter 11 then continues where this chapter leaves off by providing a conceptual model which combines many of the principles outlined here. Chapter 12 generalizes this modeling approach to the analysis of products, and also describes the process of task analysis (as does Chapter 10) wherein the detailed descriptions of tasks are developed.

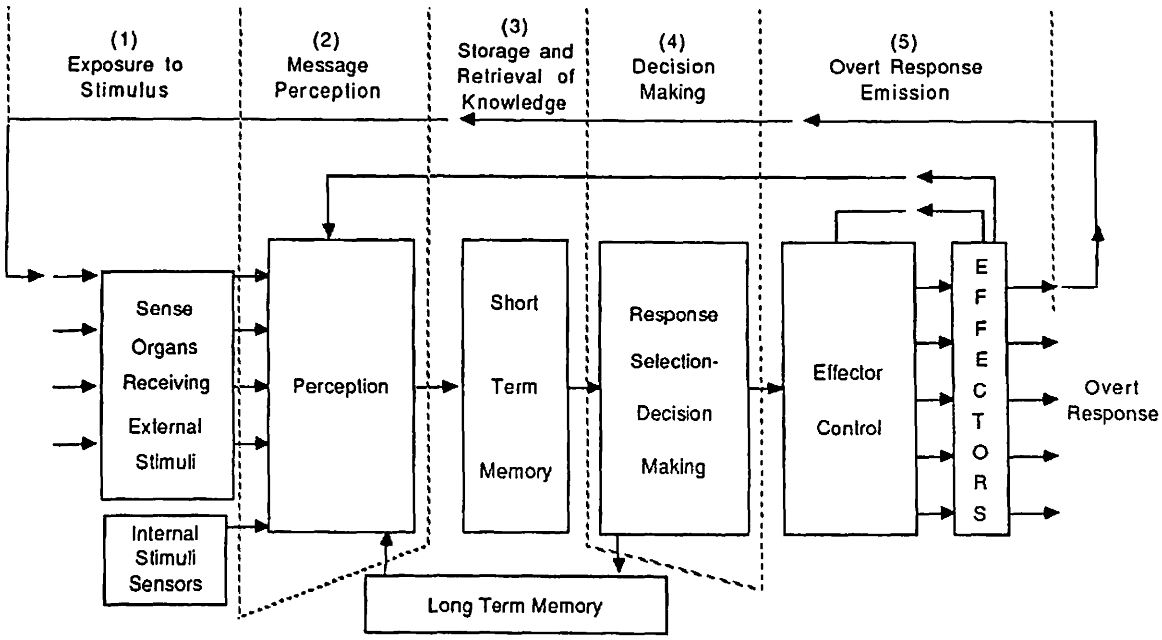

Figure 2−4 An Organized Set of Procedural Components Which Fall within Tasks in Which Information Is Transmitted (derived from Welford, 1976.).

At the most basic level, a task is comprised of a stimulus, given to the human, to which the human gives a response. (This is the classic Stimulus-Organism-Response "S-O-R" model used in psychology). In this view, the structural components of the task are a stimulus, a human organism, and a response. The procedural components are associated with presenting and processing the stimulus, and emitting the response. In order to gain understanding of the communication process wherein safety related information is transferred, these procedural components must be defined in more detail.

Information Processing Theory

Information processing theory provides a detailed description of procedural components along the above lines. Psychological models based on information theory, including Welford's single channel hypothesis (1967), the production system models of Newell and Simon (1972), and the associative memory model of Anderson and Bower (1973), treat the human being as an information processing system. The most basic information processing model defines several sequential stages within the human, through which information flows. Other information processing models specify detailed constraints on how this information is processed.

At its most basic level, an information processing model of the human will include perceptual-, memory-, decision-, and response-related processes. Each process roughly corresponds to a stage in the processing of information within the human. Figure 2−4 shows a simple diagram, derived from Welford (1976), which illustrates these stages and their interaction. Welford calls the interaction of these stages "the chain of mechanisms." Here, the human is modeled as a complex structure that takes in stimuli, makes decisions based upon the stimuli, and then emits decision dependent outputs.

Information flows through each of these information processing stages when the human being performs a task. The output of one stage becomes an input to a following stage, thereby corresponding to the flow of information through a chain of mechanisms. This relationship between the inputs and outputs of the different stages specifies the transient nature of information as it flows through the human being. Accordingly, the flow of information can be blocked at any stage within this chain of mechanisms, since every information processing stage is limited. Such effects occur as a function of how much information enters a stage, and as a function of the allocated or available information processing resources. In particular, certain types of information are essential to the adequate performance of a task. If such information is lacking, performance will be degraded. Other types of information are not essential to a task's performance. Such data must be screened out, since they may interfere with the processing of more essential information. This latter effect is accentuated by the limited information processing capability of the human.

In summary, when using a product, the human performs a task. When a task is performed, the following basic stages of information processing occur: 1) exposure to the stimuli, 2) message perception, 3) storage and retrieval of knowledge, 4) decision making, and 5) overt response emission. A brief overview of these stages will be given below. The next section then introduces some commonly used models that describe these stages in more detail.

Stimulus Exposure The far left side of Figure 2−4 depicts how sense organs take in stimuli from external and internal sources. External stimuli transmit task-related information from external sources to sensors within the human. These sensors are associated with the human's visual, auditory, gustatory, olfactory, tactile, thermal, and equilibrium (acceleration or gravity) senses. All of these sensors respond to stimuli from the external environment. Consequently, they are frequently referred to as exteroceptors (Jacob, Francone, and Lossow, 1978). Often external stimuli will provide feedback regarding the performance of a task. In other situations, the external stimuli are simply inputs from the task environment.

Internal stimuli transmit task-related information from sources within the human. Kinesthetic sensors inform the human of movements, exertions, and the location of musculo-skeletal components. The information provided by the kinesthetic senses regarding musculo-skeletal states (such as positions, forces, movements) of the body is critical during the performance of manual tasks. Those stimuli conveyed to a variety of chemical receptors within the body constitute a second type of internal stimuli. Such stimuli affect arousal levels or the activation of the sympathetic nervous system. A third form of internal stimuli is described by the information transferred from long term memory to short term memory. Such transfer of information does not fall within the common definition of stimuli, but viewing it as such is useful from a pragmatic modeling viewpoint.

Message Perception Simply presenting a stimulus does not guarantee that the message will be transmitted. This point is emphasized by Garner (1974), who states "stimulus energy provides activation of the sense organ, but it is stimulus information or structure that provides meaning." This point is implied in Figure 2−4, which shows that the human must perceive the message, if the message is to be understood and ultimately transmitted.

Perception encompasses at least two primary processes, pattern detection and attention allocation. Both processes will be more extensively discussed later in this chapter. At this point, it will simply be noted that human perception is notable, not for the information actually processed, but by the human's ability to exclude and not process huge amounts of irrelevant data. Welford (1976) states, "it is well known that far more data are transmitted by our sense organs to the brain than we in fact perceive." For example, the transmission rate of the optic nerve could be said to be around 1 million bits/second, while the rate at which information enters short term memory, in activities such as in reading, is probably around 100 bits/second (Kelley, 1968). These values are, of course, rough estimates, and similar effects were discussed earlier in regard to the message (Figure 2−3).

Such effects are intimately related to the allocation of attention. If the human could not selectively attend to individual aspects of the task, performance would be impossible. Selective attention results in the filtering out of large amounts of incoming data at an early stage in the perceptual process (Welford, 1976). Inexperienced subjects, learning a task, tend to have difficulty because they devote too much attention to irrelevant aspects of the task (Salvendy and Seymour, 1973). As the level of skill increases, the amount of filtered or ignored information also increases (Kay,1957).

Storage and Retrieval Perception, as well as decision making, is dependent upon memory. In perception, both attention and pattern recognition require that recent events be stored in memory (Norman, 1976). In other words, to attend to something, a human needs to remember what he is to pay attention to; and to recognize something, a human needs to store patterns in the memory so that they can be compared with new patterns. Complex mental processes require the memory of past conditions and appropriate actions associated with these conditions.

There are three basic processes related to memory. These are 1) encoding information, 2) storing information, and 3) retrieving information (see Murdock, 1974). "Encoding" is the process wherein a physical stimulus is transformed into a code that can be interpreted by the nervous system. For the purposes of this book, encoding is equivalent to perception. "Storage" is the maintenance of coded information, with the loss of this information being forgetting. "Retrieval" is the accessing of stored information. Occasionally, stored information may be inaccessible because of inadequate retrieval mechanisms. This reflects the active nature of retrieval.

Several types of memory are used by the human while performing tasks. These include a sensory store (Sperling, 1960), short and long term memory, and external memory (Newell and Simon, 1972). External memory is not within the human; the other forms of memory are internal or within the human.

Sensory Store Sperling (1960) found that humans see more than they can store consciously. The sensory store seems to act as a buffer within which a large number of sensory images are placed, as an early step in perception. The sensory store has also been called visual short-term memory, and similar effects have been noted for auditory stimuli.

Short Term Memory can contain approximately 7 ± 2 items for limited periods of time (Miller, 1956). Items in short term memory are experienced or rehearsed by the human. Interestingly, the items in short term memory can vary in structure. Through "chunking" (the encoding of additional information within a single item, as when decimal numbers are used to represent binary numbers), larger amounts of information can be stored in short term memory. However, the number of chunks allowed in short term memory is also said to be limited to 7 ± 2 (Miller, 1956).

Long Term Memory refers to memory that retains information for extended periods. Long term memory is typified by its associative nature (Anderson and Bower 1973). In other words, items in long term memory are organized into structured patterns. Long term memory is also typified by its essentially unlimited capacity.

External Memory refers to quickly accessible information external to the human. For example, this can include data written on paper or displayed on CRTs. External memory is usually visual in form, but can use other channels. Braille pads for example use the tactile sense. Written warnings are a form of external memory that reminds the human of potential hazards, as do many nonverbal stimuli.

Decision Making

At the decision-making stage, the human must select an appropriate response based upon the perceived or retrieved information. A basic distinction can be drawn between problem-solving behavior and skilled or rote performance (Welford, 1976; Rouse, 1980). Problem-solving behavior is characterized by many mistakes, and a tendency to backtrack to the point where a mistake was made. In skilled performance, on the other hand, decisions are well entrenched, and performance is characterized by few mistakes and little backtracking.

Overt Response Emission

The final stage in the information processing model describes the emission of an overt response. An overt response can be quantitatively defined in terms of the information conveyed by the activity of the human's effectors, or qualitatively defined in terms of classes of activity. The most common approach is the qualitative one, which often classifies activity in terms of the involved effectors. Commonly considered effectors fall into musculo-skeletal and sensory-motor categories, as discussed earlier.

Two more general categories of overt human responses exist: the discrete and the continuous. Discrete responses are ballistic in nature and do not involve feedback or motor control. Continuous responses, on the other hand, involve both feedback and motor control. A continuous response is actually a sequence of several closely coupled, discrete responses, where later responses are influenced by earlier responses. In other words, earlier responses influence the stimuli entering the chain of mechanisms in a way that can be modeled by a feedback loop (see Figure 2−4).

MODELING THE PROCEDURAL COMPONENTS

We will now consider detailed models which have been used to describe the activities within the various information processing stages. Several potentially useful models are available (see Table 2−2). The goal here is to use these models to more precisely define the subproblems within each stage. This discussion is at very much an abstract level; no attempt is made to define the models at a level where they could be applied. Also, the production system model will not be discussed until Chapter 11. It will then be used to organize the procedural components discussed in this chapter, so that more detailed analysis can be performed.

The following discussion roughly follows the organization of Table 2−2. The first of the several topics considered is perception, followed by memory, decision making, and overt response performance.

Models of Perception

Within this topic, we can find models that are applied to describe lower level processes. Such models describe the chain of events leading from stimulus exposure to comprehension. Other

Table 2–2
Some Relevant Information Processing Models.

PERCEPTUAL PROCESS	RELEVANT MODEL	ATTRIBUTES OF MODEL INPUTS	ATTRIBUTES OF MODEL OUTPUTS
EXPOSURE psycho-physics	Stevens' model Weber fraction	energy threshold, energy type/level, chemical type/level	perceived signal strength, differential threshold
ATTENTION divided attention, loading	queuing theory	processing rate, loading rate	queue length, waiting time
goal-driven or data-driven attention	production systems	conditions in short-term memory, long-term memory, external memory	actions in short-term memory, long-term memory, external memory
GENERAL PERCEPTION	signal detection theory	noise strength and distribution, signal strength and distribution, utility of false identification, false rejection, correct rejection, correct identification	Receiver Operating Characteristic (ROC) Curves
MEMORY recall storage organization	spreading activation theory levels of processing production systems, semantic networks	memory cues, associations levels of processing	recalled items, recall time associations
DECISION MAKING	utility theory	subjective and objective probability, subjective and objective utility	optimal decisions
RESPONSE PERFORMANCE continuous	manual control theory	input function, human operator output function	mean error and variance, time to reach steady state, instability conditions

models are primarily applicable to attention, which is a higher level process. A final model, signal detection theory, applies to the overall perceptual process.

Lower Level Perceptual Processes The process of pattern recognition directly corresponds to the hierarchy of information referred to earlier (see Figure 2−3). At the lowest level, the term "stimulus structure" refers to continuous energy patterns which are independent of the observer. After contacting sensors, these energy patterns are transduced into discrete sensor-activation patterns. These discrete sensory patterns undergo much filtering before being translated into primitive perceptual features. These perceptual features are then combined into perceptual constructs equivalent to primitive symbols. Primitive symbols are then combined to define higher level symbols, groups of which define more complex meanings. The point at which meaningful symbols enter short term memory then defines comprehension.

At the lowest level (which corresponds to stimulus exposure), three primary criteria must be satisfied before stimuli are transduced into sensory patterns. First, the message must be encoded by symbols which possess energy or are composed of material. Second, the energy or material which encodes the message must be sufficient to activate receiver sensory organs after it travels the distance between the source and receiver. Third, the energy-possessing symbols must contact functioning sensory organs within the receiver. If any one of these three criteria is not met, the receiver will not be exposed to the stimuli.

That the message be encoded by energy or material bearing stimuli is the only one of these criteria that is independent of the human. In regard to the second two criteria, actual contact of energy or material with sensors, resulting in their activation, is very much a function of the load on the sensory channel. The degree of activation of sensors, following contact, can be described by certain power laws. For example, squaring the intensity of the stimulus might cause the perceived intensity level to double. At a slightly higher level of perception, the ability to discriminate between stimuli follows Weber's Law. Here, the minimal perceptible change in stimulus intensity is a constant fraction of stimulus intensity, resulting in a logarithmic relationship between discriminable changes in intensity and the base level of intensity to which changes are compared.

Pattern recognition becomes much more complex at the higher levels. No attempt will be made here to specify exactly how features appear in the sensory store and ultimately reach short term memory. However, the accumulator model (Vickers, 1970) provides some insight into how this process might work. Specifically, during the discrimination of stimulus features, the lower level sensory processes might accumulate evidence for each considered feature until some threshold value is reached. Once this threshold is reached, the feature is perceived. For example, assume that the task is to discriminate between two weights, the weights being held in the left and right hands respectively. The model assumes that several samples are taken of the sensory firing intensity from the respective hands. For each sample, these intensities are compared and the results are then added to one of two stores. The first store would sum the number of observations in which the weight of the object in the right hand is greater and vice versa. Once the value in one store was greater than a threshold value, the associated object would be perceived as being heavier.

It must be emphasized that expectations or goal-driven processes interact with such bottom-up or data-driven processing to influence the features extracted from sensory patterns. The simpler the stimuli, the less the influence of goal-driven processing becomes. Conversely, the comprehension of complex meaning, since such meaning is primarily derived from a stimulus's external structure, is likely to be primarily goal-driven. This means that many decision processes will come into play when the human is deriving high level meanings. In particular, decisions must be made as to which stimulus dimensions to discriminate upon.

Attention Two types of attention can be distinguished, that which is data-driven and that which is goal-driven. Data-driven attention is elicited by exposing the human to external stimuli that have a particularly high energy level or salience. (This of course raises the apparent paradox of attention that is attracted by perception without attention, which is explained by assuming that attention is not a unitary resource, but instead is a resource that can be focused at different levels of intensity (see Kahneman, 1973).) Goal-driven attention is elicited when particular forms of information are sought from specific sources, which may be known or unknown. There is a great deal of overlap between data- and goal-driven attention, since perception associated with both data- and goal-driven attention involves the same lower level processing stages, and at the highest level involves comprehension.

Attention has been viewed as an underlying resource of the human that influences task performance to a very major degree (Kahneman, 1973). In this approach, subtasks, when performed, require varying levels of attention in proportion to their difficulty. It is also assumed that attention can be allocated between simultaneous tasks (Navon and Gopher, 1979), and that the total amount of attention which can be allocated is a function of arousal (Kahneman, 1973). Arousal refers to the activity of the autonomic nervous system. The general relationship between arousal levels and performance is an inverted U. Greater levels of arousal increase performance up to some optimal point, after which performance decreases as arousal increases. Kahneman provides an excellent discussion on arousal and information processing.

It should be emphasized that attention plays an important role during the extraction of stimulus meaning. As already noted in the previous section, the meaning of a message is dependent upon semantics, syntax, and pragmatics. Of major importance here are the context-related aspects of stimulus meaning. In other words, stimulus meaning, attention, and stimulus loading all interact. If loading is high, attention can only be focused on very abstract, probably nonverbal stimuli, causing the context-specific aspects of the stimulus to become especially important. If loading is very low, it will be easier to allocate the time required for the perception of more detailed stimuli which fully specify semantic and syntactic information.

Several mathematically-based modeling approaches have been used to model the divided attention of a human performing a task. In particular, queuing theory has been applied (Schmidt, 1978; Carbonnel, 1968). Here, the human is modeled with a service time distribution (typically, and in the simplest case, a negative exponential), while tasks, or more specifically subtasks, are modeled with an arrival time distribution (also typically a negative exponential). In other words, the task is very abstractly modeled as a set of subtasks which arrive according to some statistical distribution and are completed by the human according to some service time distribution. With the use of computer-aided queuing theory techniques, arbitrarily complex arrival time and service time distributions can be modeled. The application of such techniques requires, of course, knowledge of subtask completion times and the expected patterns and arrival times of such tasks. A major problem, however, is that such models tend to ignore the detailed underlying structure of the human and task to which they are applied.

Signal Detection Theory As noted above, perception can be roughly divided into attention-related and pattern recognition-related processes. However, one should realize that certain models commonly applied to perception do not explicitly consider either attention or pattern recognition. In particular, signal detection theory does not emphasize either aspect of perception, but is quite useful in certain applications and has seen wide application.

In signal detection theory, a signal or a stimulus is presented to a subject over a noisy channel. The subject's task is to discriminate the signal from noise alone; in other words, he must indicate whether a signal was or was not sent over the channel. The subject is usually assumed to receive some reward for correct identifications or rejections (of the presence of the signal) and a penalty for false identifications or rejections, as in a vigilance task.

This modeling approach has been applied almost exclusively to tasks in which the subject focuses his attention on a display wherein the signals are very weak. In such applications, it is feasible to represent the signal-with-noise and noise-alone as two statistical distributions. The difference between the means of the two distributions in standard deviation units is referred to as d'. The subject is assumed to respond that a signal is present when the perceived signal strength is greater than a value x_c, where x_c is referred to as the cutoff point (see Figure 2−5). At the cutoff point, the likelihood ratio beta (β) is equal to $f_{s+n}(x_c)/f_n(x_c)$. In the example shown, $f_{s+n}(x_c)$ and $f_n(x_c)$ are equal at the cut-off point x_c, resulting in a β of 1. Note that as shown in the figure, $f_{s+n}(x)$ and $f_n(x)$ are probability density functions, in which the value of each function depends on the value of x.

By applying decision theory, it can be shown that the optimal beta can be calculated as:

$$\beta_{opt} = \begin{array}{l} ((\text{probability of noise alone})/(\text{probability of signal})) * \\ ((\text{payoff for a correct rejection}) + (\text{penalty for an incorrect identification})) / \\ ((\text{payoff for a correct identification}) + (\text{cost of an incorrect rejection})) \end{array}$$

where each of these factors in this equation are self-explanatory. The particular value of β exhibited by a subject's performance can be mathematically combined with the signal and noise probability density functions to predict subject performance.

In particular, Receiver Operating Characteristic (ROC) Curves can be developed in which the likelihood of false alarms versus correct identifications are plotted as a function of β and the respective density functions.

This modeling approach can be applied to perceptual tasks other than those involving the identification of very weak signals presented against a background of noise. However, when the signals become stronger, the amount of overlap between the signal-with-noise and noise-alone distributions will tend to become insignificant. (The overlapping area in Figure 2−5 is shaded.)

Without significant overlapping, it becomes almost impossible to empirically develop quantitative descriptions of human performance using signal detection theory because very large samples of data have to be collected. Non-quantitative methods, however, can show the directional influences of modifying noise distributions. For example, when competing stimuli are described as noise, signal detection theory can be used to make simple predictions; the theory predicts that the presence of competing stimuli will reduce the probability of correct identifications. In other words, too many warnings may be as bad as no warning.

Models of Memory

The production system model considered in Chapter 11 places a large emphasis on the role that different types of memory play within certain task phases. Accordingly, the following discussion will first consider such task dependent roles of memory. Other information processing models with specific implications toward different aspects of memory will then be considered, beginning with the levels of processing model and ending with models of memory organization.

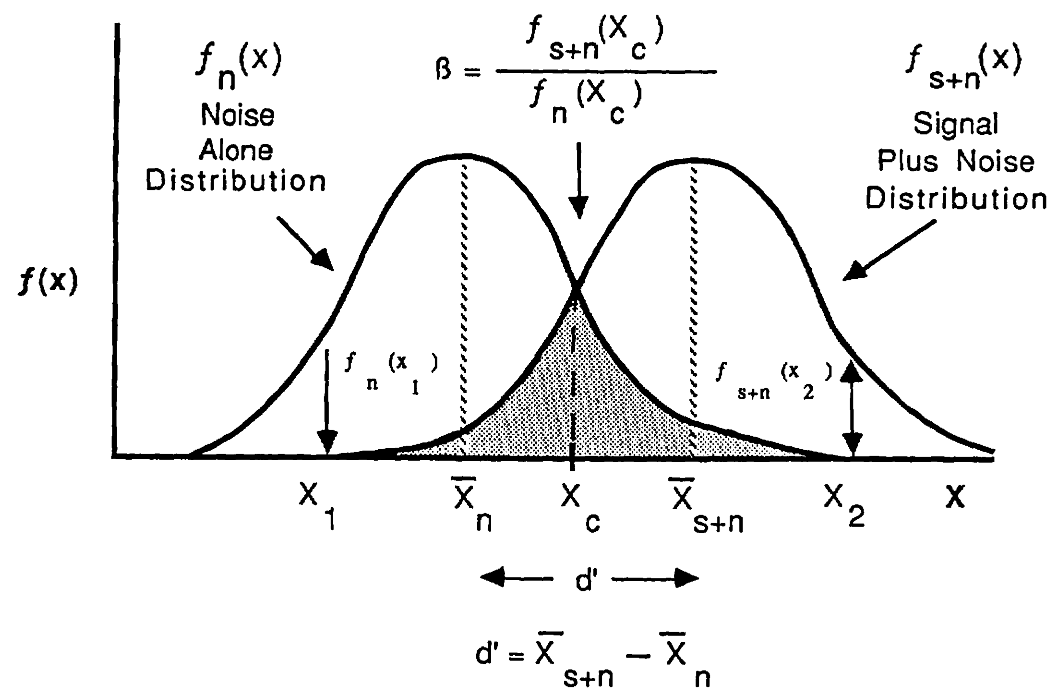

Figure 2–5 The Basic Paradigm of Signal Detection Theory.

Relating the Task to Memory In the production system model, information from both external and long term memory enters short term memory. When the information comes from long term memory, it is retrieved. When the information comes from external memory or the environment, it is perceived. Also, at any given time, items in short term memory can act as cues that trigger the retrieval of new items from long term memory or the goal-driven perception of stimuli from external memory. This latter process also results in the transfer of items into short term memory. Consequently, particular items enter short term memory in a way determined by the flow of information within the task.

If the human is to emit a task-related response at a particular time, the response must be in short term memory prior to its emission. Most responses are stored in long term memory, which means that appropriate memory cues must be presented in order to retrieve the response (Collins and Loftus, 1975). However, since the short term memory of a human is limited to only 7 ± 2 items at a time, much of the information in short term memory will be lost very quickly, and will be replaced by other information unless it is placed into long term memory.

The general process whereby information enters long term memory is determined to a great degree by the extent to which information is processed and by the organization of knowledge in long term memory. Consequently, the following discussion will introduce both of these topics in relation to memory.

The Levels of Processing Approach In the levels of processing approach (Craik and Lockhart, 1972), memory is a function of the extent to which information is processed. With more processing, an item becomes more likely to be retrieved at a later date. This approach does not distinguish between a sensory store, short term memory, and long term memory. Instead, it is held that memory is better defined by considering the amount (or level) of processing done on the information.

In this approach, a sensory store could be viewed as the output of lower level processing. These outputs consist of lines, shapes, and so on. Short term memory, then, consists of a finite group of objects which have been processed to a moderately greater level. Such objects are very superficially related (e.g., they are being processed at the same time to approximately the same degree). Items in long term memory have been extensively or deeply processed. "Deep processing" simply means that many associations have been built. Items with many associations are easier to retrieve and are remembered longer.

The levels of processing hypothesis has a simple relationship to the hierarchy of information referred to earlier in this chapter. The higher levels of the hierarchy correspond to more extensive processing. It can reasonably be assumed that the rate at which information is transferred will become lower when the processing is more extensive. This corresponds to the experimental findings, where progressively smaller rates of information transfer are observed for the sensory store, short term memory, and long term memory, respectively. McCormick (1976) cites research in which the rate at which information is transferred into long term memory is estimated as only .7 bits/sec. This transfer rate is vastly lower than the rate at which information enters the sensory store, and much less than that observed for entry into the short term memory.

The levels of processing approach to memory implies that memory is an active process. This conclusion leads one to predict that presenting messages in a way that elicits active processing will result in better retention of information. This point was noted by Kanouse and Hayes-Roth (1980) and is consistent with the findings of Bradshaw (1975). More specifically, active processing results in a highly organized arrangement of information within the brain.

Both the retrieval and storage of information involve complicated processes which modify or access this organized information. Much of memory theory has been refined by developing and studying computer simulation models of memory (see Quilliam, 1968; Anderson and Bower, 1973). These models evaluate the complex associative properties of memory by applying powerful concepts or techniques found within artificial intelligence, graph theory, operations research, etc., and will be briefly introduced below.

The Organization of Long-Term Memory Models of memory based on computer simulations typically describe memory with networks formed from interconnected nodes. Within these networks, nodes typically correspond to objects, while connections between nodes correspond to relations. For example, the concept, "dog" could be a node within a network. In this network, the dog node is connected to several other nodes by associative links. These link-node pairs connected to "dog" might include "IS A mammal," "HAS a name," or "IS OWNED by George." (The link, which in each case shows a relationship, is capitalized.) Adding other link-node pairs leads to the formation of a complex, structured network. In such a network, certain nodes can act as supersets. "Mammal" is an example of a superset, and "dog," "cat," etc. are subsets of this higher level node. Note that this concept of supersets and subsets directly corresponds to a hierarchical structure of information and, more specifically, of meaning.

In these models of memory, storage is the building of links between nodes. The building of links requires more processing than simply entering data into long term memory. In other words, the data first must be understood and encoded. To illustrate how the building of links can result in the storage of information, consider a hypothetical example where a certain human is unfamiliar with the concept "dog." If this human has stored the concept "mammal," "dog" could be stored by adding the link "IS A" between the new concept "dog" and the old concept "mammal." A more sophisticated conception of "dog" could then be built by building links to other nodes. Retrieval is conversely a search process, triggered by a stimulus or cue, that follows paths defined by these linked nodes. More specifically, the cue activates nodes which are linked to the cue (assuming that the cue is recognizable element also stored in long term memory). These nodes, in turn, activate other nodes, which leads to a spreading activation pattern throughout the network (Collins and Loftus, 1975). Returning to the above example, the concept "mammal" could be retrieved when the cue "dog" is presented, since "dog" and "mammal" are linked by the "IS A" relation.

Several factors affect the probability that information will be stored and retrieved. First, humans are better at remembering meaningful stimuli than nonmeaningful stimuli (Postman and Rau, 1957). Humans also remember items that evoke high levels of mental imagery better than those which evoke low levels of imagery (Paivio, Youille and Madigan, 1968). Similarly, increased repetition and active (rather than passive) assimilation of the information lead to greater retention. Other related factors include the effectiveness of mnemonics, and the importance of organization. Mnemonics involve the addition of information to the stored item (see Norman, 1976), as does the organizing of the information. When the network memory model is considered, these effects can easily be explained. Specifically, all of the above effects correspond to increasing the number of connections made between the object to be stored and other items in memory. When more connections are present, the object and cue are more likely to be connected, thereby increasing the likelihood of retrieval (Anderson and Reder, 1979).

Other important factors related to retrieval include possible interference effects, and the clustering phenomenon. Previously learned material can interfere with material that is being learned (this is called proactive interference), while recently learned material can interfere with the retrieval of previously learned material (this is retroactive interference). The clustering phenomenon refers to the tendency of humans to recall items in related groups. Both interference and clustering effects can be explained by the memory model presented here. Interference is related to the existence and rebuilding of links between objects in memory. Both types of interference can be expected when previously formed links must be modified; proactive interference might occur because certain links that were formed earlier describe associations that conflict with newly formed links; retroactive interference might occur because the newly formed links replace old links or describe conflicting associations. The clustering effect can be explained by the distance (in terms of intermediate linkages) between objects. When an object is recalled, other closely linked objects are more likely to be recalled than those more peripherally linked objects.

Another important retrieval-related effect is the reconstructive nature of retrieval. Human memory fills the blanks with information that seems likely. Information perceived as being likely most probably corresponds to closely linked elements within memory. As such, reconstructive effects can also be described with these network-based models.

A final retrieval-related factor is repression. In certain instances, individuals may repress unpleasant or disturbing memories, such as involvement in an accident. It is unclear how such effects should be modeled or how prevalent such effects are.

Models of Decision-Making

The decision-making process is very dependent upon both short term and long term memory. It may also be greatly influenced by external memory. Both points follow from the production system model (Newell and Simon, 1972), where short term memory is the register within which the decision-making process is performed. At the most basic level, a decision is simply the association, within short term memory, of an action with a condition. The decision-making process may, however, involve several more complicated, intermediate steps which lead to the final condition-action pair. More specifically, many decisions involve a large number of subdecisions. The process of making these subdecisions can be modeled as a special type of task with an associated problem space, as discussed in Chapter 11.

Other existing models of the decision-making process will be considered below to clarify some of the important aspects of decision-making.

Utility Theory Utility theory (see Savage, 1954) is the classic approach to modeling human decision-making behavior. Here, humans are assumed to make rational decisions, equivalent to those based upon mathematical calculations, in terms of the probabilities and utilities associated with a set of events. The utility associated with an event is described by some monotonically increasing function of the events outcome. For example, the utility of money might be a logarithmic function of value.

Nonprobablistic Approaches. Once the causes and effects of actions are known, rational decision-making can be initiated. In the simplest case, (as for responding to a hazard when risk is unknown) the likelihood of consequence-producing events is unknown. In this situation, nonprobablistic decision-making approaches can be applied. These nonprobablistic approaches evaluate those events which are associated with specific actions. This basic approach is summarized on the left side of Figure 2−6 for a scenario in which two actions (a_1, a_2) are compared. The actions will result in particular outcomes (U_{11}, U_{12}, U_{21}, U_{22}) that depend upon which of events (e_1, e_2) occur. As shown in Figure 2−6, within the utility matrix, if action a_1 is taken and event e_1 occurs, the outcome has a utility U_{11}.

Rational decisions can be made by comparing the consequences associated with particular actions. Alternative decision-making approaches include choosing the action that maximizes the maximum potential benefits (the "maximax" approach), choosing the action that minimizes the maximum potential loss (the "minimax" approach), or other heuristic approaches. One of the more standard of these alternative methods is to make decisions using regret values. "Regret" is quantified as the difference between the outcomes associated with the optimum action and those associated with any alternative action, given that a certain event takes place. Assuming that $U_{21} > U_{11}$ and that $U_{12} > U_{22}$, a regret matrix can be calculated for the situation modeled above, as also shown in Figure 2−6.

A common decision-making strategy used in this situation is to select the action with the minimum regret. Considering regret, along with the untransformed utilities, incorporates more information into the decision-making process, when simple strategies such as minimax are used.

It must be emphasized that the above discussion considers only the simplest type of decision-making, because the decision is made at a single stage. More complex decision-making tasks involve sequences of decisions, in which the decisions made earlier influence the conditions under which later decisions are made. Such decisions are called multi-stage decisions; collectively they form decision trees. Figure 2−7 illustrates a simple multistage decision tree. Note that the best decision at Stage 2 is entirely determined by the decision made at Stage 1. (This discussion is also simplified, because it does not consider the influences of uncertainty upon decision-making.)

Probablistic Approaches. When the probabilities associated with particular events are known, more sophisticated methods of evaluating risk can be applied. The nonprobablistic approaches only give weight to the events according to their outcomes. When the probabilities of the events are known, events can also be weighted by their probabability.

Utility Matrix

		events	
		e_1	e_2
actions	a_1	u_{11}	u_{12}
	a_2	u_{21}	u_{22}

Regret Matrix

		events	
		e_1	e_2
actions	a_1	$(u_{21} - u_{11})$	0
	a_2	0	$(u_{12} - u_{22})$

Figure 2–6 Example Utility and Regret Matrices.

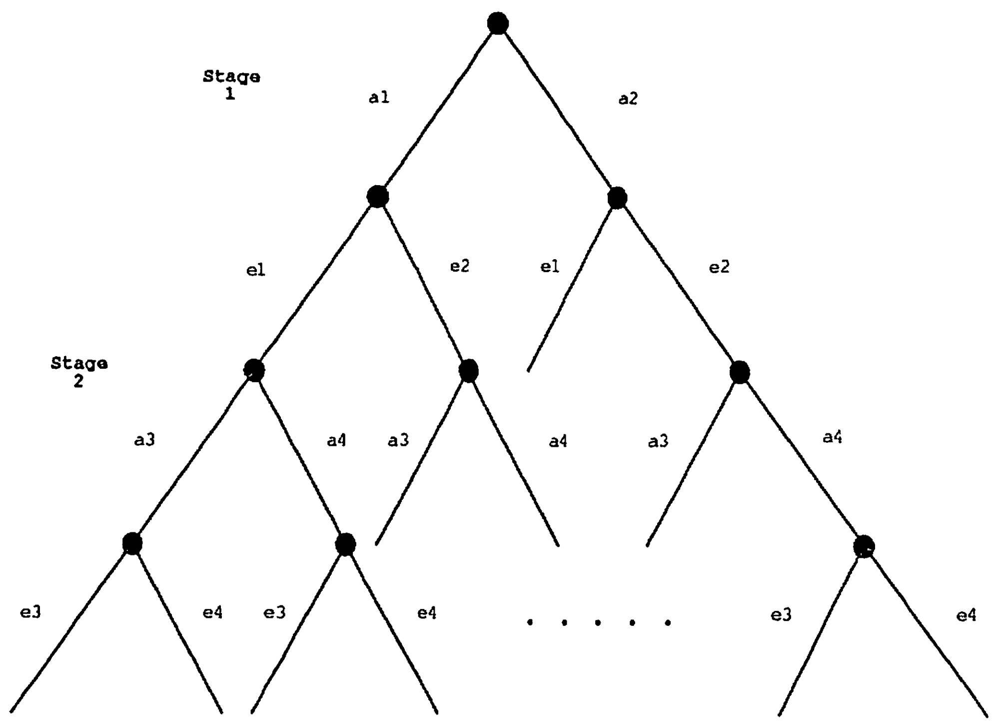

Figure 2–7 A Simple Multi-Stage Decision Tree.

The decision-making approaches discussed above are still applicable when the outcomes are weighted by their probability of occurrence. However, in this situation emphasis is generally placed on evaluating expected utility, where the expected utility of an action is the sum of the probablistically weighted utilities associated with particular events. When decisions are based on the expected utility of an action, the action with the highest expected utility is generally chosen, where the desirability of a decision is a monotonically increasing function of expected utility. The shape of the utility function can also reflect either risk-seeking or risk-aversive types of behavior; a convex function reflects risk-seeking behavior; a concave function reflects risk-aversive behavior. Certain, more complicated, utility functions may have regions that are concave and other regions that are convex.

Extensions. The expected utility model assumes that product users make decisions based upon the expected values of various courses of action. In other words, the product user chooses the alternative perceived to have the greatest expected utility. Such decision-making processes (which may be conceived of as decision trees) are easily modeled with production systems, since a group of rules can form a decision tree. A production system can also model the flow of information within a task, upon which the decision is based. This latter point is important because the particular task can determine the utility, at any given moment, of performing certain actions. For example, if a product user is under time pressure, saving time has a higher utility than it normally has.

Expected utility models say little about the limited decision-making ability of the human. In particular, the influences of workload are not explicitly considered. Under high workload conditions, the degradation of human performance is generally quite graceful, in that the less important elements are the first to deteriorate (McCormick, 1976). Such degradation could be predicted by a model which uses expected utility, if it is assumed that only those actions with very high utilities are performed. Since accidents are typically low probability events, and the antecedent events associated with accidents usually have a low correlation with accidents; safety-related actions might be neglected in situations where the workload is high.

The expected utility model also assumes that humans are able to consider probabilistic information in a rational way. In reality, humans do not tend to use probablistic information in the way defined by utility theory. Instead, humans often use heuristic methods to estimate probabilities (Tversky and Kahneman, 1974). For example, people tend to weight events as being more probable when they can remember a similar event taking place, or when the event happened to them. Even more interestingly, people do not always follow the logical ordering principles used in expected utility theory (Slovic et. al. 1977). For example, it is frequently found that if a person prefers alternative A over B, and alternative B over C, he may still prefer alternative C over A. These characteristics lead to a tendency toward biased and occasionally irrational decisions. Such heuristics used by the human correspond to particular rules, and could theoretically be included in a production system model of the human.

Personality and Stress-Related Factors Risk-taking models are commonly used to explain human decision-making and behavior. Such models generally assume that people make rational decisions based on the costs and benefits associated with various actions. Although it has been difficult to predict accidents by personality factors, and the theory of "accident proneness" seems to lack validity (Surry, 1968), certain individuals have many more accidents than the average.

Factors related to personality and to stress are also used to explain decision-making characteristics. Certain individuals may be more prone to behave in risky ways than others, and especially so when under great stress.

Models of Overt Responses

In regard to overt responses, the production system model discussed later in Chapter 11 can be used to make an interesting distinction between continuous and discrete tasks. Specifically, continuous tasks should be modeled with forward-chaining control strategies, while discrete tasks can be modeled with forward, backward, or mixed control strategies. This follows because continuous tasks are very dependent upon perceived feedback information, which corresponds to the bottom-up flow of information (or, in other words, to data-driven attention). Discrete tasks, on the other hand, are more likely to involve goal-driven attention.

Continuous Tasks For continuous tasks, perhaps the classical modeling approach is manual control theory. Here, the human is assumed to act as a servo error nulling device. In the simplest case, the human makes responses that lag behind error signals by a time constant that is assumed to equal his reaction time. The error signal to which the human responds is generally equal to the summed value of the human's response and the input signal which the human is trying to match. In other words, the human's response is added to the input signal to describe a new error level.

Performance of such a task can be elegantly modeled using fairly simple mathematics (Rouse, 1980). In discrete form, the human's response is simply:

$$y(t) = K * e(t-1)$$

where y(t) is the human's response at time t, K equals the gain or the ratio of the human's output to the error value, and e(t-1) equals the error observed one reaction time ago. The error at time t, e(t) then, is as follows:

$$e(t) = (e(t-1) + f(t) - y(t))$$

where f(t) equals the input signal at time t.

This general model can be extended to a great degree by adding additional terms which are hypothesized to correspond to lags induced by the dynamics of particular effectors, or lead terms corresponding to predictive information generated by the human that arises from the ability to respond to the rate of change in the error. Analytical solutions can also be derived for a wide variety of input functions f(t).

Discrete Tasks For discrete tasks, a sizable collection of data has been collected for the purpose of predicting performance times. Such data define what are called synthethic or predetermined time prediction systems. Common systems of this type include the Motion-Time-Measurement (MTM) system, the Work Factor system, and the Basic Motion Time System (Neibel, 1976). In such systems, commonly performed elemental motor tasks (which include reaching, grasping, moving objects, and applying pressure) are defined, and elemental times are assigned that depend upon task-related factors.

In Chapter 10, we will provide a more detailed summary of some of these traditional elemental tasks, along with ways of combining them to describe tasks.

ORGANIZING THE STRUCTURAL AND PROCEDURAL COMPONENTS

There are a number of structural and procedural components that are respectively associated with the processing of information or the behavior of the product, as discussed earlier in this chapter. Information processing models organize the components associated with the processing of information, while a number of tree-based models have been developed to model the behavior of products.

Variants of information processing models can be described as being 1) linear sequences of stages, 2) branching sequences of stages and events (a flowchart), 3) inputs which map to outputs (an input/output matrix), and 4) production systems. The basic information processing model discussed earlier in this chapter is an example of a model that emphasizes a linear sequence of stages. The following discussion will individually consider flowcharts, and input/output matrixes, as means for organizing these and other elements of the warning process. It will also introduce "Fault Tree Analysis" (FTA) and "Failure Modes and Effects Analysis" (FMEA) as means for describing a product's behavior. A much more extensive discussion of these topics can be found in Chapters 11 and 12.

A Flowchart-Based Approach

The human error model defined by Lawrence (1974) uses a flowchart to describe the sequential stages of human information processing. These stages are listed in a sequence on one axis of the flowchart, while feasible combinations of accidents, danger, and injury are listed on the other axis (see Figure 2– 8). An accident is defined as an unplanned event which may cause injury if danger and certain chance factors are present. A warning, then, is taken to be information which, when perceived, recognized, and responded to, eliminates the possibility of an accident. These concepts are represented in Figure 2–8 by the line corresponding to the flow of information from the work activity to the final, appropriate response. The appropriate response then leads to two possible events where no injury occurs.

The diagram also shows that breaking the flow of information at any particular information processing stage results in an error. Given certain chance factors, an error may then result in an accident; given other other chance factors and the presence of danger, the accident may then result in injury.

This model is quite useful because, within a simple conceptual framework, it shows the relationship between information, errors, accidents, and injuries. The model does not, however, consider the more detailed activity that takes place within these stages, nor does it recognize that particular information processing stages might be arranged as a tree or network when they occur within a task. This model also fails to consider how other factors might interact with or influence these information processing stages. In particular, the model does not consider the product or the ways in which the functions and malfunctions of a product affect human performance.

An Input/Output Matrix Approach

Table 2–3, adapted from McGuire (1980), displays a sequence of outputs that must be elicited from, or take place within the human for a warning to be effective. Each of these outputs are influenced by the specific factors defined by the communication theory model (i.e. factors related to the source, message, channel, receiver, and destination).

McGuire interrelates these factors within an Input/Output matrix, where one axis is specified by the specific factors defined by communication theory, and the other axis is specified by the stages of the information processing model. The factors defined by communication theory comprise the inputs to the communication process, while the stages of the information processing model comprise the outputs.

This modeling approach provides an elegant description of the steps involved in any particular communication. Like the flowchart model, however, it neither provides insight into how the input and output factors interact, or a detailed description of the product and its relation to safety.

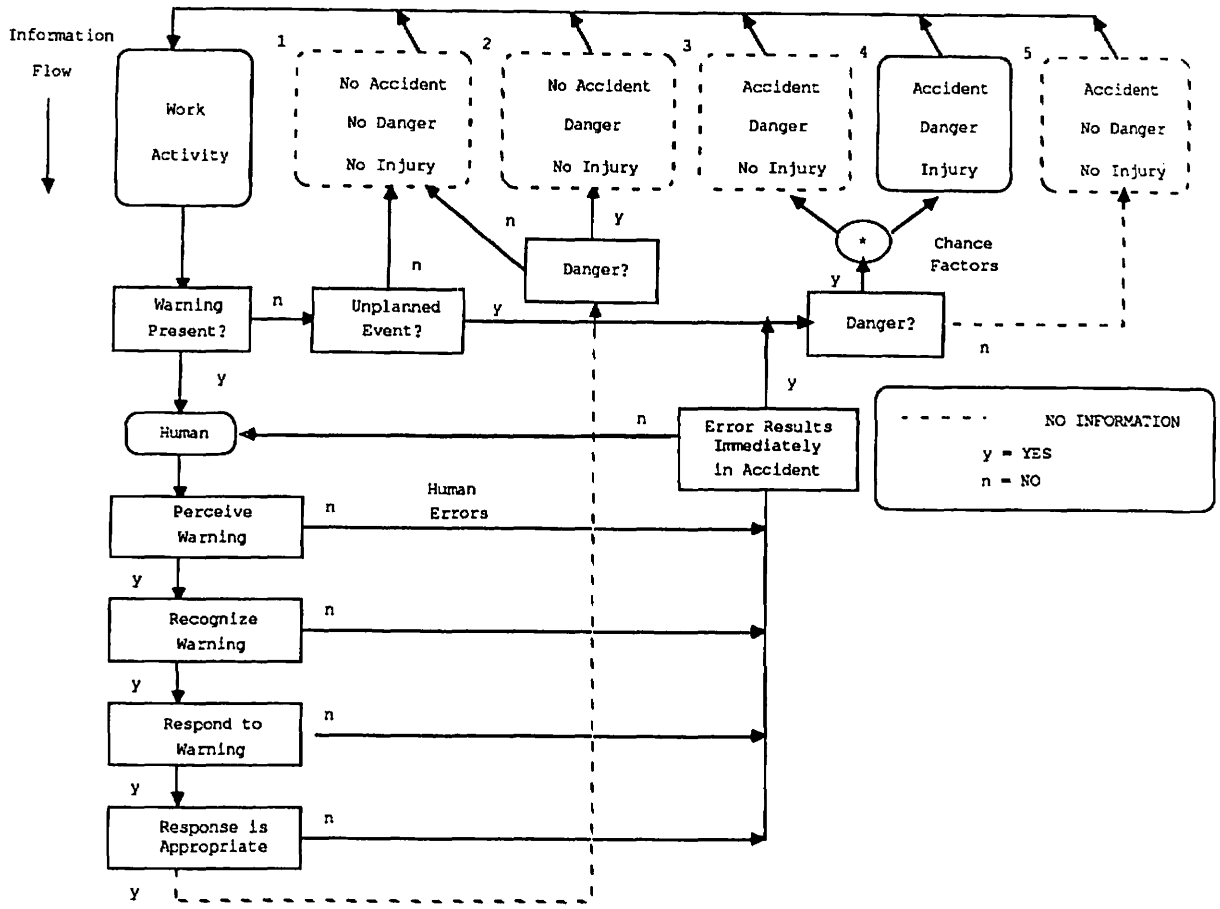

Figure 2-8 A Modified Version of Lawrence's Human Error Model.

Fault Tree Analysis and Failure Modes and Effects Analysis

Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA) are two related modeling approaches that are frequently applied to analyze the safety of products. In both FTA and FMEA, accidents are modeled as groups of logically related events that lead to an accident. (An event-based description is fundamentally different from a flow-based description, as will be expanded upon in Chapter 12.) The techniques differ only in that FTA analysis begins with the accident and works down to the events that could cause the accident, while FMEA begins with malfunctions and works up to the possible accidents caused by the malfunctions. Consequently, FTA is frequently referred to as a "top-down" approach, while FMEA is referred to as a "bottom-up" approach. It should also be noted that the inverse of both FTA and FMEA can be performed, where only the events that do not lead to accidents are considered. This results in the definition of positive trees.

Both FTA and FMEA can be very formal modeling techniques that strictly follow the rules of mathematical logic and probability theory. This is because both techniques define trees or networks wherein the considered events are interrelated using logic gates. Figure 2-9 shows a fault tree in which the top level event, A, can occur only if events B and C occur. As also

Table 2−3

The Communication-Persuasion Model, as adapted from McGuire 1980. (The five basic components form the x-axis of a matrix; the outputs form the y-axis.)

The five basic components of a warning are

1) the source of the message
2) the message itself
3) the channel by which the message is transmitted
4) the receiver of the message
5) the destination or type of behavior that the message aims to foster

To attain the goals of the warning, the following outputs within the receiver of the message must be elicited.

1) The receiver must be exposed to the message.
2) The receiver must attend to the message.
3) The receiver must react affectively to the message by expressing interest, liking, etc.
4) The receiver must comprehend the contents of the message.
5) The receiver must yield to the argument.
6) The argument and agreement must be stored and retained within the receiver.
7) Information search and retrieval must be performed when the message's information is pertinent.
8) The receiver must decide on an appropriate action on the basis of the retrieval.
9) The receiver must behave in accordance with his decision.
10) The appropriate behavior must be attached, in the receiver's mind, to the potential accident scene.

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shown, event B can occur only if event D or event E occurs. The logic gates are, of course, the nodes labeled OR and AND while the the events are the rectangles A, B, C, D, and E. Since the fault tree is defined entirely by the connected set of events and logic gates, it directly follows that the fault tree's behavior will be consistent with the laws of mathematical logic. Consequently, if conditional probabilities are assigned to each event, a fault tree can define the probabilities of higher-level events as a function of lower-level events. For example, the probability of event A in Figure 2−9 is equivalent to the probability that both events B and C occur. Note that Figure 2−9 could also have been developed during FMEA, or could have been a positive tree.

The techniques of FTA and FMEA are very useful during hazard analysis, assuming they are performed carefully. The derived trees (or networks) provide a clear, formal description of the hazard and allow the relative significance of particular hazards to be measured. These techniques are also very general. For example, such trees have been used to model human errors (Swain, 1963), organize safety principles (Johnson, 1975), evaluate product failures (Hammer, 1980; Dreissen, 1970) or specify elements of expert systems (Lehto, 1985).

Because of their very general nature, however, FTA and FMEA have seen less application than would be expected. The major reason for this limited application is that neither of these techniques contain any domain-specific knowledge. Such knowledge must be added during a laborious process wherein a product's designer or other individual builds such a

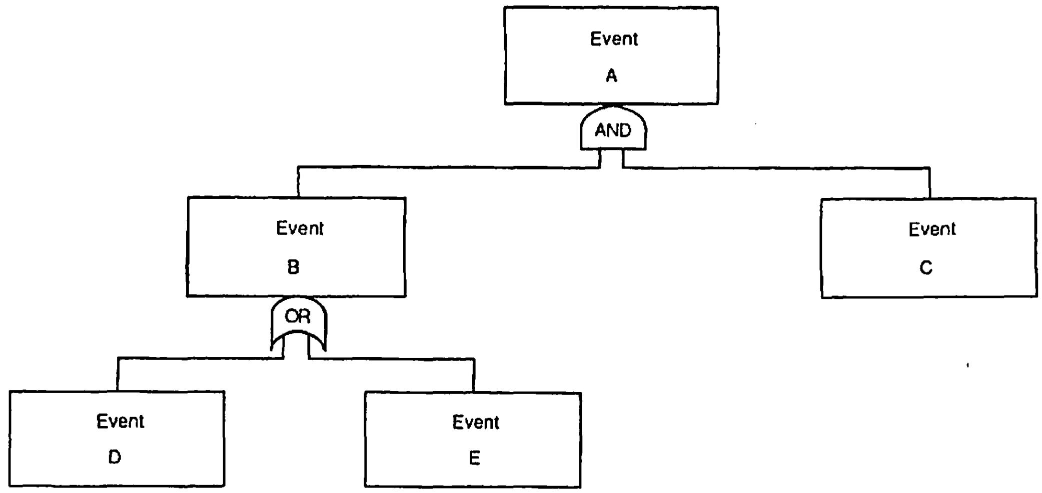

Figure 2–9 An Example of a Simple Fault Tree.

tree. Consequently, the trees and networks defined for a particular problem frequently have little applicability elsewhere. The great generality of FTA and FMEA, however, increases the potential of combining these techniques with other modeling approaches, as will be done in Chapters 11 and 12 (for other examples, see Johnson, 1975; Lehto, 1985).

SUMMARY

This chapter began by introducing some warning definitions. It became clear from this discussion why there is uncertainty as to what warnings are. Attention was then directed toward defining the structural and procedural components of the general communication process within which the transfer of safety information falls. The next section addressed some pertinent modeling approaches that could be applied at each processing stage. A finding of particular importance was the dependence of human performance on retrieving information from long term memory and perceiving information from external memory. Retrieval and perception are consequently emphasized in the further analysis of the communication process. The final section then explored some alternative ways of organizing these structural and procedural components, in a way directly applicable to safety.

We are now ready to consider some more specific aspects of the warning issue. The information processing approach outlined in this chapter provides the needed groundwork for analyzing the effectiveness of warnings, as explored in the immediately following section. More generally, the discussion also provides some needed background for developing operational approaches to describing, analyzing, and designing warnings, as explained in later sections.

SECTION II.

THE EFFECTIVENESS OF WARNINGS

This section consists of Chapters 3 through 6, and is specifically concerned with evaluating the effectiveness of warnings. These chapters will be of great interest and significant benefit to many professionals, including lawyers, psychologists, and engineers. Chapter 3 discusses the difficulties in evaluating effectiveness and provides a general approach to such evaluation. The next three chapters then consider particular aspects of warning effectiveness. Chapter 4 is concerned with the ability of warnings to attract attention, Chapter 5 with the comprehension of warnings, and Chapter 6 with the effects of warnings on memory, decisions, and actual behavior.

CHAPTER 3

A METHOD FOR EVALUATION OF EFFECTIVENESS

CHAPTER 3

A METHOD FOR EVALUATION OF EFFECTIVENESS

Imbedded within the legal concept of duty to warn is the assumption that the use of warnings makes products safer (see Philo, 1983). This legal doctrine seems to be consistent with the opinions of the general population. For example, McGuiness (1977) found that 84% of surveyed consumers felt that warning labels would reduce the incidence of lawnmower related accidents, and Ursic (1984) found that college students held positive attitudes in regard to safety of products with explicit warning labels. Various safety consultants (Cunitz, 1981; Peters, 1984a, 1984b; Middendorf, 1984) also advocate the extensive use of warning labels to increase safety.

This chapter lays the groundwork for the three following chapters which address specific effectiveness related issues. Primary emphasis is placed in these following chapters on evaluating the general effectiveness of what are broadly classified as being "warning labels" (as well as, signs, posters, or tags), rather than focusing on the general effectiveness of the more pure forms of "warnings." Less emphasis is placed on evaluating the relative effectiveness of particular label designs. It turns out, however, that many of the findings in the following chapter are also applicable to evaluating the effect of stimuli other than warning labels on performance; this includes aspects of task performance that have little to do with safety.

Within this particular chapter, the most substantial topics pertain to 1) the need for valid measures of effectiveness, and 2) the warning tree model. Each topic is discussed below.

THE NEED FOR VALID MEASURES

It has been shown that the provision of essential information to people while they perform a task can increase safety (as when markings are placed on roads, May and Wooller, 1973). However, it is unclear whether or not placing warnings labels on products makes them safer. One of the main reasons for this uncertainty is that few studies have attempted to evaluate the effectiveness of warning labels.

Warning labels often are arbitrarily assumed to be either effective or ineffective without adequate research upon which to base such assumptions, much like safety communication campaigns were automatically assumed to be effective in the 1960's (Haskins, 1969;

1970). The difficulty in assessing the effectiveness of warning labels is more profound than would be caused by a simple lack of research. Limited research does address particular aspects of warning effectiveness, but the existing studies are notable for their failure to measure effectiveness in terms of safety-related behavior or responses. The existing studies also focus on very small portions of the overall problem of effectiveness, and tend to ignore the larger and more practical issues.

The simple lack of relevant research is the easiest problem to remedy. A more difficult problem is associated with the measurement of effectiveness, as discussed below.

The Difficulty in Evaluation

As noted by Belbin (1956a; 1956b), behavioral responses (related to safety) may or may not be related to intervening measures such as recall, recognition, or knowledge. Consequently, the effectiveness of a given warning must be measured in terms of the change in behavior that its presence alone can produce. Ultimately, the research base may become adequate to describe the correlation between intervening measures and safety related behavior. However, in past research efforts, there has been no attempt to combine and/or organize the existing research findings, in a way that recognizes this need to evaluate behavioral responses when measuring the effectiveness of warnings.

The measurement of effectiveness is also complicated by the differing functions of the so-called warning labels. Many "warning labels" often perform persuasive or educational functions long in advance of when the task is performed, rather than performing alerting functions within the task. It is logical to assume that stimuli which effectively perform alerting functions might not be particularly effective as educational or persuasive tools, and so on.

Information that alerts the human to those task related conditions which require actions is likely to be essential, making the question of its general effectiveness tautological. Such information is often best provided by many types of stimuli which are usually much less explicit than a warning label, but which originate in task-related contexts. The relative effectiveness of particular modes of providing such information is an important open research question. The evaluation methodologies discussed in Chapter 10 provide an approach to measuring the relative effectiveness of particular modes of presentation.

The general effectiveness of warning labels is not obvious, because the persuasive or educational functions confounded within a "warning" type label are closely related to training and/or the provision of propaganda. As such, much of the attention in the following three chapters is directed to this topic.

A WARNING TREE MODEL

To influence safety-related behavior, warning information must successfully flow through several information processing stages within the human, as discussed in Chapter 2. An abstract model of this process is developed in this chapter that illustrates the tree-like process that determines whether or not a warning will be effective. This abstract model also associates receiver-, source-, channel-, message-, and task- related factors with the required outputs from the human during the successful transmission of information (see Figure 3 − 1).

In Figure 3 − 1, rectangles, except for the top two, correspond to required outputs from the human, the rounded rectangles correspond to components of the communication process (that

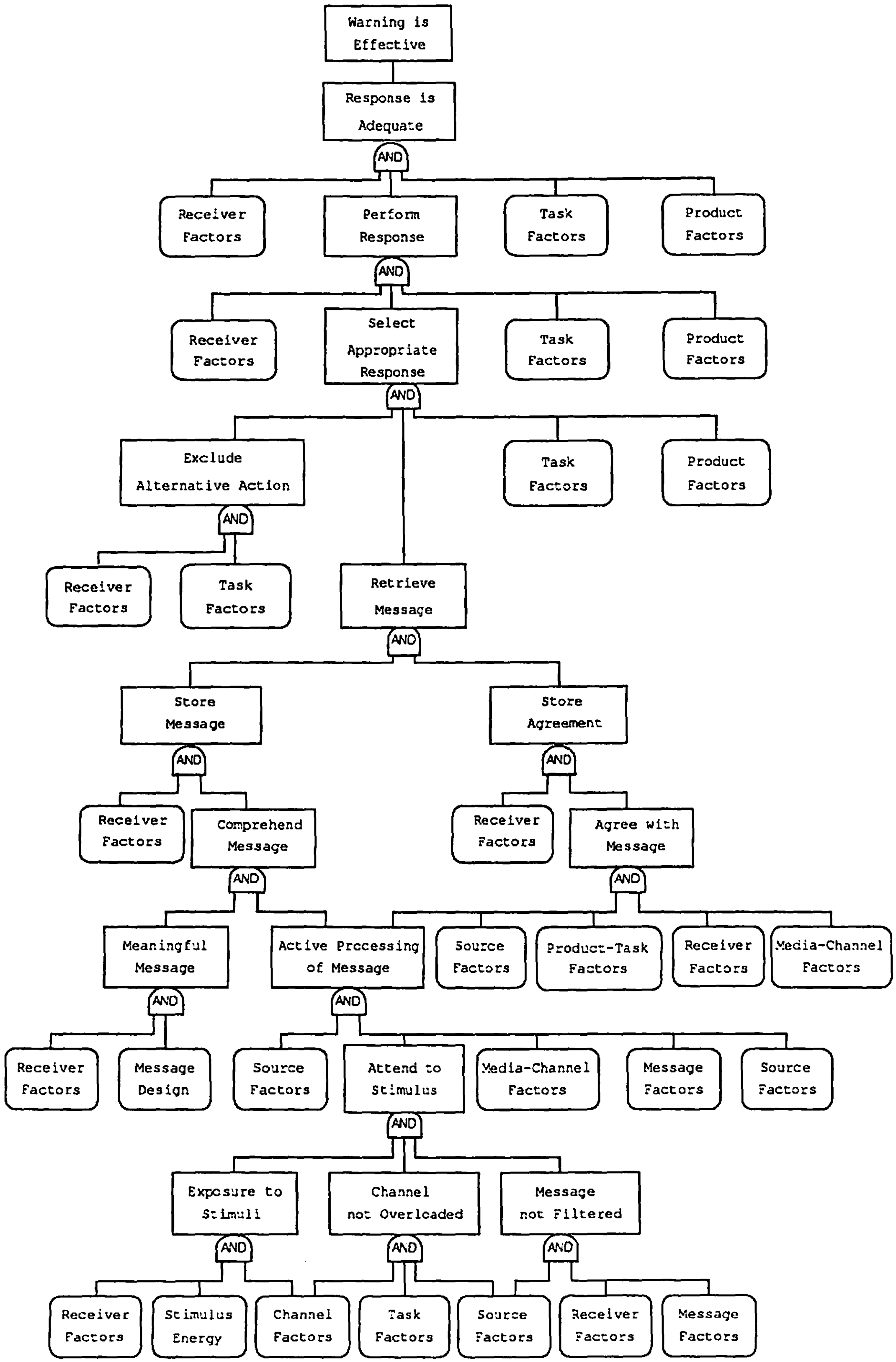

Figure 3 – 1 The General Warning Tree Information Processing Model.

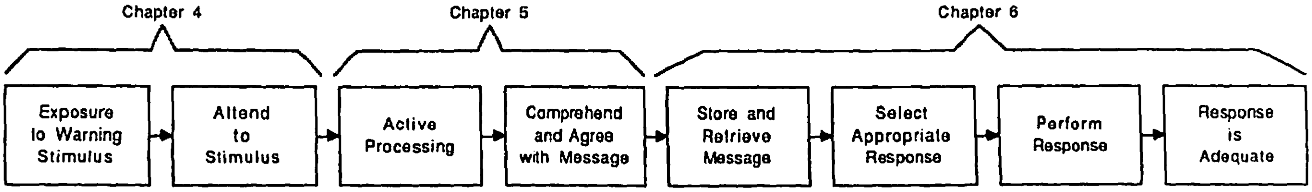

Figure 3-2 A Linear Sequence of the Outputs Within the Human.

is, receiver, source, channel, message, and task-related factors), and the lines indicate relationships.

The activity that takes place within the human when information is transmitted is quite complicated, as can be easily inferred from the modeling approach described in Chapter 11. Also, because of the recursive nature of many tasks, particular activities can occur in complicated sequences. The abstract version of the warning tree model shown in Figure 3-1 does not attempt to illustrate this complexity. Instead, it assumes that the activities which occur within the human are simply outputs elicited by a stimulus, and that these outputs occur in a simple linear sequence after a warning label is presented, as shown in Figure 3-2.

Although a linear sequence is not entirely accurate, it is easy to understand. A linear sequence is also consistent with other approaches used to model human activities related to the communication of warning information, such as those used by McGuire, (1980), Lawrence, (1974), and Deutsch, (1980).

A Probablistic Approach Within this linear sequence from exposure to an adequate response, the probability of eliciting each output from the human depends upon many factors. When it is assumed that each output of the human will be elicited with a certain conditional probability, such effects are easily modeled with diagrams along the lines of Figure 3-1.

The probablistic nature of the overall communication process has several important implications toward effectiveness. The most important one is that effectiveness can never be greater than that at the weakest (least effective) link in the sequence. (This point has also been noted by McGuire (1980) in a related context to explain why persuasive communications are frequently ineffective.) It also implies that failure can occur at several different points, and that effectiveness can be measured at each stage as the probability that a particular output will be elicited.

The criticality of the weakest link in the sequence becomes obvious, when some simple probability theory is considered. Specifically, the probability that a warning will influence behavior is equal to the product formed by multiplying every conditional probability within the sequence from exposure to an adequate response. Since the conditional probability of each output must be less than or equal to one, the product of the conditional probabilities will be less than the lowest conditional probability in the sequence (which is the probability of the weakest link).

For example, consider the hypothetical situation where, 1) 50% of the population read the warning, 2) 50% of those individuals understand the warning after reading it, 3) 50% of those individuals, who read and understood the warning, retain and retrieve the warning from memory, 4) 90% of those individuals act in accordance with the warning after they retrieve it, and 5) the action is sufficent to avoid the accident 90% of the time. This results in a probability of .10 that the warning will be effective.

The following three chapters will trace this flow of outputs, as might be elicited by a warning stimulus (see Figure 3 − 2). An extensive set of pertinent research will be considered in an attempt to evaluate the likelihood of eliciting each output or, equivalently, to evaluate the warning's effectiveness at each information processing stage. It will occasionally be helpful to consult Figure 3 − 1 during this discussion of effectiveness. For readers who desire information beyond that given in the text, those referenced sources that are especially applicable to the warning problem are available in abstracted form in *Warnings: Volume II. An Annotated Bibliography*.

CHAPTER 4

THE EFFECTIVENESS OF WARNINGS IN ELICITING ATTENTION

CHAPTER 4. CONTENTS

CHAPTER 4

THE EFFECTIVENESS OF WARNINGS IN ELICITING ATTENTION

In this chapter, emphasis is placed on evaluating the extent to which warnings can be expected to attract attention. The ability of warnings to attract attention comprises one partial measure of effectiveness. Other determinants of effectiveness are addressed in Chapters 5 and 6.

There are two basic conditions that must be satisfied if a warning message is to be attended: the human must be exposed to the stimulus, and the message must not be filtered away. The extent to which each of these conditions are satisfied determines the attention-related effectiveness of a warning. Many factors described by particular types of warnings and scenarios for warning influence this partial measure of effectiveness.

The following two major sections organize and evaluate the implications of these factors that influence the attention-related effectiveness of warnings. These sections are respectively entitled "The Exposure to Warnings," and "The Filtering of Warnings."

THE EXPOSURE TO WARNINGS

Exposure takes place when energy or material bearing stimuli contact a human's sensors. Stimulus exposure is a basic requirement for the correct perception of a message. However, stimuli may be incorrectly perceived as being present (a false alarm), even when exposure does not take place.

Much emphasis has been placed on stimulus exposure in litigation (Schwartz and Driver, 1983; Dorris and Purswell, 1978), and within warning-related standards. The tendency to emphasize exposure may be due to its fundamental position within the sequence of outputs elicited by warning-related stimuli. (Recall that Chapter 3 discusses this sequence.) In other words, the importance of exposure is more obvious than that of the activities that take place within the human. From a more pessimistic point of view, exposure might be emphasized because it is the easiest stage for which a warning label can be shown effective when simplistic approaches to evaluating effectiveness are used.

There is no evidence that supports a greater emphasis on exposure rather than on other factors. In the most related study found in this review, Lawrence (1974) found that people were not exposed to any form of warning in only 3 out of 405 accidents involving fatalities in 26 different gold mines. Nearly 70% of the human errors associated with these accidents were said to involve inadequate inspection techniques or underestimates of the hazard, illustrating the importance of factors other than simple exposure.

Stimulus Energy Level

With respect to exposure, one approach to evaluating effectiveness is to compare the energy level of the stimulus to upper and lower threshold values. This approach appears reasonable for two primary reasons. First, it has been clearly demonstrated in the literature related to psychophysics that the likelihood of perception increases with greater stimulus energy. (The dependence of perception on signal strength is a basic tenet of signal detection theory.) Second, this literature shows that increasing stimulus energy beyond certain limits will not increase the probability of perception. In fact, too strong a stimulus can be very stressful to the human, and can interfere with the perception of other stimuli.

There are commonly available sources of energy threshold criteria (McCormick, 1976; Van Cott and Kinkade, 1972; Woodson, 1981; Westinghouse, 1981; FMC, 1980). Criteria given in such sources will be summarized and critiqued in Chapter 9.

Modern labels and signs will generally meet these threshold criteria. Exceptions do occur, as found in regard to the poor nighttime legibility of guide signs (Hahn et al., 1977), or in regard to the low conspicuity of exit signs in smoky buildings (Lerner and Collins, 1983). The more pressing problem concerns the value of increasing energy levels well beyond threshold values. In a related context, it has been shown that increasing the signal strength of motorcycle warning lights has increased the perception of motorcycles by motorists (Ramsey and Brinkley, 1977). Similarly, the incorporation of a third braking signal on the rear of automobiles has reduced rear end collisions (Voevodsky, 1974). In a context closer to consumer products and warning labels, it has been shown that increasing the stimulus strength (brightness) of oven (range-top) warning lights did not have notable effects (Stefl, and Perensky, 1975). Other studies have evaluated the effects of sign reflectance (Dahlsted and Svenson, 1977; Hahn et al., 1977; Olson and Bernstein, 1979; Sivak et al., 1981; and others), among other factors, on the legibility distance of signs. These studies generally showed positive effects due to increased energy levels, but excessive reflectance can reduce the legibility of certain components of signs (such as text).

In conclusion, the existing research is inadequate to justify large indiscriminate increases in stimulus energy levels for warnings. There are, however, grounds for increasing energy levels above threshold values (such as the need to accommodate people with degraded sensory capabilities), but no conclusive research specifies the needed increment. Rules of thumb are, of course, available, such as designing for the 95th percentile human.

Stimulus Contact

In regard to exposure, the effectiveness of a warning label will normally be determined by whether or not the stimulus actually contacted the human's sensors, rather than by the amount of energy in the stimulus. One reason for emphasizing this more specific criteria is that in normal use nearly all labels will meet the energy threshold criteria. A second reason is that contact can be reasonably expected to follow the sequence of information flow within a task. The experimental study regarding oven safety by Stefl and Perensky (1975) supports this approach, since they found no effects on performance due to stimulus energy (brightness of the warning lights indicating a burner was on), while significant effects were explained by the location of the warning lights on the range-top and the type of ancillary task performed by the subjects.

It appears that stimuli, as defined by warning labels, will almost always contact human sensors at some point during the human's interaction with a product. In the most simplistic approach to measuring effectiveness, contact with warning stimuli is effective at any time, prior to its need, during the interaction between the product and the human. In terms of such criteria, a warning label is indeed effective. However, a more relevant question is whether such stimuli are likely to contact the human's sensors at critical times during the use of the product (not to mention elicit all of the other required outputs that occur within the human). Using this latter criteria, warning labels are much less likely to be effective, since attention will usually be focused elsewhere rather than on the label.

From the preceding paragraph, we see that there are two criteria for evaluating the effectiveness of contact with a stimulus. The first criteria defines effective exposure independently of the task, while the second criteria emphasizes the provision of stimuli at critical times within the task. The first criteria seems to be applicable only to the educational and persuasive functions of warning labels. This follows because a persuasive or educational function can theoretically be performed at any stage in the interaction between the human and product, including before use of the product commences. Applying this first criteria indicates that warning labels do effectively expose the human to educational or persuasive material. The first criteria, however, is not at all applicable to evaluating warning labels that perform alerting functions during a task. Instead, the second criteria must be applied.

There is available research that indicates warning labels will not meet the second criteria within many tasks (Dorris and Purswell, 1978). We also have performed work relevant to this point. In particular, we examined the warning labels on approximately one hundred commonly used consumer products. For these products, only a small percentage of the referred to hazards could be indicated at the critical point in product use by a warning label. (For example, a warning label on a tire cannot indicate that the tire is going flat while it is being used.) For the vast majority of products, however, the products themselves emit cues when the hazard is present. (For example, a tire in use may create a noticeable vibration and pull before going flat.)

Consequently, at the basic exposure-related level, warning labels frequently are an ineffective means of indicating hazard when compared to the cues directly provided by the product. This is not to say that warning labels never effectively expose the human to such information. Examples can be found where warning labels are integrated into a task, as when a lockout tag is placed next to an activated lockout, when switches are labeled on a control panel, or when a sign placed on a door warns you not to enter. Such examples, unfortunately, comprise a decreasing (and already too small) proportion of the warning labels currently placed on consumer products.

In conclusion, a warning label appears to unequivocally expose the human to educational and persuasive messages. On the other hand, a warning label is much less apt to expose the human to informative messages at critical times. Exposure, however, is only a small part of the problem. We shall now consider how effectively warning labels sustain attention.

THE FILTERING OF WARNINGS

Humans selectively attend to stimuli, ignoring irrelevant stimuli. A major difficulty in designing an effective warning label is to design it so that it will not be filtered out. At one level, stimuli are filtered away because of exposure-related factors. When this occurs, the stimulus's energy is often insufficient to overcome the effects of noise and other stronger stimuli. In other words, the stimulus-orienting response is not evoked. This problem, as noted above, has the potential to be solved by increasing stimulus energy. A second, more complicated, problem is to determine when and how much warning information is filtered out, as a result of receiver-dependent and task-dependent characteristics.

Several interesting experiments and studies have addressed the filtering of written warnings. They have addressed two important questions: 1) What proportion of people actually pay attention to the warning after being exposed to it?, and 2) Under what conditions do they attend to warnings?

Do People Filter Warnings?

The first experiment considered here was reported by Dorris and Purswell (1977). In this experiment, 100 students performed a hammering task. Three types of warning labels were placed on the hammer, one of which was the warning label supplied by the manufacturer. The other two labels directed the subjects not to use the hammer. Interestingly, no subjects noticed the labels. In a second experiment, Wright et al. (1982) studied 52 subjects using 60 different consumer products. It was found that, 34% of the time, subjects stated they would not read any of the instructions that came with a product; 53% of the time the subjects said they would read all the instructions. A third experiment, related to drug warnings, was performed by Wright (1979). As part of the experiment, an in-store sign that warned of the dangers associated with antacids was placed on the antacid display counter. Only 9% of the regular antacid buyers were observed to spend time reading the sign.

Several additional experiments indicate that even traffic signs are frequently filtered. Among these studies, Ruchel and Folkman (1965) found that 15% to 30% of motorists did not recall seeing forest fire safety signs. Shinar and Drory (1983) found that the average recall by motorists of the last two road signs they passed (they were stopped 200 meters away from the signs) was 4.5% and 16.5% during the day and night respectively. Johansson and Backlund (1970) found that sign recall levels varied from 21% to 79% for motorists stopped 710 meters after passing a traffic sign. Most interestingly, Summula and Naatanen (1974) found that motorists failed to notice only 2.95% of the passed signs, when they were explicitly asked to look and then report the signs to an investigator in the back seat of the car.

Other estimates of the extent to which people read warning labels are provided by surveys wherein claimed reading behavior is tabulated. In a survey of 4012 households, Tokuhata et al. (1976) compared accident-free households to households whose members had recently incurred product-related injuries. The members of both sets of households claimed that they read labels approximately 80% of the time. Related data are given by Schwartz (1980), who summarized an FDA survey performed in 1974. In this survey, 70% of the respondents said they would pay attention to the price label on food items. Only 41% of the respondents said they would pay attention to the ingredients; 26% said they would pay attention to information concerning additives and preservatives, and 26% said they would pay attention to information concerning nutritional value.

Determinants of Filtering

The above research indicates that warnings will be filtered out in many situations. The studies of traffic signs provide the clearest evidence of filtering, since Summula and Naatanen (1974) showed that the information available on the signs can be perceived if the subjects so desire. It should be emphasized, that in every study where the behavior of people was actually observed, very significant filtering took place. Even the claimed reading behavior was quite low in the study by Wright et al., (1982). The highest level of claimed reading behavior was obtained in the survey by Tokuhata et al. (1976). This study, however, showed no difference between the accident and accident-free groups, implying that either the responses were biased or that reading labels had little safety related influence.

These data, as discussed above, do not, however, determine when warnings will be attended rather than filtered. Many factors can theoretically influence filtering. Among such factors are the perceived risk, information overload, noise, conspicuity, and message tone. Some of the available research addressing the influence of these factors is summarized below.

Perceived Risk Effects When the overall task performed by the human is considered, it becomes apparent that warnings may be ignored if they seem to be irrelevant to task performance. Experienced users might be more prone to ignore warning-related information because of past, benign experience, in which accidents rarely occur (Robinson, 1977). Along these lines, Slovic et al. (1978) hypothesize that people exhibit rational forms of behavior in which they ignore safety related advice regarding low probability events. The following paragraphs will summarize the existing research that addresses the relationship between risk perception and the tendency to read warning labels.

Wright et al. (1982), in the experiment discussed above, investigated product-related factors that affected instruction-reading behavior. In this study, when people were less familiar with the product, and the product was perceived to be complex, unsafe, or expensive, they were more likely to read the product's instructions. For example, 76.6% of the subjects said they would read all the instructions for complex electrical products, and 17.1% said they would read no instructions. For non-electrical tools, 41.8% of subjects said they would read all the instructions and 47.9% said they would read no instructions. Complexity and frequency of use correlated significantly with the propensity to read instructions ($r=.473$ for the former and $r=-.24$ for the latter). Similarly, Johansson and Backlund (1970) (also referred to earlier) found that the best recall of traffic signs occurred for those signs the people perceived as being important. In particular, the best recall of signs was for signs that indicated speed limits or the presence of police control. The worst recall was for signs that indicated the presence of wild animals, general danger, or pedestrian crossings.

Godfrey et al. (1983), in a study of household products, found that undergraduate students looked at warnings more often when the product was perceived as being hazardous. The correlation between a perceived hazard and perusal of the warning label was 0.53. They also found an interaction between a perceived level of hazard and familiarity with the product as follows: When hazard was perceived to be great, the subject's familiarity with the product did not change the likelihood that he would look at the warning. However, when the hazard was perceived to be unlikely, the probability that the subjects would look at the warning was lower for products with a high familiarity rating than for products with low familiarity ratings.

Information Overload Effects The amount of information provided on a warning label is another factor which may influence the filtering of information, as is the extent to which other information processing takes place. Presenting a large amount of information may result in information overload (Jacoby, 1977). A similar point was made by Dorris et al. (1977), who distinguished information as being the useable portion of data, and noted that too much data degrades performance. In particular, Jacoby et al. (1974) found a curvi-linear relationship between the amount of information provided to housewives and the "correctness" of their buying decisions. Either too much or too little information resulted in poorer decisions. Jacoby concludes that there are many unanswered questions regarding the desirable types, amounts, and organization of the information provided to consumers.

Some evidence was found in this review showing that people prefer short non-redundant warnings. Specifically, Wogalter, et al. (1985) found that their subjects frequently rated warning labels as being more effective when information was left out. The two types of statements, of which elimination was commonly approved, either defined the hazard or specified consequences. These effects occurred when either of the two statements could easily be inferred from the remainder of the warning label. Although such effects do not demonstrate that the subjects were suffering from information overload, the results show that adding obvious or redundant information to warning labels, as appears to be required by certain legal guidelines regarding effectiveness, might be viewed negatively by people.

A few other studies were found in this review that have bearing on this topic. Morris and Kanouse (1980) increased the amount of information provided by drug package inserts that contained warnings, along with other information. The subjects were college students. Here, increased amounts of information resulted in no significant changes in performance. It is possible, however, that if the subjects would have been members of the general population (who tend to have lower reading skills than college students) adverse effects would have been found. Gordon (1981) investigated the effects of increasing the information on highway guide signs. It was found that including non-guidance information on signs did not increase reaction times to the signs, while the presence of additional signs did increase reaction times. The reaction times were the greatest when the information added to the sign was missing, since additional navigational decisions were thereby required. Guide signs, however, tend to bear small amounts of nonredundant information that is directly relevant to the driving task. Consequently, it is difficult to determine whether this experiment has implications toward the topic of information overload.

It is unclear how much information, when presented on a warning label, will result in information overload. However, there is evidence that increasing the number of items on a label can cause a division of processing time among the items presented (Scammon, 1977). This study by Scammon involved increasing the number of independent items or dimensions by which two products could be compared. The labels gave nutritional information to the demographically representative sample of Californians. It was found that the subjects remembered important product related information better, if fewer dimensions or items were listed. They also tended to remember different items, depending upon the number of dimensions.

In another related study, Elman and Killebrew (1978) evaluated methods for increasing the use of seat belts. In the first phase of their experiment, they found that presenting an unrelated safety message actually decreased the use of seat belts. However, the significance of this finding is difficult to determine, since in later phases of the experiment this effect was not demonstrated.

Noise Effects Presenting many different messages also corresponds to increasing the noise level, since stimuli other than those relevant at a particular time must be screened out. Noise induced by roadside advertisements (or other non-traffic-related signs) has been shown to influence the perception of traffic signs (Holahan, 1977; Boersema and Zwaga 1985). Holahan was able to show that traffic accidents at a "stop sign" increased with the presence of commercial signs. Boersema and Zwaga, in an experimental study, showed that the presence of advertisments interfered with the perception of routing signs.

Noise has also been evaluated in other settings. For example, Lerner and Collins (1983) found that the presence of smoke significantly degraded the visibility of exit signs. Although these effects are primarily related to exposure, similar effects on filtering might be found. Other studies which considered noise as a factor were performed by Noyes (1980) and Hoffman and MacDonald (1980). Noyes found that the presence of other words on maps could act as noise that reduced the probability of perception. Hoffman and MacDonald performed more specific experimentation regarding traffic signs. They found that the addition of symbolic distractors interfered more with symbolic signs than with verbal signs, while verbal distractors interfered more with verbal signs than with symbolic signs. However, Hoffman and MacDonald conclude that the results were not practically significant.

Warnings themselves can become noise. For example, Loomis and Porter (1982) discusses some of the negative experiences of pilots with ground proximity warning systems (GPWS). Although the prevention of accidents by the GPWS's has been documented, there has been a problem with false alarms, to the extent that certain pilots have been quoted as wondering whether the cure is worse than the disease. It has also been shown that certain warnings with very high conspicuity (voice warnings in airplanes) actually have distracting effects (Wheale, 1983) that may degrade pilot performance. No studies have yet explored whether warning labels can act as noise, but the possibility is great.

If a warning label acts as noise, it is less likely that it will directly interfere with performance than an auditory stimulus (as those auditory signals described above do), because a warning label should be easy to filter out. A more troublesome possibility is that habituation will occur. In other words, since the warning is seldom relevant, it is ignored. Similar points were made by Robinson (1977), and evidence that may indicate such effects for signs is given by Manstead and Lee (1979). They specifically found that a new sign asking motorists to act as witnesses to traffic accidents was more effective for drivers than was an older version, while the old sign continued to be more effective for pedestrians. Manstead and Lee conclude that the new sign was probably more likely to be noticed by the drivers. The greater tendency to notice the new sign might be related to habituation, wherein the old sign lost its attention-getting value. Such an effect would not be unexpected, because a witness appeal sign is unlikely to be frequently perceived as being relevant by drivers.

Conspicuity Effects Another factor which hypothetically influences the filtering of warnings is their conspicuity. A surprising finding was that no research was found demonstrating that conspicuous warning labels were less likely to be filtered than inconspicuous labels. Of course, several studies have shown that different factors can influence the perception of safety signs. For example, research indicates that nonverbal symbols, as opposed to alphabetical symbols can be perceived at greater distances (Jacobs et al. 1975), or that they are less sensitive to the influences of degradation.

On the other hand, another researcher showed no significant effect due to the methods of highlighting warnings in assembly instructions (Zlotnik, 1982). A more consistent general conclusion is that auditory stimuli are less easy to filter than visual stimuli (McCormick, 1976; Woodson, 1981; and many others).

Warning (Message) Tone Effects Another factor which hypothetically affects the filtering of warnings is the tone of the message. More direct, explicit, or frightening warning labels for lawnmowers were selected as most effective by consumers (McGuinness, 1977). Modifying messages along these, or similar, lines alters the tone of the message. However, no studies were found in this review that demonstrated the influences of message tone on the filtering of warning labels. Several related studies were found that provided somewhat ambiguous findings.

Sell (1977), in a review of safety propaganda (posters are emphasized), cites the following: a study where industrial workers preferred a serious as opposed to a humorous safety poster (Harper and Kalton, 1966); a study where drivers cited frightening posters as more effective than non-frightening ones (Sheppard, 1970); a study where low threat dental hygiene information had a greater positive influence on teeth cleaning behavior and visits to the dentist than did high threat information (Janis and Fesbach (1953); a study where high fear appeal was more convincing for subjects who rarely drive than for regular drivers (Berkowitz and Cottingham, 1960); and a study where smokers given the lowest fear arousal message were most likely to state they were going to quit smoking (Levanthal and Niles, 1964). Similarly, Evans et al. (1970) found that high fear arousal messages induced changes in reported dental hygiene related behavior in students, but had little influence on actual behavior. Sell concludes that safety posters should not involve horror, or be negative or general. The rationale for his conclusions was that 1) horror incites shock, but has no lasting effects, 2) that negative information simply shows incorrect ways of behaving, and 3) that general information is of little use because all people think they behave safely.

Weinstein (1979) compared college students who did and did not take advantage of an opportunity to obtain information regarding cancer rates. Both the seekers and nonseekers of information tended to prefer threatening messages. Lack of concern was cited as the primary reason individuals did not ask for information. Also, the choice of threatening as opposed to reassuring messages depended upon the students' personal view regarding seriousness. Those students who thought cancer was a serious threat were most likely to prefer the threatening message.

Conclusions Regarding Filtering

The above research indicates that the filtering of warning information is a complex process that depends upon the receiver, and that, in many situations, people are unlikely to read warning labels. This failure to observe the reading of warning labels could have occurred for many different reasons. Two very simple reasons might be that consumers feel that they already know the information or that they view the warning label as being irrelevant. The following discussion will individually consider the implications of the findings just reported regarding the effects of perceived risk, information overload, noise, conspicuity, and message tone.

Perceived Risk Implications The earlier summarized research indicates that people are more likely to attend to warnings placed on products perceived as being dangerous. Extending this logic, if the perception of danger exactly corresponds to the actual danger associated with a product, warning labels on dangerous products are likely to be attended, making those particular labels effective. Conversely, if the perception of danger does not correspond to actual danger, warning labels are much less likely to be effective.

Unfortunately, the perception of product-related danger by humans does not correspond well to objectively measured danger. Dorris and Tabrizi (1978) reported finding a correlation of only 0.03 between the perceived hazard (of a group of 200 middle class to upper middle class respondents) and the National Electronic Injury Surveillance System (NEISS) ratings of hazard for sixteen consumer products. Dunn (1972) found that the ratings of risk by experienced chain saw operators did not significantly correlate with the objective measures of risk obtained by analyzing 250 chain saw related accidents. Lichtenstein et al. (1978), in a very extensive study, found large biases in the judged frequencies of death as opposed to the measured frequencies. The evaluated people comprised a large group of college students and members of the League of Women Voters, and 41 causes of death were evaluated, including diseases, accidents, homicide, suicide, and natural causes. Martin and Heimstra (1973) performed a study in which it was shown that children provided significantly higher estimates of risk than did the experts. The most positive findings are reported by Rethans (1980), who evaluated the subjective perception of the risk presented by 29 products chosen to span the frequency range of CPSC data and the severity range of NEISS data. Rethans found a correlation of 0.5 between subjective ratings of severity and the NEISS data. He also found a correlation of 0.72 between subjective ratings of frequency and the Consumer Product Safety Commission (CPSC) data. Even these correlations reflect very significant discrepancies between objective and subjective measures of risk.

Slovic et al. (1980) discusses the many difficulties humans have in interpreting risk-related information. Individuals tend to use heuristics, rather than probabilistic reasoning to interpret hazards, which leads to serious biases and inaccurate perceptions of risk. These inaccurate perceptions are especially apparent for improbable events, and may be influenced by the media. For example, Combs and Slovic (1979) found that the discrepancies between actual and perceived frequencies of death (Lichtenstein, et al., 1978) corresponded to biases found in newspaper reporting, wherein violent catastrophical events are over-reported. Individuals also tend to be excessively optimistic; Slovic et al. (1980) notes that the majority of individuals feel that their chance of having an accident is lower than average.

Godfrey et al.'s (1983) finding, that the perceived hazard associated with a product tended to decrease with increased familiarity with the product, is consistent with the conclusions of Slovic et al. (1980). Perceived hazard appears to be based upon personal, limited experience with the product (or similar products) rather than probabilistic thinking based upon existing data on accidents. This follows from the availability heuristic which is frequently used by humans to estimate risks (Tversky and Kahneman, 1974). In other words, people tend to give higher probabilities to events they can easily remember (especially those from personal experience). Improbable events are by definition unlikely to happen to any given individual. Consequently, they tend not to be available in memory.

The above discussion is somewhat pessimistic, as it implies that risk perceptions tend to be biased; thereby implying that warnings labels are likely to be filtered even when they are important. The second point follows from the first point, both because the evidence indicates that warning labels are frequently filtered, and because they are most likely to be filtered when the perceived risk is low (when perceived risk is low, the danger may well be high). If risk perceptions could be easily modified (that is, by eliminating the biases), a more positive conclusion would result. Hypothetically, people would continue to read warning labels when they perceive the risk to be high, but their perceptions would be more accurate. Therefore, there would be less filtering of important warnings. The feasibility of modifying risk perception will be considered when we reach the section regarding decision-making in Chapter 6.

Information Overload Implications The referred to research indicated that increasing the number of messages on a product, by including warning labels. might lead to a division of the human's information processing resources. If so, presenting a long list of messages with a warning label could be quite counterproductive. This problem would be most serious when messages vary extensively in importance, since processing the less relevant messages may consume resources that should be allotted to the important messages.

Kanouse and Hayes-Roth (1980) emphasize the need for a balance between information overload and the presentation of relevant information. Current research only indicates that such balancing is required. In order to attain such a balance, the existing research must be significantly extended. It is likely that the findings will be very specific to particular categories of people and tasks. Also, the findings might be quantifiable in terms of reading skills and task demands.

Noise Implications The above research indicated that 1) noise might influence the perception of warning labels and 2) that warning themselves can become noise. Further research is justified regarding both possibilities, because of their important implications. Further research would include determining which factors act as noise and to what extent of significance; and also determining when warnings themselves act as noise. If particular warning labels do act as noise, their presence may actually be counterproductive to safety. Other work is suggested in conjunction with isolating the influence of false alarms provided by warnings. Signal detection theory provides a framework for such research, and clearly implies that the presence of false alarms will increase the tendency to filter stimuli.

Conspicuity Implications Evaluating the effects of conspicuity on the filtering of warning labels is a fertile area for research. The earlier discussion on contact with the stimulus, wherein the integration of the warning label into the task is emphasized, has major implications toward such research. In particular, emphasis should be placed on evaluating the relative importance of integrating a message into the flow of task related information as opposed to increasing energy levels or conspicuity. This is a research topic of pressing interest.

It should also be realized that there is a tradeoff between the costs and benefits of conspicuity. A stimulus can actually be too conspicuous. One reason for avoiding over-conspicuous warning labels is that they can be aesthetically displeasing. As Coates (1973) notes, very large deviations from expected values (as in severe color or brightness contrasts) can be unpleasant. Hypothetically, over-conspicuous warning labels might be removed from products by consumers for aesthetic reasons or might induce resistance. Although certain surveyed consumers have been found to prefer explicit, very conspicuous warnings (McGuinness, 1977), other consumers have been motivated (by such warnings) to acts such as disabling seat belt interlock systems (Robertson, 1975). Further investigation would be helpful to clarify this topic.

A second reason for avoiding over-conspicuous warning labels is that they may attract unwarranted attention or interfere with other functions of the product. An interesting example is given by Schneider (1977) where conspicuous writing (DANGER-POISON) or symbols such as the skull and crossbones caused the containers they were placed upon to become more attractive to young (42 to 66 months old) children. Although this study did not rigorously demonstrate that less conspicuous warning labels would necessarily be better, it demonstrates the complexity of the problem and the need for further investigation. A less relevant example is the study by Ramsey and Brinkley (1977). Here, the provision of large warning lights increased the conspicuity of motorcycles, but it was concluded that the size of the lights might interfere with the acceptable projection of the headlight onto the driving surface.

Warning (Message) Tone Implications While worth listing as a topic of potential interest, few substantive implications could be derived from the literature review, regarding the effects of message tone on filtering. It is unclear whether the shortage of information, is due to a lack of research, the factor's lack of significance, or simply its complexity.

Having completed this chapter's consideration of the attention eliciting properties of warnings, the book proceeds to the next requirement in the sequence which is requisite for warning effectiveness to be a reality; that is, we will consider the comprehension of warning labels.

CHAPTER 5

THE EFFECTIVENESS OF WARNINGS IN ELICITING COMPREHENSION

CHAPTER 5. CONTENTS

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THE EFFECTIVENESS OF WARNINGS IN ELICITING COMPREHENSION

Simon and Hayes (1976) provide an interesting discussion of comprehension, much along the lines of Chapter 11, and state that the following of instructions is one of the most difficult tasks people ordinarily face. This chapter will show that even the basic comprehension of symbols placed on warning labels is a difficult task for many people.

For comprehension to occur, attention must result in active processing and the message must be meaningful. Agreement with the message can also be desirable. The discussion begins with a brief introduction to the need for eliciting active processing and agreement with warning messages. Major emphasis is then placed on evaluating the meaningfulness of symbols used in warnings. During this latter discussion, many different types of symbols are evaluated in terms of several different criteria.

THE NEED FOR ACTIVE PROCESSING

For quite some time, psychologists have understood that the active processing of information leads to better comprehension than does passive processing. Active processing by the receiver influences the receiver's agreement with, and comprehension of, the message. In other words, the receiver must actively process the message after it attracts attention, if it is to either be comprehended or agreed with.

No information was found that specifically addressed the extent to which warning labels elicit active processing within tasks. The earlier discussion, on the filtering of warning labels, does imply that the active processing of warnings is frequently unlikely to take place. In fact, for the earlier referenced studies, the filtering of warning labels can not be distinguished from a failure of the warning labels to elicit active processing. Consequently, the earlier discussion regarding the filtering of warnings is also relevant here.

The studies by Ursic (1984) and McGuinness (1977) indicate that warning labels might elicit active processing, since in both studies the majority of subjects gave positive ratings to warning labels. Neither study, however, was performed in a task related context.

The most relevant study found was performed by Wright (1979) in which the in-store behavior of shoppers was observed. Here, 37% of shoppers spent time reading an in-store warning sign (an antacid drug warning), shortly after viewing a television commercial that explicitly told them to read package warnings in the store. Only 11% of those shoppers who did not view the television commercial spent time reading the in-store warning signs. These latter results demonstrate that the potential for eliciting active processing can be modified by factors external to the warning label (Wright emphasizes that effects due to television viewing are likely to be transient). They also clearly demonstrate the importance of observing warning related behavior in a task related context, as was also emphasized earlier in regard to exposure and filtering.

AGREEMENT WITH WARNING MESSAGES

Related to comprehension is the need for agreement with the message. The need for agreement with messages before they are responded to has been demonstrated by a large number of studies (McGuire, 1980). In regard to safety, Robertson (1976) provides relevant examples regarding messages intended to increase seat belt wearing behavior.

Several studies have evaluated methods of increasing agreement with safety or health related messages. Kanouse and Hayes-Roth (1980) cite some of these studies in which elaborating a message by specifying action-oriented instructions increased the acceptance of health recommendations. Source effects can also influence the potential for agreeing with a message. If the message comes from a source perceived as knowledgeable and trustworthy, the message is more likely to be viewed as credible (see McGuire, 1980). Other source-related effects are implied in a study by Chaiken (1976). Here, videotaped, as opposed to written messages, were more persuasive when the conveyed material was easy to understand. The opposite effect was noted when the material was difficult.

THE MEANINGFULNESS OF WARNING MESSAGES

Given that a warning message is actively processed, it should be comprehended if it is encoded with meaningful symbols. The following discussion will evaluate the comprehension of verbal and nonverbal symbols commonly used in warning labels. The approach will be consistent with Chapter 12, in which the product is viewed as a complex object. A similar approach to describing products is taken by Gregory (1982), who views products as collections of meanings.

Particular aspects of symbol meaning that will be emphasized include symbol semantics, syntactics, and context. Attention will also be given to the relative advantages of verbal versus nonverbal symbols, along with some related issues such as the learning of symbols.

Verbal Symbols – Semantic Considerations

In order for auditory or visual verbal symbols to be understood, the most important requirement is that the receiver understand the language. Collins et al. (1982), in their review of the literature on the perception of symbols, noted that: 1) about 5 million individuals in the United States (as of 1976) reported difficulties in speaking or understanding English; and 2) between 2 and 64 million adults in the United States are functionally illiterate (this great variation, of course, reflects differing definitions of literacy). These findings indicate that written labels will not be meaningful to a large group of individuals, even if they are well designed. If technical terms are used, even fewer individuals will be able to understand verbal messages (Wright, 1981).

General Comprehension A relatively small number of studies have directly addressed the extent to which written warnings are comprehended by people. Pyrczak and Roth (1976) evaluated the statements of "warning" and "caution" that appeared in the directions for ten aspirin-type drugs. Using the Dale-Chall readability formula they found that many samples could be read only by individuals with reading skills at or above the eleventh or twelfth grade level. For another sample of directions, the required reading skills were at a college level. Interestingly, some of the words identified as giving difficulty are commonly used in warning labels (words such as accidental, contact, immediately, persists, conditions, consult, affecting).

Also in regard to drug warnings, Wright (1979) found that less than 10% of the shoppers leaving a store after purchasing antacids could correctly identify one or more of three at-risk groups (for reactions to the drug). This information was explicitly given on an in-store warning sign and on the package. No differences in knowledge were observed between those shoppers observed to read or not read the in-store warning, or between those shoppers who spent less than or over 10 seconds examining the package. It must be emphasized that this study does not explicitly show that the shoppers were unable to comprehend the meaning of the words (semantics) within the written warnings, since the syntax might have been too complex. The readers also might have forgotten what they read before leaving the store or quickly filtered it out because it was perceived as being irrelevant.

Signal Words A related issue that has received recent attention is the use of very particular signal words to signify levels of hazard. Particular words which have been proposed, listed in decreasing order of their signified severity, are DANGER, WARNING, and CAUTION. Several commonly referenced sources (see Chapter 9) including the FMC labeling system, use this terminology, while the ANSI Z35.1 standard uses the terms DANGER and CAUTION.

One study (Bresnahan and Bryk, 1975) has addressed the perception of the terms "danger" and "caution" by industrial workers. Here, it was found that greater levels of hazard were associated with the term "danger" than with "caution." It is unclear, however, whether the term "warning" has a stereotypical association with levels of hazard that fall between "danger" and "caution." It is also unclear whether members of the general population, who have not been exposed to industrial safety signs, view the term "danger" as implying greater hazard than the term "caution."

There are theoretical reasons explaining why such associations are not obvious. The three words do not naturally or inherently correspond to differing levels of hazard. In fact, they have very different types of meanings as can be easily determined by consulting a dictionary. Further research is consequently necessary, before assuming that these three terms should be used to signify the level of hazard to members of the general population. A simpler system might use the phrases extreme-danger, serious-danger, and moderate-danger.

Conclusion It is very difficult, if not impossible, to select words that will be meaningful to all people. The use of concrete, rather than abstract, words within warning labels (Wright, 1979) might reduce such problems in comprehension. However, as implied by Wright (1981), it is very difficult to write material that is understandable to individuals with low reading skills. This is one of the reasons emphasis has frequently been placed on nonverbal symbols. The following discussion will explore this alternative.

Nonverbal Symbols – Semantic Considerations

Collins et al. (1982) provide an excellent review of existing research regarding nonverbal symbols. They note that nonverbal symbols can be more effective than written symbols. However, nonverbal symbols are frequently not understood and may actually transmit the opposite of the desired meaning (Lerner and Collins, 1980).

As noted earlier in Chapter 2, nonverbal symbols can be distinguished as being either abstract or as pictographs. The following discussion will occasionally distinguish between these two forms of nonverbal symbols. However, this distinction is not heavily emphasized because the semantics of both types of nonverbal symbols are evaluated in the same way. In this discussion, the first topic considered is the simple comprehension of nonverbal symbols. Then attention shifts to the more basic associations between nonverbal symbols and concepts.

Simple Comprehension Many studies have evaluated the extent to which people correctly comprehend the meaning of nonverbal symbols. These studies have not separately evaluated the semantic and syntactic meanings of such symbols. However, since such symbols generally convey few meanings (usually one per symbol), the meaning of each symbol is captured well by its semantics. The following discussion will consider several substantial and well-known research efforts which evaluate the simple comprehension of nonverbal symbols. Two categories of application will be considered: general consumer signs or labels, and industrial signs or labels.

Consumer Signs. Within the first category are those nonverbal symbols directed toward consumers. Easterby and Hakiel (1981) tested all known symbols pertaining to fire, poison, caustic, electrical, and general hazard. Approximately 4000 consumers participated in the survey. The comprehension of the best signs was only about 20%, when the criterion of correctness was stringent. When the criterion was lax, comprehension of the best signs increased to 50%. Markedly worse performance was observed for the poorer signs (5% or worse with the lax criterion). Easterby and Zwaga (1976) also surveyed public information signs, finding large variations in understandability.

Collins and Lerner (1982) investigated 25 fire-safety signs for a sample of 91 subjects. Comprehension of the symbols varied from nearly zero to nearly 100%. Green and Pew (1978) studied the comprehension of 19 pictographs used in automobiles. Only 6 of the 19 symbols met the criteria of 75% recognition and 5% errors. In other studies (Brainard et al., 1961; Griffith and Atkinson, 1977, 1978), a large percentage of subjects failed to perceive the meaning of traffic signs.

A finding general to all of these studies was a trend toward markedly poorer performance for more abstract symbols.

Industrial Signs. Within the second category are those nonverbal symbols directed to industrial workers. Collins, et al. (1982) studied the comprehension of symbols used to convey 33 messages related to hazards, protective gear, first aid and emergency equipment, prohibited actions, and egress. The surveyed individuals consisted of 222 employees. Substantial variation was found for the evaluated symbols. For example, between 18% and 58% of the subjects correctly identified the meaning of at least some "no exit" symbols. In contrast, between 90% and 100% of the subjects correctly identified the meaning of at least some "eye protection" symbols. In a subsequent study, Collins (1983) studied 72 mine safety symbols conveying a total of 40 messages. The surveyed subjects were 267 miners located at 10 different mine sites. The results showed that 34 of the 40 messages were correctly interpretted by 85% or more of the subjects.

In general, as for consumers, the studies of industrial workers found that abstract symbols or those that referred to unfamiliar topics were much less likely to be correctly interpretted than those which were concrete and/or referred to familiar topics.

Symbol Associations

A variety of experiments have evaluated the so-called natural (or stereotypical) associations between symbols and concepts. Such studies might be viewed as providing an initial basis for constructing symbols from more basic symbols. The rationale being that if there are meanings associated with primitive symbols, more complex meanings can be inferred by combining the primitive symbols. The following discussion will only consider some findings regarding very abstract noun-like or predicate-like characteristics of symbols relative to safety. No attempt is made to evaluate the meanings associated with the more concrete pictographs.

General Findings One finding which has been quite consistently shown is that pointed shapes, such as diamonds, triangles pointing downward, or other regular figures with a vertex pointing downward, have greater hazard association values than shapes like rectangles oriented parallel to the ground or circles (Jones, 1978; Riley, et al., 1982; Collins, 1983; Cochran et al., 1981). These effects might reflect stereotypes people develop from observing traffic signs.

Another commonly cited stereotype is the association between different colors and the perceived degree of danger. Bresnahan and Bryk (1975) found that industrial workers appeared to associate the colors red and yellow with greater degrees of hazard than they did for the colors green and blue. Jones (1978) tested the importance of color cues in the comprehension of European road signs. Mixed results were obtained. Removal of the red color cue associated with signs that indicated hazard had no significant effect. A negative effect was noted, however, when the blue color cue for information signs was removed.

In general, Jones' study indicated that (for European traffic signs) the shape cues were more important than the color cues. Researchers such as Moses et al. (1979), Knapp (1984), Carter (1979), and Wheatley (1977) have explored other associations between symbols and concepts that are less related to safety.

Future Directions Other work more directly oriented toward the isolation of primitive symbols has been performed by Szlichcinski (1980) and Marcel and Barnard (1979). Such work appears to be of direct relevance in the area of safety symbols. However, as emphasized by Easterby and Hakiel (1977), a large degree of variation is common for safety-related stereotypes. Their conclusion was based on a study in which subjects generated warning signs. Smith (1981), after experimentally evaluating several stereotypes between nonverbal stimuli and responses, concludes that a taxonomy is needed before predictions can be made with any power.

Verbal Symbols – Syntactic Considerations

Syntax is equivalent to grammar. If an arrangement of verbal symbols does not follow the standard rules of grammar, incorrect meanings (or garbled messages) can be transmitted. As noted by Chapanis (1965), information on products is occasionally written in a nearly incomprehensible form. Chapanis also discusses some of the ways human error can be caused by poorly written messages and gives examples of accidents caused by such writing. One of his more humorous examples is of a sign on an elevator that advises the user of the elevator to "walk up one floor or down two floors for better service." The misled reader would find the same message (at the door of the same elevator) after changing floors in an attempt to find better service.

A more up-to-date, excellent introduction to the topic of syntax is given by Bailey (1982). Perhaps the most general rule is to use simple, short sentences, constructed in the standard subject-verb-object form. Wright (1981) provides such recommendations: she also notes that negations and complex conditional sentences frequently create comprehension problems. A very large set of recommendations can be found in other sources regarding writing (Broadbent, 1977; Kanouse and Hayes-Roth 1980; Hartley, 1978, 1981; Westinghouse, 1981; and many others).

Writing text that poor readers can comprehend is not an easy task. Kammann (1975) cites what he calls the two thirds rule. This rule implies that only two thirds of written verbal material will ever be comprehended, if the material is at all complex.

Safety-Related Phrases Safety standards (ANSI Z35.1 Industrial Signs and ANSI D6.1 Traffic Signs, for example) and other standard sources (Westinghouse, 1981; FMC, 1980) list examples of messages to be used in warning signs. The messages prescribed in such sources often are short fragments of sentences (phrases) that describe actions or conditions. It appears that such phrases, although syntactically incomplete, should be easily understood. No research was found, however, that directly evaluates the extent to which such statements, when used within warning labels, are comprehended by the general population. Nor has research been found that conclusively demonstrates that phrases conveying conditions are preferable to those conveying actions, or vice versa.

For safety-related phrases, Easterby and Hakiel (1981) recommend the use of prescriptive statements (that is, statements that recommend an action) or descriptive statements (that is, statements that describe conditions). Both Easterby and Hakiel (1981) and Sell (1977) recommend against proscriptive statements (that is, statements that state an action should not be performed). Little research demonstrates relative effects of such statements on comprehension. However, Easterby and Hakiel (1981) conclude, based on their extensive survey of symbol comprehension, that descriptive signs tend to be more well-understood than proscriptive signs, but that the results are by no means unequivocal.

To convey procedural information, Dixon (1982) found that stating actions before conditions was frequently preferable. If many possible actions were possible, the opposite trend appeared, as giving conditions first improved performance.

Nonverbal Symbols – Syntactic Considerations

Syntax is important within messages comprised of nonverbal symbols, even though the syntactic principles used to specify meaningful patterns of nonverbal symbols are not as well understood as those principles applied to verbal symbols (as in linguistics). As Easterby (1967, 1970) indicates, nonverbal symbols must convey the same basic subject-verb-object information that an equivalent verbal message would convey.

Szlichcinski (1980), along with Marcel and Barnard (1979), provide more recent insight into the problem of combining nonverbal symbols to define an understandable message. These researchers are all exploring ways of documenting the syntax of nonverbal symbols; eventually, certain principles from artificial intelligence are likely to see great application. Difficult aspects of this problem have been noted by these and other researchers, but few studies were found that directly evaluated the syntax of nonverbal symbols, as might be required when evaluating warning labels.

We find it useful to distinguish between external and internal syntax. External syntax refers to those rules of syntax that are used to graphically combine well defined abstract symbols and pictographs within a message. Certain forms of external syntax are very well-defined. Internal syntax refers to those rules of syntax that are used to combine the elements of a symbol into a meaningful symbol. Little information is available regarding the internal syntax of nonverbal symbols. The following discussion separately considers each form of syntax.

External Syntax Means of graphically describing syntax, or the relations between symbols are available. In particular, flow charts, logical trees or decision tables can be used (Wright and Reid, 1973; Kammann, 1975; Green, 1982). The symbols used in flow charts or logical trees are either nodes or links, and may be verbal (written words) or nonverbal. The nodes generally correspond to nouns or noun-like symbols, while the links (often arrows) indicate the relations between the nodes. Decision tables use a matrix to associate conditions with particular actions, but are rarely used for nonverbal symbols.

Green (1982) emphasizes the utility of flow charts for describing complex concepts, but little research definitively documents the extent to which the general population understands this form of syntax.

Verbal Symbols. Certain studies have evaluated the use of graphic syntax using verbal symbols. Among these studies are those by Kammann (1975) and Wright and Reid (1973). Kammann (1975) compared a standard directory and a flowchart alternative as methods for conveying the procedural information needed in telephone dialing problems. With the use of the flowchart, housewives were found to attain significantly better performance both in terms of comprehension (measured in terms of dialing accuracy) and speed. Engineers and scientists similarly were better able to comprehend the procedural information when the flowchart was used. In a field study, employees using the directory had a comprehension of 65%, while those employees using the flowcharts had a comprehension of 80% to 85%.

Wright and Reid (1973) compared bureaucratic prose, lists of short sentences, flow charts, and decision tables, as methods for providing information needed during problem solving. Bureaucratic prose and lists of short sentences resulted in the worse comprehension when the task was difficult. The flow chart resulted in the best comprehension on difficult tasks, but was not significantly better (at the $p>.05$ level) than the decision table. For the easy tasks, bureaucratic prose resulted in the worst comprehension, while no significant differences were present between the other alternatives.

Nonverbal Symbols. Twyman (1979) provides an extensive set of example figures that illustrate the use of each form of graphic syntax described above, to combine nonverbal symbols, including pictographs, into messages. Twyman provides no data relevant to evaluating the comprehension of these particular figures.

No studies were found that evaluated the comprehension (by consumers) of safety-related messages, when the nonverbal symbols were organized within logic trees or decision tables. However, several studies were found that evaluated the comprehension of pictographs when they were combined into sequences of events or actions. The considered sequences were generally linear, corresponding to simple flow diagrams, and the problems in comprehension were most likely to occur when the conveyed concepts were complex or consisted of multiple meanings.

In particular, Johnson (1980) notes that it is difficult to convey abstract/complex concepts with pictographs. He discusses research where his group was unable to develop an easily comprehended pictorial method of describing to passengers (making emergency exits from planes) that they had to open either a door or a hatch. Positive conclusions were given in regard to more simple sequences. Support for the latter point is given by Booher (1975) who found that simple action sequences, describing the use of a task simulator to naval personnel, were well conveyed by sequences of nonverbal symbols. However, Winter (1963) notes how simple sequences of nonverbal symbols were misinterpreted by black South African workers. Time was interpretted as progressing from the right to left, rather than left to right, when sequential frames (like in a comic book) were used to combine pictographs.

Stern (1984) provides an example illustrating the difficulty of conveying complex messages that combine actions and objects with nonverbal, instead of verbal symbols. Here, the written and nonverbal modes were compared as a means of describing how to operate an automatic teller machine. The nonverbal symbols alone performed relatively poorly. Chaiken (1976) found that written messages were comprehended better than videotaped messages, if the message was difficult. The opposite effect occurred when the message was easy.

Many of these problems associated with complex messages appear to be caused by difficulties (of people) in comprehending branching logic where multiple meanings are combined. A study was performed by Galer (1980) that illustrates similar problems in combining elements of meaning using nonverbal symbols, even though the study was not explicitly designed to evaluate syntax. It was found here that 79% of lorry (truck) drivers (from a sample of 497) understood the meaning of a commonly used sign that indicated the available headroom beneath low bridges. However, only 36% of the drivers understood the meaning of a slightly more complex sign that indicated the locations of such bridges. This maplike sign contained a symbol, similar to the available headroom sign, placed at those locations where low bridges crossed highways.

Internal Syntax Internal syntax refers to the way elemental components of symbols are related rather than the way symbols themselves are related. This distinction can become quite arbitrary (as for the distinction between abstract symbols and pictographs), because the elemental components of a symbol are also likely to be symbols. Recognizing that the distinction is arbitrary, internal syntax applies to those symbols that normally stand alone as single entities.

In general, the internal syntax of safety related symbols is not defined in any formal way. There are, however, examples along the lines of linguistics, as in the use of slashes to imply negation. Such examples are very rare and are primarily found for abstract symbols rather than pictographs. It must be emphasized that the internal syntax of pictographs is very difficult to assess; such assessment requires extensive knowledge of how people organize visual information.

Several studies have uncovered problems in the basic comprehension of nonverbal symbols that appear to be related to internal syntax. For example, Cahill (1976) found that certain pictographs used to indicate machine elements were poorly understood. The most poorly understood symbols were used to convey actions or combine different elements of meaning. Of course, internal syntax must be depended upon to convey the referants for actions or to specify how multiple meanings are to be combined.

Cairney and Sless (1982a) found similar comprehension-related problems for pictographs that convey several different meanings. In particular, a symbol that indicated the availability of both gas and service for cars was commonly misunderstood. Jones (1978) provides an example of how even the prohibitive slash interacted with the type of symbol it was expected to negate. Specifically, when the symbol to be negated was abstract (shape and/or color coding only), the message was correctly identified 50% of the time. When the symbol to be negated was concrete (an arrow, pedestrian, vehicle, etc.), the proportion of correct identifications rose to 89.9%.

Verbal and Nonverbal Symbols – Contextual Considerations

The importance of emphasizing the context within which a symbol is presented has been noted by Cahill (1976). Specific effects of the context on comprehension are frequently found for both verbal and nonverbal symbols. The following discussion will consider the effects of culture, receiver, and task related contexts.

Culture-Specific Influences The use of nonverbal symbols is frequently justified on the assumption that their meanings can be inferred across cultures (Mead, 1968; Dreyfuss, 1970; Kolers, 1969). More recent research has shown that this is not necessarily true (Easterby and Zwaga, 1976).

It has also been proposed that the average comprehension of nonverbal symbols changes across cultures, while their relative comprehension remains consistent (Cairney and Sless, 1982b). In other words, it is hypothesized that culture has an effect on the mean level of comprehension, but the best symbol in one culture will be the best in all cultures. The alternative hypothesis would state that the best symbol is culture-specific (an interactive effect). There is little question that the mean comprehension of particular symbols varies greatly across cultures (Easterby and Zwaga, 1976; Cairney and Sless; 1982b). The potential of interactive effects is less clear.

The study by Winters (1963), referred to earlier, illustrates a culturally dependent, contextual effect that changed people's perception of nonverbal symbol syntax. Here, black South Africans did not interpret sequences of symbols from left to right as corresponding to a temporal sequence. Cultural difference along these lines would definitely have to be considered during the design of a warning label or instructions. Based on this study, the best symbol for Europeans would probably not be the best symbol for black South Africans.

Sinaiko (1975) discusses other culturally dependent, contextual effects caused by differences between Vietnamese and American cultures. In particular, he noted that cultural differences appear when three dimensional figures are represented using two dimensions (that is, as drawings). Cairney and Sless (1982b) also note the presence of culture related effects, which resulted in the profound misunderstanding of certain nonverbal symbols by Vietnamese immigrants when compared to Europeans.

Receiver-Specific Influences Other contexts are defined by differences between people in their age, experience, knowledge, acquaintances, and so on. Cahill (1975) emphasizes the role of prior knowledge in symbol comprehension. She notes the paradoxical situation where "symbols are almost superfluous for the highly experienced operator" while inexperienced subjects are unable to use almost any symbol. Cahill goes on to state that symbols are most likely to be useful for operators at intermediate levels of experience. Conversely, Szlichcinski (1979) claims that the people who use or need instructions may be unusually incompetent. No conclusive research was found that demonstrated either of these claims to be true in regard to safety. However, Cahill (1975, 1976) did find significant differences, as a function of past mechanical experience, in the ability of people to comprehend certain nonverbal symbols used to signify elements within the cabs of machinery.

Other significant differences in the comprehension of nonverbal symbols by people, as a function of age and sex, will be briefly considered later in this chapter.

Task-Specific Influences Cahill (1976) noted that a machine serves as a context within which symbol meaning is interpreted. To test the influence of such contexts, an experiment was performed in which one group of subjects received a drawing of cab within which the symbols were said to be used. A control group of subjects was given the symbols alone. The subjects who received contextual information correctly identified 62% of the symbols, while the subjects in the control group correctly identified 44% of the symbols. This experiment shows a sizable effect due to the context, but a comprehension of 62% cannot be considered particularly high.

Galer (1980), in the study referred to earlier, also evaluated the influence of a task-related context on the comprehension of signs (by lorry drivers). A comprehension rate of 71% was found when no contextual information was given. Of those drivers who did not understand the sign, 37% were able to understand it when contextual information was given; contextual information was provided by a photograph in which the sign was mounted on a low bridge. Other evidence regarding the importance of task-related contextual information is provided by Simpson and Williams (1980). These researchers found that the total reaction time to auditory warning messages was reduced by providing an initial voice message that provided a semantic context for the warning; the total reaction time included the time required to provide the initial voice message. The voice message provided a semantic context by specifying the part of the airplane to which the following auditory warning message would refer.

We have performed some related research regarding the effects of context on the comprehension of safety-related information cues in boating. This testing involved a large group of subjects who completed pen-and-paper tests, in which certain questions provided varying amounts of contextual information. It was clearly shown that the provision of contextual information using either graphical diagrams or text, resulted in higher levels of comprehension.

CONCLUSIONS

One general conclusion, which will come as no surprise to researchers familiar with the area, is that both verbal and nonverbal symbols must be carefully developed, since subtle differences in design might significantly affect comprehension. A second general conclusion is that there is a pressing need for fundamental research which explicitly separates the influences of semantics, syntax, and context.

A number of more specific implications can be drawn, most of which are related to symbol semantics, syntactics, and context. Within these topics there are many more specific points related to the relative advantages of verbal and nonverbal symbols, learning, and other issues.

Semantic Implications

The public's poor comprehension of symbols (both verbal and nonverbal) is a serious problem. Carefully designed warning messages might reduce this problem, but it is doubtful that the semantic meaning of any verbal or nonverbal symbol will be universally understood.

Verbal versus Nonverbal Symbols Although the surveyed results indicate that many currently available nonverbal symbols, relevant to safety, are poorly understood in comparison to equivalent verbal messages, it must be emphasized that much more controlled research is needed. The surveyed studies did not explicitly consider the effects of context or syntax, nor did they consider the effects of learning. Consequently, encompassing statements, such as "the meanings of verbal symbols are more easily comprehended than those of nonverbal symbols" are undoubtedly misleading.

In particular, the failure to understand nonverbal symbols may be due to a lack of standardization of symbol designs and a lack of opportunity for people to learn the meaning of the symbols (Collins, et al., 1982). Dreyfuss (1970) notes that comprehension problems are likely when new symbols are introduced, while Kann (1970) presents anecdotal evidence regarding the confusion introduced by new symbols developed by the International Civil Aviation Organization. The hypothesis that a lack of exposure to symbols results in poor comprehension is supported by the findings of Easterby and Hakiel (1981). In this study, housewives identified a smaller percentage of symbols correctly than did either working females or males. Also, individuals over the age of 55 years identified fewer symbols correctly than did young or middle aged individuals. Similarly, Drury and Pietrazewski (1979) found that older subjects were less likely to understand the hand signals of bicyclists, while Collins and Lerner (1982) found a correlation of -0.3 between age and the comprehension of twenty fire safety symbols. Other support for this hypothesis is given by the relatively high comprehension by workers of industrial signs found by Collins (1983), since industrial workers can be expected to see such signs frequently.

Along other lines, the feasible number of meanings conveyed by nonverbal symbols should be compared to that conveyed by verbal symbols. The set of meanings that can be conveyed effectively by nonverbal symbols is likely to be small in comparsion to the vast number of meanings conveyed by verbal messages. (The written Chinese language illustrates the limitations and difficulty of a language that emphasizes ideographic symbols, which are very similar to pictographic symbols.) It is possible that the number of meanings effectively conveyed by nonverbal symbols (when contextual information is missing) is so small that an individual with an equivalent verbal vocabulary would be considered to be at a profound level of illiteracy. If so, the estimates of illiteracy commonly cited to justify the use of nonverbal symbols may be leading us to an unjustified emphasis on nonverbal symbols.

Abstract Symbols versus Pictographs In all of the above studies, there was a general trend toward poorer comprehension of abstract, as opposed to pictographic, symbols. The understanding of abstract symbols was always very low for naive subjects, while pictographic symbols occasionally met a criterion of 85% correct comprehension.

Although these studies of comprehension indicate that pictographs are easier to comprehend, research is needed in which the use and structure of pictographs, as opposed to abstract symbols, is carefully compared. Pictographs might be currently used to convey messages that are innately simpler than those conveyed with abstract symbols. This would force greater dependence upon syntax when abstract rather than pictographic symbols are used.

Obviously, if abstract symbols are used to convey more complex concepts than those for which pictographs are used, the comprehension of abstract symbols can be expected to be lower.

A final point is that pictographs may be less legible than abstract symbols (Lerner and Collins, 1980). This indicates that their comprehension related advantages may be counteracted by perceptual effects.

Other Issues Very few studies have addressed the learning of nonverbal symbols. Among the particular studies, Green and Pew (1978) found that the ease of learning the meaning of pictographs was not related to initial measures of comprehension. Cairney and Sless (1982a, 1982b) found that most pictographs which gave trouble to their subjects in initial testing were readily learned. They also found high levels of retention (85% or better) for the majority of symbols when the subjects were re-tested one week later. Further research is needed regarding whether people get adequate opportunities to learn the meanings of such symbols, as is research on the long-term retention of such meanings. From an anecdotal perspective, people have complained about the recently introduced nonverbal signs in the U.S.A. that indicate a stop sign is ahead.

There is also a need for more careful evaluation of the comprehended meaning of safety related words. In particular, the semantic differential scale (Osgood, et al., 1957) should be used to evaluate the meanings associated with terms proposed as signal words. Other words commonly used within warning labels should be equivalently evaluated. Note that readability indexes are probably inadequate for determining the extent to which such terms included in warnings are correctly comprehended.

Syntactic Implications

The earlier referred to studies indicate that it is difficult to explain moderately complex concepts, which require the use of syntax, with nonverbal symbols. However, graphic forms of external syntax can be very effective for explaining complex concepts, when verbal symbols are used; for simple concepts, the graphic forms of syntax do not appear to have advantages over sentences. Caution must be taken in drawing conclusions, because the studies have not explicitly tried to compare syntactically equivalent sets of verbal and nonverbal symbols.

For both verbal and nonverbal messages, it is of major interest to determine the influence of syntactic deficiencies. Simple examples of syntactic deficiencies are easy to develop. We have already noted examples of verbal safety-related messages that are syntactically deficient. In regard to nonverbal messages, consider the type of pictograph one would design to warn individuals to wear hard hats. The symbol's subject would be "the particular worker," the verb would be "wear," and the object would be "hard hat." A pictograph that only depicts a hard hat would be syntactically incomplete since neither the verb (wear) nor the subject (the particular worker) is included in the symbol. A pictograph showing a worker wearing a hard hat still has syntactic problems. since there is no predicate that precisely specifies the subject. In other words, the graphic symbol does not specify that it is referring to the reader of the sign. Clearly, a string of verbal symbols like "everyone must wear hard hats" is much less ambiguous when only syntax is considered.

In general, more attention has been given to the syntax of verbal messages than for nonverbal messages. Conversely, the semantics of nonverbal symbols is greatly emphasized, as in the development of explicit drawings that correspond closely to physical objects. Further work regarding the syntax of nonverbal messages is needed because the seriousness of the influences of syntactic deficiencies are unclear, and because the existing research has not separated the relative influences of semantics and syntactics. The approaches of Szlichinski (1980) or Marcel and Barnard (1979) are of particular interest, since they have the potential to isolate categories of nonverbal symbols that correspond to nouns, verbs, and predicates. Perhaps their approach can be extended to where one day we will have a true graphic science.

Contextual Implications

As noted here and by others (Cairney and Sless, 1982a), the influence of context has been neglected in studies of comprehension. In general, the summarized research has shown that comprehension is likely to depend on the specific culture-, receiver-, and task-related contexts. Similar effects were shown earlier in regard to the filtering of symbols (for example, Shiner and Drory (1983) found that drivers were much more likely to remember seeing traffic signs at night than at day). Additional work would be useful in which the effects of different contexts are systematically studied. In particular, an operational taxonomy is needed that organizes and prioritizes these various contexts.

A final point is that the context-related studies imply that the comprehension of symbols, as normally measured with surveys or tests, might be artificially low. Surveys or tests do not usually provide the contextual information found within a task. It follows that actual comprehension of those same symbols might be better in actual use than as measured in such studies. This topic obviously deserves further investigation.

CHAPTER 6

THE EFFECTS OF WARNINGS ON MEMORY, DECISIONS, AND RESPONSES

CHAPTER 6. CONTENTS

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Even if a warning is perceived and comprehended, it will not be effective unless it induces people to behave safely. Before a warning can do this, it always must influence the decisions people make, by either being remembered or perceived at the appropriate time. The utilization of long term memory and the resulting decisions and responses are all at a high level in the sequence of outputs (within the human) that might be elicited when a warning is given. Since memory, decisions, and responses are very much related, they are considered together in this chapter.

The chapter begins with a discussion of the effectiveness of warnings in eliciting the storage and retrieval of information. Since little research specifically considers the effects of warnings on memory, this discussion places much emphasis on theory. Attention is then directed toward evaluating the influence of warnings on decisions. More relevant research is available concerning this topic, allowing fairly strong conclusions to be made. The final portion of this chapter considers the influence of warnings on safety-related responses. Little available research emphasizes the influence of warning labels on safety-related responses. However, a large body of research addresses the influence of educational and persuasive programs, allowing many inferences to be made concerning the ultimate effectiveness of warning labels.

ELICITING STORAGE AND RETRIEVAL

Because memory is so interrelated with other information processing stages, it is difficult to isolate safety-related literature that is strictly relevant to memory alone. However, based on theory, we can confidently say: 1) The meaning of a warning message always must be stored before it can be retrieved. 2) To be effective, the meaning always must be retrieved at the appropriate time.

The following discussion will consider some important memory-related findings that have implications toward the effectiveness of warning labels. Elements of this discussion will fall into the categories of capacity/contextual effects, retrieval effects, and processing effects.

Capacity/Contextual Effects

Limitations in the capacity of human memory have implications toward the effectiveness of warnings. Since these limitations become important in particular tasks (a task defines the context), capacity-related effects are context dependent. No research was found that considered the relationship between capacity/contextual effects and the effectiveness of warning labels. However, the general warning tree model described in Chapter 11 has several implications toward this topic. In the following discussion, such implications are separately considered for long-term and short-term memory.

Long-Term Memory A severe filtering takes place before information is transferred into permanent memory. Illustrating such effects, McCormick (1976) cites research in which the information transfer rate into long term memory is estimated as only 0.7 bits/sec; this is much lower than the rate at which information enters short term memory during perception.

Filtering has negative implications toward the effectiveness of warning labels that are expected to perform educational or persuasive functions. In particular, people will probably have to spend much time reading (or even studying) warning labels if they are to learn and remember the presented information. The likelihood that people will spend time learning or memorizing warnings appears to be low for the reasons discussed earlier in Chapter 4, but more research is needed before firm conclusions can be drawn.

Short-Term Memory As a general rule, only 7 ± 2 items can be stored in short term memory, or consciousness, at any given moment. A person cannot be expected to retain the information given by any warning in consciousness indefinitely. Instead, this information will be quickly replaced by other information that is either retrieved from long term memory or perceived from external memory. Consequently, a warning must be placed into short term memory at the appropriate time, either by perceiving or retrieving it, if the warning is to be effective. Those warning messages that are read from a list or label will be eliminated from short term memory as soon as task performance begins, unless the reading of such a list or label is an integral element of the task (as when an airplane pilot reads a checklist before leaving the ground).

In accordance with these above points, the task-specific context is a primary determinant of warning effectiveness. In other words, warnings that are well-integrated into a task-specific context are the most likely to usefully exploit the human's knowledge, since such warnings can act as cues that trigger the retrieval of additional, and hopefully relevant, information from long-term memory.

The Retrieval of Warning Information

Memory research has primarily been directed toward understanding the nature of memory. Along these theoretical lines, several factors have been found that affect the storage and retrieval of information. People are better at remembering meaningful stimuli than nonmeaningful stimuli (Postman and Rau, 1957). They also remember items that evoke high mental imagery better than those which evoke low levels of imagery (Paivio, Youille and Madigan, 1968). Similarly, increased repetition and active, rather than passive, assimilation of the information leads to greater retention. Other related effects include the effectiveness of mnemonics and the importance of organization.

There has been little applied research that measures the ability of people to remember information given by warning labels. The theoretical work discussed in Chapters 2 and 11 does imply ways by which memory of warnings can be improved. The following discussion will consider what research is available regarding the retrieval of information given by warning labels. The influence of some of the factors mentioned above will then be considered in the next section.

Some General Findings People appear to be only marginally able to remember the warnings or instructions given to them. As summarized below, such results have been documented for warning labels, propaganda posters, traffic signs, verbal presentations, and to a lesser degree for symbols. These results imply that warning labels or safety signs are unlikely to effectively perform tangible educational functions. However, before firm conclusions can be drawn, further work directly oriented to evaluating warning labels is necessary.

Warning Labels. Very little research was found that documented the ability of people to remember the information given in warning labels. In the most related study found in this survey, Wright (1980) discovered that less than 10% of the purchasers of antacids remembered even a portion of an instore warning label (placed next to the antacid display) when they were questioned while leaving the store. The level of recall stayed the same even if the shoppers were observed to read the warning, and the time spent reading the label also had no effect.

Propaganda Posters. More research was found in regard to the ability of people to remember propaganda posters. Among such studies, Harper and Kalton (1966) placed two posters in a coal mine and then measured the extent to which the employees recalled and recognized the posters. One of the posters was humorous, the other serious. The findings were as follows: first, 18.2% of the subjects recalled and 49% recognized both posters; second, 52.3% recalled and 26.7% recognized neither poster; third, 18.3% recalled and 14.6% recognized only the humorous poster; and fourth, 11.2% recalled and 9.7% recognized only the serious poster.

Belbin (1956b) tested the recall of six traffic safety posters presented to subjects who were exposed to the posters in a room for approximately three minutes. Only 2 of the 200 subjects said they did not see the posters. An average of about 42% of the posters were recalled. No significant differences occurred as a result of whether the type of posters was pictorial, horror, verbal positive, or verbal negative. When the subjects were retested one day after viewing the posters, recall dropped to about 28%, after one week the recall was 15%, and after two weeks the recall was about 3%.

In another experiment (Belbin, 1956a), a propaganda display (a sign) was placed next to subjects who were learning a task. This display described strategies that supposedly would improve task performance. Approximately 70% of the subjects were able to at least partially recall the display after performing the task. Of those subjects who were able to recall the display, 32% understood it.

Traffic Signs. A number of studies, which were also referred to earlier in Chapter 4, measured the extent to which people remembered the traffic signs they drove past. In summary, Johansson and Backlund (1970) reported that the percentage of drivers who recalled a road sign after passing it varied from 21% to 79%, depending upon the particular sign; Shinar and Drory (1983) found percentages of 4.5% and 16.5% during the day and night, respectively.

Verbal Presentations. Ley (1979) reviews several studies regarding the retention of instructions by patients of information given to them by physicians. He summarizes these findings with a regression equation in which approximately one half of the items given to the patients are forgotten shortly after the information is given.

Belbin (1956a) tested the recall of safety propaganda presented with slides or by talks by police. The subjects were children, and the propaganda was related to inducing safe road crossing behavior. The children were able to recall significant portions of the propaganda two days after viewing it.

Nonverbal Symbols. The ability of people to remember the meaning of safety-related symbols has seen much less study than this topic deserves. However, many of the comprehension-related studies summarized in Chapter 5 may have actually been measuring the ability of people to remember the meaning of such symbols. As summarized there, the comprehension (or perhaps the recall) of symbol meaning was generally low, especially for abstract symbols.

The most relevant studies we found that directly evaluated the ability of people to remember the meaning of nonverbal symbols were performed by Cairney and Sless (1982a; 1982b). Many of the symbols they tested were safety-related, and during their initial testing subjects were told the meaning of the considered symbols. They reported that one week after this initial testing, their subjects were able to recall the meanings of nonverbal symbols well. Most of the symbols were comprehended 85% or more of the time during the second session.

Processing Effects Factors which influence perception or cognition can be expected to also influence memory because of the commonality between perception, cognition, and encoding. It is difficult to say that the intervening steps in perception and comprehension were successfully completed in many of those particular experiments reported above. Consequently, most of the documented failures in recalling information could also be related to the failure to perceive or comprehend, or, more generally, to the failure to deeply process information.

It is rather arbitrary to distinguish many forms of information processing activity from memory-related processes, and such a distinction is unlikely to serve a useful purpose. As such, the following discussion will consider some findings and implications of active processing, deep processing, memory reconstruction, and repression.

Active Processing. It has frequently been found that presenting messages in a way that elicits active processing leads to better retention of information. A common approach to eliciting active processing is to use concrete (or specific) rather than abstract (or general) symbols.

The potential value of using concrete rather than abstract messages has been emphasized by Kanouse and Hayes-Roth (1980), in regard to safety and health. Along these lines, Bradshaw (1975) found that concrete messages did appear to increase recall. In this study, 51% of the women subjects remembered the instruction "you must lose 7 lbs" while only 16% remembered the instruction "you must lose weight." Wright (1979) also found consistent effects when concrete rather than abstract words were used. Ley (1979), in a review article, notes that the largest effects, of a variety of approaches used to increase the retention of medically related information, occurred when concrete-specific rather than general-abstract advice was given.

Because of these findings, it seems appropriate that research regarding the warning labels commonly used on consumer products be reconsidered, in terms of the implications of these general trends. The most specific research related to this topic has been performed by Ursic (1984). Here, the use of a pictograph, the strength of the signal word, and the use of capital lettering were shown to have no significant influence on remembering warning messages.

Deep Processing. Deep processing is a concept very much related to active processing. Information can be said to be deeply processed when its meaning is extracted and weighted heavily during a decision-making process. The obvious implication is that deeply processed information is likely to be remembered. The less obvious implication is that the decision to behave or not behave in accordance with the information is also deeply processed, and that this decision may be remembered and applied to other similar forms of information.

Olson (1980) brings forth the interesting hypothesis that the deep processing of certain types of warnings may actually result in an overall loss of effectiveness for all warnings. The rationale is that a decision to ignore a particular warning might be stored and then negatively influence decisions as to whether or not to behave in accordance with other warnings. He specifically mentions the warning given on cigarette packages, as one example of a warning that is understood but consciously ignored.

If further research demonstrates that such effects do indeed occur, the clear conclusion is that warnings that will only be ignored should not be used.

Memory Reconstruction. Human memory is notable for its tendency to fill in the blanks with information that seems probable. This point might have implications toward warning effectiveness, especially when warnings give information that seems unlikely to users or when the messages are incomplete. In both situations, information perceived as being more likely than that the warning was intended to convey might be retrieved.

In particular, when messages are incomplete, the missing information is likely to be filled in; correctly if the missing information seems likely or obvious; incorrectly if the missing information seems unlikely. No specific evidence for either effect was found in the literature pertaining to warning labels. However, Wogalter et al. (1985) found that subjects occasionally rated warning labels as being more effective when information was left out. In these cases, the missing information appeared to be easily reconstructed. More work definitely needs to be performed regarding this topic, if a balance between information overload and the theoretical memory effects associated with missing information is to be attained.

Repression. In certain instances, individuals may repress unpleasant or disturbing memories. If humans repress the unpleasant or disturbing information given in a warning label, the warning may lose its effectiveness.

No evidence was found of such effects. Contrary evidence is provided by Ursic (1984) who found that college students rated bug killers and hair dryers as being more safe and effective, when safety warnings were given on placards that also listed their price and other characteristics. It is consequently unclear as to whether repression-related effects are important enough to deserve emphasis in future research, given the large number of other pressing issues.

Other Factors. The influence of many other factors on the retention of health-related messages are summarized by Ley (1979). Among the factors which had been shown to have significant effects were: the use of shorter words and sentences; rated importance; serial position in lists; explicit categorization of the information; repetition of messages; moderate levels of anxiety; and the presence of greater medical knowledge. However, Ley also reports that the results were somewhat ambiguous for repetition, explicit categorization, primacy, and stress on importance.

The extent to which any of these factors influence the recall of the warning messages given on consumer products is unclear, reflecting the complexity of predicting recall and the need for additional research.

MODIFYING DECISIONS

Once a warning message has been comprehended, the recipient must decide whether to comply with it. Many different characteristics of people, tasks, and products influence such decisions. Unfortunately, very little research directly evaluates the influence of warning labels on decisions. Consequently, the following discussion will emphasize the influences of knowledge and factors related to risk perception on safety-related decisions, the closest topic about which there is some useful information.

The General Influence of Knowledge

The knowledge people possess is frequently assumed to influence their safety-related decisions and behavior. A number of studies (Fhaner and Hane, 1974; Olshavsky and Summers, 1974; Staelin and Weinstein, 1973) have shown that the knowledge of safe practices is correlated with reduced accident rates. Unfortunately, it is impossible to determine whether knowledge actually causes safe behavior from correlational studies (Staelin, 1978). Staelin therefore concludes that investigations of the effects of knowledge on safety-related behavior must be longitudinal rather than correlational. Few studies meet this criteria, as is clear from examining the studies discussed later in this chapter.

A reasonable conclusion is that people will make decisions that are consistent with safety-related knowledge when they perceive the hazard to be high and/or when the safety-related action will require little subsequent effort or cost. Predicting behavior becomes much more difficult when the hazard is perceived to be low, or when the effort or cost of the action is high.

Buying Behavior Schwartz (1980) surveyed the literature related to the attitudes of consumers toward labeling. In general, safety labels were rated as being important by consumers, but not as highly as many other forms of labeling. Tokuhata et al. (1976) surveyed the ratings given to factors used in purchasing decisions by accident-free, as opposed to accident-incurring, households. Both groups rated price, appearance, and quality as the most important factors used in their buying decisions. The group of households that had recently incurred an accident rated safety as the fourth most important factor; the accident free households rated usefulness as the fourth most important factor, followed by safety. Schwartz et al. (1983) showed using multiple regression, that ratings of effectiveness, cost, and safety were all significantly ($p<.001$) related to the rated propensity to buy cleaning products. The subjects in this experiment were 24 undergraduates.

The above results show that safety information is likely to be considered during buying decisions, perhaps in appropriate ways. Conversely, the results of Ursic (1984) do not support the conclusion that providing a warning label causes people to avoid buying dangerous products. In fact, Ursic's study implies that people are attracted to products that have warning labels. One could speculate that there are individuals who seek products whose use might appear to involve more risk, skill or challenge and that, in some way, the presence of a warning connotes this. One could also speculate along the lines of Ursic (1984) that products with warning labels are perceived to have more powerful ingredients. In any case, an attraction to products with warning labels could turn out to be counterproductive to safety, especially if dangerous products which have warning labels are chosen rather than substitutable products which are less dangerous and don't have warning labels!

The Influence of Risk Perception

If people don't perceive a product as being dangerous, the likelihood that they will read product warnings appears to go down (Godfrey et al., 1983). It seems likely that users will make safety-related decisions in an analogous way. In other words, if a product is perceived as being dangerous, safe decisions become more likely, or conversely, if a product is perceived as being safe, the likelihood of safe decisions might go down. This point is important since people's preconceived impressions regarding product safety are expressed by behavior patterns that are very difficult to modify. For example, Robertson and Haddon (1974) found that buzzers and warning lights in automobiles did not influence the use of seatbelts. Similarly, it is doubtful that warnings on cigarette packages significantly modify the decisions of smokers.

As noted by Belbin (1956a) even if people understand and are able to recall safety-related knowledge, they may behave in conflicting ways. Many other studies document similar effects. Rather than belabor this point, let us consider some reasons explaining why people behave inconsistently with their safety knowledge or that given to them.

Conflicting Objectives Among the limited number of studies which evaluate the effects of knowledge upon safety-related behavior, the study by Fhaner and Hane (1974) is exceptionally interesting. They found that perception of discomfort tended to outweigh people's knowledge of the effectiveness of seatbelts. In other words, factors other than the safety-related knowledge were used to make safety-related decisions. Slovic et al. (1977, 1978) explain why knowledge regarding safety might be deemphasized. A primary reason is that people often perceive the probability of an accident to be very low, causing other considerations to become relatively more important. If the value of behaving safely is made explicit, as when people are paid to behave safely, these "so-called" irrational decisions to avoid behaving consistently with safety knowledge become less prevalent. For example, Elman and Killebrew (1978) showed that if people were paid to wear seltbelts, the incidence of use increased greatly.

One of the more extreme examples of conflicting objectives has been described by Goldman (1984). Here, it is reported that approximately one-half of the nonscientifically surveyed runners and other top athletes stated they would be willing to take a drug that would allow them to win a top event (such as the Olympics), even if the drug was likely to kill them. The high incidence of steroid use by athletes is also consistent with the effects of conflicting objectives.

Actual Belief in Danger One of the most obvious principles is that people are more likely to act in accordance with safety related information if they believe it to be true. Perry (1983) summarizes a number of findings regarding the response of people to volcano, flood, and nuclear power plant related warnings. The belief that real situational danger was present, as when officials or police warned them, was a very major determinant of behavior. If people believed the warning was relevant, they were apt to heed it. If they didn't believe the warning (as when newspapers reported problems), they were much less likely to behave in accordance with the warning. Consistently, McGuire (1980) notes that credible sources are more likely to be persuasive. Craig (1978) also found such effects with regard to messages sent to public utility customers. Here, messages stated to come from the public service commission were more likely to elicit effects than those from the electrical utility.

If messages from companies are not perceived as being credible, the implication is that warning labels are not likely to be persuasive. Perhaps the credibility of the source could be improved by stating that the message is required by law, is recommended by fire departments, etc. This topic, as pertinent as it may be, is too lacking in directly relevant research for firm conclusions to be developed.

Risk Taking Taylor (1976) places special emphasis on intentional risk taking and the tendency toward risk justification. In regard to intentional risk taking, Taylor states that risk may have pleasureable attributes for a subsector of society. These individuals seem to seek out activities in which they experience a loss of control over their environment. For such individuals, warnings might have even a negative value, because the warning could point out risks such people might intentionally choose to take. Risk justification refers to the tendency of certain individuals to justify risk-taking. These individuals claim to take risks for purposive reasons. In other words, risk is incurred while attempting to attain some goal.

The relationship between risk-taking behavior and accident rates has been studied. Cohen et al. (1955, 1956) found a wide variation in the degree of risk that people were willing to take, and also found that experience could influence risk-taking behavior. In particular, individuals who are overconfident in their ability to avoid accidents may have higher accident rates. Williams and O'Neill (1974) found that licensed race car drivers experienced more accidents and a higher accident rate (accidents per miles driven) than ordinary drivers. Robertson (1983) cites this study, along with two studies for motorcycle riders, in an attempt to support this conclusion. Other studies, however, have not shown that risk-taking behavior correlates with accident rates. For example, Rockwell et al., (1961) in a study of industrial workers, found risk-taking to be weakly correlated with traffic violations. No correlation was found between accident rates and risk-taking behavior.

Risk Compensation The concept of risk or danger compensation holds that people will neutralize the influences of safety devices by taking greater risks. Thygerson (1972) provides a discussion along these lines in his introductory book. However, Evans et al., (1982) found no evidence of risk compensation in a large sample of automobile drivers. It was found that, regardless of whether or not drivers wore seatbelts, they kept the same separation distance between their car and the car they were following.

Risk Coping Styles Sims and Baumann (1972) uncovered evidence that risk coping styles may explain differences in tornado-related deaths between the northern and the southern regions of the U.S. The two areas were shown to have approximately equivalent patterns of storm severity, and warning systems. Yet, the death rates were much higher in the South. The researchers contend that the differing responses to warnings might reflect greater fatalism, and passivity on the part of Southerners. In other words, the Northerners appear more likely to aggressively cope with risk by taking action.

Risk Acceptability A number of factors influencing the acceptability of risk are described by Slovic (1978) and Starr (1969). In general, higher levels of risk are perceived as being acceptable if the risk is; 1) voluntary rather than involuntary, 2) controllable rather than uncontrollable, 3) familiar rather than unfamiliar, 4) known rather than unknown, and 5) immediate rather than delayed.

For many products, the presence of a warning label, assuming that the message is comprehended, hypothetically will make the risk more voluntary, controllable, familiar, and known. The above findings indicate that the acceptable levels of risk for such products would then increase. The desirability of such increases in risk acceptability is unclear. Perhaps such increases are either desirable or undesirable, depending upon the situation.

Education and Persuasion

Educational or persuasive programs are frequently used in an attempt to modify the knowledge of receivers. Such programs have the ultimate objective of modifying decisions either by increasing people's knowledge or persuading people to choose certain behavior. The following discussion will separately consider the effects on safety-related knowledge of education and persuasion. A separate discussion of the effects of such programs on behavior will follow in the next section.

Educational Programs Several studies have shown that safety education can alter people's knowledge of safety (Staelin, 1978; McLoughlin, 1982; Edwards and Ellis, 1976). Whether people actually believe and act in accordance with the safety-related information they learn is not known. However, certain researchers have found that information about safety is frequently misinterpreted. For example, McKennel (1964) found that a film intended to show that smoking causes lung cancer convinced many smokers that human lungs are strong and not easily damaged by smoking. Research regarding the use of seatbelts currently underway also demonstrates the tendency for receivers to develop contrary opinions which have little correpondence to the true facts, even when receivers have been exposed to excellent information (UMTRI, 1983).

Of course, it is very difficult to generalize about the influence of such educational programs. An experiment performed by Staelin (1978) illustrates how other factors may complicate the influences of a training program. Here, high school students were educated about product safety. The educational program consisted of eight 30-minute, professionally developed modules designed to teach principles regarding the safe operation of products. The course was taught by a female engineer.

The results from this experiment were as follows: 1) Theoretical courses (i.e. physics, chemistry, shop, home economics, and auto laboratory) were negatively correlated with safety knowledge. 2) Practical courses (i.e. automobile repair, television repair, appliance repair) were positively correlated with knowledge of safety. 3) A knowledge of safety was correlated with reported safe behavior. 4) Males had more knowledge of safety than females. 5) Females were more apt to behave in a way consistent with their knowledge of safety, and learned more from the program. 6) The program itself was negatively correlated with reported behavior.

Of importance was that certain classes were negatively correlated with an increased knowledge of safety, while other classes were positively correlated with such knowledge. Also, the special education program increased the students' knowledge of safety, but the program itself negatively affected reported safety behavior. This negative effect almost outweighed the positive influence of the subject's new knowledge. In other words, the education program resulted in a small net increase in reported safe behavior.

Persuasive Programs Education and persuasion are similar, but persuasion differs in its emphasis on convincing people of the importance of behaving consistently with information they probably have already been exposed to. It does appear, as noted by McGuire (1980), that obtaining the agreement of people is at least as important as teaching them the relevant information. This implies that a person may understand the message quite well, but if he is not in agreement, the message will be ignored. Conversely, if people agree with a message, they might act in accordance with it even if they don't entirely understand it. These interesting ideas should be evaluated specifically for their implications to warning labels.

Several studies have shown that safety-related persuasion is difficult. In particular, Haskins (1969; 1970), Sell (1977) and Robertson (1977) document a consistent trend in which communication campaigns that emphasize safety propaganda are ineffective.

MODIFYING ACTUAL RESPONSES

One of the more perplexing problems faced in evaluating the effects of knowledge on decisions, is that the behavior people claim to follow frequently does not correspond to their actual behavior. Belbin (1956a; 1956b) emphasizes this point and provides examples where safety-related knowledge was not used. Robertson (1976) notes the significant discrepancies between claimed and actual use of seatbelts, while Olshavsky and Summers (1974) note similar discrepancies between people's intention to quit smoking and their actual behavior. Evans et al., (1970) found that fear appeals had a greater influence on reported behavior than on observed behavior.

Along more practical lines, Robertson (1975) notes that large discrepancies were present between the actual effectiveness of buzzer-light systems, as a means for inducing the wearing of seat belts, and the effectiveness reported by the subjects in the experiments that were used to justify the use of such warning systems. Such results demonstrate the dangers in assuming that reported (by the involved people) and actual behavior are equivalent. In this case, a costly investment was predicated on inadequate research and turned out to have no value in increasing safety.

In summary, the research shows it is difficult to change people's responses and that those changes reported in contrived experiments may have little correspondence to actual behavior. Consequently, no experiment that only documents effects on perception, memory, comprehension, or reported decisions due to a warning label definitively demonstrates the warnings effectiveness. The only way to do this, given the current state-of-the-art, is to observe the behavior induced by the warning in a nonexperimental setting. Hopefully, newer approaches such as the one proposed here by this book will reduce the problems associated with relating these intervening measures (that is, measures of perception, memory, etc.) to the final behavior.

Warning Signs

Only two studies were found that showed any influence on safety-related behavior due to safety signs. No studies that showed positive effects were found for warning labels. The following discussion first considers those two studies that showed safety signs could be useful; related research findings are then considered in the next section.

Laner and Sell (1960) evaluated the influence of safety posters which told coal miners to hook slings. An average increase of 7.8% (a change from 37.6% to 45.4%) in hook-slinging behavior was observed when the safety posters were present. It was also observed that in shops with low ceilings, where the value of hooking slings was more easily perceived, the measured increase was 13.5% (a change from 42.2% to 55.7%). A follow-up measure taken 6 weeks later showed that the hooking behavior increased by an average additional percentage of 4.5%. Interestingly, the observed change in behavior was lowest in shops where hook-slinging behavior was previously either very high or low, perhaps implying that it is easiest to change middle-of-the-road behavior.

The reduced effect in those shops where hook-slinging behavior was low has negative implications toward the value of these signs, if there actually was a need for behavioral change. In regard to this latter point, Laner and Sell concluded that the perceived relevance of the message (in this study it was assumed to be high in those shops where the largest effects were noted) has a large influence upon behavior. It also appears reasonable to assume that the warnings in these more effective instances were reminding rather than educating or persuading.

A second study, summarized in National Safety News (1966), evaluated the effect of placing posters on the steps entering an aircraft. The three posters considered were a picture of a man holding the rail, a picture of a man stumbling, and a picture of a man sprawled at the bottom of the stairs. During the course of the experiment, 2000 passengers were observed while entering an aircraft. A 6%, 13%, and 21% increase in railing-holding behavior was associated with the above posters, respectively.

In both of these studies, the changes in observed behavior, while positive, were not particularly high. Given the earlier research findings, this is not particularly surprising. The signs did meet criteria that seem important to effectiveness in that they presented specific, easily understood information with which the receivers were likely to agree. There is also little question that the receivers perceived the information given by the signs as relevant, since the defined hazards were quite obvious. Such perceptions of the people within Laner's and Sell's study maybe were not present in those shops which had particularly low rates of hook-slinging behavior, both before and after presentation of the safety sign. Consistent results have been found for disaster warnings (Perry, 1983), wherein the warnings were effective only when people believed the messages.

Education and Persuasion

It is frequently assumed that by persuasion or education, people's behavior can be modified to be safer. Table 6−1 summarizes several studies found in this survey that test this assumption. Perhaps the most notable conclusion which can be drawn from this table is that educational and persuasive campaigns are frequently ineffective; a conclusion that is not especially surprising, given the results summarized by Sell (1977) and Haskins (1969; 1970). Programs of this type may be ineffective for many reasons. Rather than redundantly discussing those studies summarized in Table 6−1, we will consider some factors that partially explain why certain programs were or were not successful.

Task-Related Factors It appears that task-related factors are likely to be important. The importance of considering the task when designing information can not be over-emphasized. (See Kroemer and Marras (1980) for a good example illustrating such design.) The importance of integrating warnings into the task has been emphasized throughout the earlier portions of this chapter. Two other very much related considerations are workload and feedback.

Workload. The task itself defines the utility at any given moment, of performing certain actions. If the user of a product is under time pressure, saving time becomes of greater than normal value. Increasing the utility of time might result in a rational decision to ignore a warning message. In other cases, irrational decisions may arise because of the limited decision-making ability of humans. The level of workload is probably the most important task-related factor. If the task demands more of the human than he is able to give, his performance will be impaired and certain task elements will not be performed. Since accidents are typically improbable and the antecedent events associated with accidents usually have a low correlation with accidents, actions necessary to improve safety might be neglected in situations where the workload is high.

Table 6.1
The Influence of Education and Persuasion on Safety Related Behavior

Desired Behavior	Modification Program	User Group	Resultant Behavior	Reference
Safety at Work				
safe operation of cranes	safety posters	crane operators	8% increase in desired safe behavior	Laner & Sell, (1960)
safe use of grinder	feedback via water spray, instructions	college students	large reduction in simulated injuries for group receiving feedback, smaller reduction for group given only instructions	Rubinsky & Smith (1973)
reduction of unsafe acts	feedback via charts which displayed the incident rate of unsafe acts	employees in a food manufacturing plant	safe acts increased by about 30%	Komaki et al., (1978)
reduction of unsafe acts	training alone or with feedback	vehicle maintenance employees	training alone resulted in slight improvement, with feedback the effects were substantial	Komaki et al., (1980)
use of ear plugs	feedback of temporary hearing loss, by giving hearing tests	industrial workers	increase in use from 10% in control group to 85 to 90% in experimental group	Zohar et al., (1981)
safe practices and conditions in paper mill	feedback on charts that reported behavior	500 paper mill employees	significant increase in safe practices, 50% decrease in accidents ($p < .1$), some groups of employees were not effected	Fellner & Sulzer-Azaroff, (1984)

Table 6.1 (continued)
The Influence of Education and Persuasion on Safety Related Behavior

Desired Behavior	Modification Program	User Group	Resultant Behavior	Reference
Safe Vehicle Driving				
safe motorcycle use	training program	motorcyclists	increased accidents	Raymond & Tatum (1977), Kraus et al., (1975)
reduced auto violations and accident rates	warning letters	drivers with poor driving records	standard letter resulted in no change, personalized letter had small effect on drivers under 25 years of age	Kaestner et al. (1967)
reduced auto accident rates	crash-avoidance training	members of Sports Car of America	participant accident rate stayed above normal	Williams & O'Neil (1974)
safe auto driving	high school drivers education	high school students	unchanged accident rate	Shaoul (1975)
reduced auto accident rates and violations	training program	individuals with four accidents or violations in a 12 month period	slightly reduced accidents and violations for selected groups	Edwards & Ellis (1976)
safe auto driving	defensive driving course	drivers seeking insurance discount	unchanged accident rates, fewer violations	Mulhern (1977)
reduced auto accident rates	defensive driving course	traffic law offenders	unchanged accident rates, fewer violations	Hill & Jamieson (1978)
reduced auto accident rates and violations	counseling	Wisconsin drivers with violation records	no effects shown for program	Fuchs (1980)

Table 6.1 (continued)
The Influence of Education and Persuasion on Safety Related Behavior

Desired Behavior	Modification Program	User Group	Resultant Behavior	Reference
Seat Belt Use				
use of seat belts	mass media campaign	general public	no significant effect	Fleischer (1972)
use of seat belts	television audience targeted, consequences emphasized	general public	no influence	Robertson et al., (1974)
use of seat belts	buzzer-light system	auto drivers	no significant increase in use, system was disengaged by users	Robertson & Haddon (1974)
use of seat belts	interlock system	drivers of 1974 cars	shortlived but large increase in use, systems were disabled, law was rescinded	Robertson (1975),Phillips (1980)
use of seat belts	monetary rewards	licensed drivers	substantially increased use of seat belts	Elman & Killebrew (1978), Geller et al. (1980), Geller (1981)
Safer Households				
reduced household hazards	informative discussion and booklet, free plastic outlet covers and cabinet locks given to informed and control groups	upper middle class parents	no change in hazards, slightly increased use of outlet covers by groups given discussion and booklet	Dershewitz (1979)
reduced household hazards	health department inspections	public	code violations reduced from 17 to 0%, noncode violations reduced from 13.1 to 6.6%	Gallagher et al., (1982)

Table 6.1 (continued)
The Influence of Education and Persuasion on Safety Related Behavior

Desired Behavior	Modification Program	User Group	Resultant Behavior	Reference
Safe Care of Children				
reduced infant falls	counseling by pediatrician and written material (signs in physicians office and pamphlets)	parents	7% reduction in reported injuries for infants due to falls	Kravitz (1973)
use of infant restraints in cars	literature, persuasion, or free car seat	mothers of new-born infants	literature, persuasion inneffective, free restraint increased use slightly	Reisinger & Williams (1978)
reduced entry into street by children	intensive use of story books and parent training	pre-school children	observed reduction of entries into street, parents reinforced appropriate behavior	Embry & Malfetti, (1980)
increased use of infant restraints in cars	counseling by pediatrician, prescription for restraint and demonstration of proper use	parents of new-born infants	efforts resulted in 23,72,9, and 12% increase in use after 1,2,4, and 15 months over the control group	Reisinger et al., (1981)
Reduced Suicidal and Drug Tendencies				
reduced use of alcohol and drugs	drug education program	high school students	increased use by educated group	Stuart (1974)
reduced suicide rates	clinical counseling	suicidal patients	no influence	Lester (1974)

Table 6.1 (continued)
The Influence of Education and Persuasion on Safety Related Behavior

Desired Behavior	Modification Program	User Group	Resultant Behavior	Reference
Fire and Burn Prevention				
reduced fires	30,000 leaflets describing safe use of chip pans sent to consumers	consumers	significantly reduced fires	Chambers (1970)
use of smoke detectors	pediatrician discussed fire hazard and value of smoke detectors, gave parents a brochure and sold detectors at cost	parents	nearly 50% of parents purchased smoke detectors, no parents in control group bought detectors	Miller et al., (1982)
reduction of burn injuries	mass media campaign	general public	increased knowledge of 44% of group, 29% of group had behavioral change, change persisted for only 19%, only 13% applied knowledge in an emergency situation	McLoughlin et al., (1982)

No conclusions regarding the influence of workload on the overt responses prescribed by warning labels could be obtained directly from the surveyed research. Such evaluation is another question worthy of more investigation. However, there is stress-related research that has implications toward this topic. For example, Finch and Smith (1970) analyzed data in which 80% of the victims involved in fatal accidents were subjected to significant life stress within the 24 hours preceding the accident. Similar findings have been reported by Alkov (1972) and Levinson, et al. (1980). When stressed, as within particular tasks, individuals may be prone to ignore warning-related information. This hypothesis, however, requires research before it can be verified.

Feedback. Feedback can be defined as the knowledge of results. Nearly all of the successful educational programs summarized in Table 6−1 incorporated direct feedback. As discussed below, feedback and warnings are related in two primary ways: 1) Warnings can serve as feedback, if they are given after inappropriate responses occur. 2) Feedback can be given to people as a mechanism for sustaining the behavior recommended by a warning.

Warnings as Feedback. When warnings serve as feedback, they become an integral part of the overall task, and ideally are given only when unsafe behaviors or conditions occur. This conclusion follows directly from the definition of feedback (that is, the knowledge of results), and implies that static warnings (such as certain labels), when used strictly as feedback, should be placed in locations where the individual will see them only after unsafe conditions or actions take place. It also implies that warnings should be dynamic. In other words, warnings should appear only when they are needed to provide feedback pertaining to a hazardous condition. Dynamic warnings, can be fairly non-traditional signals, such as sprays of water (Rubinsky and Smith; 1973), vibrations that occur at unsafe speeds in automobiles, or unusual engine noise. Many traditional warnings, such as warning tones for backing trucks, or visual displays are also dynamic.

With regard to the value of dynamic warnings, several studies in the transportation area were found which show advantageous effects on behavior (Perchonok and Hurst, 1968; May and Wooler, 1973; Voevodsky, 1974; Lewis, 1973; Loomis and Porter, 1982). In all of these cases, the warnings are directly and obviously integrated into control tasks.

From among those studies summarized in Table 6−1, we see that warnings that act as knowledge of results have been shown both effective (Rubinsky and Smith, 1973; Zohar et al., 1981; Komaki et al., 1978, 1980; Fellner and Sulzer-Azaroff, 1984) and ineffective (Robertson and Haddon, 1974). Among those studies describing effective warnings, Rubinsky and Smith (1973) used sprays of water to help convince users of grinders that they shouldn't stand directly in front of the grinding wheel. Zohar et al., 1981 gave industrial workers hearing tests at the end of the working day, to help convince them they should wear ear protection. Komaki et al., (1978; 1980) and Fellner et al., (1984) performed similar experiments where feedback was provided to workers on charts in which incident rates of unsafe acts were summarized. The presence of the charts apparently reduced the incidence of such acts. Among those studies describing ineffective warnings, Robertson and Haddon (1974) evaluated the extent to which buzzer-light systems convinced drivers to wear seatbelts. This latter study indicates that fixated behavior is unlikely to be changed even if the warning is dynamic.

In the majority of applications, it is doubtful that warning labels can serve effectively as feedback, in comparison to more dynamic warnings. This conclusion is well supported by findings throughout this research effort, beginning at perception and ending here.

Feedback Regarding Warnings. Feedback can be used to reinforce the behavior prescribed by a warning. However, feedback other than that provided by incurring an accident is likely to be necessary to maintain the behavior prescribed by a warning. In particular, a dependence upon accidents to provide feedback (that is, knowledge of the effects of ignoring the warning) that reinforces the behavior prescribed by a warning is not likely to lead to effective warnings. Accidents are a poor form of feedback because they rarely occur, whereas effective feedback is frequent and consistent.

In the successful uses of feedback illustrated in Table 6−1 (including the use of warnings that serve as feedback), diverse sources of information were used, such as physiological measures, physical stimuli, or charts. These sources provided frequent, consistent information as a function of exhibited behavior.

Therefore, if feedback is consistently provided as a function of the behavior prescribed by a warning label, the desired behavior will theoretically be strengthened. However, the feedback, may actually have a more significant influence on behavior than the label itself. It may also be difficult to provide frequent, consistent feedback, especially for consumer products used by a wide variety of users in a wide variety of environments.

MODIFYING THE ADEQUACY OF THE RESPONSE

A frequently overlooked point is that even if a warning elicits a response, it will not have effectively increased safety unless the performed response is adequate to avoid an accident. An adequate response is the final test of a warning's effectiveness, it is also the least reliably evoked of any measure of effectiveness considered in this book. In developing such measures of effectiveness, it is important to consider 1) the skill, ability, and training of people who will perform the response and 2) the task- and product-related factors.

Skill, Ability and Training

The skill, ability, and training level of the human can influence the performed response greatly. In certain cases, people might not be able to adequately perform desired responses, because of inadequate abilities, training, or design of the human-machine interface. Warnings, to be effective, must prescribe actions that do not exceed the abilities of the receiver. To attain this goal, the abilities of the user must be carefully matched to the requirements of the action prescribed by the warning. This process of matching abilities with requirements is discussed later in Chapters 10 and 12.

Matching abilities and skills to task-related requirements becomes difficult, because the conditions under which the recommended actions prescribed by a warning become relevant often occur infrequently. In this situation, the receiver is likely to have had little practice in the emergency situation and therefore may be prone to perform the task inadequately. To remedy this problem, the user must be well trained or the task must be very simple and well designed.

It seems quite likely that many consumer accidents are caused by inadequate training. For this reason, a warning must often be supplemented by training, design innovations, laws, and so on. Although no research found here directly considers the relation between warning labels and training, many of the observed failures to alter safety-related behavior (see Table 6−1) might be due to inadequate training rather than people's inherent resistance to change. For example, the failure to reduce accident rates with driver education programs may reflect inadequacy in the taught techniques (e.g. the subjects learned how to avoid traffic violations, but not how to avoid accidents). Given these substantial problems with extensive training programs, it seems unreasonable to expect a warning label to train people to behave correctly.

The Task and Product

Task- and product-related factors can obviously be expected to influence the ability of people to perform the actions prescribed by a warning. For example, products may have addictive properties which are contrary to their user's self-interest. Obvious cases include drugs, high-powered vehicles, weapons, and so on. For such products, a warning will frequently be recommending forms of behavior contrary to those for which the product is designed. In this paradoxical situation, it is doubtful that warnings will influence behavior. Other inherent product characteristics might also make the prescribed action difficult to perform. Such use of the product might require strengths, reaction times, computations, memory, etc. beyond those people can reasonably be expected to provide.

It is also possible that a malfunctioning product will alter tasks in undesirable ways, by increasing the need for skill, ability or training. People might fail to perform the action prescribed by a warning, because of these increasing task demands. Such effects can be expected to be especially significant, if product malfunctions create new, unforeseen hazards.

In each of the above examples, it becomes important to document both task demands and abilities of the human. Methods of documenting the different types of warnings and scenarios within which they appear, along with a description of task analysis, are the topic of the following section.

SECTION III.

TYPES OF WARNINGS, THEIR APPLICATION, AND DESIGN

This section consists of Chapters 7 through 10, and specifically addresses a number of design-related issues. As such, this chapter is of interest to those professionals who apply, design, and recommend ways of warning. Chapter 7 provides an initial structure to the design issue by classifying the different types of warnings and their applications. Many of the principles and much of the terminology used in this chapter is based on the more theoretical material given in Chapter 2. Chapter 8 introduces an approach for initially selecting warning applications. The approach is based on risk and effectiveness-related criteria derived from the second section of this book. In Chapter 9 design guidelines recommended in safety standards and the criteria found within human factors handbooks are summarized and critiqued. Chapter 10 then presents a multistage description of the warning design process. This material emphasizes the application of task analysis, criticality analysis, and other evaluation methodologies especially applicable during warning design.

CHAPTER 7

CLASSIFYING WARNINGS AND THEIR APPLICATIONS

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The previous chapters have indicated some of the complexity of the warning issue. From these earlier chapters, it becomes apparent that there are many different types of warnings and applications. A warning taxonomy can be used to classify both the many different forms of information which act as warnings and the many different settings within which such information is transferred. A warning taxonomy consequently provides a means for distinguishing and comparing the different types of warnings and applications. As such, the development of a warning taxonomy is an initial step toward the scientific analysis of warnings.

Before a warning taxonomy can be developed, important factors must be uncovered which both typify and distinguish warnings. The structural and procedural components given in Chapter 2 can serve such a purpose. Many of these components are directly incorporated into the warning taxonomy described in this chapter. The "warning taxonomy" itself consists of two taxonomies which respectively distinguish between various warnings and warning scenarios. The taxonomy of "warning types" exclusively consists of factors intrinsic to a warning. The taxonomy of "warning scenarios" includes factors that are related to the task, user, and product.

The following discussion will separately consider the two taxonomies. The first section will address the taxonomy of warning types, the second will address the taxonomy of warning scenarios.

TAXONOMY #1: WARNINGS TYPES

The taxonomy of warning types is primarily concerned with describing forms of transferred information that act as warnings. Consequently, the taxonomy has great similarities to the structural components of the communication process described in Chapter 2.

In this proposed taxonomy, various types of warnings are classified using four basic strata also given in Chapter 2. These strata allow a thorough classification based on 1) the source, 2) the external channel, 3) the message, and 4) the sensory channel. Each of these strata are listed and further subdivided in Table 7 – 1. Since the following discussion will directly correspond to Table 7−1, headings in the text correspond to those used within the table.

Strata #1: The Source

This strata distinguishes between those sources of warning information that are A) energy emitters, B) energy reflectors or absorbers, or C) material absorbers or emitters. Within each of these categories, a similar set of more detailed factors are used to classify a particular source.

A. Energy Emitter Sources that emit energy differ in the type of energy emitted, the energy level of the outputs, and the activation conditions for which the energy is emitted. Both the type and level of energy emitted by a source are self-explanatory (see Table 7−1). In Chapter 9, consideration will be given to the minimal levels of energy required in specific settings for particular types of energy.

An energy emitter is activated when it emits energy. The conditions under which such sources are activated are also shown in Table 7−1; at the most general level, an internal energy supply and some triggering condition are necessary. The internal energy supply provides the energy tapped by the source when it emits energy. For example, most home fire alarms contain batteries and are therefore examples of sources that contain an internal supply of electro-chemical energy. The designed triggering conditions of an energy emitter can be divided into those associated with energy/force inputs above or below a threshold, or those associated with material inputs above or below a threshold. In regard to energy/force inputs we can more specifically consider mechanical energy (or force), heat (or temperature), electrical current (or voltage), and the frequency (or flux) of radiant energy. Material inputs can be distinguished as solids, liquids or gases.

B. Energy Reflector/Absorber Sources which reflect or absorb energy differ in their response to different types of energy, output levels, and activation conditions. As for energy emittors, the type and/or level of energy responded to and/or output is quite self explanatory. For example, a printed warning sign will reflect varying fractions of the radiant energy which falls upon it, as a function of the radiant energy's frequency.

An energy reflector or absorber will be activated whenever it contacts an external energy supply that is above a threshold value for the form of energy the source reflects or absorbs. Such activation conditions usually differ significantly from those noted earlier for energy emitters, but may be similar. To illustrate a fundamental difference, consider the difference between an automotive warning light (an energy emitter) and a printed warning sign (an energy reflector). The warning light is activated only when sensors react to very specific triggering conditions. In contrast, the warning sign is always activated whenever light is present. However, a warning sign can sometimes be designed so that it is activated only under very specific conditions. For example, a sign inside the cover of an electrical appliance is activated only when the cover is removed.

C. Material Emitter/Absorber Sources of this type emit or absorb particular types of material rather than energy at specific concentration levels. The activation conditions of such sources may be a function of energy or force transfer above or below threshold values, or of material transfer above or below threshold values. A simple example of a material emittor is a stove that emits ordorifous compounds when certain temperatures are exceeded.

Table 7 – 1
Taxonomy #1: A Classification of Warning Types Broken Down by Source, Channel, Message, and Receiver Factors.

<u>**Strata #1: The Source**</u>

A. Energy Emitter
- 1. Energy Type Emitted
  - a. mechanical
  - b. thermal
  - c. radiant
  - d. electrical
- 2. Energy Level of Outputs
- 3. Activation Conditions
  - a. internal energy supply
    - 1. mechanical
    - 2. thermal
    - 3. electrical
    - 4. radiant
  - b. triggering conditions – sensor
    - 1. energy/force input above/below threshold
      - a. mechanical energy/force
      - b. heat/temperature
      - c. current/voltage
      - d. frequency/flux
    - 2. material input above/below threshold
      - a. solid
      - b. liquid
      - c. gas

B. Energy Reflector/Absorber
- 1. Energy Type Reflected/Absorbed
  - a. mechanical
  - b. radiant
  - c. thermal
- 2. Energy Level of Outputs
- 3. Activation Conditions
  - a. energy/force transfer above/below threshold
  - b. material transfer above/below threshold

C. Material Emitter/Absorber
- 1. Material Type Emitted/Absorbed
  - a. solid
  - b. liquid
  - c. gas
- 2. Concentration Level of Outputs
- 3. Activation Conditions
  - a. energy/force transfer above/below threshold
  - b. material transfer above/below threshold

Table 7 – 1
(Continued)

Strata #2: The External Channel

A. Channel Composition
  1. Solid Material
  2. Liquid
  3. Gas
  4. Vacuum

B. Transferred Elements
  1. Energy
    a. type
      1. mechanical
      2. thermal
      3. electrical
      4. radiant
    b. level
      1. upper/lower thresholds
  2. Material
    a. type
      1. solid
      2. liquid
      3. gas
    b. levels
      1. upper/lower thresholds

C. Attenuation/Accentuation

D. Noise

Strata #3: The Message

A. The Information Code – discrete vs continuous
  1. Temporal
  2. Intensity
  3. Spacial
  4. Verbal
    a. auditory
    b. visual

B. General Symbol Structure
  1. Verbal
  2. Abstract
  3. Pictograph

Table 7 – 1
(Continued)

C. Message Meaning
   1. Derivable Knowledge Components
      a. hazard definition
         1. cause
         2. magnitude
         3. probability
      b. countermeasure definition
         1. response
         2. context – before, during, or after accident
      c. hazard indication
   2. Explicit Knowledge Components
      a. asserted and/or negated conditions
      b. asserted and/or negated actions
   3. Implicit Knowledge Components
      a. symbol semantics
      b. symbol syntax
      c. symbol pragmatics

D. Message Function
   1. educational/persuasive
   2. informative/alerting

E. Message Tone
   1. Descriptive
      a. asserted or negated conditions
   2. Prescriptive
      a. asserted or negated conditions and actions
      b. actions alone
   3. Proscriptive
      a. asserted or negated conditions and negated actions
      b. negated actions alone

Strata #4: The Sensory Channel

A. Sensors
   1. visual
   2. auditory
   3. olfactory
   4. vestibular
   5. tactile
   6. kinesthetic

Strata #2: The External Channel

The external channel is the medium between the receiver and the source. As briefly discussed below, external channels vary in their A) composition, B) transferred elements, C) attenuation/accentuation, and D) noise.

A. Channel Composition The composition of a channel can vary greatly. Certain channels are composed of solid, liquid, or gaseous materials. Other channels are literally composed of nothing (i.e. they are vacuums). As discussed immediately below, the composition of a channel has great influences on the types of elements which can be transferred over a channel.

B. Transferred Elements The elements which can be transferred over a channel can be defined in terms of energy and material. Certain channels transfer energy of particular types when the transferred energy is at a level that falls between certain upper and lower thresholds. Other channels transfer materials of particular types when the transferred material is at a concentration level that falls between certain upper and lower thresholds. In many cases, channels transfer combinations of energy and materials.

The composition of a channel influences the forms of energy and matter that can be transferred in fairly complex ways. For example, some solids (such as glass) efficiently transfer many forms of radiant energy; others (such as wood) do not. On the other hand, a vacuum does not transmitt mechanical energy (with the exception of energy transferred via gravitational effects), while it efficiently transfers radiant energy.

C. Attenuation/Accentuation The attenuation or accentuation level of a channel simply describes the mathematical relationship between the channel's input and output levels. Most channels attenuate (i.e., reduce) the power of the channel's input in a way described by a linear or quadratic function of the distance between the source and receiver. A few channels, such as amplifiers, accentuate (i.e. increase) the power in the channel's input.

For example, in the simplest case, the energy in light and sound decreases as a quadratic function of distance from the source. It must be realized, however, that attenuation or accentuation effects can become very complicated when reflections occur. Reflections can cause energy to be stored in the channel; usually such stored energy becomes noise.

D. Noise A final channel-related variable is noise. Most channels add some noise to the input signal. The noise level is occasionally a function only of the energy level or material concentration within the channel when no signal is present. Under such circumstances, the noise can be modeled as random inputs that occur independently of the inputs to the channel; this allows fairly simple probability theory to be applied. In many cases, however, noise may be related to the strength of the signal; this significantly increases the difficulty of modeling noise with probability theory.

Strata #3: The Message

The message transmitted by a warning can be broken down in an analogous way. At a general level, the breakdown can be in terms of A) the information code, B) the general symbol structure, C) the message's meaning, D) the message's function, and E) the message's tone.

A. The Information Code Information codes and their role in the transmission of information were discussed in Chapter 2. Recall that different codes may be used for internal as opposed to external channels. Also recall that the considered codes were temporal, intensity, spacial, or verbal.

Here, we only consider the codes used in external channels. For each of these considered codes, it is possible to distinguish between discrete and continuous versions. A discrete code has a finite number of levels, while a continuous code has an infinite number of levels. It should also be emphasized that most real messages use combinations of coding methods. For example, a digital windspeed indicator with ten different values uses a verbal-discrete-intensity code, while an analogue (pointer on a scale) windspeed indicator uses a verbal-spacial-continuous-intensity code.

B. General Symbol Structure It is normally easier to classify message conveying symbols in terms of their general structure rather than information code. In such an approach, we only distinguish between verbal, abstract, and pictographic symbols. There are subtle overlappings between these categories, but for an initial classification, the categories are useful. During the detailed evaluation of a warning, however, it may be necessary to consider the specific forms of internal and external coding, which often will, of course, require substantial research.

C. Message Meaning Both Chapters 11 and 12 emphasize an approach of describing meaning that distinguishes among derivable, explicit, and implicit knowledge components (as also summarized in Table 7−1). Rather than referring the reader to these chapters, a brief summary is given below.

Derivable Knowledge Components. Those components of a message's meaning which arise from the interaction of explicit knowledge components (in the message) and implicit knowledge components (stored within the receiver's memory) are derivable. As summarized in Table 7−1, the derivable knowledge components may 1) define a hazard in terms of cause, magnitude, or probability, 2) define a countermeasure in terms of responses and the context within which the response is relevant, or 3) indicate the presence of a hazard. Each of these forms of knowledge are significantly expanded upon in Chapters 11 and 12.

Often, the derivable knowledge components are directly retrieved from long-term memory, with the explicit knowledge components acting as memory cues. However, knowledge can also be derived by consulting knowledge references, as typified by the use of external memory such as the product itself or reference texts.

Explicit Knowledge Components. An explicit knowledge component is entirely specified in the message and always consists of asserted or negated conditions and/or actions. As will be discussed later in Chapter 11, combinations of conditions and actions can describe rules and other more complex elements of meaning.

Implicit Knowledge Components. An implicit knowledge component is never specified in the message itself. Instead, its meaning is an overlearned association within a person's memory that describes symbol semantics, syntax, and pragmatics. Symbol semantics and syntactics are easily seen to be implicit. For example, sentences rarely attempt to describe the meaning of alphabetical characters or the rules of grammar which they use. It takes a little more effort to understand the implicitness of symbol pragmatics. However, returning to the siren example, the ability of people to sometimes interpret the siren as a warning and at other times interpret it as a lunch signal, obviously, requires the use of well-learned knowledge that is not explicitly found within the message.

D. Message Function Messages may be directed toward serving educational, persuasive, informative or lasting functions. To serve an educational function, detailed information and definitions that the human is not likely to know are provided, as when training people to respond appropriately to hazards. Persuasive messages attempt to convince people to act in accordance with information they already know or have been exposed to.

The vast majority of warnings simply indicate or alert people to the presence of hazards or the need for taking countermeasures. Such messages are usually minimally explicit and make use of the ability of people to derive information by applying their knowledge.

E. Message Tone Another way of categorizing warnings is given by Easterby and Hakiel (1981), who define descriptive, prescriptive, and proscriptive warnings. Descriptive warnings identify the hazard (e.g., "high voltage"), while prescriptive warnings specify a positive course of action which should be taken in the presence of the hazard (e.g., "put out cigarettes"). Proscriptive warnings prohibit a specific action in the presence of the hazard (e.g., "no smoking allowed").

Descriptive, prescriptive, and proscriptive messages can be defined by asserting or negating explicit knowledge components. As shown in Table 7−1, a descriptive message consists of asserted or negated conditions; a prescriptive message consists of asserted or negated conditions and asserted actions, or asserted actions alone; a proscriptive message consists of asserted or negated conditions and negated actions, or negated actions alone.

Strata #4: The Receiver's Sensory Channel

The sensory channel used to convey warning information was briefly discussed in Chapter 2. As discussed there, this channel is an internal channel, since it is within the human. In particular, warning information can be conveyed over visual, auditory, olfactory, vestibular, tactile, and kinesthetic sensory channels. Specific channels may be more desirable than others for certain warnings.

An Example Application

The warning taxonomy shown in Table 7−1 can be easily applied to define, and distinguish between, different warnings. Table 7−2 presents the results obtained when four different warnings were classified. These warnings are quite divergent: they include a fire alarm, speed bumps, noxious chemicals in natural gas, and a "Do Not Smoke" sign. Some general findings regarding these warnings are summarized below.

First, each of the warnings uses a distinct source. The fire alarm's source is an mechanical energy emitter; the speed bump's source is a mechanical energy reflector; the noxious chemical's source is a gaseous chemical emitter; and the sign's source is a radiant energy reflector. Also, with the exception of the "Do Not Smoke" sign, all of the sources are activated only while conditions requiring response from the receiver are present.

Second, the channels used by the warnings vary in a variety of ways, and are connected to different receiver sensors. The fire alarm uses a gaseous channel that transmits mechanical energy received by auditory senses; speed bumps use a solid channel that transmits mechanical energy received by kinesthetic and auditory senses; the noxious chemical uses a gaseous channel that transmits a chemical received by olfactory senses; the warning sign uses a gaseous channel that transmits radiant energy received by visual senses.

Table 7-2
Example Warnings Classified Using the Taxonomy Described in Table 7-1

Defining Dimension of Warning	Fire Alarm	Speed Bumps	Noxious Chemical in Natural Gas	"Do Not Smoke" Warning Sign
Source – Strata #1	bell	speed bumps	chemical	sign
energy emitter	yes	no	no	no
type emitted	mechanical	–	–	–
energy level	90 dB	–	–	–
activation condition	temp>360°F	–	–	–
internal energy	battery	–	–	–
trigger	temp>360°F	–	–	–
energy reflector	no	yes	no	yes
energy type	–	mechanical	–	radiant
energy level	–	high	–	variable
activation condition	–	car hits bump	–	light
material emitter	no	no	yes	no
material type	–	–	gas	–
concentration level	–	–	x parts/billion	–
activation condition	–	–	natural gas present	–
Channel – Strata #2	air	frame of car	air	air
channel composition	gas	solid	gas	gas
transferred element	energy	energy	material	energy
energy type	mechanical	mechanical	–	radiant
material type	–	–	gas	–
information code	continuous	continuous	continuous	discrete
attenuation	x dB/feet	–	1/1000	$1/x^2$
noise	40 dB	low	low	varies
Message – Strata #3				
symbol structure	nonverbal	nonverbal	nonverbal	verbal
message meaning	get out	slow down	don't smoke	hazard
high level meaning	fire in building	drive too fast	gas leak	don't smoke
explicit components	asserted condition	asserted condition	asserted condition	negated action
implicit components	semantics/ pragmatics	semantics/ pragmatics	semantics/ pragmatics	semantics/ syntax
message tone	descriptive	–	descriptive	proscriptive
Receiver – Strata #4	human	human	human	human
sensor	auditory	kinesthetic	olfactory	vision

Third, the messages transmitted by the various warnings vary extensively in their structure and explicitness. The fire alarm, the speed bumps, and the noxious chemical provide only a nonverbal condition, the meaning of which is very context-dependent. Conversely, the sign provides a verbal, negated condition, the meaning of which is not context-dependent.

It should be emphasized that a more detailed breakdown can be performed within each of the above strata. For example, several variants of each warning could be considered and exact values could be developed for each strata. More specific aspects of these general strata will be considered in Chapter 10 when the general methodology for analyzing warnings is discussed. The integration of these strata and their particular values with the taxonomy of warning scenarios will be discussed later in this chapter, and will be further elaborated in Chapter 10.

TAXONOMY #2: WARNING SCENARIOS

The second classification scheme developed here by these authors has the objective of specifying by categories the combination of circumstances within which a particular warning occurs. The rationale for the development of this second taxonomy is that the extent to which a particular warning or label, as described by the first taxonomy, is effective is likely to depend upon the "scenario" within which it occurs.

This second taxonomy places specific emphasis on defining scenarios in terms of strata which focus on the receiver, task, and product/task interaction. Within each of these strata, factors complementary to those factors considered in Table 7–1 are presented. Table 7–3 presents this classification system. As for the earlier discussion, the major headings in the table and text will be the same.

Before discussing the strata within the table, it should be noted that nearly every factor within the various strata first lists the context. The context is hierarchical, as it ranges from general use phases, down to goals within elemental tasks (such an approach is consistent with the modeling approach later discussed in Chapters 11 and 12). Consequently, Table 7–3 describes a way of documenting receiver, task, and product/task related elements within very particular contexts.

To document the use of a particular warning, the relevant contexts must first be developed. Then, within each context, the remaining factors listed under the various strata are specified.

Strata #1: The Receiver

Receivers vary in A) knowledge, B) behavior patterns, and C) skills and abilities. The knowledge of receivers includes that which is available from long-term, external, and short-term memory. The behavior patterns of receivers can be defined in terms of goals, objectives, and utilities. Skills are also related to knowledge and are influenced by abilities. A receiver's abilities include the sensitivity of his sensors, effector capacity or control, and memory capacity. Each of these receiver related factors are further subdivided in Table 7–3, and discussed below.

A. Knowledge A general point is that the user population may be either informed or uninformed about the hazard addressed by the warning. Informed people can be expected to know and understand the hazards associated with the product before seeing a warning. In this situation, warnings act only as reminders that trigger previously learned responses in their

Table 7 – 3

Taxonomy #2: A Classification of Warning Scenarios Broken Down by Factors Related to the Receiver, Task, and Receiver-Task Interaction.

Strata #1: The Receiver

A. Knowledge
- 1. Long-Term Memory
  - a. context
    - 1. use phase – operation, maintenance, storage
    - 2. subtask
    - 3. elemental task
    - 4. goal
  - b. declarative – static
    - 1. symbol semantics
    - 2. symbol syntax
    - 3. symbol pragmatics
  - c. procedural – dynamic
    - 1. rules
    - 2. schemas
- 2. External Memory
  - a. context
    - 1. use phase – operation, maintenance, storage
    - 2. subtask
    - 3. elemental task
    - 4. goal
  - b. declarative
    - 1. performance aids
      - a. gauges
      - b. displays
      - c. etc.
    - 2. product interface
      - a. switch positions
      - b. etc.
    - 3. environmental interface
  - c. procedural
    - 1. performance aids
      - a. instructions
      - b. checklists
      - c. manuals
      - d. etc.
    - 2. product interface
      - a. control groupings/sequences
      - b. functional components
      - c. etc.
    - 3. environment
- 3. Short-Term Memory
  - a. context
    - 1. use phase – operation, maintenance, storage
    - 2. subtask
    - 3. elemental task
    - 4. goal
  - b. declarative – conditions
  - c. procedural – goals

Table 7-3
(Continued)

B. Behavior Patterns
  1. Objectives or Goals
    a. context
      1. use phase – operation, maintenance, storage
      2. subtask
      3. elemental task
    b. warning related
    c. receiver related
  2. Receiver Assigned Utilities
    a. context
      1. use phase – operation, maintenance, storage
      2. subtask
      3. elemental task
    b. warning related goals/actions
    c. receiver related goals/actions
  3. Behavioral Consistency
    a. context
      1. use phase – operation, maintenance, storage
      2. subtask
      3. elemental task
    b. match between goals
    c. relative weights (utilities)

C. Skills and Abilities
  1. Sensor Sensitivity
    a. energy threshold/resolution
    b. material threshold/resolution
  2. Effector Capacity
    a. accuracy
    b. force
    c. speed
  3. Memory Capacity
    a. write/read times
    b. short term memory capacity

<u>**Strata #2: The Task**</u>

A. Receiver Workload
  1. Context
    a. use phase – operation, maintenance, storage
    b. subtask
    c. elemental task
    d. goal
  2. Workload Components (continued on next page)
    a. sensory (for each channel)
      1. heavily loaded
      2. lightly loaded

Table 7-3
(Continued)

2. Workload Components (continued)
    b. memory (STM and LTM)
        1. heavily loaded
        2. lightly loaded
    c. central processor
        1. heavily loaded
        2. lightly loaded
    d. effectors
        1. heavily loaded
        2. lightly loaded

Strata #3: The Product/Task Interaction

A. Hazard Type
    1. Context
        a. use phase – operation, maintenance, storage
        b. subtask
        c. elemental task
        d. goal
    2. Energy/Material Type
    3. Temporal Characteristics
        a. transient hazard
        b. non-transient hazard
    4. Damages
        a. magnitude
        b. probability
    5. Complexity
        a. cause
        b. effect
    6. Number of Hazards

B. Location of a Warning
    1. Context
        a. use phase – operation, maintenance, storage
        b. subtask
        c. elemental task
        d. goal
    2. Distance
        a. temporal
            1. continuous
            2. intermittent
                a. random presentation
                b. selective presentation
        b. spatial
            1. task phase
        c. logical
            1. levels of derivation
    3. Permissable Response Time

memory. Trained industrial users and informed consumers, fall within this category, as do the users of products that pose obvious hazards. Uninformed people, on the other hand, do not know or understand the the hazards associated with a product. Such people might be using products which pose unobvious hazards, or could be uninformed for other reasons. Warnings for these users are sometimes used with the objective of educating them.

A more specific point is that receiver knowledge can be stored in long-term memory, external memory, and short-term memory. The availability of knowledge from each of these forms of memory is dependent upon the task-related context, and the knowledge itself can be either declarative or procedural. Declarative knowledge roughly corresponds to static facts, while procedural knowledge corresponds to methods by which new facts are derived. Table 7−3 summarizes these principles, wherein the context (since it is determined by the task) is the same for each source of receiver knowledge.

It is well worth comparing the various forms of declarative and procedural knowledge listed respectively under long-term, external, and short-term memory in the table.

B. Behavior Patterns A general point is that receivers will normally behave either consistently or inconsistently with particular warning messages. The degree to which normal behavior patterns (or those perceived to be desirable by the receiver) conflict or agree with a warning message will influence the effectiveness of a warning. One method for determining this tendency is to evaluate the receiver's goals, as well as the perceived utility of attaining particular goals within task specific contexts.

This is the approach documented by Table 7−3, where the consistency of behavior patterns with those prescribed by a warning are specified in terms of goals, and utilities. Also note that two types of goals are present, those within the warning and those within the receiver, and that within particular task-related contexts the receiver assigns utilities to each type of goal. The consistency between the prescribed and actual behavior patterns is then a function of both the extent to which the goals of the warning and of the receiver match, and of the respectively assigned utilities.

C. Skills and Abilities Receiver skills and abilities are the only considered factors which are relatively independent of the task related context. However, within a task, the receiver's ability will be either adequate or inadequate to allow the actions recommended by the warning to be performed. Consequently, the context will have to be considered when evaluating the adequacy of receiver skills and abilities.

In particular, a receiver's sensors have energy or material thresholds and resolving capacity. If the transmitted energy or material is beneath the threshold values, the message will not be transmitted. Similarly, the feasible outputs of receiver effectors fall within upper and lower limits on accuracy, force, and speed. If the actions prescribed by a warning message exceed these limitations, performance will be degraded.

Memory limitations are the major factor limiting performance in many situations. Highly skilled performance requires that overlearned schemas be present in long-term memory. Problem-solving performance places heavy demands on short-term memory, as does multi-tasking. The primary memory limitations can be described in terms of the time required to retrieve and store information, and in terms of the capacity of short-term memory.

Strata #2: The Task

The task-related strata is primarily concerned with defining the workload of the product's user. User workload is defined in terms of the task-related context and the workload components within particular contexts. Within each context, different workload components are present that place different demands on receiver skills, abilities, or resources.

Components of workload can consequently be broken down into the categories of sensory load, memory load, central processor load, and effector load. As an initial approximation, each of these workload components can be specified as being heavy or light.

Strata #3: The Product/Task Interaction

The interaction between a product and a task specifies A) the hazard type and B) the location of the warning. To determine the hazard type which is present, the energy/material type, temporal characteristics, damages, complexity and number of hazards must be considered.

A. Hazard Type A hazard can be associated with the transfer of mechanical, electrical, thermal, or radiant energy. Hazards can also be associated with the flow of materials. Hazards associated with these various types of energy or material can be either transient or nontransient. Transient hazards are hazards that occur only during certain phases of the use of a product (e.g., its maintenance), while nontransient hazards are continually present (e.g., flammable chemicals).

The damages associated with a hazard may vary in probability and magnitude. Products may pose low or high probability of sustaining large or minor damages. The complexity of a hazard also varies as the causes or conditions associated with the undesired events can be either easy or difficult to understand. The number of particular hazards is a final point that should be considered.

B. Location of a Warning The location of a warning in relation to the phases of a task and the existing level of hazard may vary in time and space. It may also vary in the amount of logical derivation necessary to determine its meaning. Consequently, it is possible to speak of temporal, spacial, and logical distance of the warning from the denoted hazard. Complementary to these measures of distance is the permissible response time that is associated with a safe response. In other words, the measures of distance affect the required time to respond to a warning and can be compared against the permissible response time.

In regard to temporal characteristics, warnings can either be continuously activated (for example, a warning label), or intermittently activated (for example, a warning light). An intermittent warning will either randomly present its message, or present its message when particular activation conditions occur. Such activation conditions may be either independent or dependent on the presence of hazard. When activation is dependent upon the presence of hazard, it is important to consider the time between emission of the warning and the need for action.

A warning may be spatially located close to the hazard or far from the hazard. The spatial proximity of the human to the warning as a function of a phase of a task is an important consideration, especially when the hazard is a function of the task phase.

Similarly, the logical distance of a warning from the denoted hazard may vary. A short logical distance means that little inference is necessary, as when responding directly to a perceived hazard. Longer logical distances appear when abstract symbols (written text for example) are translated into concrete symbols closer to reality.

SUMMARY

Two taxonomies are described in the chapter: A taxonomy of warning types and a taxonomy of warning scenarios. Specific combinations of the two taxonomies correspond to particular applications of warnings. For example, consider a warning that proscribes smoking in an industrial paint room. In this example, the warning (do not smoke) is classified in Table 7−2. The scenario can then be described using Table 7−3. An attempt to describe the scenario using Table 7−3 quickly reveals that much highly detailed analysis must be performed to define the task-related contexts within which particular elements of the strata are considered. Chapters 10 and 12 offer a more detailed discussion of how such analysis can be done.

Warnings that are defined by certain combinations of the classifying variables may be effective. Other combinations of the classifying variables may lead to ineffective warnings. This general approach provides an excellent framework for future research concerning the warning issue. It also provides a way to examine the unwieldy problems regarding the application and design of warnings. In particular, both the description of selecting warning applications in Chapter 8 and the general warning design methodology given in Chapter 10 apply elements of these two taxonomies.

CHAPTER 8

SELECTING EFFECTIVE APPLICATIONS OF WARNINGS

CHAPTER 8. CONTENTS

CHAPTER 8

SELECTING EFFECTIVE APPLICATIONS OF WARNINGS

This chapter is intended to guide the preliminary selection of effective applications of warnings to products in terms of the respective costs and benefits to consumers and manufacturers alike. These respective costs and benefits can vary greatly between different applications. There are few logical reasons for providing warnings that do not provide tangible benefits by effectively reducing the incidence of accidents. Consequently, the developed approach is designed to screen out those applications that are unlikely to be effective by applying the conclusions developed during the review of warning effectiveness given in Chapters 4, 5, and 6.

Several other approaches have been used in deciding whether a warning should or should not be applied to a product. Among these approaches, legally-based criteria have had the most influence upon the application of warnings. Less emphasis has been placed on approaches that consider the effectiveness of warnings, because human factors research related to warnings is still in its initial stages. However, since the legally-based criteria continue to be important, they are briefly considered in the following discussion.

After introducing the legal criteria, discussion shifts to describing rational ways of addressing risk. This latter discussion sets the stage for describing a risk and effectiveness based methodology for selecting applications of warnings.

THE LEGAL CRITERIA

Legal theories such as "duty to warn," "duty to instruct," and the "continuing duty to warn," place a responsibility on manufacturers and product suppliers to provide warnings. Conversely, the "patent danger test" eliminates their responsibility to warn in certain situations. All of these theories are intrinsic to the warning issue and intimately related to the theory of strict liability. In the following discussion, strict liability, the duty to warn, and the patent danger test will first be briefly described and then their general implications will be summarized and critiqued.

Strict Liability

Strict liability has become a primary cause of action in product liability cases (Sales, 1982). Under this legal theory, a claimant must prove four basic conditions in order to recover damages from a manufacturer or product supplier: 1) The product is defective. 2) The product reaches the consumer without substantial change. 3) The product's defect renders it unreasonably dangerous. 4) The unreasonably dangerous defect causes injury to the product's user.

The defect in the product may be related to its manufacture, design, or marketing (Ross, 1981). Manufacturing defects occur when the the product's design deviates from its design specifications. (For example, a manufacturer may fail to follow engineering blueprints.) A typical test for a manufacturing defect is to compare the product in question to a "good" product from the same manufacturer (Weinstein et al., 1978). Design defects are said to exist when the product is designed in a way that presents unreasonable danger to product users. The determination of whether a design defect is present typically involves a balancing process in which the cost of a design modification that reduces the hazard is compared to the utility or benefit to be gained from redesigning the product (Weinstein et al., 1978). This balancing process is similar to using the methodology for selecting applications of warnings described later in this chapter.

Marketing defects, on the other hand, can involve 1) the failure to provide any warning of the risks involved in the use of the product, 2) the failure to provide an adequate warning of the risks involved in the use of the product, or 3) the failure to provide appropriate, adequate instructions and directions for the safe use of the product. More simply, a marketing defect is said to be present when a product free of manufacturing and design defects is unreasonably dangerous because of the absence of warnings (Sales, 1982).

The Legal Duty to Warn

The legal duty to warn is very much related to the concept of a marketing defect, and has important implications to manufacturers. Sales (1982) provides an excellent summary of this topic which is briefly discussed below.

A manufacturer held to have the duty to warn may become liable for damages. In determining whether a manufacturer has a legal duty to warn, several product-related characteristics must be determined. A manufacturer is generally required to warn if 1) the product presents a risk of harm, 2) the risk arises with the intended or reasonably foreseeable use of the product, and 3) the manufacturer or product supplier knows or can be reasonably expected to foresee the risk of harm (Sales, 1982).

The Patent Danger Test

The patent danger test is a commonly used defense against allegations that a warning is needed on a product. This defense arises from legal theory wherein a warning is deemed as being unnecessary when the danger is open and obvious (Keeton, 1970). However, there is a great deal of uncertainty as to what connotes an open and obvious danger. A simple means of addressing this question is is given below in the summary and critique of the legal requirements.

Summary and Critique

In summary, the legal requirements indicate that all hazards inherent in a product or its use must be warned against, with the possible exception of those hazards that are open and obvious or not foreseeable. However, clear, academically-based criteria for determining whether hazards are obvious or foreseeable have not been defined. Consequently, manufacturers have been held liable for not warning against extremely remote risks, simply because the cost of placing a warning on a product appears to be small (Twerski et al., 1976). This motivates manufacturers to use extremely comprehensive warnings (Schwartz and Driver, 1983). Such warnings are likely to be ineffective, and, under such circumstances, warnings are useful only to manufacturers in their attempt to avoid liability.

The patent danger test provides an initial basis for eliminating many ineffective warnings from consideration. This point logically follows because a nonverbal warning message might be interpretted as making a hazard open and obvious. As described earlier in Chapter 7, and in a view contrary to the common perception of the term, a warning can be given in many nonverbal and not necessarily explicit ways. For those people who are not familiar with the concept of a nonverbal warning, as defined in this book, equating nonverbal warnings with open and obvious danger is a very reasonable interpretation; especially because the legal community has emphasized the view that warnings are always explicit lists of "dos" and "don'ts". As such, this book provides a basis for clarifying the ambiguous "patent danger test."

On the other hand, some applications of the patent danger test may eliminate potentially useful warnings from consideration. Warnings should, in fact, be considered when the danger is obvious (where "obvious danger" is defined as danger which is readily perceivable with minimal special training) because a warning might be effective under such conditions. In other words, whenever a hazard is present, a warning may be warranted. As emphasized above, however, a warning, is not necessarily a list of explicit verbal statements. The critical problem is to determine the appropriate amount of information that should be given explicitly instead of being derived by the product's user from a less explicit message.

In justification of this view, several studies surveyed in Chapters 4, 5, and 6 support the conclusion that warnings are more likely to be effective when the danger that is warned against is readily perceived by the receiver. For example, Wright et al. (1980) indicated that people were more likely to read warnings for products they perceived as hazardous, while Laner and Sell (1960) found increased compliance with their warning when the safety-related benefit of heeding the warning was more obvious. It also makes sense to warn against obvious danger, because in this situation it might not be necessary to change people's normal behavior in order to avoid damages (as summarized in Chapter 6, it is hard to change behavior). Another reason to warn of obvious danger is that people are prone to forget health-related knowledge (see Ley, 1980). A warning of obvious danger might serve as a reminder to knowledgeable users, reducing the likelihood of accidents due to nearly inevitable memory lapses. In this situation, a well-designed warning, especially when in implicit nonverbal form, could act as feedback that reinforces existing safe habits.

In conclusion, the problem of an oversaturation of warnings might be avoided if only the reasonably obvious hazards were warned against. Warning against obvious danger is also likely to result in the greatest benefit to both consumers and manufacturers, simply because the majority of damages are caused by hazards which can be understood by most reasonably knowledgeable users.

A WARNING-RELATED RISK ASSESSMENT TAXONOMY

Few individuals would argue with the idea that warnings should be applied only when they will reduce the frequency and severity of product-related injuries. In fact, this idea is innate to the so-called "balancing" performed by the courts where the cost of a warning is compared to the benefits of providing a warning. In other words, to justify a decision to provide a warning, the safety-related benefits must outweigh the costs of applying the warning, as frequently noted by several authors (Schwartz and Driver, 1983; Weinstein, et al., 1978; McCarthy et al., 1982).

To rationally perform this decision-making process, methods are needed for defining, measuring and analyzing the costs and benefits of particular warnings. This topic is part of risk assessment, and falls within the field of safety science. To organize the particular concepts needed during warning-related risk assessment, we have developed a simple taxonomy exactly along these lines. As shown in Table 8−1, the taxonomy consists of three basic strata: 1) generic costs and benefits of warning, 2) elements of risk, and 3) methods of risk analysis. The taxonomy as a whole describes necessary elements of warning-related risk assessment. The first strata defines some generic costs and benefits; the second strata describes concepts necessary to the measurement of these costs and benefits; and the third strata describes some concepts applicable when analyzing risk. The following three sections correspond exactly to these three basic strata.

Strata #1 Generic Costs and Benefits

Since the desirability of a particular warning is rarely obvious during the initial stage of product design, the respective costs and benefits of warning versus not warning should be evaluated. The following discussion describes some costs and benefits associated with the use of warnings. Although this discussion is at a very general level, these costs and benefits can be more specifically measured for particular applications of warnings.

As described in Table 8−1, the costs and benefits associated with a particular application of a warning can be roughly divided into those incurred by the consumer versus those incurred by the producer of a product. In certain scenarios, the costs to the consumer directly translate into benefits to the producer, and vice versa. For example, overwarning may provide litigation-related benefits to the producer while providing no benefit to the consumer and eliminating the consumer's legal remedy for damages. In other scenarios, the costs or benefits may be mutual, as in underwarning.

Table 8−2 describes some of these general costs and benefits associated with appropriate, over, and under-warning that are incurred by either the consumer or the producer of a product. As summarized in the table, the benefits to the consumer of receiving appropriate warnings might include reduced hazards and the facilitation of informed choice of products and actions. The cost to the consumer might be the elimination of legal recourse for marketing defects. For a producer, the benefits of providing appropriate warnings are primarily associated with reduced liability. The costs include those associated with designing, applying, and maintaining the warning, and perhaps lost sales. (That appropriate warnings result in a loss in sales is debatable. Ursic [1985] found warnings to be associated with positive consumer attitudes toward products.)

Overwarning results in the same costs and benefits to a producer as does the use of appropriate warnings, since overwarning has apparently not yet been perceived as a marketing defect. However, as noted in the paper by Twerski and Weinstein (1976), the indiscriminate use of warnings may lead to oversaturation and cause warnings to lose effectiveness, which is clearly a direct cost to the consumer and an indirect cost to the producer. Also, the

Table 8–1
A Decision Taxonomy Related to Warning Application

Strata #1 – Generic Costs and Benefits (see Table 8–2)

- A. Consumer Related
- B. Producer Related
- C. The Scenario
  - 1. appropriate warning
  - 2. over warning
  - 3. under warning

Strata #2 – Elements of Risk

- A. Probability
  - 1. warning present
  - 2. warning not present
- B. Consequences
  - 1. warning present
  - 2. warning not present
- C. Conditions/Causation
  - 1. warning present
  - 2. warning not present

Strata #3 – Methods of Risk Analysis

- A. Expected Severity
  - 1. dimensions
    - a. probability
    - b. consequences
  - 2. criterion
    - a. maximize/minimize
- B. Cut-off Criteria
  - 1. dimensions
    - a. probability
    - b. consequences
    - c. conditions/causations
  - 2. criterion
    - a. single dimension maximum/minimum
    - b. each dimension maximum/minimum
    - c. other
- C. Dimensional Weighting
  - 1. dimensions
    - a. probability
    - b. consequences
    - c. conditions/causation
  - 2. criterion
    - a. weights
    - b. maximize/minimize

Table 8-2
Generic Costs and Benefits Associated with the Application of Warnings.** (The scenarios are listed on the x-axis, and influenced concerns are on the y-axis.)

Concern	SCENARIO		
	Appropriate Warning	Over Warning	Under Warning
Consumer	(no legal recourse for marketing defect) useful information, hazard reduction, informed choice	(no legal recourse for marketing defect) (lost effectiveness of warnings), (lost utility of useful products), (emotional distress)	(unreasonable danger), (inadequate information), legal recourse for marketing defect
Producer	(design cost), (application cost), (maintenance cost), (lost sales), reduced liability	(design cost), (application cost), (maintenance cost), (lost sales), (lost effectiveness of warnings), reduced liability	(increased liability), increase sales

** note: items in brackets are costs, while items not in brackets are benefits

indiscriminate use of warnings may cause product users to avoid using beneficial products because most users lack the ability to objectively evaluate risks (Slovic, 1980). Underwarning, conversely, makes the producer liable for damages on the grounds of a marketing defect, but may increase sales of the product. Underwarning does allow a legal remedy for damages to consumers, but may result in unnecessary injuries.

Strata #2 Elements of Risk

"Risk" is a concept which has been defined in numerous ways. Many of the differences in interpretation of this concept can be explained by the tendency of researchers to emphasize those aspects of risk that are of special interest to them. The three most fundamental aspects of risk are the A) probability, B) consequences, and C) conditions/causation of accident related events. Different ways of combining and measuring these fundamental aspects of risk lead to different definitions of risk. These fundamental concepts are also frequently used to define other terms, such as "hazard," "danger," and "severity," as discussed in Chapter 11 which relates them to the knowledge components of a warning.

A. Probability Probability reflects the uncertainty in predicting events. With respect to warnings, probability provides a way of measuring the likelihood that certain costs and benefits will be incurred given that a warning is or is not present. The following discussion will address some important issues related to determining probabilities.

An initial point is that probability is a meaningful concept only when it is assigned to events. By definition, the sum of the probabilities for all possible events must equal 1. Consequently, when evaluating probabilities, it is very important that all possible events be considered. As noted by Fischhoff et al (1978a), people may have problems in exhaustively generating sources of risk. This of course leads to faulty estimates of risk. Conditional probabilities are especially important in the evaluation of risk, as they can be used to model situations where the state of an event depends upon the states of other events.

Although probability is a well-defined mathematical structure, controversy exists as to how probability should be used to infer the likelihood of actual events (Savage, 1954). The probability of events can be inferred by two general methods which are called objective and subjective. The objective method consists of first observing several repetitions of a process, and then assigning probability values to the observed events based upon their relative frequencies. The National Electronic Injury Surveilance System (NEISS), used by the Consumer Product Safety Commission (CPSC) to estimate the frequency of injuries associated with the use of specific consumer products, illustrates the application of this approach.

In subjective probability methods, probabilities are assigned based upon the beliefs of a particular individual. Since it is difficult to obtain objective probabilities for many "real world" events, probability is frequently assessed by subjective methods. The distinction between subjective and objective assessments of the probability of incurring damage has been noted by several researchers (Fox, 1961; Taylor, 1976).

B. Consequences The term consequence is quite self-explanatory, but as viewed here, takes a special connotation. Specifically, it is associated with the outcomes of accident-related events, typically in terms of damages. As such, consequences can be used to describe the benefits and costs associated with the presence or absence of a warning.

Measures of the consequences of specific events are essential to the evaluation of risk. Objective measures can be taken, typically in terms of accident frequency, severity, and monetary cost. More subjective measures are also feasible. The classic approach to developing subjective measures has been to transform objective measures into perceived utilities. This means that the objective measure of a consequence is weighted to make them correspond to the subjective perception of the consequence's magnitude.

Risk assessment usually emphasizes measures of undesirable or negative utilities. For example, Pearson (1982) describes "danger" as the harm which could be caused by a product, while "severity" quantifies this harm. Severity scales, of course, directly correspond to utility functions, since they attempt to rate objective measures of undesired consequences, such as injuries and deaths on a unidimensional scale, by scaling these objective measures so that they roughly correspond to subjective ratings.

C. Conditions/Causation Both the probability and consequences of accident-related events occur under or are caused by specific conditions. Determining whether the presence or absence of a warning has any causal influence on the probability and consequences of accidents is of primary concern here. If such causality is not understood, it is impossible to rationally make a decision to warn or not warn. This latter point logically follows because the actions of a rational decision-maker must be made in response to some condition or cause.

Conditions/causation will normally be described by characteristics of the human, environment, and product. If the relationship between these conditions and the probability, events, and consequences associated with a risk are known, the effect of actions taken by the decision maker can be predicted.

Strata #3 Methods of Risk Analysis

The very general costs and benefits associated with providing or receiving a warning that are summarized in Table 8−2 can be measured in terms of the above given risk terminology. Methods of risk analysis combine such measures of probability, conditions, and consequences in general ways, allowing global measures to be developed of a warnings desirability. Among such methods are those based upon A) expected severity, B) cut-off criteria, and C) dimensional weighting.

A. Expected Severity "Expected severity" is a standard measure which combines the probability and utility associated with an accident-related event by multiplying them. Measures of expected severity can be used to evaluate potential applications of warnings, as advocated by McCarthy et al. (1982). McCarthy et al. claim that warnings should be used only when hazards pose a high expected severity.

Some method of specifying a high, as opposed to low, expected severity must be specified, if an approach based on expected severity is to be used. This can be very difficult if objective measures of severity and probability are not available. Another limitation of using expected severity alone, is that this measure does not specifically consider the cause of accidents.

B. Cutoff Criteria The "cutoff criteria" method considers all three risk-related dimensions. In this method, the probability, consequences, and conditions are first considered in isolation. Cutoff criteria are then defined on each dimension which must be exceeded before a warning application is recommended. Examples of decisions based on cutoff criteria include the following: 1) Apply a warning if the cutoff criteria are exceeded on any individual dimension. 2) Apply a warning only if the cutoff criteria are exceeded on all dimensions. 3) Apply a warning under any other permutation of the dimensions and cutoff criteria.

As for the expected utility method, some method must be applied to determine the value on each dimension at which the cutoff should be made. The risk and effectiveness decision hierarchy discussed later in this chapter provides an initial set of criteria which can be used for this purpose.

C. Dimensional Weighting In the "dimensional weighting" method, each risk-related dimension is assigned a relative weight for a given application. Such weights are assigned so that the numerical measures on the respective dimensions are of the same order of importance. After each dimension has been weighted, the values of the weighted measures can be combined into an aggregate score.

Monetary cost/benefit analysis is a classical application of this method. In this approach, each cost and benefit is assigned a monetary value that is typically based upon expected utility. The costs and benefits are then compared, usually by subtracting costs from benefits or dividing benefits by costs. The alternative with the highest difference or quotient is then selected.

RISK AND EFFECTIVENESS BASED SELECTION

Chapters 4, 5, and 6 explored the effectiveness of warnings. Somewhat pessimistic conclusions were drawn, since the research related to warnings indicates that warnings will not influence behavior in many situations. Consequently, it becomes clear that it is invalid to automatically assume that a warning will be beneficial. However, based on that research, it is possible to describe general criteria for when warnings are more or less likely to have value. These criteria are organized within the risk and effectiveness decision hierarchy described below and illustrated in Figure 8−1.

This hierarchy incorporates many of the elements of the decision taxonomy discussed above and summarized within Table 8−1. Specifically, some simple cutoff criteria based upon effectiveness and risk are organized within a hierarchical structure that can be used to make preliminary decisions regarding the application of warnings. This hierachical structure allows these dimensions to be evaluated sequentially, and quickly screens out clearly inappropriate applications. It should be emphasized, however, that the hierarchy is not intended to provide insight regarding borderline applications. Such decisions require a more detailed evaluation, similar to that summarized in Chapter 10. The hierarchy is most applicable to the evaluation of warning labels, and other highly detailed and explicit forms of warning.

The elemental components of the decision hierarchy can be divided into risk- and effectiveness-based categories. The risk factors that are considered include 1) conditions, 2) probability, and 3) consequences. The factors influencing effectiveness that are considered include 1) the knowledge of the users, and 2) the existing behavioral patterns of the users.

Effectiveness-Related Factors

Beginning at the top of Figure 8−1, we see that the knowledge of the target population is the first screening variable. It was concluded in Section II that warnings will be effective when they reinforce information that the user already knows and believes (that is, when they serve to remind the user). In other words, a warning should be used as a reminder rather than as an educational or persuasive tool for modifying behavior. Educational functions, if absolutely necessary, are better served by other methods, such as training, because modifying human behavior is a very complex and difficult process. Persuasive functions are difficult regardless of the method used; even legally mandated penalties for not wearing seat belts fail to persuade many people to wear them.

Warnings can be used to remind knowledgeable users. If users cannot be expected to know the information in a warning, the warning is likely to be ineffective. Determining whether users have the necessary level of knowledge to recognize a warning is a fairly complex problem which frequently will require substantial research.

The next effectiveness-related stage in Figure 8−1 considers existing behavioral patterns of the user population. If the user's current behavioral patterns are consistent with the warning, the warning serves to reinforce the correct behavior. If user behavioral patterns are inconsistent with the warning, a warning is unlikely to elicit the desired behavior. This point was clearly implied by the research regarding behavior modification summarized in Chapter 6. As for assessing knowledge, the determination of user behavioral patterns is a fairly complex problem which often requires substantial research.

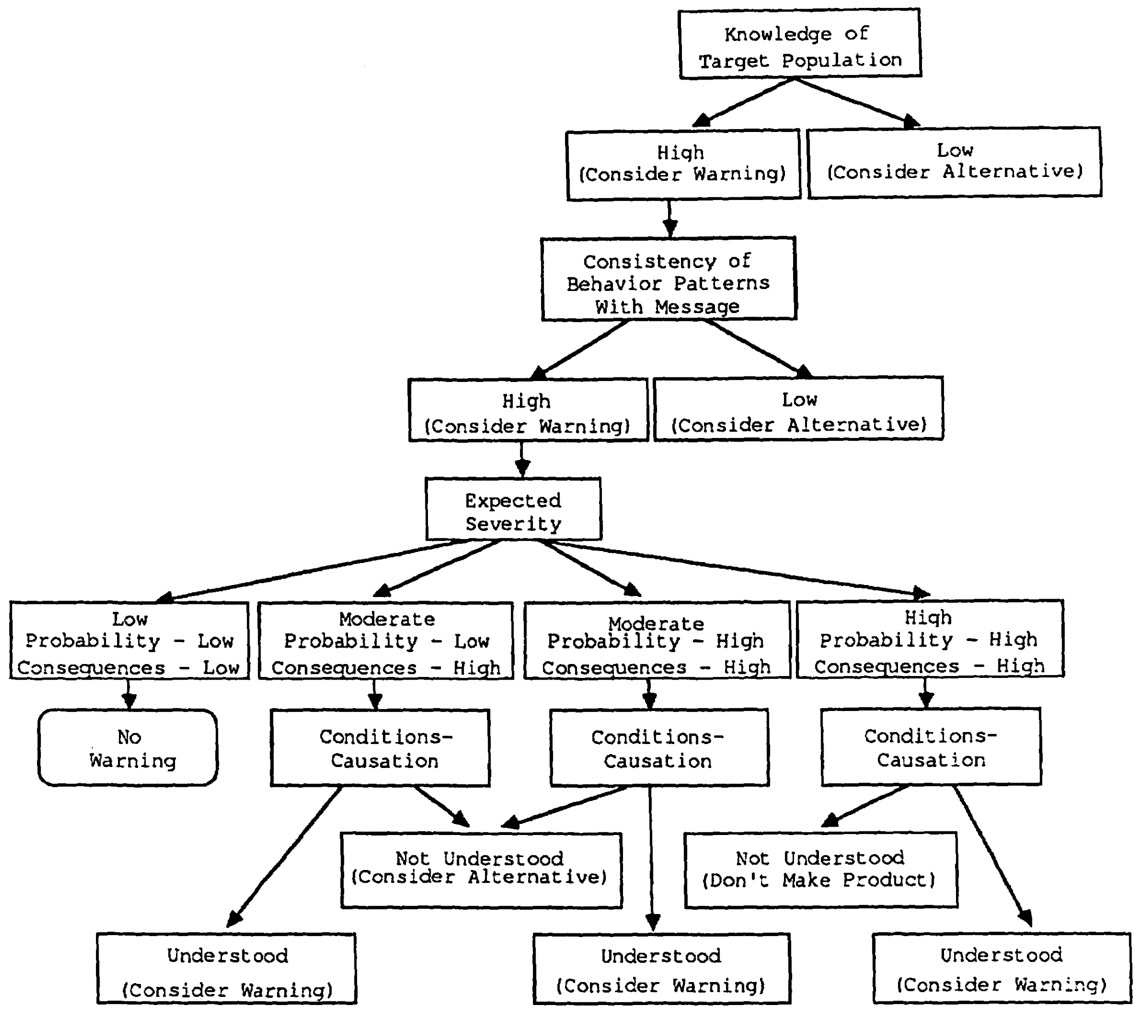


Figure 8–1 The Risk and Effectiveness Decision Hierarchy.

Risk-Related Factors

If these two effectiveness-based criteria are met, the risk-based measures should be considered. Perhaps the most classic method of determining when warnings are necessary is to base the decision on the expected severity of the potential accident. Warnings are traditionally used when the expected severity of the potential accident is high. Expected severity does not, however, provide information as detailed as that which can be obtained by using cutoff criteria individually on each dimension.

The probability, events, consequences, and conditions of the damages are all individually considered for the potential applicability of a warning. For any given warning, a rating can be developed for each of these dimensions. Probabilities can range from 0 to 1, consequences can range from minor to severe, and conditions can be poorly or well understood. Although the above ratings are not given on a common metric (e.g. probability is a ratio scale, while the measures given above for consequences and conditions are ordinal), methods of combining these dimensions exist, as mentioned earlier. In particular, the dimensional weighting approach might be desirable, especially if cost-benefit analysis is performed.

A. Probability The first risk-related dimension to be considered is the probability of the undesired event. Assuming that the consequences and conditions are held constant, the desirability of a warning increases with the probability of an undesired event. Warnings should be used for events of relatively high probability rather than for improbable events, since the probability distribution associated with accidents typically is a Pareto distribution. In other words, a small number of fairly probable events cause most accident-related damages. This becomes very apparent when available consumer accident data (such as those provided by the NEISS fact sheets) are considered.

If all possible damage-producing events are to be warned against, a long list of warnings will be required for nearly all products, with most warnings directed toward extremely unlikely events. As noted earlier in the section on the effectiveness of warnings, warnings as currently applied are already of limited effectiveness. It seems likely that presenting numerous lists of warnings will be ineffective, for three primary reasons.

First, long lists of warnings are likely to result in an overload of information. When individuals are overloaded with information, they are likely to filter out much of it. (i.e., they will fail to read the warnings). This is the oversaturation problem discussed by Twerski and Weinstein (1976). Second, within a long list of warnings, warnings associated with unlikely events may divert attention from more important warnings. As was noted earlier, people are more likely to read warnings when the danger is perceived. Third, considering the heuristic nature of human decision-making, warnings which describe events easily perceived as being likely are much more likely to be consistent with people's knowledge and behavioral patterns.

It should also be noted that if the probability of the damage-producing event exceeds a certain limit, other means of reducing the hazard should be considered. When it is highly probable that damage will result from the use of a product, design modifications or removal of the product from the marketplace should be considered because warnings never completely eliminate a hazard. Warnings can never completely eliminate a hazard because the warning process involves so many complex steps. This point should become very clear when the design methodology in Chapter 10 is examined.

B. Consequences The second risk-related dimension is described by the consequences of the event that is warned against. The desirability of applying a warning increases as the severity of the warned-against consequence increases. The majority of undesired events associated with the use of a product result in minor damages. Warning against all possible minor consequences, then, leads to the problems associated with long lists of warnings. Also, humans tend to concentrate on events which present large dangers that can be readily perceived, just as they concentrate on events which can easily be imagined or remembered (Kahneman and Tversky, 1974; Slovic, et al. 1980). As was noted in Section II, warnings are more likely to be effective when humans agree with the warning that the risk is significant.

C. Conditions The third risk-related dimension is described by the conditions associated with the undesired events. If these conditions are not well understood, warnings can not be expected to give constructive countermeasures against the undesired event, and consequently have little potential for reducing the hazard. The undesired events associated with damages can be caused by a large number of factors. Some of these factors will be much more likely than others to be associated with accidents. This small subsector of potential factors should be concentrated upon if such a subsector can be isolated.

In summary, as shown by Figure 8−1, warnings should not be used when the probability of the undesired event is improbable and the consequences of it are mild. If the event is probable or the consequences are severe, warnings should be considered; that is, assuming the users normally behave consistently with the warning and are knowledgeable enough to consider, and act in accordance, with the warning. At this hypothetical point in moving through the decision hierarchy, if the conditions associated with the undesired events are well understood, warnings remain a viable solution; if not, other approaches, such as limiting the marketing of a product, should be considered until those conditions are understood.

The Relationship to Warning Design

The risk and effectiveness hierarchy defines a general approach that is intimately related to warning design, since this hierarchy can be used to quickly screen out obviously inappropriate warning applications. However, other factors not shown in Figure 8−1 need to be considered when determining the effectiveness of particular warnings. These include the function of the warning, the time-related characteristics of the warning, the purpose of the warning, the number of other warnings included with the product, and other factors described by the taxonomies of warning types and scenarios developed in Chapter 7. Often, these more detailed factors must be considered before a decision can be made as to the applicability of a warning. This point is clearly indicated at the bottom of Figure 8−1, where the final conclusions are that a warning or other alternative should be considered.

The next two chapters define a more detailed design methodology that is compatible with this decision hierarchy. The application of this design methodology allows a much more sophisticated analysis to be performed for those applications that are not screened out by the risk and effectiveness decision hierarchy.

CHAPTER 9

GUIDELINES FOR WARNING DESIGN

CHAPTER 9. CONTENTS

CHAPTER 9

GUIDELINES FOR WARNING DESIGN

During the design of warnings, it is helpful to have criteria which can be applied while determining the adequacy of proposed warnings. Standard making organizations and various industrial groups have developed a number of guidelines assumed to specify desirable specifications for warnings. Along with these guidelines, recommendations can be obtained from the human factors literature.

This chapter summarizes and critiques many of these guidelines and design recommendations that are specified in safety standards or found in the human factors literature. The chapter begins by briefly describing several standard sources of warning design principles. Then emphasis shifts to describing systems, for designing warning labels or signs, that have either been incorporated into safety standards or are recommended by certain industrial groups. The final, and most substantial portion of the chapter, dwells on a number of perception related criteria that were obtained from the human factors literature. This latter discussion is then continued in Chapter 10, which describes a design process along with methods of evaluating aspects of warnings other than those aspects associated with perception.

STANDARD SOURCES

There are several standard sources of warning design principles. Of primary application are safety standards, both consensual and governmental, industrial guidelines, and human factors handbooks. The discussion to follow will introduce some of the particularly relevant sources. The final portions of this chapter will then provide more detail concerning the recommendations found in these sources.

Consensual Standards

Both consensual and governmental safety standards specify ways of designing warnings, and are available to anyone who desires to consult them. These standarized designs have usually been developed for very particular products, and also tend to distinguish between industrial and consumer settings.

Many consensual standards relevant to the design and application of warnings exist. Table 9−1 summarizes several consensual standards of this type. No attempt is made to comprehensively describe all of the possibly relevant standards, since there are so many standards that provide such recommendations.

Governmental Standards

There also are, of course, many governmental standards which include labeling requirements. A number of these are related to the FDA labeling requirements for food and drugs. The EPA has developed several labeling requirements for toxic chemicals, that are somewhat similar to those of the DOT regarding the labeling of transported hazardous materials. The CPSC provides several specific labeling requirements for consumer products, with a particular emphasis on products for children. The OSHA has incorporated new requirements for the labeling of hazardous materials in the workplace, and has recently cooperated with the NBS to conduct a study on workplace symbols (Collins, et al., 1982). Specific references to the various types of governmental standards mentioned above are given in the bibliography of this book.

Industrial Guidelines

Standards and guidelines for the design of warning labels and signs have been developed by various industrial groups. Of particular interest are the guidelines developed by the FMC Corporation (1980, 3rd edition) which include a number of recommendations regarding the design of symbols used in safety signs. The FMC guidelines also suggest design recommendations for safety signs themselves. A second source of information that is roughly comparable to the FMC system is the Westinghouse guidelines (1981). The great similarities between these two approaches reflect the use of equivalent resources.

Human Factors Design Handbooks

Human factors handbooks are available that summarize earlier research, some of which is applicable to warning design principles. Later in this chapter, information applicable to warning design found within these handbooks is organized and critiqued.

Among such handbooks, McCormick (1976), Van Cott and Kinkade (1972), Woodson (1981), and Morgan et al. (1963) all provide possible guidelines. The technical reports by Collins et al. (1982), and Easterby and Hakiel (1977) also provide a large amount of more recent information concerning warning symbols and their application. Numerous other relevant references can be found in the bibliography of this document. The book *Warnings, Volume II: Annotated Bibliography* published concurrently with this volume provides substantial information regarding these references.

SYSTEMS FOR SIGN OR LABEL DESIGN

Several standards-making organizations and industrial groups have developed systems for designing warning labels. Table 9−2 organizes many of these recommendations. These systems specify warning designs that often incorporate redundancy, signal words, symbols, and colors to convey hazards in a rather stereotypical and explicit way. However, among the various systems, a wide diversity of design recommendations exists. Some of these recommendations

Table 9-1
Commonly Available Consensual Standards.

Standard Making Organization	Name of the Standard
ANSI-Z-129.1	Hazardous Industrial Chemicals-Precautionary Labeling
ANSI-Z-35.1	Specifications for Accident Prevention Signs
ANSI-Z-35.2	Specifications for Accident Prevention Tags
ANSI-Z-35.4	Specifications for Informational Signs Complementary to ANSI Z35.1-1972, Accident Prevention Signs
ANSI-Z-35.5	Biological Hazard Symbol
ASAE-S-276.3	Slow-Moving Vehicle Identification Emblem
ASAE-S-277.2	Mounting Brackets and Socket for Warning Lamp and Slow-Moving Vehicle (SMV) Identification Emblem
ASAE-S-350	Safety-Alert Symbols for Agricultural Equipment
ASAE-S-441	Safety Signs
ASTM-ES-6	Labeling Ceramic Art Materials for Chronic Adverse Health Hazards
ASTM-ES-9	Cautionary Labeling of Portable Kerosine Containers for Consumer Use
ASTM-F-839	Cautionary Labelling of Portable Gasoline Containers for Consumer Use
ASTM-F-926	Cautionary Labeling of Portable Kerosine Containers for Consumer Use
ASTM-C-1023	Labeling Ceramic Art Materials for Chronic Adverse Health Hazards
ASTM-D-4267	Labels for Small-Volume (Less Than 100mL) Parenteral Drug Containers
EIA-RS-257	Mercury Warning Label
IEEE-C-95.2-1982	Radio Frequency Radiation Hazard Warning Symbol
NEMA-IB-1	Definitions and Precautionary Labels for Lead-Acid Industrial Storage Batteries
NEMA-EW-6	Guidelines for Precautionary Labeling for Arc-Welding and Cutting Products
NEMA-260	Safety Labels for Padmounted Swichgear and Transformers Sited in Public Areas

Table 9−1 (continued)
Commonly Available Consensual Standards.

Standard Making Organization	Name of the Standard
SAE-J-115	Safety Signs
SAE-J-179	Labeling − Disc Wheels and Demountable Rims-Trucks
SAE-J-943	Slow-Moving Vehicle Identification Emblem
SAE-J-1164	Labeling of ROPS and FOPS
TAPPI-UM-586	Aging Test to Predict the Potential Life of Pressure Sensitive Adhesive (PSA) Based Label Stock and Tapes

conflict with each other, as will be apparent from the following discussion which follows Table 9−2 closely.

Systems have also been developed that provide recommendations for auditory warning signals. Such systems are, however of little interest here because their applications are so specialized.

Signal Words

Attempts have been made to develop standardized terminology to indicate the level of hazard present in a particular product. As Table 9−2 illustrates, different organizations recommend different signal words. Among the most popular signal words recommended are: DANGER, to indicate the highest level of hazard; WARNING, to represent an intermediate hazard; and CAUTION, to indicate the lowest level of hazard.

As summarized in Section II, there is little scientific evidence showing that these terms used in signal words actually describe different levels of hazards. Some evidence indicated that industrial workers perceived a difference between DANGER and CAUTION. However, no research supported the use of three terms or suggested that consumers perceive any of these terms as indicating a gradation of hazard levels.

There is currently, therefore, little scientific basis for rigorous adherence to these particular guidelines regarding the choice of signal words.

Color Coding

Color coding, also referred to as a "color system," refers to the use of particular colors to signify particular levels of hazard. As stated in Chapter 5, certain stereotypical associations between colors and perceived levels of hazard do exist, but the strength of such associations can vary

Table 9-2
A Summary of Several Pertinent Consensual Standards.
(adapted from the Westinghouse Product Safety Label handbook, 1981)

	ANSI Z35.1 Specifications for Accident Prevention Signs (1972)	ANSI Z129.1 Precautionary Labeling of Hazardous Chemicals (1982)	ANSI Z535.4 Product Safety Signs (1980 Draft)	National Electrical Manufacturers Association Guidelines (1977)	SAE Recommended Practice J115a Safety Signs (1979)	ISO Standard (1979 Draft)	Westinghouse Handbook (1981); FMC Guidelines (1980)
Signal Words	Danger, Caution	Danger, Warning, Caution, Poison	Danger, Warning, Caution	Danger, Warning	Danger, Warning, Caution	Does not use signal words. 3 kinds of labels: Stop or prohibition, Mandatory action, Warning	Danger, Warning, Caution, Notice
Color System	Danger (Red), Caution (Yellow)	Not specified	Danger (Red), Warning (Orange), Caution (Yellow)	Danger (Red), Warning (Red)	Danger (Red), Warning (Yellow), Caution (Yellow)	Stop/Prohibition (Red), Mandatory Action (Blue), Warning (Yellow)	Danger (Red), Warning (Orange), Caution (Yellow), Notice (Blue)
Message Panel Typography	Sans serif typeface. All upper case or upper and lower case.	Not specified	Sans serif, gothic typeface. All upper case.	Not specified	Sans serif typeface. All upper case.	Message panel is added below if necessary.	Helvetica bold and regular weights. Upper and lower case.

Table 9-2 (continued)
A Summary of Several Pertinent Consensual Standards.

	ANSI Z35.1 Specifications for Accident Prevention Signs (1972)	ANSI Z129.1 Precautionary Labeling of Hazardous Chemicals (1982)	ANSI Z535.4 Product Safety Signs (1980 Draft)	National Electrical Manufacturers Association Guidelines (1977)	SAE Recommended Practice J115a Safety Signs (1979)	ISO Standard (1979 Draft)	Westinghouse Handbook (1981); FMC Guidelines (1980)
Symbols and Picto-graphs	Symbols only as supplement to words.	Skull and crossbones only as supplement to words.	Symbols and pictographs.	Electric shock symbol.	Layout to accommodate symbols, specific symbols/ pictographs not prescribed.	Symbols and pictographs.	Symbols and pictographs.
Label Arrange-ment	Defines 3 components: Signal word panel, Message panel, Symbol panel (optional, attached to side of label)	Label arrangement not specified	Defines 3 components: Signal word panel, Message panel, Pictorial panel. Arrange in order of general to specific.	Defines five components: Signal word, Identification of hazard, Consequences, Instructions, Symbol. Does not specify order.	Defines 3 areas: Signal word panel, Pictorial panel, Message panel. Arrange in order of general to specific.	Pictograph or symbol is placed inside appropriate shape with message panel below if necessary.	Recommends 5 components: Signal word, Symbol or pictograph, Hazard identification, Result of ignoring warning, Avoiding the hazard
How to Classify Hazards	Not specified.	Provides guidance about how to select signal words.	Provides guidance.	Not specified.	Provides guidance.	Not specified.	Provides guidance about how to select signal words.

greatly. These associations can also confict with basic guidelines related to conspicuity and legibility.

For example, red is used in all of the standards in Table 9-2 to represent the highest level of danger. Unfortunately, the human eye is relatively insensitive to the color red in both day and night viewing conditions. Blue lights are much more efficiently perceived in the dark, while the color yellow is much more efficiently perceived in sunlight.

It is also unclear as to how strong the associations between color and danger level are in comparsion to other factors. This is especially true in comparsion to cognitive factors. For example, is a red car perceived as being more dangerous than a yellow car? For these reasons, strict adherence to color coding systems has not, as yet, been proven valid.

Message Panel Typography Safety standards and guidelines are notable for their explicit recommendations regarding typefaces. The choice of typeface is of some importance, as various typefaces do influence legibility. In particular, the presence of serifs can increase the tendency of text to become illegible under adverse viewing conditions. The influence of other typographic factors considered in these standards may be more related to personal preference than legibility. For an excellent introduction to research in this area, the reader should consult the papers by Reynolds (1984; 1979a; 1979b).

Symbols and Pictographs

The available standards and design guidelines for warning labels provide varied recommendations with respect to the use of symbols and pictographs. Also note that the standards fail to emphasize that written words are in fact symbols. The FMC and the Westinghouse systems advocate the use of symbols/pictographs to define the hazard and to convey the level of hazard. Conversely, the ANSI Z35.1 standard recommends symbols only as a supplement to words.

As noted in Chapter 5, the comprehension of symbols/pictographs varies extensively. For these reasons, caution must be taken in regard to placing nonverbal symbols rather than verbal symbols on signs. In particular, one of the recommended symbols emphasized in the FMC and the Westinghouse systems is the hazard alert symbol (an exclamation point enclosed by a triangle). This symbol was found to be very poorly understood by consumers (Easterby and Hakiel, 1981).

Message Explicitness

Although not listed in Table 9-2, another area of substantial variation among standards pertains to the required explicitness of the message listed on a warning label. The FMC and the Westinghouse systems both emphasize very explicit verbal messages. The following guidelines are suggested: 1) identify the hazard, 2) list the results and consequences of ignoring the warning, and 3) instruct the user on how to avoid the hazard.

Based on the research in Chapter 5, it becomes apparent that for most hazards, there is no need to explicitly list all three of these statements. People are unquestionably able to comprehend vast amounts of material by using contextual information and their knowledge from long term memory. In other words, people are able to derive much information from small inputs. Gregory (1970) provides an introductory paper on the topic of "how so little information controls so much behavior."

Although each of the three components, mentioned above, often must be derivable to avoid accidents, explicitly and exhaustively listing them for the many hazards that can be found for nearly any product would result in an overwhelming effect. McCarthy et al. (1982) present a practical example along these lines for glass bottles. As discussed in Chapter 4, information overload is likely to have negative influences on warning effectiveness.

Arrangement/Anatomy

Table 9−2 lists a variety of recommended label arrangements given by various standards-making organizations. These arrangements generally include elements from the above discussion. Examination of the table reveals a wide degree of variation in these arrangements. Other ways of describing the arrangements of label components can also be found.

For example, Easterby and Hakiel (1977; 1981) discuss the "anatomy of a warning symbol." Therein are identified four structural components of a sign and they, together with the dimensions along which they may vary, are: Image − graphic content, color; Background − shape, color; Enclosure − shape, color; and Surround − shape, color. The image is used to convey the argument component of the expression, while the three remaining components are used to encode the mode of the expression.

The relative advantages of these various arrangements can not be inferred from the literature.

Summary

The design parameters specified in these various standards are generally notable for being consistent with "common sense," as opposed to being justified on scientific research. These standards also: fail to recognize other, less explicit, warning stimuli; fail to provide measures of effectiveness for different design configurations; fail to specify when warnings are needed; and neglect the process of warning development.

A final point is that the guidelines suggested in existing approaches almost exclusively emphasize the conspicuity of warnings. Little consideration is given to the knowledge based aspects of warning design or to behavioral factors. While much more research is needed, these authors believe that the factors related to knowledge and behavior will frequently outweigh the more basic conspicuity related issues. The design methodology proposed in Chapter 10 and expanded upon in Section IV will explicitly consider many of these issues.

CONSPICUITY RELATED DESIGN CRITERIA

Criteria can be gathered from the human factors literature and other sources that can be applied in order to design easily perceived warnings. In presenting those criteria which seem most relevant to warnings design, the following discussion will emphasize the commonly available sources of human factors data, as described in design handbooks, textbooks, and standards. It will quickly become apparent when one attempts to apply that data to real design questions that, although much data is available, there are significant short-comings.

The term "conspicuity" is used here to describe the effects of stimulus energy, stimulus resolution, and noise. Conspicuity is a basic requirement because it affects perception, which is the lowest stage in the general chain of human information processing that ends with a response. Being the lowest, and perhaps most easy stage to evaluate, the largest proportion of human factors related knowledge relevant to warnings applies to perception. A large data bank is available for visual and auditory stimuli that specifies appropriate stimulus energy levels, dimensions, and locations (see McCormick, 1976; Van Cott and Kinkade, 1972; Woodson, 1981, Westinghouse, 1981; FMC, 1980). Less data is available that describes the influence of noise or that considers stimuli other than visual or auditory signals.

There are a number of criteria by which the factors related to conspicuity can be evaluated. No attempt is made to comprehensively describe these factors; however, we outline many of the most applicable of these findings and criteria. Chapter 10 then considers ways of evaluating the degree to which these criteria are met in a particular design. The discussion will now progress through visual, auditory, tactile, kinesthetic, vestibular, and olfactory forms of stimuli.

Visual Stimuli

Many warnings use visual channels. The light borne information may be directly transmitted to the receiver, or may be reflected off an intermediary medium. Important factors which need to be considered when evaluating visual stimuli are 1) the frequency of the light waves (this determines color), 2) the amplitude of the light waves (this determines energy), 3) the contrast between the emitted light and the background illumination, 4) the visual angle subtended by the stimulus, 5) the perceptual field, and 6) the noise level.

Energy and Frequency Criteria Frequency and amplitude together define the energy spectrum of light waves. Any source of incoherent light emits light waves at particular frequencies with varying energy at each frequency. When light reflects off an object, its energy spectrum is determined by both the energy spectrum of the emitted light and the energy absorption spectrum of the viewed object.

The perceived brightness of a stimulus depends on the energy spectrum of the emitted or reflected light. It also depends on whether the human is using scotopic vision (using rods, as in the dark) or photopic vision (using cones, as in bright environments). Figure 9-1 describes this relationship, where frequency (or equivalently color) is on the x-axis of the figure and a luminosity factor is on the y-axis of the figure. One curve corresponds to scotopic vision and the other to photopic vision. It might also be very important to warnings design that certain individuals are unable to differentiate between light waves of certain frequencies (color blindness).

The perceived brightness of a particular stimulus can be described using photometric units. Here, the energy in the light at each frequency is weighted by the luminosity factor. The problem becomes quite complex when evaluating reflected light because the energy spectrum of the reflected light depends both on the spectrum of the ambient light and the energy absorption characteristics of the reflector. Evaluation of such effects requires the use of sophisticated equipment.

That the perceived brightness of a stimulus depends on color, and that the effects are different in daytime versus nighttime viewing conditions is an important point that must be considered during the design of visual warnings. The relative advantages of various colors, assuming that the energy levels are constant can easily be determined from Figure 9-1. For example, the color red is normally a poor choice for nighttime viewing conditions because the luminosity factor is very small. However, the energy in the incident light at particular frequencies (that is, its energy spectrum) may be a more important consideration. Simply put, if the available light is weighted toward certain frequencies, these frequencies should be taken advantage of, even if the luminosity factor is low. The energy spectrum of nearly all forms of incident light is likely to be heavily weighted toward certain frequencies in the visible range. Data is available on the energy spectrum of various forms of lighting in the IES Lighting Handbook (1981).

A large amount of work has been performed regarding the required levels of illumination. Greater levels of illumination are needed for older subjects, dynamic viewing conditions, and visual tasks where the location and presentation times of stimuli are unknown. Again, the IES Lighting Handbook (1981) summarizes guidelines for a variety of tasks. For work that requires the occasional performance of visual tasks, the recommended illumination in footcandles is 10 to 20; when the visual tasks are of high contrast, the recommended illumination is 20 to 50; when the visual tasks are of medium contrast, the recommended illumination is 50 to 100; when the visual tasks are of low contrast or very small size, the recommended illumination is 100 to 200. Higher levels of up to 2000 footcandles may be recommended for very demanding tasks that involve performance for extended periods, extremely low contrast, and small stimulus size.

Under the most common viewing conditions for warning labels, however, the need to be concerned about illumination is generally low. For most settings under sunlight and artificial light, the illumination conditions are well within the ranges given above. It generally becomes important to consider illumination only under special viewing conditions, as in the nighttime or when contrast is low. For such situations the designer should consult the references mentioned above.

Contrast Criteria Although the brightness of a stimulus is an important consideration, the effects of brightness are almost always outweighted by the effects of contrast. This is fortunate, especially in regard to the design of warning labels, because the brightness of background illumination is almost impossible to control. Contrast describes the difference in the perceived brightness of a stimulus and the perceived brightness of its background. Contrast is generally more important than brightness because people have an outstanding ability to adapt to changing levels of brightness. The ratio of the highest to lowest energy thresholds is at least ten billion to one (using the threshold values given in Van Cott and Kincade (1972)). Contrast can be measured in many different ways; the most common approach is to specify the luminance contrast ratio. This contrast ratio (CR) is simply:

$$CR = \frac{(B_1 - B_2)}{B_1}$$

where B_1 is the brighter of the two areas and B_2 is the dimmer of the two areas. Although not emphasized in reference texts, the brightness values used in calculating the luminance contrast ratio should be measured in photometric units. Measurement in terms of photometric units, of course, will require very sophisticated equipment or extensive calculations based on the energy spectrum of the emitted light, the energy absorption spectrum of the considered surfaces, and the luminosity factors associated with perception.

The relationship between the ease of perception and contrast is logarithmic; the effects of changing contrast are larger when the contrast is low. It is difficult to determine conclusive specifications for required contrast from the literature. In general, problems with visual acuity for many forms of stimuli seem to be relatively minor as long as the contrast ratio is above

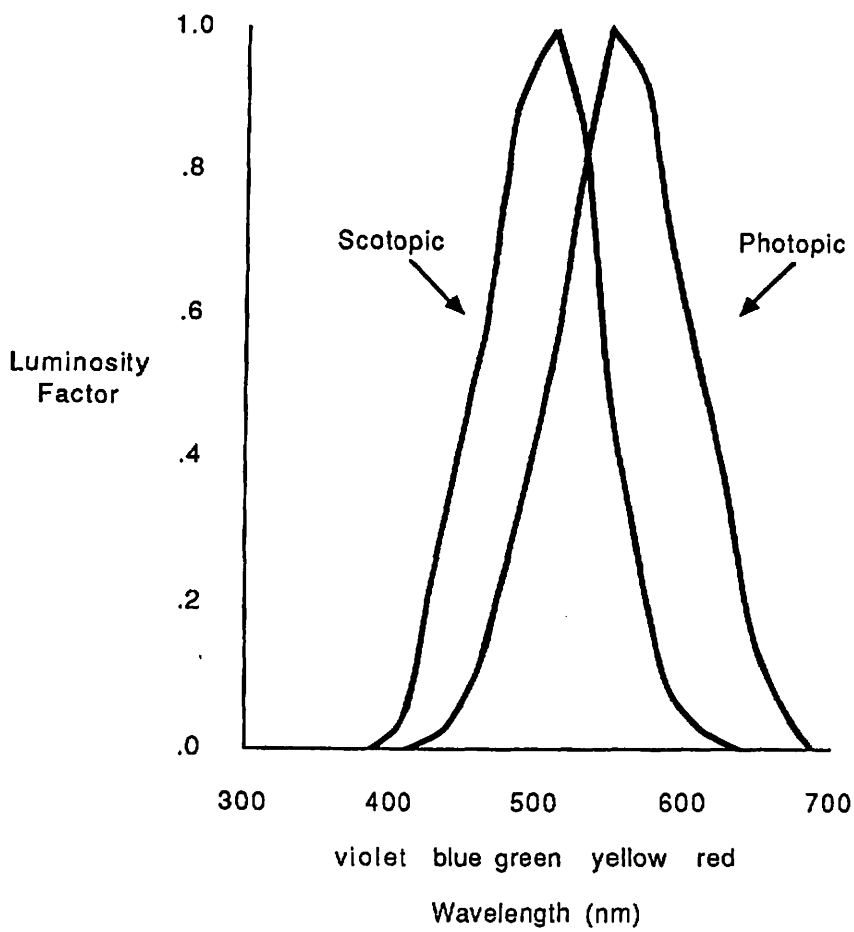


Figure 9 – 1 Photopic and Scotopic Luminosity Factors Plotted at 20-nm Intervals. (Original source of data, Kaufman, 1974.)

50% and the illumination level is reasonably high (see Morgan et al., 1963). For printed material using black on white, the contrast is generally well over 80%. Consequently, Kantowitz and Sorkin (1983) and Smith (1984) claim that the contrast is generally of little concern for most printed material.

Difference in color can also provide a form of contrast. As noted in Morgan, et al., (1963) color contrast can aid perception when the luminance contrast is low. However, they state that color contrast has little effect when luminance contrast is high. That the effect of color contrast can make up for low luminance contrast is fortunate, because low levels of luminance contrast are likely to occur when colors are used to provide the contrast. However, under lighting conditions where the energy spectra is unbalanced, certain forms of color contrast will disappear.

Visual Angle Criteria The visual angle subtended by a stimulus is defined by the width of the stimulus and its distance from the human observer (see Figure 9 – 2). Visual acuity is usually defined in terms of visual angle. Different measures of acuity are obtained depending upon the type of stimulus. The average visual angle at which lines are detected can be as low as 2 seconds (0.00056 degrees), that for distinguishing the separation of lines may be as low as 30 seconds (0.0083 degrees). Normal vision as measured with the Snellen eye chart corresponds to the ability to perceive the letter E, which consists of three horizontal strokes and the space between them. Here, the vertical height of the letter normally must substend a visual angle of 5 minutes (0.083 degrees) to be correctly perceived.

As implied by these varying measures of visual acuity, evaluation of the legibility of a symbol can be difficult without performing tests. This is true because the legibility of the components within the symbol can vary, and because certain components may have varying importance during the identification of the symbol. The apriori evaluation of legibility could be attempted by measuring the visual angles subtended by lines and the separations between lines; a complicating effect is irradiation in which light lines on dark backgrounds become less legible at high levels of illumination. In regard to the design of nonverbal symbols, no clear guidelines exist in regard to such evaluation of legibility. This approach does, however, indicate that complex symbols used in warnings or labels will be generally less legible than simple symbols.

Similar approaches can be applied to alpha-numeric symbols to determine the influences of stroke width and letter height. In regard to letters, standard recommendations have been developed. McCormick and Sanders (1982) recommend that the strokewidth to height ratio be 1:13.3 for white numerals on a dark background and 1:8 for black numerals on white backgrounds. These are, however, only general recommendations, legibility can be good for ranges of at least ±25% around the latter value. Most commonly used letters and numerals meet these requirements. The major problem is the degrading effects of serifs on the legibility of letters and numerals. However, such effects are reduced if the letters or numerals are large, provide high contrast, and are used under adequate illumination.

For letters and numerals, a number of researchers cite visual angles of 10 minutes as being reasonable. This value is twice the Snellen visual acuity of 5 minutes. Smith (1984) evaluates a number of recommendations regarding visual angles based on his own and other studies. His conclusions specifically apply to the letters used in words on labels. The evaluated recommendations range from 5 minutes (normal visual acuity) to 37 minutes. (MIL-STD-1472B 1974 recommends this latter value for critical data in variable positions at low luminance). Smith found in a field study of over 2000 subjects that the smallest visual angle at which the perception of alpha-numeric characters occurred was less than 2 minutes; the average level was about 6 minutes; and that 90% legibility occured at about 9 minutes. The influences of increasing the visual angle tapered off greatly for visual angles greater than 9 minutes. For 12 minutes of arc the legibility was approximately 95%, 16 minutes of arc resulted in approximately 98% legibility, while legibility at around 25 minutes of arc was nearly 100%.

Smith (1984) also concludes that visual angle alone captures the effects of distance and stimulus size quite well. However, at viewing distances less than 2 meters, somewhat larger visual angles may be required than at greater distances. In general, the visual angle appears to be the primary criteria for evaluating the legibility of symbols used in warning labels. It should also be noted that for older subjects, under poor lighting conditions, the contrast may be of greater importance. Such effects were shown by Evans and Ginsburg (1985) who found that contrast sensitivity explained age related differences in the perception of road signs, while Snellen visual acuity did not.

One final point is that given the large amount of research that has been performed regarding visual angle, luminance, and contrast, it is surprising that the guidelines are so vague. It appears that there has been little systematic emphasis on design. Further studies using loosely controlled measures of contrast, luminance, etc. are not what is needed. What would be useful is the development of approaches for quickly and painlessly generating

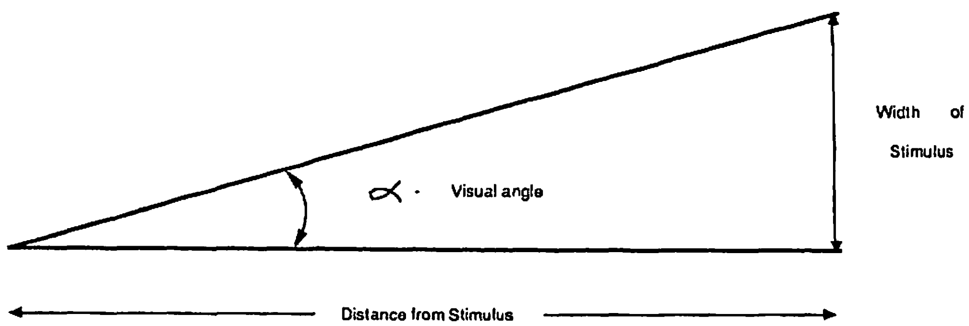


Figure 9-2 A Simple Schematic Diagram Illustrating the Concept of Visual Angle.

estimates of legibility. A start is given by the approach of Olson and Bernstein (1979), who have developed a computer model that estimates the legibility distance of road signs, using a number of parameters which influence contrast such as the reflection spectrum of materials, colors, eye position, and illumination. Such approaches are needed because of the straightforward but extensive calculations that are required when rigorously evaluating legibility.

Perceptual Field Criteria Before an object can be seen, it must be in the human's visual field. The visual field can simplistically be described as a cone extending out along the line of sight. Estimates vary as to the dimensions of this cone; as a rough approximation it is ±45 degrees vertically and ±90 degrees horizontally (see Woodson, 1981 for more detail). With head movements, the visual field becomes essentially unlimited. When the eyes alone are allowed to move, the horizontal field goes to ±166 degrees, but the vertical field changes very little.

In many situations, it is important to distinguish peripheral from more focused vision. The cone within which focus can occur is approximately ±15 degrees in both vertical and horizontal directions. Objects outside this cone can not be focused without moving the eye. As also summarized by Woodson (1981), color vision primarily occurs in this cone. This means that color contrast will not be perceived using peripheral vision.

It is often desirable to determine what percentage of the visual field must be filled by a stimuli in order for it to attract attention. This is very much a neglected issue. General guidelines, like the following, are often found: "because flashing lights are much more noticeable than continuous lights or signs, flashing lights can be smaller than continuous lights or signs." The value of such simplistic rules to any but the most naive designers is, however, questionable.

It should be possible to develop guidelines that quantify the ability of stimuli of varying sizes to attract attention, for those situations where explicit search for the stimulus is not taking place. It is likely that this ability is largely determined by the proportion of the visual field filled by the stimulu. Other possible influences include contrast, and brightness. Such guidelines might therefore be similar to the visual angle criteria used to define legibility, but would logically be at greater values. However, much research is needed before any conclusions can be made regarding such design guidelines.

Noise Criteria Little information is available regarding the influence of noise. Reynolds (1984) provides evidence that certain typefaces are more susceptable to the influences of degradation, which can be viewed as a form of noise. Glare has also been shown to have significant influences on the legibility of symbols. The effects of noise can also include the influences of distracting visual stimuli. Ways of counteracting noise related effects include increasing contrast and visual angle, and reducing whatever can be identified as being noise.

However, few guidelines are available that either provide conclusive recommendations for acceptable noise levels, or that provide measures of the required increases in contrast or visual angle to counteract noise effects.

Auditory Stimuli

Many of the commonly recognized warnings (particularly in the public/environmental domain) use auditory channels. Here, the information is conveyed by pressure waves conveyed over a gaseous, liquid, or solid channel. Important factors to be considered when evaluating auditory stimuli are 1) the frequency of the sound waves (this determines pitch and influences loudness), 2) the amplitude of the sound waves (this influences loudness), and 3) the contrast between the emitted sound and background noise. Note that the perceptual field is not emphasized for auditory stimuli because such effects are found only for very high frequency sounds.

A vast collection of information is available regarding auditory stimuli and warnings. However, only a small amount of this information is actually useful during the design of warnings. The following discussion is only intended to introduce this topic.

Energy and Frequency Criteria Sound as well as light has an energy spectrum. Any source of sound emits sound waves at particular frequencies with varying energy at each frequency. Also, as for light, the sound that reaches the human is influenced by the energy absorption spectrum of environmental components. High frequency sounds are absorbed at the greatest rate. Sound differs from light in that it is much more quickly attenuated by environmental components. This effect generally causes the distance from the source to become a more critical factor for sound than light. The energy in sound is also stored in enclosed spaces, creating the so-called reverberant effects.

The perceived loudness of a stimulus is a function of both frequency and amplitude. People are most sensitive to sound waves between 500 and 3000 hertz, but usually can perceive sound waves between perhaps 40 to 17,000 hertz. When no noise is present, extremely quiet sounds can be heard.

According to Morgan et al. (1963), for auditory signals, the most desirable sound levels are between 20 to 80 decibels above the perceptual threshold. Age is a very important factor which influences the perceptual threshold; older people have special problems perceiving high frequency sounds. More detailed discussion, but few additional design-related guidelines that are particularly relevant for product warnings can be found in Morgan, et al. (1963), McCormick (1976), Kantowitz and Sorkin (1983), Bailey (1982), Van Cott and Kinkade (1972), and Woodson (1981).

Contrast Criteria The simple influence of energy and frequency is almost always outweighted by the contrast between the stimulus and background noise levels. (Note the wide range of 20 to 80 decibels given above by Morgan, et al.) The presence of background noise interferes with the perception of the stimulus. This tendency is frequently called masking. The effects of masking can be viewed as increasing the threshold at which perception takes place. Another, more fundamental, approach is given by signal detection theory, which explicitly models the effects of signal and noise strength. However, because the parameters used in the models based on signal detection theory have values that are so situation specific, the following discussion will emphasize the observed effects of masking.

As discussed by Morgan, et al. (1963), tones, or coherant noise, have the greatest masking effect on auditory signals that are at frequencies close to those of the noise. At high energy levels, noise tones tend to mask signals at frequencies higher than those of the noise, but have little influence on signals at frequencies one half or less than the tone. As a rough approximation, at the frequencies where masking is greatest, the presence of a masking tone increases the threshold for perception of a signal (at that frequency) to a value 20 decibels less than the energy of the masking tone. White noise at energy levels above 10 decibels results in a fairly consistent increase in the stimulus threshold of pure tones. The increase in the threshold is approximately 20 decibels greater than the average energy level of the individual frequencies that make up the white noise.

Morgan, et al. (1963) state that a signal 15 decibels or above its masked threshold (the signal strength at which the signal can just be perceived when the masking noise is present) will result in good perception. A sound at this level should be perceived as being very loud in comparsion to the noise. The ANSI/ANS N2.3-1979 standard for immediate evacuation signals recommends a 10 decibel increase over ambient noise levels. In each of these cases, if an approach based on signal detection theory is taken, the noise alone and signal plus noise distributions would be widely separated. In special instances, as for sleeping people, larger than 10 decibel differences may be needed. Kahn (1983) found that fire alarms that delivered sound 35 decibels higher than the background noise at the pillow were more likely to wake sleeping subjects than when the fire alarm was 10 decibels higher than the background noise!

Morgan, et al. (1963) also summarize results related to the effects of noise on speech. Speech is a good, and obviously realistic application, because it is a complex sound. (Many of the testing results are derived from experiments involving pure tones, which almost never occur in practical applications.) It also must be realized that, because of its complexity, speech is more difficult to perceive than many other auditory stimuli. The summarized results show that information can be obtained from stimuli even if the background noise is greater than the signal's strength. Specifically, it was found that when the signal to noise ratio is −18 decibels, all consonants are confused; at a ratio of −12 decibels two groups of consonants were distinguishable from each other; at a ratio of 0 decibels, there are seven easily distinguishable groups of consonants; at a ratio of 12 decibels, all of the consonants are readily distinguishable.

In conclusion, it seems that a contrast (or equivalently a signal to noise ratio) of 10 decibels between the stimulus and noise level will result in the perception of the stimulus a very large percentage of the time even when attention is not directed toward it. When attention is focused on the stimulus, much smaller differences are likely to lead to perception. A rough rule is that 3 decibels is a "just noticable difference." However, these results are far from being clear-cut design guidelines. More complex modeling techniques which guide experimentation will frequently be needed.

In particular, the difference between the signal's strength and the expected noise level must be large to justify the use of simple thresholds. If the noise and signal levels randomly fluctuate, or if the signal to noise ratio is low; the more complex techniques of signal detection theory should be used to guide the experimental evaluation of the provided signals. These techniques will be further discussed in Chapter 10.

Tactile Stimuli

Tactile stimuli are less commonly recognized as providing warning information than are the visual or auditory channels. Such stimuli do, however, occasionally serve warning or alerting functions. Kantowitz and Sorkin (1983) provide an example where tactile stimuli are used to convey warning information in aircraft. They also describe several other uses. McCormick (1976) discusses the use of shape, texture, and size coding of controls. In general, tactile stimuli appear to have more value than the current number of applications would indicate.

Relatively little study of tactile stimuli has been performed, in comparsion to that of visual and auditory stimuli. Important factors which need to be considered when evaluating tactile stimuli are 1) the frequency of the pressure waves, 2) the amplitude of the pressure waves, 3) the temperature of the stimuli, and 4) the locations of the stimuli on the body.

Frequency and Pressure Criteria Pressure and the deformation of the skin are both sensed by the human. Both pressure and deformation can be defined in terms of amplitude and frequency. When frequency is a factor, the stimulus is vibrating.

The sensitivity threshold of touch, according to Van Cott and Kincade (1972) varies from .04 to 1.1 erg, where one erg is approximately the kinetic energy of one milligram (mg) dropped 1 centimeter (cm). This value was obtained for the fingertips. Van Cott and Kincade also state that the lower limit of sensitivity to frequency is 0 (constant pressure), while the upper limit is 10,000 hertz at high intensities. When movement stops, corresponding to a frequency of 0, there is an initial sensation of pressure which soon disappears. This latter effect corresponds to adaption.

Kantowitz and Sorkin (1983) provide a more extensive consideration of tactile displays of information. They summarize the results of Verrillo (1966) who extensively analysed vibro-tactile thresholds. Here, it was shown that the threshold is at a minimum (the lower the threshold, the greater the sensitivity) for stimulated areas greater than .02 square cm, when the frequency is 200 hertz. Sensitivity dropped off quickly at frequencies above 1000 hertz. Also, the threshold was found to decrease when larger areas of skin were stimulated.

Temperature Criteria Skin also has the capability to sense the temperature of stimuli. Bailey (1982) notes that normal skin temperature is about 91.4 degrees Fahrenheit. Discrepancies from this value are sensed. Van Cott and Kincade (1972) provide an estimate of the threshold sensitivity which is 15×10^{-5} gm-cal/cm^2/sec for a 3 second exposure of 200 cm^2 of skin.

As Bailey notes, thermal adaptation can occur when skin temperature is between 60 and 105 degrees Fahrenheit. Temperatures above or below this range will result in a continuous feeling of warmth or cold, respectively.

Location Criteria The sensitivity to tactile stimuli depends on the location of the human body that is contacted. The sensitivity to multiple stimuli depends on the distance between the stimuli. Kantowitz and Sorkin (1983) provide data on this topic. Sensitivity is greatest for the hands, fingers, and face. It is substantially lower for most other skin surfaces, and females are more sensitive in general than males.

Kinesthetic and Vestibular Stimuli

Both kinesthetic and vestibular stimuli can provide warning information, even though this point is frequently not recognized. In particular, the kinesthetic sense provides information regarding body locations more efficiently than any other form of stimuli. It also allows the human to determine the location of objects which are being manipulated. The vestibular sense efficiently provides information regarding accelerations. Both forms of information may have great relevance to hazards.

Even less design related information is available for the kinesthetic and vestibular senses than is available for the tactile sense.

Kinesthetic Criteria The kinesthetic senses access position and movement related information pertaining to the limbs of the human body. Van Cott and Kincade (1972) describe the threshold as being .2 to .7 degrees at 10 degrees/minute (for joint movement).

The kinesthetic sense is very important when the human emits controlled movements. It is unfortunate that there are so few design related criteria that specify how this sense should be successfully exploited.

Vestibular Criteria The vestibular senses detect acceleration of the human body. Nearly all work regarding acceleration has concerned the negative effects of acceleration on the human body. Such effects include either physical damage or perceptual illusions. Very little work has addressed the use of acceleration as a source of task-related information.

Along the latter lines, Van Cott and Kincade (1972) describe lower thresholds of .08 G (one G equals the acceleration of gravity at the earth's surface) for linear acceleration, and .12 degree/second for angular acceleration. They provide upper thresholds of 5 to 8 G's for positive G forces and 3 to 4.5 G's for negative G forces. The upper thresholds are stated to be the same for either linear or angular acceleration.

It appears that design related criteria could be defined for the vestibular senses that are similar to those given for visual, auditory, and tactile senses. For these other senses, the criteria explicitly separate the influences of frequency and amplitude. In regard to the vestibular sense, the concept of angular acceleration implicitly subsumes the influences of frequency. However, it is impossible to determine from standard sources of human factors design criteria how frequency is related to the amplitude of linear acceleration.

Olfactory and Gustatory Stimuli

These two senses differ from the earlier mentioned senses in that they respond to material concentrations rather than energy. The olfactory sense responds to vaporized chemicals. The gustatory sense responds to chemical substances dissolved in saliva. These two senses will be separately considered below.

Olfactory Criteria The sense of smell is characterized by extreme sensitivity to certain chemicals. McCormick and Sanders (1982), Van Cott and Kincade (1972), and Bailey (1982) quote several examples demonstrating this extreme sensitivity, and also note that odors can be used as warnings. According to Bailey, for certain chemicals, the maximum intensity of smell occurs at concentrations of only 10 to 15 times the sensory threshold. Problems occur in the use of odors as stimuli, in that all people adapt to odors while certain people are insensitive to many odors.

No design criteria for the use of odors were found that considered frequency effects. This appears to be the case because of the very low frequencies which can be perceived and because it is difficult to quickly change odor levels.

Gustatory Criteria The gustatory sense (taste) is perhaps 1/10,000 as sensitive as the olfactory sense. Four distinct categories of taste are described by the terms sweet, sour, bitter, and salty. Taste is unlikely to be valuable as a warning stimuli, except perhaps when signifying the presence of noxious substances.

LIFE CYCLE CONSIDERATIONS

An area of warnings design which has received little recognition either in the human factors or legal field is that of the age/exposure effects on the physical mechanisms originating a warning. We label this "life cycle considerations." Life cycle considerations include issues such as the expected degradation of a warning's physical appearance/sound/feel over time: Do labels peel off as they dry? Are they usually covered with grease during normal use? Do colors fade? Are signs eventually covered by growing plants? Do mechanical sound generating devices become inoperative because of infrequent use or battery dormancy?

Obviously, the potential for a warning to be effective will depend on these life cycle related questions. A designer may be faced with the issue that a warning cannot be expected to be useful after a product has had a certain amount of use. Many important questions regarding this issue can be formulated: Can a warning's useful life be extended by choosing a different presentation? Is it worth designing, developing and installing a warning which cannot feasibly have anything but a short useful life and not be available at the time it might be potentially useful?

These are questions which are beyond what most warnings and label designers are in a position to confront, given that the more basic decisions of design have yet to be scientifically approached.

Nevertheless, towards this end, several ASTM standards provide basic testing procedures which can be used to test the durability of warnings. The proposed ANSI 535.4 also provides guidelines and requirements for the durability of product warning labels. Because of the wide variety of ways maintainability can be attained, it seems reasonable to specify such performance standards.

CONCLUSIONS

Perhaps the major conclusion which should be gathered from this chapter is that there are many theoretical ways of evaluating warning designs, but firm guidelines which are actually useable are very much lacking. It should be emphasized that many standard design handbooks tend to haphazardly list principles, and spend little effort on organizing or interrelating these principles with warning design in mind. Consequently, the substantial effort needed to organize the available research into a useable package is only beginning with the present book.

A secondary and related point is that the most sizeable body of research done to date has been concentrated on the topics least relevant to warnings. But even where research is available, the results are difficult to interpret. In particular, large amounts of research are devoted to basic threshold or legibility related criteria. However, these criteria are not at all organized into an easily applicable form. Much repetitive research has also taken place, and its relevance to real tasks is frequently questionable. Perhaps part of the reason for these deficiencies is the early emphasis of human factors on only extremely adverse environments, as faced in military settings.

Another point is that additional research is needed in regard to those warnings that are neither explicitly visual or auditory signals. These other forms of stimuli can provide information to the human much more efficiently than do either the auditory or visual senses in many situations, but the lack of research makes it impossible to document their relative advantages or disadvantages in any but the most general ways. Extension needs to be made both in regard to the methodologies which are used, and in the application of existing methodologies.

As a final point, given that much material has been gathered for this purpose, we still do not feel the existing research is in any way adequate to specify rigorous design criteria for warnings. The commonly used criteria appear to be based upon common sense, rather than the needed research. The result is ironic in that some warnings which meet commonly cited standards will frequently be ineffective, while many warnings which do not meet the standards, or which are not even considered in the standards, may be among the most effective. This is certainly a sign that the design questions have not been adequately approached with a consistent, scientifically based, group of criteria and methodologies.

CHAPTER 10

THE DESIGN PROCESS

CHAPTER 10. CONTENTS

CHAPTER 10

THE DESIGN PROCESS

From the previous chapter, it should be apparent that, prior to this current effort, a surprisingly small amount of existing data has been synthesized into a form that can be directly applied during the design of warnings. The standard approach to warning design seems to emphasize a number of fragmentary "rules of thumb" as provided by general design handbooks or texts. Much less attention has been given to the overall design process, the emphasis of this chapter.

An idealized goal during design is to produce the most effective warning for a given warning scenario. In the proposed design process, this is done by following a formulized sequence of procedures. To do this, one needs know how to distinguish different types of warnings and scenarios. One also needs to know how to match particular types of warnings to scenarios so that effectiveness is maximized.

In Chapter 7, particular warning types and scenarios were described. Also, several general conclusions can be made regarding the effectiveness of various warning in particular scenarios, as discussed in Chapter 8. The material from those two chapters and Chapter 9 can be combined with task analysis to provide an initial basis for warning design.

THE DESIGN STAGES

To formulize the design process, we propose a sequential analysis of the task-dependent flow of information through the human. As shown by Figure 10−1, there are four general stages of analysis.

In the first stage, the flow of information is initially specified during task analysis. This initial specification is at a low level of detail and is intended to define the task at an abstract level in order to guide further and more detailed evaluation.

In the second stage, those information transfers which are critical to safe performance of the task are isolated by analysing the flow of information specified in the first stage. This analysis considers the effects of breaking the flow of information, as might occur when a product

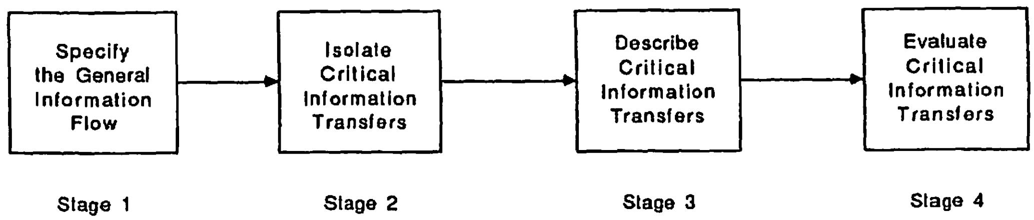


Figure 10-1 A Formalized Methodology for Warning Design.

malfunctions or human errors take place. As such, the approach is similar to combining Failure Modes and Effects Analysis (FMEA) and Criticality Analysis (CA).

In the third stage, those critical information transfers isolated in the second stage are specified in more detail. Only critical transfers are considered, since such analysis involves a very significant effort and consequently should be performed only when warranted. Completing this stage is equivalent to documenting a warning type and scenario in accordance with the warning taxonomies described in Chapter 7.

In the fourth and final stage, these detailed specifications of critical information transfers are evaluated. A number of evaluation methodologies become appropriate, depending upon which aspect of information flow is of interest.

Each stage is composed of a unique set of procedures, as elaborated upon in the following discussion.

STAGE 1 – SPECIFY THE GENERAL INFORMATION FLOW

To specify the flow of information within a task, task analysis must be performed. The objective of task analysis is to specify a task with a restricted sequence of predefined elemental tasks. This sequence of elemental tasks then describes the general flow of information during the task.

The following discussion will introduce a somewhat traditional approach to task analysis. Similar approaches have been used when designing signage systems for airports (Cook and Smith, 1980), seat belt reminder systems (Dillon and Galer, 1975), and sound mixing consoles (Hodgkinson and Crawshaw, 1985). As this discussion is an introductory overview, those readers interested in a more fundamental, knowledge-based, approach to task analysis are encouraged to consult Chapters 11 and 12, which are recommended as being unique and innovative and having significant potential for computer adaption.

The two major topics in traditional task analysis are 1) to describe elemental tasks, and 2) to combine the elemental tasks into a sequence. While both topics can become very difficult, the following discussion will not emphasize those difficult aspects. Instead, it will describe a generalized approach.

Describing the Elemental Tasks

At the most simple level, when a person uses a product, tasks are performed within some general context, and the tasks themselves are at different levels of abstraction. A general context can be viewed as a use phase within which many different tasks are performed. For example, operation and repair are different contexts within which particular tasks are performed. Tasks themselves may be highly aggregated in that they contain many different subtasks, or they may be elemental. A traditional elemental task, of course, is narrowly focused in that it contains no tasks within itself. These general ideas can be substantially extended, as will be done in Chapters 11 and 12.

Table 10−1 summarizes a number of generic contexts, aggregate tasks, and elemental tasks. The elements of Table 10−1 were derived from an exhaustive review of the literature related to task analysis. In particular, the general contexts are obtained from the review done by Lehto (1985); the aggregate tasks are derived from sources such as Woodson (1981), Meister (1971), and the Handbook for Describing Jobs (1972); and many of the elemental tasks shown in the table are derived from Berliner et al. (1964) and Lehto (1985).

Under the heading "elemental tasks," are the following four, more detailed divisions; motor, perceptual, mediational, and communication tasks. Motor tasks are categorized as continuous (e.g. regulate) or discrete (e.g. apply force). Discrete motor tasks are further broken down into the following groups: get/put, apply force, manipulate, or locomotion. Mediational tasks are related to decision-making or cognitive processes; however, no attempt is made to separate these two factors in the table. Perceptual tasks are broken down into the following groups: locate, discriminate, identify, and measure. The emphasis here is on the "locate" type tasks. Communication tasks are also included within the table.

Developing a detailed level of definition for the categories of tasks described within a task analysis is not a new idea. Such an approach was successfully taken by the Gilbreths in the early 1900s. As an example, Table 10−2 summarizes a number of other much more traditional elemental tasks first described by Gilbreth. That these more traditional approaches can be mapped into the proposed taxonomy in Table 10−1 is demonstrated by noting among the Therbligs those that have been directly mapped verbatim into Table 10−1. If other systems of task/element analysis were reviewed similarly, i.e. Berliner et al. (1964), a comparably high success in mapping to Table 10−1 would be found.

Organizing Sequences of Elemental Tasks

Describing a real task in terms of the elemental tasks given in Tables 10−1 and 10−2 can be difficult and time-consuming. The technique we recommend is to work at several different levels of abstraction, as guided by Table 10−1. A similar, but much more complex and detailed approach is presented in Chapter 12.

In explanation, the "general contexts" listed in Table 10−1 describe some phases of product use within which task analysis should be performed. Within a particular context, the next step is to combine "aggregate tasks" to describe the task. For example, if the context is "service" of an automobile, some obvious aggregate tasks include "inspecting" tires, "installing" spark plugs, or "draining" the oil.

Aggregate tasks can always then be described in terms of elemental tasks. We feel that the breakdown of elemental tasks shown in Table 10−1 is applicable to most consumer products. For example, if the aggregate task is "inspect tire," the obvious sequence of elemental tasks is something like: look at tire, get air pressure guage, measure air pressure, and so

Table 10−1
Example Contexts, Aggregate Tasks, and Elemental Tasks used in Task Analysis.

GENERIC CONTEXT	AGGREGATE TASKS	ELEMENTAL TASKS			
		Motor	Perceptual	Mediational	Communication
Storage Service Operation Troubleshooting Repair Install Replace Set-up/ Shut down Training	*Assemble/ *Dissassemble Install/ Replace Activate/ Deactivate Control Monitor/ Inspect Plan/Decide Communicate Apply Clean Calibrate Drain Fill Flush Lubricate	Continuous driving/operating tracking/adjust operating/controlling *position, align, walk, balance, regulate Discrete get/put *reach, *grasp, *move *release, insert, withdraw, set, place, remove apply force push, pull, press, depress, connect, disconnect manipulate twist, handle, finger, carry, feed, transfer, join, fasten, unfasten, attach, detach, adjust, activate, deactivate stoop, crouch, kneel, climb, crawl	Locate look read *inspect monitor verify listen receive monitor verify feel *inspect monitor verify taste *inspect monitor verify smell *inspect monitor verify Discriminate Identify Measure	Calculate Classify Interpolate Code Analyze Select Compare Estimate *Plan Synthesize Coordinate	Advise Answer Direct Inform Instruct Request Transcribe Vocal speech non-speech Non-vocal write key record signal

* Terms also appearing as Therbligs within Table 10−2

Table 10-2
Traditional Elemental Tasks Used in Task Analysis
(The Traditional Therbligs of Gilbreth)

THERBLIG NAME	THERBLIG DEFINITION
Search	Search begins the instant the eyes move to locate an object and ends the instant they are focused on the object.
Select	Select takes place when the operator chooses one part over two or more analogous parts.
*Grasp	Grasp is the elemental hand motion of closing the fingers around a part. It occurs the instant the fingers of either or both hands begin to close around an object to maintain control of it, and it ends the moment control has been obtained.
*Reach	Reach represents the motion of an empty hand. It begins the instant the hand moves toward an object or general location, and it ends the instant hand motion stops upon arrival at the object or destination.
Move	Move signifies hand movement with a load. It begins the instant the hand under load moves toward a general location, and it ends the instant motion stops upon arrival at the destination.
Hold	Hold occurs when either hand is supporting or maintaining control of an object while the other hand does useful work. It begins the instant one hand exercises control on the object, and it ends the instant the other hand completes its work on the object.
*Release	Release begins the instant the fingers begin to move away from the part held, and it ends the instant all fingers are clear of the part.
*Position	Position occurs as a hesitation while the hand or hands are endeavoring to place the part so that further work may be more readily performed.
Pre-position	Pre-position consists of positioning an object in a predetermined place so that it may be grasped in the position in which it is to be held when needed.
*Inspect	The purpose of inspect is to compare some object with a standard. It occurs when the eyes are focused upon the object, and a delay between motions is noted while the mind decides to accept or reject the piece in question.
*Assemble	Assemble begins the instant two mating parts come in contact with each other, and it ends upon completion of the union.

Table 10−2 (continued)
Traditional Elemental Tasks Used in Task Analysis
(The Traditional Therbligs of Gilbreth)

THERBLIG NAME	THERBLIG DEFINITION
*Disassemble	Disassemble occurs when two mating parts are disunited. It begins the moment either or both hands have control of the object after grasping it, and it ends as soon as the disassembly has been completed, usually evidenced by the beginning of a move or release.
Use	Use occurs when either or both hands have control of an object during that part of the cycle when productive work is being performed.
Unavoidable Delay	Unavoidable delay is an interruption beyond the control of an operator in the continuity of an operation. It is idle time in the work cycle experienced by either or both hands because of the nature of the process.
Avoidable Delay	Avoidable delay is any idle time that occurs during the cycle for which the operator is solely responsible, either intentionally or unintentionally.
*Plan	Plan is the mental process that occurs when the operator pauses to determine the next action.
Rest to Overcome Fatigue	This delay does not appear in every cycle but is evidenced periodically. Its duration will vary not only with the class of work but also with the individual.

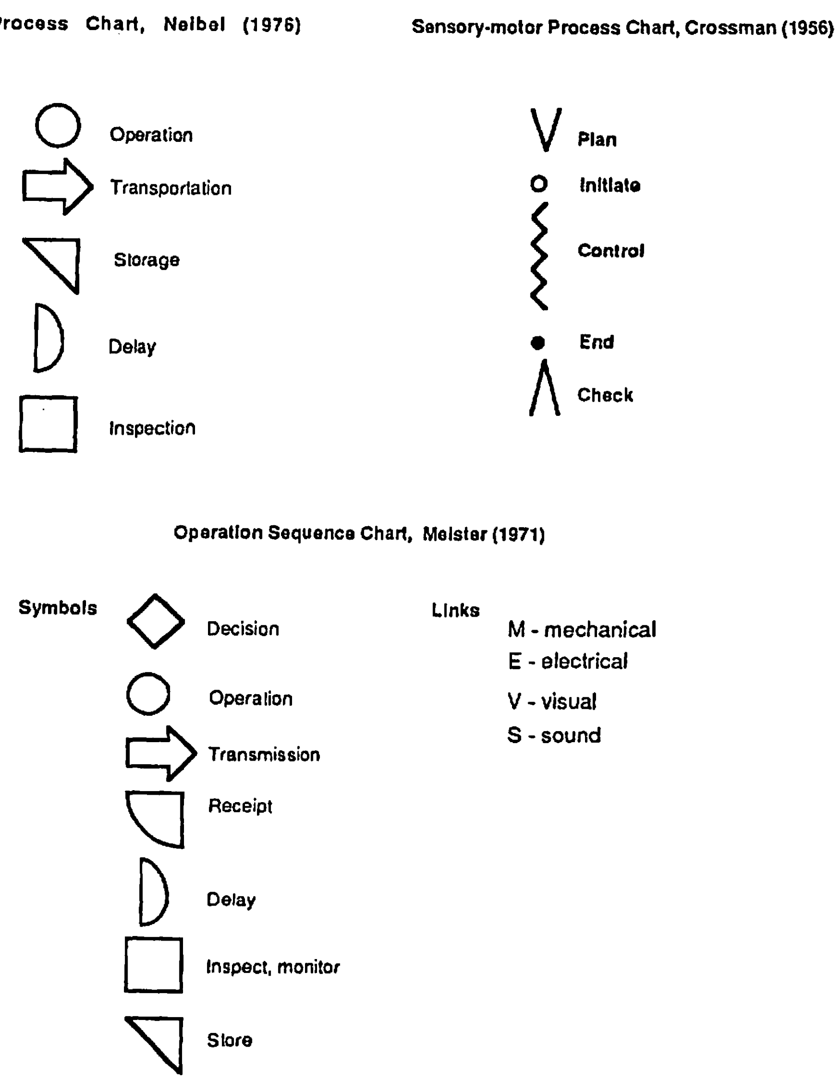
on. Many of these elemental tasks should then be evaluated in more detail, often because they are critical to safety as discussed in the next section.

Many ways of organizing the obtained sequences of elemental tasks are available. One approach that seems especially appropriate is the use of process charts (see Neibel, 1976 for an introduction to process charts). In a process chart, the processes (that is, the tasks) are linked together into a network. Note that a process chart can be equivalently developed for tasks or for a given component of a task. For example, a process chart that describes an assembly task might also describe the assembly component of a more complex task.

Certain standarized formats have been developed for process charts in which particular symbols correspond to specific types of tasks. The symbols of three different process charts are shown in Table 10−3. Of these particular charts, Crossman's approach is the most detailed, Meister's is at an intermediate level, and Neibel's is the most abstract.

To develop a process chart, the first step is to generate a sequential list of elemental tasks and represent them using the symbols provided by any of the standarized formats. Representing tasks with the provided symbols can be difficult, because not every task component in Table 10−1 has a corresponding process chart symbol. Consequently, the task components may have to be combined or broadly interpreted to conform to these symbols. The

Table 10-3 Some Examples of Symbols and Components Used in Process Charts



second step is to arrange these symbols (which now correspond to elemental tasks) into a simple network or flowchart.

Developing this simple flowchart is the final step in Stage 1 of the design process.

STAGE 2 – ISOLATE THE CRITICAL INFORMATION TRANSFERS

In Stage 2, the designer must first determine which elemental tasks are critical to safe performance of the overall task. One way to isolate potentially critical elemental tasks is to first systematically assume that certain elemental tasks are not performed adequately, and then evaluate the effects of each failure. A procedure of this type is equivalent to Failure Modes and Effects Analysis (FMEA). FMEA is a rather complex topic discussed elsewhere in this book. In Chapter 12, consideration is given to some fundamental methods for generating task performance networks that document the effects of both task and product related failures. Rather than redundantly discuss these detailed topics, we refer the interested reader to Chapter 12.

Naively performing FMEA is likely to result in the definition of a vast number of potentially critical tasks, even for the most simple products. Returning to the example given above, when the "context" is service of an automobile, each mentioned aggregate task (i.e. inspecting tires, installing spark plugs, and draining oil) is potentially critical. Here, the failure to adequately perform any of these aggregate tasks could conceivable result in serious damages. Additionally, failures on any of these aggregate tasks can occur because of failures on an even larger set of elemental tasks (i.e. the tire might not be inspected properly because of visual problems, inability to find a guage, problems using the guage, etc.).

Because such a large number of tasks are potentially critical, it becomes necessary to prune this set of tasks to a more manageable size by applying criteria related to probability and severity. In other words, if the expected severity of damages is low when a failure on a potentially critical task occurs, the task is eliminated from consideration. Once a task is eliminated from consideration, analysis is simplified because the criticality of many tasks that fall within the eliminated task no longer needs to be considered.

Such pruning is an essential aspect of Criticality Analysis (CA), as commonly performed in systems safety (see Johnson, 1980). The "risk and effectiveness decision hierarchy" discussed in Chapter 8 illustrates the application of such an approach.

STAGE 3 – DESCRIBE THE CRITICAL INFORMATION TRANSFERS

In this stage, the designer must specify each critical information transfer in detail. This process is equivalent to describing a detailed warning type and warning scenario. Information sources, corresponding to different warnings, can be documented with little difficulty using the warning type taxonomy (see Tables 7–1 and 7–2). Since Chapter 7 discussed these tables, and because Table 7–2 provides examples of classified warnings, we will not further discuss the development of such descriptions.

Table 7–3 provides a general taxonomy that can be applied so as to describe particular warning scenerios. As discussed in Chapter 7, this taxonomy specifically lists a number of factors related to people, tasks, and interactions between the task and product. Each of these factors are then described within "task-related contexts." The task-related context described there exactly corresponds a task description, as developed by completing Stage 1 of the methodology we are currently discussing.

Documenting the factors listed in Table 7–3 within each "task related context" results in a very detailed description of the task. It is clear that for nearly all products, such development will require a substantial effort, as well as expertise well beyond that available to most companies. One way of reducing the required expenditures of time and money is to only develop this taxonomy for very critical tasks. The problems associated with the need for expertise is fundamentally more difficult to solve, because there is a shortage of qualified experts.

Rather than further describe the process whereby the classifications are developed, we will outline three other potentially useful methods of describing critical information transfers in detail. These descriptive methods are 1) a sensory-motor process chart, 2) a sensory-motor input/output matrix, and 3) a task performance network. While it is debatable whether these approaches provide any advantage in terms of cost or complexity, they are mentioned in the interest of completeness.

Sensory-Motor Process Chart

A sensory-motor process chart is similar to the commonly used left and right hand chart (Neibel, 1976), but is more detailed. Within a sensory-motor process chart (Crossman, 1956) each elemental task is defined in terms of the following time sequence: 1) plan, 2) initiate, 3) control, 4) end, and 5) check. In association with each of these five steps in performance, the particular channel that provides the information should be specified. Doing this for each elemental task (within a task) results in a detailed specification of the overall task.

Table 10−4 provides part of a sensory-motor process chart that describes the tire inspection task referred to earlier. The structure of this particular chart was derived from Crossman (1956), but has been modified to make it more consistent with the terminology we introduced in Chapter 2. Note that the headings of the diagram list the elemental tasks, effectors, sensors, and the central processor. To represent the task, the elemental tasks are listed in a sequence, as are the processes that occur within each elemental task. The processes are defined in terms of the symbols listed in Table 10−3, while the elemental tasks use the terminology given in Table 10−1.

In the chart, the various processes are respectively associated with effectors, sensors, and the central processor: "Motor" processes are exclusively associated with effectors. "Control" and "check" processes are associated with sensors. "Plan," "initiate," and "end" processes are associated with the central processor. The various symbols listed in the columns beneath the headings illustrate which processes are taking place at particular times, while the task is being performed. Time, of course, proceeds downwards in the chart.

An important point made clear by the chart is that many processes occur in parallel within elemental tasks. For example, during the "get tire guage" elemental task, control processes are associated with both visual and kinesthetic sensors. At the same time, the eye and hand are performing motor activity.

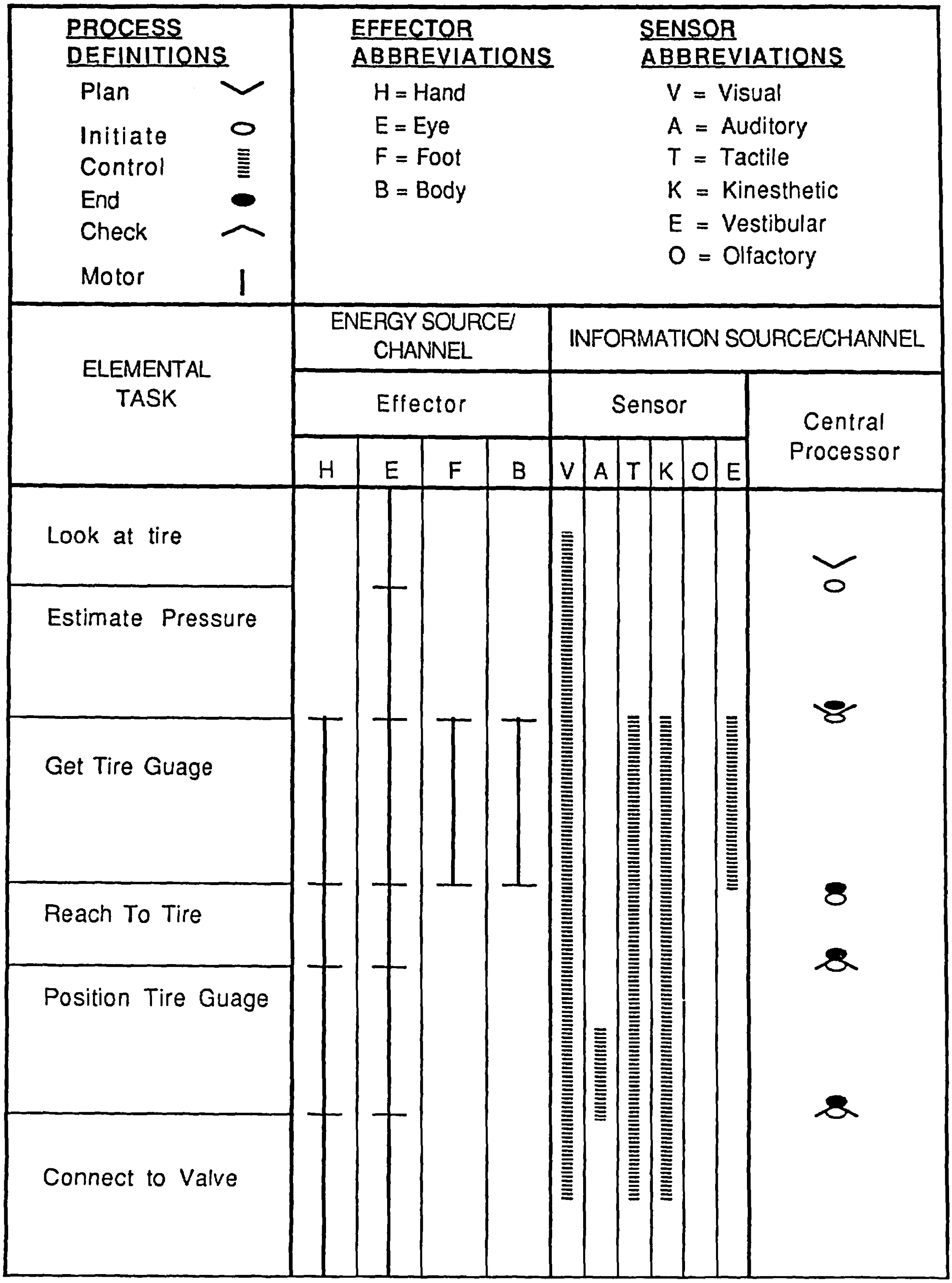
As should be clear from the example given in Table 10−4, a sensory-motor process chart is simple enough to be developed without the aid of computerized methodologies for many products. However, its complexity is still very high and the generated description is very detailed; especially in comparsion to the "common sense" methods most often used when designing warnings. This latter point probably explains why the approach has seen very little application to date.

Sensory-Motor Input/Output Matrix

McGuire (1980) discusses an input/output matrix for describing communication tasks in detail (Table 2−3). Other variations have also been proposed as described by McCormick, (1979). In such a matrix, a set of factors describing the stimulus input is on one axis, and a set of factors describing the outputs or responses elicited by the stimulus are on the other axis.

Multi-dimensional matrixes are also feasible. An obvious third dimension would consist of a set of factors that describe particular people who will be using the product. An approach that emphasizes the development of multi-dimensional matrixes would generate data similar to that documented in the taxonomies of warning types and scenarios.

Table 10–4 An Example of a Sensory-Motor Process Chart Developed for Part of a Tire Inspection Task



Advanced Model Based Techniques

Both the sensory-motor process chart and sensory-motor input/output matrix provide excellent, but difficult, means of describing or documenting information flows. Of major concern is that the two techniques do not directly evaluate the quality of the information flow. Such measures must be inferred from the respective diagrams. Few criteria exist for making such inferences.

A third approach, describes the information flow with a set of parameters for a model. Once the parameters are known, the quality of the information flow can be directly inferred from the model. For example, if the model being used is signal detection theory, one would describe the information flow in terms of 1) signal to noise distributions, and 2) payoff probabilities for various operator decisions. From these parameters, one could create what has been commonly called a Receiver Operating Characteristic (ROC) Curve, to predict performance.

In Chapters 11, and 12, we present some of our initial efforts towards describing a knowledge based modeling approach which could accept a far richer set of parameters; specifically a knowledge representation of the product, task, and human. There is no theoretical reason why such model based approaches could not accept data as represented by: sensory-motor process charts, input/output matrixes, or the warning type and scenario classifications. However, a significant amount of research and development effort remains before the techniques will become practical for application.

Although the value of knowledge based approaches has not been proven, we feel that their potential justifies the large investment required. With respect to warnings in particular, knowledge-related issues are the major concern. Therefore, knowledge based techniques may be the ultimately best way to approach the design and analysis of warnings.

STAGE 4 – EVALUATE THE CRITICAL INFORMATION TRANSFERS

In this stage, the primary emphasis is placed on evaluating the comprehension of signal meaning. Emphasis is also placed on determining whether warning signals are integrated into the task. The following discussion will discuss methods of evaluating perceptual factors, the meaning of stimuli, task specific factors, and actual behavior.

Evaluating Perceptual Factors

Two general types of evaluation methods are available. The first emphasizes direct measurement of stimulus characteristics. Frequency and amplitude related data can be collected for light, sound, shapes, vibration, and acceleration. The concentrations of odorific chemicals can also be measured. Specialized equipment is available for measuring all of these referenced factors. However, it is frequently difficult to find people who are qualified to take and interpret such measurements. Even many graduates of university level human factors programs have limited understanding and ability in this area. Because expertise is limited, there is a need for developing computer aided methodologies which would generally facilitate this evaluation process. In the second approach, responses rather than stimulus characteristics are measured. The balance of this chapter will describe some of the approaches used to measure responses.

In particular, it is important to determine how easy it is to notice the most outstanding features of the stimuli, or the particularly conspicuous parts of a warning. For example, we can equivalently speak of this characteristic as being the stimulus's "salience." We could also regard it being the stimulus's "conspicuity," or take a more detailed view in which we speak of "strength" or "discriminability."

Placing these theoretical points aside, the stimuli specified in most designs are readily perceived. Surprisingly, this makes it more difficult to evaluate alternative designs than when stimuli are hard to perceive. In other words, design changes are most likely to have easily measured effects on performance when the important stimuli were initially hard to perceive. Consequently, stimuli are often degraded, sometimes unnaturally, until they are marginally noticeable, before they are tested or evaluated. A second important point is that the results obtained from the different traditional methods of evaluating stimuli may be uncorrelated or may even conflict. For this reason, it is frequently desirable to use multiple measures.

In regard to the specific methods which are used, we will first discuss some generic approaches that are applicable to all forms of stimuli. Then some particular methods commonly used during the evaluation of visual safety signs will be summarized.

Generic Approaches Three standard approaches frequently used to evaluate the perception of stimuli are: 1) the evaluation of reaction time, 2) the evaluation of accuracy or errors, and 3) the application of signal detection theory. Each of these approaches can be applied to any form of stimuli, but almost all of the focus to date has been placed on visual or auditory stimuli.

Reaction Time. Measures of reaction time have been used in many different contexts to evaluate the salience of stimuli and symbols related to warnings. Here, a symbol that is reacted to quickly is assumed to be more saliant than one that is reacted to slowly. In regard to warnings, no studies were found other than for visual or auditory stimuli.

Reaction time measures are particularly useful when quick reaction times are an actual requirement of the task (as in the driving of automobiles). Their value becomes questionable when reaction time is not of essence to the task. This latter point follows because reaction time is frequently not related to other measures of salience.

Accuracy or Errors. The degree to which errors occur in perception has also been used to document the salience of a stimulus. One of the more standard approaches used to evaluate errors involves the development of confusion matrixes (see Table 10–5). In a confusion matrix, the various stimuli are listed in the same order on the x and y axes. Commonly, the x axis will correspond to the given stimuli, and the y axis will correspond to people's responses. Correct responses are on the diagonal line through the matrix described by cells for which the presented signal and elicited response are the same. All other cells in the matrix correspond to confusions.

To develop such a matrix, the first step is to determine which stimuli are to be evaluated. The stimuli are then presented to subjects in an experimental setting, and the ensuing responses are recorded in the matrix. Statistical techniques are required to determine whether the effects are significant. Along these lines, the matrix can be analyzed using the approaches of information processing theory, to determine how well information is transferred by certain groups of stimuli.

Much work has been performed in which auditory and visual confusions between phonemes and letters are tabulated in confusion matrixes (Hodge, 1962; Hull, 1976; Van Nes and Bouma, 1980; and others). The technique could be useful for other forms of potentially confusing stimuli, but it has as yet seen little application.

Many other experimental techniques can be performed in which errors are evaluated. "Check reading" is one of the more interesting of these techniques, and was proposed by Smith and Goodwin (1973) as a means for evaluating display legibility. In this technique, errors are introduced into the display, and display legibility is then evaluated in terms of how

Table 10–5 An Example Confusion Matrix. (The x-axis corresponds to the presented symbols, and the y-axis to the perceived symbols. Correct responses fall within the shaded cells of the matrix.)

		Perceived Symbol				
		A	B	C	D	E
Presented Symbol	A	correct				
	B		correct			
	C			correct		
	D				correct	
	E					correct

quickly and accurately the errors are discovered. Although this technique was used for visual displays, it also has potential value when evaluating other forms of stimuli.

Signal Detection Theory. Signal detection theory (see Chapter 2) has primarily been used to evaluate the perception of faint auditory signals against a background of white noise. The technique itself, however, is very general and has substantial potential to be applied to other forms of stimuli. One major problem with the technique is its apparent complexity to mathematically naive people. There is little question that the application of signal detection theory, and the interpretation of generated results requires substantial skill. A second problem is associated with the need for applied research.

In regard to the second problem, it is easy to specify values of noise and signal strength in many experimental settings, as was also the case for many of the early military applications in which people monitored displays. For practical applications, such as with consumer products, further research experience would be useful regarding ways of measuring noise and signal strength.

For example, research into the effects of meaningful distracting stimuli, as opposed to experimental studies that use white noise, would seem to have great potential payoff. This need is present because white noise has little correspondence to the distractions that occur in many real tasks. Research would also be useful in regard to describing noise and signal strength in a meaningful way for senses other than the auditory sense. Some information is available regarding visual noise, but it is unclear how visual distractions, as opposed to degraded visual images, should be modeled.

Approaches Applied to Visual Safety Signs The above mentioned approaches, with a single exception, have all been extensively used by researchers who were evaluating the perception of safety signs. This exception is signal detection theory, which has only been proposed as a method for evaluating safety signs. The following discussion will briefly introduce some other approaches that have been used specifically for evaluating safety signs.

Glance Legibility. In this approach, a visual symbol is presented very briefly to a subject. (A tachistoscope is usually used.) Symbols with a higher probability of recognition at these very short viewing times are assumed to meet the basic conspicuity related requirements. Tierney and King (1970) originally used this technique to compare verbal and nonverbal symbols for traffic signs. The technique has subsequently seen much use during the evaluation of traffic signs. Other examples of such work are given in King and Tierney (1970), Dewar (1976), Ells, et al. (1980), and King (1975), among many others.

The general value of glance legibility, as a measure of symbol effectiveness, is questionable when quick perception is not important. Several studies have found glance legibility to be unrelated to measures of comprehension or even other measures of legibility: Dewar and Ells (1977) found that semantic differential scores related to comprehension were not related to glance legibility. Ells, et al. (1980) found low correlations between glance legibility and legibility distance. Green and Pew (1978) found that reaction times were weakly correlated with the normal associations between symbols and meanings.

Legibility Distance. This approach theoretically is very simple. It consists of measuring the distance from a sign at which a human subject can identify that sign. However, practical problems arise when evaluating the legibility of large objects because the measured distances become very long. While there are several ways of measuring legibility distance, a common method requires the subject to move toward the sign beginning from a location at which the sign is not perceived. The movement toward the sign continues until the sign is recognized. At that point, the distance between the human subject and the sign is equal to the legibility distance.

This measure has frequently been used to evaluate the legibility of traffic signs (Jacobs, et al., 1975; Dahlsted and Svenson, 1977; Cole and Jacobs, 1981; Sivak, et al., 1981; Hicks, 1976). Legibility distance has also been well predicted by a computer program that considers a large number of factors including sign luminance and contrast (Olson and Bernstein, 1979).

Evaluating Cognitive Factors

Cognitive criteria are concerned with the flow of meaningful information between the human and product, as well as within the human. When applying cognitive criteria, it is normally assumed that the more basic perceptual criteria are satisfied. This assumption allows emphasis to be placed on the flow of meaningful information into and out of short term memory. Associated with these higher level criteria are several forms of analysis which emphasize stimulus meaning.

It should be realized that the meanings inferred from warning messages can vary extensively as a function of factors such as knowledge, experience, age, and context. Consequently, the design of effective warning symbols and messages will often require substantial analysis that takes into account the user/target population.

Stimulus (a stimulus can be a symbol, sign, sound, smell, and so on) meaning can be analyzed in several ways. Different forms of analysis may emphasize semantics, syntax, or pragmatics. Both symbol semantics and syntax can be evaluated using more or less standard methods. The analysis of pragmatics requires a more fundamental approach based on task analysis.

Analysis of Semantics The majority of the standard approaches used to evaluate the meaning of stimuli measure semantic meaning. Such approaches include 1) recognition/matching tasks, 2) semantic differential scales, and 3) simple readability indexes. Each approach will be briefly discussed below.

Recognition/Matching Tasks. In recognition/matching tasks, a stimulus is presented to a subject, which the subject must then interpret. In a recognition task, the subject must provide the meaning of the symbol in the absence of information that indicates possible meanings of the stimulus. On the other hand, several alternative meanings are given in matching tasks, from which the subject selects the most applicable meaning. There are many variations on these recognition/matching tasks, since they are commonly applied. For example applications, the reader is encouraged to consult Easterby and Hakiel (1977), Collins et al. (1982), Green and Pew (1978), or other references mentioned in Chapter 5.

An initial step in analysis is to specify the symbols to be analyzed. In both matching and recognition tasks, the validity of the generated results is highly dependent on the provision of an appropriate set of symbols. For a matching task, a set of possible symbol meanings must also be developed. As is true for the tested symbols, the set of possible meanings must be reasonably comprehensive if valid results are to be expected. Both generating appropriate symbols to be tested and developing possible meanings are substantial tasks.

After completing these initial steps, data can be fairly readily generated during the testing process. Analysis of the data generated in a recognition task consists of classifying responses into categories and then tabulating them for particular symbols. In practical applications, recognition tasks are less commonly used than matching tasks, because classifying open ended responses, as often obtained in a recognition task, from a large group of subjects is difficult. The approach does provide the advantage of measuring the meaning of symbols independently from other symbols (Easterby and Hakiel, 1977).

In a matching task, only a finite set of answers is possible for each symbol. It consequently becomes easier to perform formal types of analysis, as typified by developing a confusion matrix (Green and Pew, 1978). Such a matrix can be identical to the confusion matrix discussed earlier in regard to perception (Table 10−5). The two matrixes are the same when symbols are listed on each axis. A subtle variation, more oriented towards evaluating comprehension, occurs when the symbols are listed on one axis, and the meanings of the symbols are listed on the other axis. Each cell of the matrix is then an assignment of a meaning to a symbol. As for the earlier mentioned matrix, data analysis can be guided by information processing theory.

Matching and recognition tasks have primarily been used when evaluating visual symbols. The two techniques also have potential value for evaluating other forms of stimuli. However, as normally used, matching and recognition tasks do not provide the contextual information which becomes so important for nearly all forms of non-verbal stimuli, product labels and warnings being no exception. These two techniques could reflect contextual information if they were presented in an actual task environment. Another approach, coming out of our specific research, is to explicitly list contextual information on multiple choice forms. We were specifically concerned with determining the comprehension of nonverbal cues in a boating environment.

Semantic Differential Scales. The semantic differential (Osgood, et al. 1957) provides a measure of the meaning of an object or concept. This is done using scales comprised of pairs of adjectives or adverbs, upon which the subject assigns values to the rated objects. These scales are related to underlying concepts by applying factor analysis. A particular objective of performing such analysis can be to describe the meaning of a symbol or stimulus with a set of factors that are assumed to be safety related.

Among those safety related studies which have applied this or similar techniques, Dewar and Ells (1977) compared the meaning of symbols with other measures such as glance legibility and simple comprehension. Green and Pew (1978) evaluated automotive symbols on a communicativeness scale, while Fischhoff et al. (1978b) used factor analysis to define the perceived acceptability of risk in terms of two primary factors (technological risk, and severity). A small amount of other safety related research along these lines can also be found in the literature.

Analysis using the semantic differential scale seems to be appropriate for evaluating the safety-related meaning of almost any form of stimuli. The primary difficulty is that appropriate scales need to be developed for assessing relevant safety-related meanings. In a study illustrative of current practice, Caron et al. (1980) evaluated pictographs using semantic differential scales. Some of the used adjective pairs were "good/bad," "strong/weak," and "active/passive." Further development will require that more relevant adjective or adverb pairs be specified. This appears to require substantial effort toward classifying important product related meanings.

In regard to future applications, signal words proposed in various warning systems should be evaluated. Similar work should be performed regarding ways of denoting specific hazards; it would be particularly interesting to compare warning labels to other stimuli in a task-specific context.

Readability Indexes. A readability index describes the difficulty of written material in terms of word length, sentence length, or other variables. Readability indexes that emphasize simple variables, such as word length, evaluate semantics. More complex indexes evaluate syntax.

Many different readability indexes have been developed (Klare, 1974−1975). Those indexes that do not explicitly consider the meaning of words are of questionable value for evaluating written warnings, but might be useful for evaluating safety related instructions. The rationale for this conclusion is that written warnings are generally terse fragments of sentences rather than prose. On the other hand, most forms of instructive material are generally in a prose-like form.

Those readability indexes that contain dictionaries of simple words are more likely to be useful for evaluating written warnings, but the research has not been done to make this determination.

Analysis of Syntax Syntax is the most mathematically tractable aspect of meaning. As such, formal representations of various "grammars" have been developed which can describe the syntax of many different forms of messages. It would be desirable to be able to predict the influences of various forms of syntax on human comprehension. There are several approaches for evaluating the syntax of written verbal material. However, as indicated in Chapter 5, there are no standard methods that predict the influence of the syntax within nonverbal stimuli.

In particular, several readability indexes consider simple grammatical factors. The Writers Workshop, developed at Bell Laboratories and briefly discussed by Bailey (1982), analyzes syntax and is able to provide recommendations that increase readability. The capabilities of the Writers Workshop would not, however, compare favorably with those of a skilled writer.

Analysis of Context The particular task-related context is perhaps the most important factor influencing the comprehension of stimuli, except within very detailed verbal messages. The extreme importance of the context on natural language understanding has been rediscovered by researchers in Artificial Intelligence. (At first, such work emphasized syntax because of its mathematical tractability.)

Although certain researchers have emphasized the importance of context (Cahill, 1975; 1976; Green and Pew, 1978), the value of contextual information has been ignored in most sources of warning design guidelines. Consequently, methods for evaluating the influence of context on the comprehension of safety related information must be developed or taken from other areas of research. The following discussion addresses ways of evaluating contextual effects, these include 1) augmented standard approaches, 2) the Close procedure, and 3) protocol analysis.

Augmented Standard Approaches. Among the ways of evaluating contextual effects on comprehension, the simplest one is to evaluate comprehension using the standard techniques discussed earlier, but within a task-related setting (rather than within an experimental setting in which no contextual information is given). Taking this augmented approach often will require no modification of the existing ways of performing field studies. However, it does provide reasons for using techniques in the field that are normally used only in the laboratory. It also provides an additional rationale for increasing the correspondance of laboratory studies to the "real world."

In regard to the latter point, the information given to subjects in experimental settings can be enriched by providing contextual information, as we mentioned earlier. Once contextual information has been given, the earlier described methods, such as recognition/matching, or semantic differential scales can be applied.

Close Procedure. The Close procedure mentioned by Klare (1974 – 1975) is of potential value for evaluating contextual effects within written text. (The earlier comprehended material defines a context.) In the Close procedure, subjects read text that contains blanks or missing words. When subjects come upon a blank, they are asked to fill it in with points they obtained from reading the earlier material.

Application of this technique measures the comprehension of contextual meaning, because the blanks can be filled in correctly only if the preceeding information is understood.

Protocol Analysis. A very general approach is described by protocol analysis (Newell and Simon, 1972; Ericsson and Simon, 1980; Ericsson and Simon, 1984; Nisbett and Wilson, 1977). During protocol analysis, the subject performs a task while overtly thinking. Usually, this means that everything that the subject consciously experiences is verbally reported. Protocols can also be obtained by writing, videotape, or even recording keystrokes on a computer. The influence of the context on comprehension can be inferred from the sequences of items found to enter consciousness, both before and during the comprehension of a stimulus.

The primary disadvantage of protocol analysis is that it may generate massive amounts of data. Such problems can be reduced by only recording the data that is relevant to a particular design related problem.

Evaluating Task-Specific Factors

Task specific factors are particularly worthy of consideration. It is possible to distinguish between those factors that are associated with the influences of 1) operator workload, and 2) integrating meaningful stimuli into the task, as discussed below.

Operator Workload As workload becomes high, greater problems with information overload can be expected. The influences of workload on task performance is an entire book in itself (see Moray, 1979 for an example), but will not be emphasized here, despite its importance. There also are a number of commonly applied ways of assessing workload, which emphasize subjective, physiological, secondary task performance, dual task performance, critical task performance, and other measures of workload. Because of space limitations, we also will not be able to describe many of these assessment techniques, but instead refer the reader to the book by Moray.

With specific regard to the warning issue, the idea of dual tasking and its many implications is of major importance. Dual tasking, of course, refers to the case where more than one task is being performed at the same time. One particularly important finding is that dual tasks will normally interfere with each other, and that the degree of interference depends upon the particular tasks that are being performed. A simple rule of thumb is that the amount of interference between two different tasks becomes large if they use common resources. For example, a visual task will usually conflict more with another visual task than it would with an auditory task.

In particular, when warnings are not directly integrated into a task, the perception, comprehension, and response to a warning becomes a task that is performed concurrently with the primary task. The extent to which the two tasks interfere with each other will influence the effectiveness of the warning. In certain cases, it may be desirable for the warning to interfere severely with the primary task. For example, a fire alarm should interfere with normal activity sufficiently to attract attention. In other cases, it is undesirable for a warning to interfere with the primary task. For example, a warning label should not attract attention away from normal activity, as might be the case where a very conspicuous symbol makes it difficult to concentrate on the text it appears with.

A few studies were found in which auditory warnings were tested in conjunction with primary tasks such as tracking (McClelland, 1980) or flight simulation (Wheale, 1983). No such studies were found for warning labels; the most related study evaluated warning lights on a stove (Stefl and Perensky, 1975).

Integrating Stimuli into the Task Another set of task specific factors is associated with presenting meaningful stimuli (possibly a warning) at the appropriate time and location; the appropriate time is the period during which the warning message is pertinent, while the appropriate location is at the particular sensor. To document the extent to which stimuli are integrated into a task, it is useful to develop measures such as 1) sensory-motor charts and matrixes, or 2) graphical depictions of the problem space.

Sensory-motor Charts and Matrixes. As noted earlier, both the "sensory-motor process chart" and the "sensory motor input/output matrix" provide a detailed documentation of information flows. It can be difficult to generate the basic data organized in these respective charts or tables, and extensive research is often required. It is also frequently found that such research results in the generation of too much data. For example, sophisticated equipment is available for measuring eye movements, but immense amounts of data are generated during actual studies of behavior.

In comparsion to the difficulty of generating the basic data, it is even more difficult to develop firm conclusions strictly from sensory-motor charts or tables. No standard formulas are available that describe how to analyse these charts or tables; consequently, developing valid conclusions from these charts or tables is definitely an art rather than a science.

The Problem Space. A considerably more complicated approach is to measure the problem space (see Chapter 11). Protocol analysis is the most commonly used method for attaining this goal: Extremely detailed measures can be developed in terms of the task-related information flow into and out of the human's short term memory. Also, these flows can be graphically depicted as discussed in Chapter 11.

Protocol analysis can be combined with the knowledge based modeling techniques outlined in Chapters 11 and 12. Similar, but less ambituous, knowledge-based approaches have been used to describe task performance for real-world products (Kieras, 1985). All of these knowledge based applications require the use of substantial computer software and hardware, and the involved researchers have been highly knowledgeable in both psychology and artificial intelligence. Except for the rare individual who has both adequate skills and computer resources, application of these newer techniques is currently difficult for all but the simplest products and tasks.

Evaluating Behavior Patterns

Analysis of the behavior ultimately induced by a warning is necessary. This typically requires data collection under controlled experimental conditions, wherein actual behavior of humans using the product is observed. Serious problems are faced during such data collection, especially if the desired behavior is inconsistent with normal behavior patterns (as when people who normally don't wear seatbelts are observed). Under such circumstances, the simple presence of an observer is likely to change the behavior patterns of the subjects. It therefore becomes important to observe behavior in a very realistic setting where the observed people do not know that their behavior is being observed.

Evaluation becomes less difficult if the information flow is a normal element of the task, and when the information is readily understand and agreed with. Under such circumstances, the observed behavior will probably vary little from normal behavior, making less realistic experimental settings likely to be adequate.

There are many different approaches which can be taken during the evaluation of behavior. Some of these approaches include developing experimental mockups, simulating accidents, analyzing accident reports and data, performing large scale surveys, and so on. Also, statistical techniques become of importance when evaluating the significance of any observed behavioral effects. In general, these techniques are well known to experts in human factors engineering, and as such will not be considered further here.

SUMMARY

This chapter describes a four-stage design methodology that emphasizes the analysis of information flow within a task. In the first stage, the flow of information is initially specified during task analysis. Critical flows of information are then isolated in the second stage by systematically considering the effects of breaking this flow of information, as might occur when a product malfunction or human error takes place. Those critical transfers isolated in the second stage are then specified in detail in the third stage, by following any of several described methods. The fourth stage, concerned with evaluating those precisely specified information transfers, is emphasized in this chapter. A variety of approaches are described here for evaluating perceptual, cognitive, and other task-specific aspects of information flow.

In describing the overall design process, this chapter, when combined with the material in the preceding three chapters, provides a means for systematically making and justifying decisions regarding the design and application of warnings. For those groups with adequate resources and personnel, taking such an approach obviously poses advantages. Other concerns with limited resources will be less able to immediately apply these methods because of its research-oriented emphasis. Consequently, there is a pressing need for further development of simplified, yet demonstrably valid, approaches to the difficult problems of warning design. Unfortunately, validity and simplicity appear to be naturally exclusive attributes of the potential solutions to the warning related questions.

With the continuing advancements in computer science, especially the recent trend toward knowledge processing rather than data processing, it appears reasonable to assume that computer programs capable of assisting these groups with limited expertise will become available. Development of such computer programs will require substantial effort and input from qualified professionals who are knowledgeable about the many complex warning issues. It will also require insight into the modeling of large complex problems with knowledge based techniques. The next section is specifically concerned with laying out the basic aspects of such modeling of the warning issues.

SECTION IV.

ADVANCED TOPICS

This section consists of Chapters 11 and 12, and addresses the potential application of knowledge based approaches during warning design and evaluation. A primary goal in these chapters is to represent the human, task, and product with consistent knowledge structures. The two chapters are at an advanced level, reflecting the complexity of the topic. The modeling techniques are not themselves easily applied using traditional approaches; instead they may best be applied using recently developed computer tools, which include those used in Artificial Intelligence (AI), or more precisely, object-oriented computer programs. Chapter 11 specifically considers a knowledge-based approach to the modeling of human performance, as illustrated by the development of a production system-based model of elemental tasks. The chapter also considers traditional techniques such as Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA). Chapter 12 takes an even more fundamental approach toward modeling tasks and products with knowledge-based techniques.

CHAPTER 11

A KNOWLEDGE BASED APPROACH TO HUMAN PERFORMANCE

CHAPTER 11. CONTENTS

CHAPTER 11

A KNOWLEDGE BASED APPROACH TO HUMAN PERFORMANCE

Several topics of important theoretical interest are addressed in this chapter. The presented material describes a novel, to the area of safety science, way of modeling tasks, people, and knowledge with production systems, and also shows how to combine this model with Fault Tree Analysis (FTA). Perhaps of greatest immediate value is the description of how meaning can be modeled. The remaining material describes a unique, innovative, and very generic approach to product safety. The generic nature of the approach is of major interest, since it extends the possible applications to almost any product. A drawback, of course, is that substantial development work will be necessary whenever a particular analysis is performed.

The chapter is subdivided into two general sections. The first section describes the production system model referred to in Chapter 2. The related discussion emphasizes the ways in which production systems can describe tasks, people, and knowledge consistently with other more commonly applied safety techniques such as FTA. The second section describes a new model called the "general warning tree." The general warning tree explicitly combines elements of FTA and production systems. Throughout this chapter, most of the modeling principles will be graphically, rather than verbally, defined.

THE PRODUCTION SYSTEM MODEL

A production system, at the most general level, is a particular type of computer program developed in Artificial Intelligence related research. Such programs are notable for their emphasis on representing procedural knowledge with groups of antecedant/consequent clauses. (Other terms used instead of antecedant/consequent include if/then, or condition/action.) An antecedant/consequent clause is equivalent to a rule which can be applied whenever its antecedant is satisfied. Application of the rule, of course, results in the consequent. Many variants of production systems exist. They differ primarily in the way rules are selected before being applied: If rules are selected on the basis of their consequents. a production system exhibits goal directed behavior (also called backward chaining). If rules are selected on the basis of their antecedants, a production system exhibits data directed behavior (also called forward chaining).

Production systems, when used to model human performance, (Newell and Simon, 1972) provide an elegant extension of the basic information processing model, and are suitable for modeling complicated sequences of elemental tasks. The following three sections will address this topic.

The first section, "A General Task Description" will show how the production system model can be applied, to generically describe tasks. Here, a task corresponds to human activities that are directed toward attaining a goal; and within a task, several intervening goals usually have to be specified and attained. The second section, "A General Description of the Human," will describe the human using the production system model. This description subsumes the human information processing stages discussed earlier in Chapter 2. It also shows how individual goals define the context within which particular information processing activities or stages become relevant. The third section, "Information and Its Flow," will provide more detailed definitions of information and information flow which emphasize meaning rather than uncertainty. Emphasis is placed on showing how these definitions can become specific enough to be applied during the analysis of warnings.

A General Task Definition

When a task is performed, the stimuli impinging upon the human are very task-dependent. In other words, if the task is broken down into sub-tasks, each sub-task requires the processing of different sets of stimuli. When the sub-tasks are performed in a sequence, the outcome of one sub-task becomes an input for the following task.

If such effects are defined in terms of goals, conditions, and actions, a useful task description can be obtained by applying the production system model. In such a definition, a "task" specifically consists of 1) an "initial state" described in terms of "conditions," 2) a "goal state" described in terms of unattained conditions or unperformed actions, and 3) "activity" which takes place between the initial and goal states. Here, the outcome of a subtask is determined by people's actions, and specifies conditions for the next task. Actions are taken in order to attain goals, the overall process corresponds to task related activity.

Describing Task-Related Activity In the simplest case, activity transforms an initial state into the goal state in a single step; or, equivalently, an action prescribed by a single rule is taken. More generally, the activity consists of intervening conditions, subgoals, and actions. In other words, the goal is not reached in a single step. Instead, several intervening steps take place, during which subgoals are generated and attained by performing actions (that is, several different rules are selected and applied). These intervening steps are equivalent to performing subtasks. (As an aside, this approach is equivalent to means-end analysis as described by Simon, 1969.)

The Problem Space. Activity performed between the initial and goal states can be described by a network formed of connected goals and subgoals. Along these lines, a schematic diagram illustrating a simple network is given (Figure $11-1$), in which subgoals are those goals beneath other goals. Note that this network is similar to a flowchart that specifies the steps taken when performing a task. In other words, attaining certain combinations of subgoals results in attaining goals. Also, goals and subgoals might always occur in certain sequences.

This type of network is called a "task definition network" since it defines the way goals and subgoals fit together to define a task. Such networks can be used to hierarchically represent tasks of arbitrary complexity. Since only goals and subgoals are present, task failures are not considered in the task definition network. The even larger network defined by every possible combination of applied rules (including those which lead to failures) defines what Newell and Simon call the "problem space." The specific sequence through this problem space which a human follows when performing a task can vary greatly, since the conditions which trigger the application of rules are determined by task-dependent stimuli.

Representing Tasks To represent a specific task, it is necessary to define the activity that takes place between the initial and goal states. One way of doing this equates attaining each goal with successfully completing certain elemental tasks. A similar approach is taken within the General Problem Solver (GPS), a production system-based program whose performance on puzzle-solving tasks was compared to human performance in Newell and Simon (1972).

The same general idea can also applied when describing more practical tasks. For example, the "Goals Operators Methods States" (GOMS) methodology of Card, Moran, and Newell (1983) takes a similar approach, and has provided useful results in regard to describing human/computer interaction. Production system models have also been used to model air traffic controllers (Wesson, 1977) and the acquisition of flight skills (Goldstein and Grimson, 1977).

In the upcoming section on the "general warning tree," an extensive description of human tasks will be given along these lines. Before commencing this discussion, attention will be directed toward describing the human and information in ways that are consistent with such a task representation.

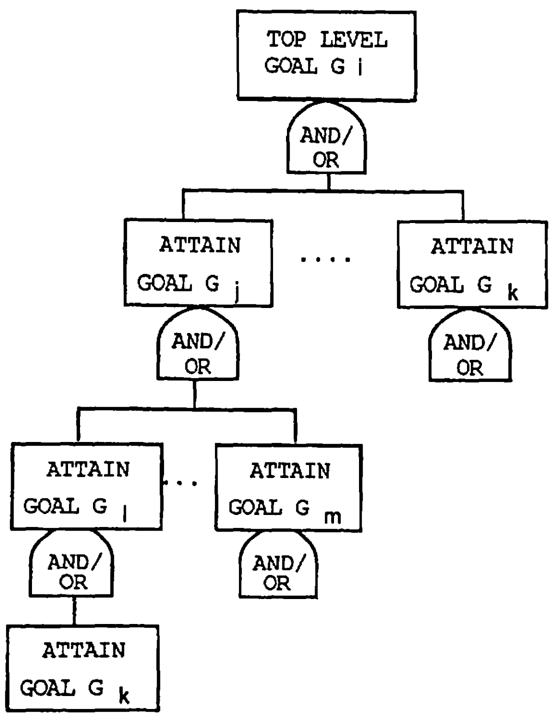


Figure 11–1 A General, Goal Tree-Based Task Definition Network. (Note that the goals are interrelated by the AND/OR gates.)

A General Description of the Human

The structural and procedural components of human information processing (recall that this distinction was given in Chapter 2) can be organized in a very general way using the production system model. Figure 11−2 presents such a model of the human. In this diagram, the boxes correspond to structural components that are either internal or external to the human, while the lines between boxes represent activities or information flow. This model subsumes all the stages of the basic information processing model. It also relates structural components to procedural components in a very flexible, task-specific way which can be applied to tasks in the "real world."

This general model, as shown in Figure 11−2, emphasizes the interactive roles of memory, perception, and retrieval in explaining the particular sequences of task-related responses emitted by the human. (Consequently, the production system model integrates memory with other information processing stages very well.) The following discussion will briefly examine these roles and their implications. Activities within the model, represented by the lines between boxes, will be considered in much greater detail during the discussion of the general warning tree model.

The Role of Memory Short term memory is the limited register within which all information the human is conscious of is stored. The 7 ± 2 items which can be stored in short term memory is very small in comparison to the vast amount of information which can be stored in long term memory or external memory. The capacity of short term memory appears much larger because of the human's ability to chunk items in short term memory. Each chunk can be decomposed into many different more elemental components.

In the view of Newell and Simon (1972), long term memory contains a large set of condition-action pairs (recall that a condition-action pair is equivalent to a rule). When information in short term memory matches the conditions of a condition-action pair stored in long term memory, the associated actions are written into short term memory (or equivalently, the information is retrieved from long term memory). Geyer and Johnston (1957) estimate the capacity of long term memory within the human brain as being anywhere from 10^8 to 10^{15} bits of information.

External memory contains knowledge external to the human, and is retrieved by perceiving it. There are no obvious limits to the capacity of external memory. There are, however, significant limitations in the rate of retrieval.

The Interactive Roles of Perception and Retrieval The information within short term memory is always retrieved from long term memory or perceived from external memory. Also, all conscious outputs by the human are sent, through various intermediary processes, from short term memory to the effectors. Since short term memory is severely limited, human performance is very dependent on placing information into short term memory at the appropriate time. The specific information which enters short term memory is determined by the flow of information, and involves a complicated interaction between perception and retrieval.

Since short term memory is severely limited, the major portion of available knowledge is stored either in long term or external memory. At a practical level, external memory can be viewed as a map, described by the product, from which information is perceived. Perception and retrieval interact extensively because only a few goals can be simultaneously considered in short-term memory. When new information is placed in short-term memory, old information is

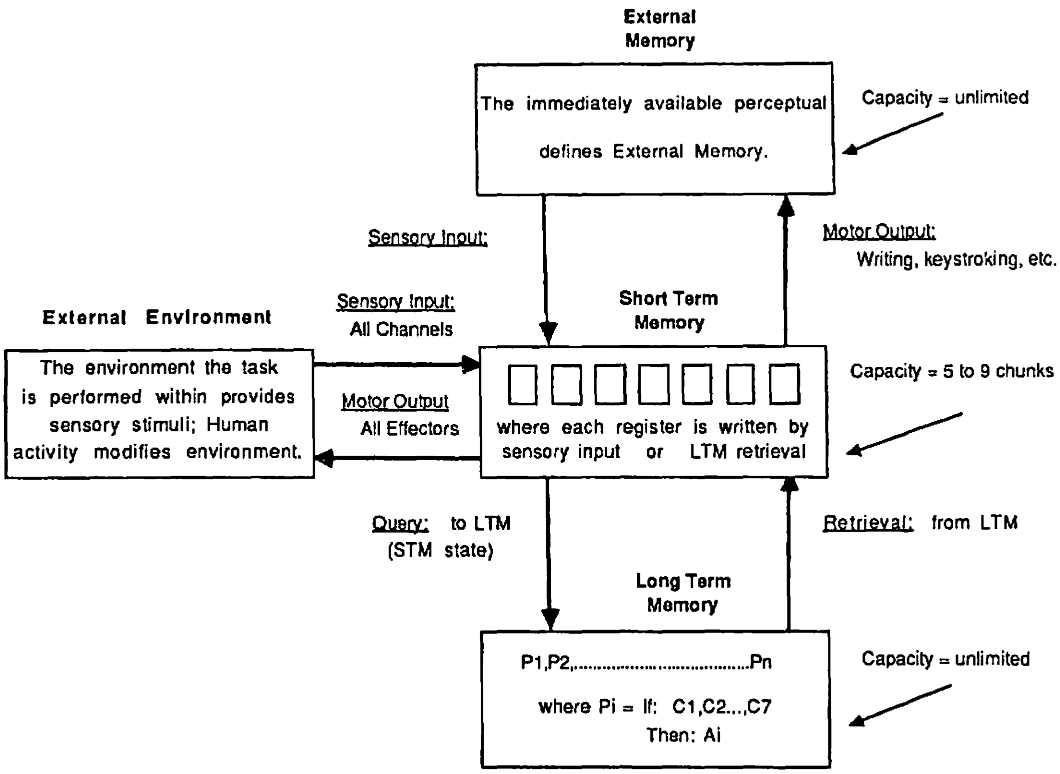


Figure 11−2 A Production System Based Model of Human Information Processing. (Elements within rectangles are human or environment objects. The arrows between rectangles indicate flows of information or energy between objects.)

overwritten and will have to be retrieved or perceived once again if it is to be used. This can occur when extremely deep goals in the problem space are pursued or when many goals at the same level are generated.

Implications These limitations in performance, brought about by the limited amount of short-term memory and the interactive roles of perception and retrieval, have very important effects on task-related activity. First, for complex tasks, the human is not likely to move through the problem space in a simple, sequential manner. Second, the human is likely to frequently repeat high level subtasks and, more generally, those subtasks which do not provide obvious or easily perceived cues as to whether the task has been completed. Third, the human will need to develop aggregate views of problems, wherein those high level concepts that can be broken down into very detailed concepts are kept in the memory. Fourth, performance will tend to be very dependent upon external and long term memory, since the flow of information into short term memory, associated with both retrieval and perception, is a critical determinate of performance for all but the most simple tasks.

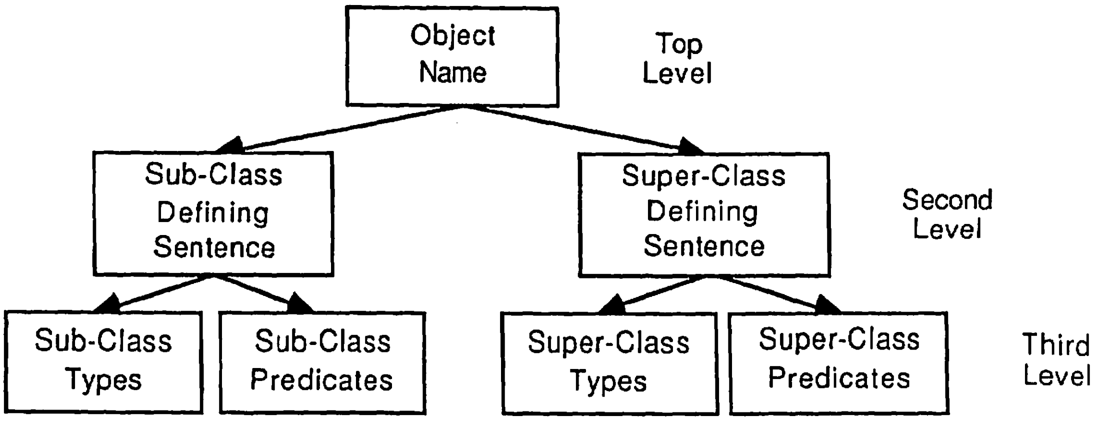


Figure 11−3 The Relationship between Objects and Predicated Super-Classes and Sub-Classes.

Information and its Flow

Recall that in Chapter 2, an initial discussion took place concerning the message within the communication process. That discussion emphasized that the message could be modeled using a classic information processing or knowledge based approach. The information processing approach emphasized "uncertainty" while the knowledge based approach emphasized "meaning." The goal here is to more precisely define "meaning" so that it can be modeled. Then attention will shift to the flow of information.

The Modeling of Meaning The adequacy of safety related messages and their comprehension are two of the most emphasized warning issues. In this subsection, we will consider safety messages beginning from a very fundamental description, and ending with some general safety terms. The discussion itself describes 1) knowledge primitives, 2) conditions/actions, and 3) safety knowledge.

Knowledge Primitives. Among the different types of knowledge primitives are objects, actors, and predicates. Chapter 12 also uses these same knowledge primitives within a general modeling approach; however very particular knowledge primitives are defined there which capture generic meanings.

Objects roughly correspond to nouns, actors to verbs, and predicates to either adjectives or adverbs. Objects, actors, and predicates all have semantic meanings. These meanings can be hierarchically defined using classification theory, where a particular knowledge primitive has superset and subset relations to others (see Figure 11−3). A knowledge primitive can be defined by predicating its superclass (that is, assigning a value to) its superclass. Analogously, a knowledge primitive can also be predicated to define an element of a subclass. For example, the predicates "domesticated" and "carnivorous" transform the meaning of the superclass object, "mammal" into something closer to the meaning of the subclass object "dog." Similarly, the predicate little transforms the meaning of the superclass object, "dog," into something closer to the meaning of the subclass object, "poodle." Note that in this example, the term "dog" was both a superclass and a subclass. This effect occurs because superclasses and subclasses are relative concepts.

Strings of objects, actors, and predicates have syntactic meaning; those strings which follow the rules of grammar of a particular language are called sentences. (Note that "language" refers to any formal system which uses syntactic contraints, such as computer languages, natural languages, mathematical logic, and set theory.) The three types of sentences considered here are propositional, declarative, or conditional. Propositional sentences apply actors to objects. Within a propositional sentence both the objects and actors are frequently predicated. Declarative sentences simply indicate the values of objects or actors. Conditional sentences apply actors to objects if certain declarative or propositional sentences imbedded within them are true. Context refers to the set of predicated objects and actors which influence the meaning of a message, but which are not explicitly given within the message. Contextual meaning is therefore the meaning inferred from, but not given within the message alone.

Conditions/Actions. Knowledge is represented in the production system model with groups of rules. The rules are composed of paired clauses (equivalent terms include antecedants/ consequents, conditions/actions, or ifs/thens), and the clauses themselves are composed of more primitive symbols. The goal here is to relate these knowledge components used in production systems to the knowledge primitives described above.

Knowledge primitives alone or their combinations are easily seen to be consistent with the representation of meaning used in production systems (that is with rules, conditions, actions, and goals). In summary, a rule is simply a conditional sentence. (A group of rules or a complex conditional sentence can be equivalent to a frame, schema, or script, which are other forms of knowledge representation.) A condition can be simply a predicated actor or condition. More complex conditions are equivalent to declarative sentences. Conditions not found within the message define the context. An action is always a propositional sentence in which a actor is applied to an object; both the actor and object may be predicated. A goal is frequently a predicated object or a declarative sentence. In certain cases, however, a goal may be a propositional sentence.

Predicated objects and declarative sentences define static information (conditions), or data, while conditional statements (rules) define dynamic information, or knowledge. Dynamic information manipulates static information, and is itself partially composed of static information. Consequently, both forms of information are essential elements of the external structure of stimuli. However, knowledge is more apt to be stored within the human's memory, while the static information is more apt to be encoded within the stimulus.

Safety Knowledge. Information which can be either given explicitly by a warning or derived from a warning does one of three things. It can 1) define the hazard, 2) indicate the presence of a hazard, or 3) define the countermeasure. Normally, a hazard definition consists of a group of rules, a hazard indication consists of conditions alone, and a countermeasure consists of actions alone or rules.

Warning-related meanings and the more basic knowledge components which define them form a hierarchy of risk-related knowledge. Within this hierarchy, the lower level terms are combined with logic gates to define the higher level terms (Figure 11 − 4). The five most basic knowledge components from which these meanings can be constructed are conditions-cause, event, consequence, likelihood, and action. These components are shown at the bottom of the figure. Individually, none of these five basic components, provide complete safety related meanings; they must be combined to do this. Meanings corresponding to common safety scenarios are easily generated from the basic components. The following three paragraphs separately consider meanings which respectively provide hazard definitions, indications, and countermeasures.

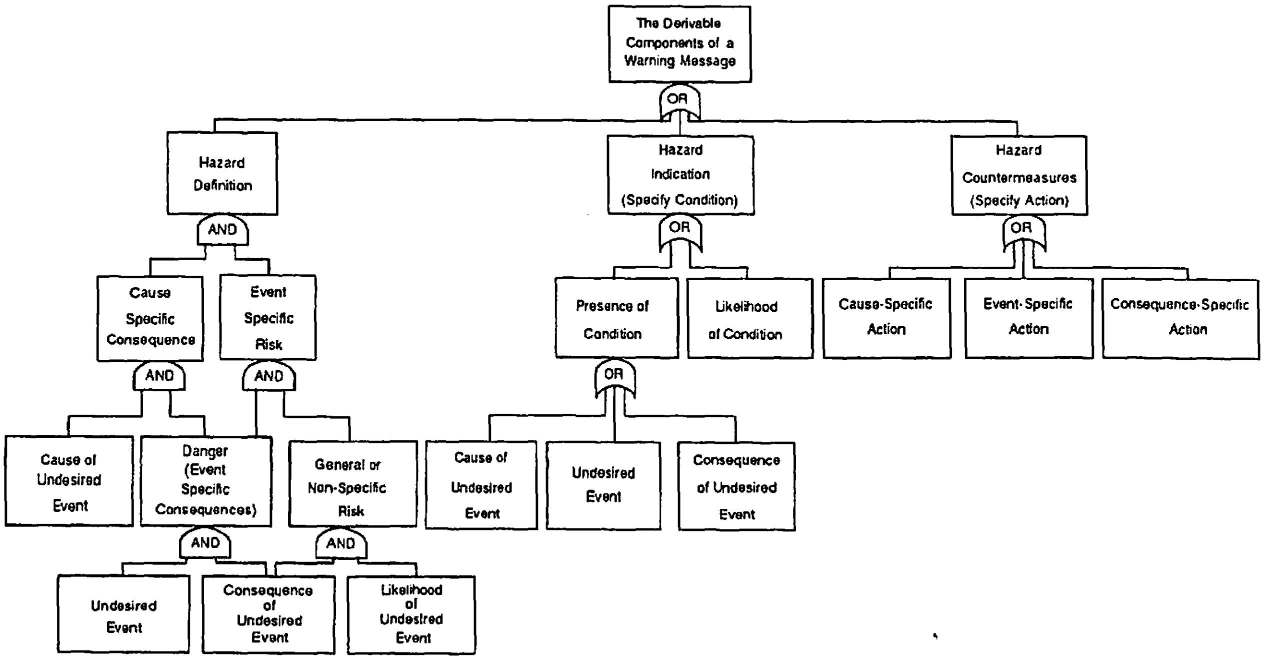


Figure 11−4 The Derivable Knowledge Components of a Warning Message. (These subdivide into three categories: hazard definition, hazard indication, and hazard countermeasures. Terms within these categories are all ultimately defined in terms of consequences, causes, actions, events, and likelihood.)

In regard to defining the hazard, consequences, combined with their likelihood, define general risk. General risk refers to a situation in which the likelihood of damages is known, but no conclusions can be drawn as to how or why the consequences occur. This scenario is very similar to that faced by a product designer when only highly aggregated accident data is available. Consequences also combine with events to define danger. In this situation, the decision maker knows how the damage occurs, but does not know the cause or likelihood of the damage producing event. Aggregated components can also be combined, as when danger and general risk combine to define an event-specific risk. Here, the likelihood of specific events which present specific outcomes is known. The cause of the events, however, is still unknown. Similarly, danger and the cause of the undesired event combine together to define a cause specific consequence. In this situation, actions which modify that danger can be rationally proposed. When a cause specific consequence is combined with an event-specific risk, the most complete or explicit definition of hazard is specified.

A message which indicates the presence of a hazard (this corresponds to the general alerting function of a warning), conveys its meaning with the same basic components used to define the hazard. The message must, however, specify whether the hazard is or is not present in a given situation; this is the fundamental difference between the definition of a hazard and its indication. Figure 11−4 describes the essence of messages that indicate the presence of a hazard. Such messages indicate the presence or likelihood of a condition, where the condition might specify the cause of an undesired events, an undesired event, or the consequence of an undesired event. It is important to realize that the term condition is used in its general sense, that is, as a knowledge component used in a rule.

A message which provides a countermeasure to a hazard also conveys its meaning with the same basic knowledge components. A message which provides a countermeasure is similar to a message which indicates a hazard. However, countermeasures normally describe actions rather than conditions. As for the term "condition," the term "action" is used in its general sense, that is, as a knowledge component. In particular, a action may be cause, event, or consequence specific.

Information Flow Within any portion of a task, there is a flow of information which is presented in concordance with some arbitrary schedule. When emphasis is placed on the meaning rather than uncertainty of stimuli, information flow can be precisely modeled. As shown in Figure 11−5, the flow of information consists of "knowledge components" and a "presentation schedule." The knowledge components considered here are directly derived from the production system model and are conditions or actions alone, or combinations of conditions and actions. Combinations of knowledge components can describe safety related knowledge as discussed earlier.

In regard to the provided knowledge components, when a message containing conditions alone is given, it acts as a cue which simply informs the individual, thereby triggering the retrieval of other knowledge components from long-term memory. These triggered knowledge components can be said to be derived from the message. The vast majority of task related information flow is in this form. When a message giving actions alone is given, it again acts as a cue from which meaning can be derived, but is somewhat more specific as it explicitly defines a response. When both conditions and actions are given, the message is exactly equivalent to knowledge, since both the cue and the associated response are given.

As also shown in the figure, the knowledge components within a message can provide situation-related or response-related information using any combination of conditions and actions. This follows because additional knowledge can be derived from conditions or actions once they enter short term memory. Response-related information is equivalent to feedback or knowledge of results, while situation related information generally defines change. Reference knowledge is not stored in long term memory and consequently must be explicitly given rather than derived. As such, only combinations of conditions and actions, or actions alone can convey reference knowledge.

A final point is that the presentation schedule can be either data-driven or goal-driven (Figure 11−5). In a data-driven presentation schedule, the information inputs are conditions defined by the task. This corresponds to a forward-chaining control strategy, in which the human reacts to information defined by outside, noncognitive events. Such a scenario is likely to be externally rather self-paced. In a goal-driven presentation schedule, the information inputs are controlled by the value of the action side of production rules stored within human memory rather than by specific environmental conditions. This corresponds to a backward-chaining control strategy, in which the human searches for specific data which confirm hypotheses. Both forms of presentation schedules are considered further within the general warning tree model.

The Derivation of Meaning The knowledge components and higher level forms of information given in Figure 11−4 and referred to in Figure 11−5 can be either explicitly given or derived. The relationship between derivable, explicit, and implicit knowledge components reflects the need for variation in level of detail and breadth of coverage of warnings. Certain warnings may be very explicit in their level of description, while other warnings may simply indicate a condition from which the hazard and countermeasure are derived. Similarly, a warning might list all the possible hazards associated with a product, or simply concentrate on the most important hazards.

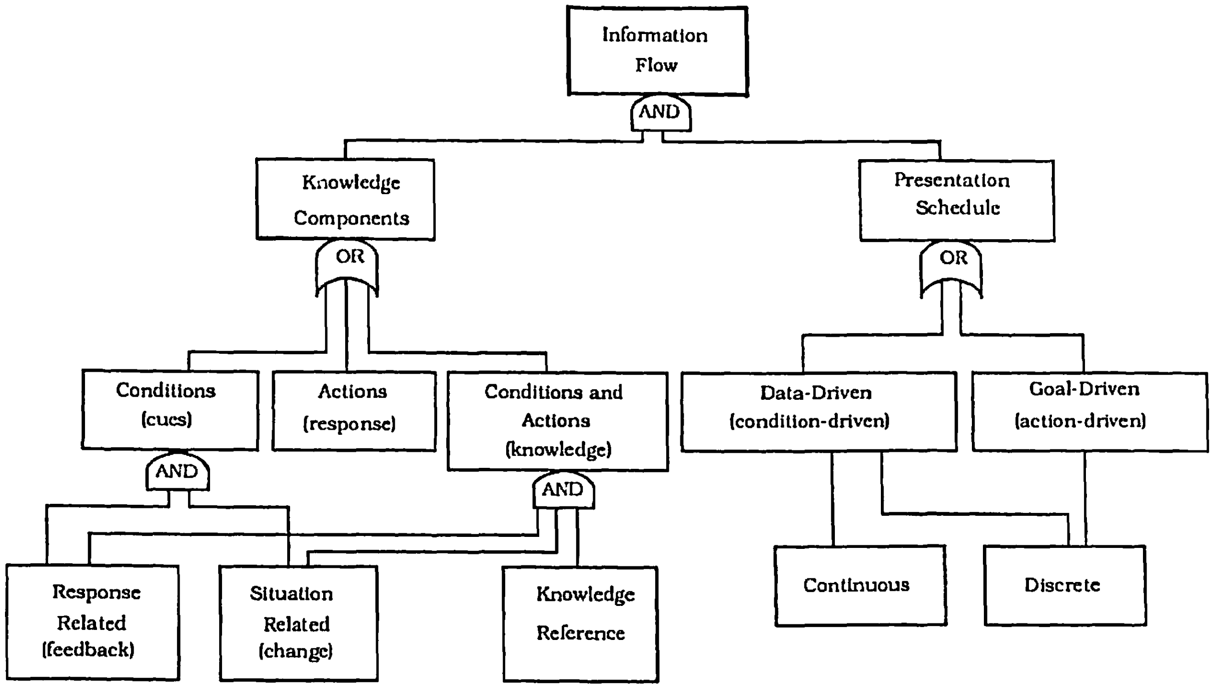


Figure 11−5 An Elemental Breakdown of High Level Information Flow. (Information flow consists of knowledge components presented in accordance with a presentation schedule.)

In regard to the explicitness of the provided information, at one extreme, each information component illustrated in Figure 11−4 is given as a combination of conditions and actions. At the other extreme, a single condition or action is given. Either approach or some compromise can be desirable in certain situations, depending upon the receiver's knowledge and the time available to him. The following discussion will briefly address messages that 1) define hazards, 2) indicate hazards, and 3) provide countermeasures.

Messages that are intended to define hazards are normally directed toward developing the prerequisite knowledge for safe performance on the task, or equivalently to building an appropriate model within the human's long term memory. Under these circumstances, the message should explicitly describe that knowledge the individual is unlikely to possess from previous experience. Providing such knowledge should be regarded as training wherein aspects of product use, the potential hazards, indications of hazard, and countermeasures are learned.

Conversely, when the message is intended to indicate hazard or countermeasures, the required explicitness may become much lower, assuming that appropriate knowledge that defines the hazard is stored within long term memory. The presence of such knowledge should allow the meaning of messages to be derived. A very general effect along these lines is shown by Figure 11−4, wherein the basic components which are used to indicate hazards or countermeasures fall under OR gates. The OR gates are used to show that conditions or actions can be specified in various ways. For example, the presence of a hazard might be derived from 1) a message that indicates a cause is present or 2) a message that indicates an undesired event has occurred.

Similarly, a countermeasure might be indicated by specifying either a cause-specific action or an event-specific action. Also, once a basic context has been determined, it is likely that countermeasures can be derived from messages that indicate hazards, or vice versa. For example, non-specific stimuli like buzzers are frequently used as warnings in state-of-the-art applications of human factors engineering, instead of using synthesized speech which could more explicitly define the hazard.

THE GENERAL WARNING TREE INFORMATION PROCESSING MODEL

The goal here is to extend the useful aspects of the human information processing models by combining them with Fault Tree Analysis (FTA) and Failure Modes and Effects Analysis (FMEA). To attain the above goal, a general warning tree model is defined. This model organizes both the structural and procedural components of human information processing within a variant of the production system model, and incorporates many of the concepts of FTA to relate the events associated with the use of a product to the production system model of the human. The resultant model is a very general network that is a variant of a rule network diagram (see Lehto, 1985). Such diagrams can equivalently represent production systems and fault trees. They also provide graphical rather than verbal descriptions of complex systems.

The following discussion will first consider how FTA and the production system model can be integrated to develop a general way of representing tasks. The next section will then provide a detailed approach to defining elemental tasks that is consistent with this approach. An important concept emphasized in both sections is the Task Performance Network which is described below.

Integration with Fault Tree Analysis

A Task can be successfully or unsuccessfully performed. Task performance can be evaluated by measuring the extent to which goals are attained after performing the task. Successful performance is equivalent to satisficing essential goals, while unsuccessful performance is equivalent to not satisficing essential goals. Consequently, task performance can be specified by predicating goals, where each predicate specifies the extent to which certain goals are attained. Such an approach is compatible with FTA and FMEA.

In FTA and FMEA, events are organized within trees, using logic gates. Such events correspond to either failures or designed system functions. The unsuccessful performance of a task is analogous to a failure, while the successful performance of a task is analogous to a designed system function. This implies that task performance can be modeled with trees analogous to fault trees. Such modeling has great potential because it allows the performance of the product, task, and system to be modeled in exactly the same way.

Figure 11−6 shows how a task defined by the production system approach can be organized into a network composed of predicated goals and logic gates. Figure 11−6 specifies a task performance network because each goal is predicated. More specifically, at the top level of Figure 11−6, the top OR gate distinguishes between attaining and not attaining goals. The task performance network is consequently composed of two different trees. The first tree, associated with attaining goals, is equivalent to a positive tree. The second tree, associated with not attaining the top goal, is equivalent to a fault tree. Since the nodes of the network are simply predicated goals, the network encompasses the problem space defined by the production system model. A partially completed task performance network specifies performance at a given moment. Also, since goals can be predicated by external events related to the product and environment, the network contains product- and environment-related fault trees and positive trees.

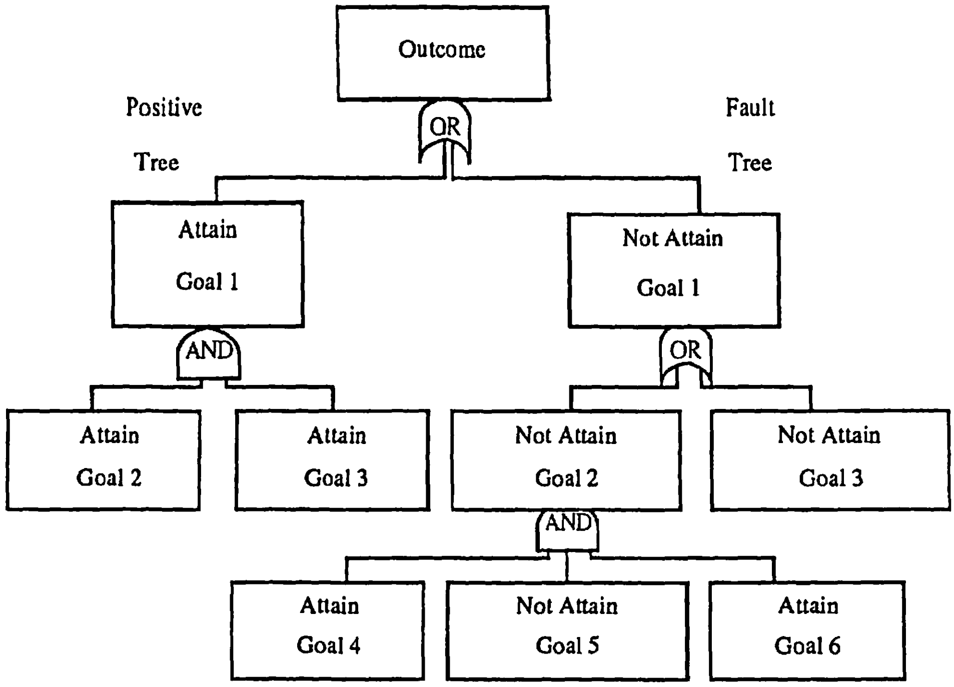


Figure 11−6 Task Performance Network. (The network can be decomposed into a positive tree and a fault tree. Within both trees, events are related using logic gates.)

Figure 11−7 presents a simple example that shows how the task performance network can relate task performance to hazards associated with the product and environment. The figure is a particular instance of a task performance network, since it defines the way the task is being performed at a given moment. (The task performance network as a whole describes all possible ways of performing a task.) This example also shows how goals can be predicated. At the top of the positive tree, the goal is to perform a grinding operation on an object safely and efficiently. More specifically, the goal is to grind an object, and the possible predicates are "safely" and "efficiently." The positive tree corresponds to satisfying each of these predicates of the top goal. Consequently, the subgoals "grind safely" and "grind efficiently" are defined, both of which must be satisfied to satisfy the top goal. Similarly, the fault tree corresponds to not satisfying these two subgoals. In this particular example, as shown by the positive tree, the subgoal of grinding efficiently is attained. However, as shown by the fault tree, the subgoal of grinding safely is not attained because goggles are not worn. The goal of wearing goggles is not attained, since the flow of information between the human and the product is broken. (This could happen for several fundamental reasons that are not shown in the figure.)

Imbedded within the above discussion are a number of general concepts that can be used to define task performance networks. These concepts, along with more specific concepts that define successful and unsuccessful performance, can be graphically described. Figure 11−8 presents a graphic description along these lines and will be discussed below.

First, as shown at the top of the figure, performance is synonymous with the satisfying of goals. Goals can be directly satisfied by correctly performing tasks, which corresponds to selecting and executing an appropriate action. Goals can also be satisfied by rectifying human errors or product malfunctions that prevent the attainment of a goal. Rectifying the problems

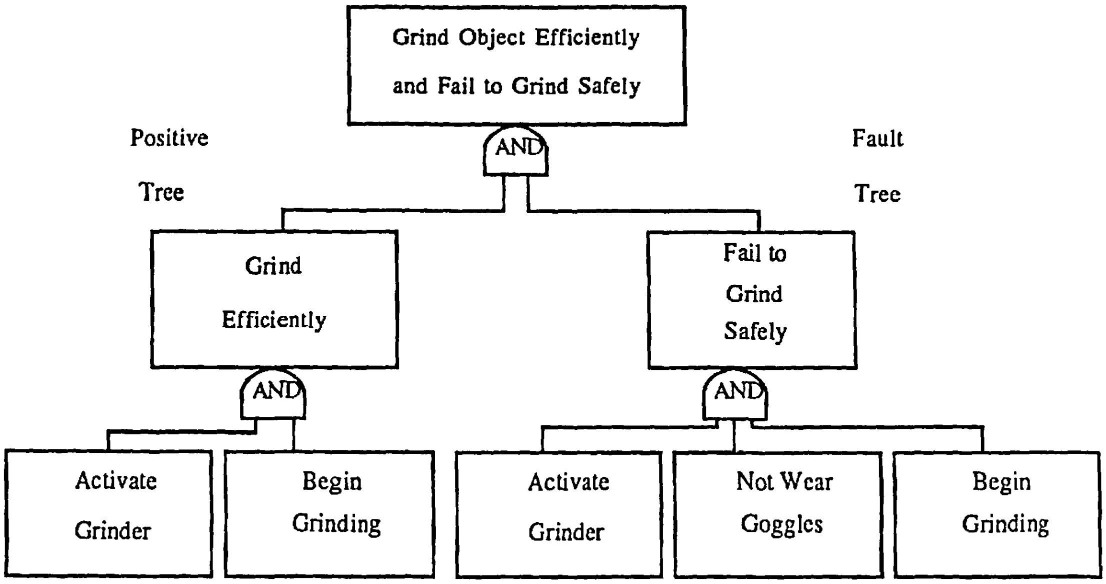


Figure 11−7 An Example of an Instance of a Task Performance Network. (At this point in time, the goal of grinding efficiently is met, while that of grinding safely is not met.)

that prevent the attainment of goals also corresponds to selecting and executing appropriate responses. Human errors can be divided into errors of commission and errors of omission (Altman, 1964). An error of commission can involve either the selection of an inappropriate action which is then executed, or the selection of an appropriate action which is executed inappropriately. An error of omission generally involves the failure to select the appropriate action. There is some overlap between errors of omission and commission. Careful examination of the bottom of Figure 11−8 should clarify the distinction between the two terms.

Detailed Definition of Elemental Tasks

Recall that the general task definition, given earlier in this chapter, was entirely based on the production system model, and emphasized goals, conditions, and actions. Also recall that task-related activity transforms an initial state into goal state. In accordance with this earlier discussion, a task can be viewed at any level of abstraction. A task and a subtask can be equivalent; any task performed within a task is a subtask. An elemental task traditionally is a task which contains no subtasks, but (as does a task) will have an initial state, a goal state, and intervening activity between these states.

The developed approach defines a task recursively in terms of two procedures, as shown in Figure 11−9. These procedures are, respectively, the generation of subtasks and the execution of elemental tasks. Observe that at the top of the figure, the top level goal is to perform the task. If the task is an executable elemental task (that is, a task which can be performed without first generating and then performing subtasks), it is executed. Such execution often results in immediately attaining the goal. In most cases, however, the top level task is not an executable elemental task; performing it requires that several subtasks and elemental tasks must be generated. The human generates subtasks by either perceiving subtasks from external stimuli or by retrieving subtasks from long term memory. As at the top level, each subtask is then either executed or further broken down into subtasks. Since the process of performing

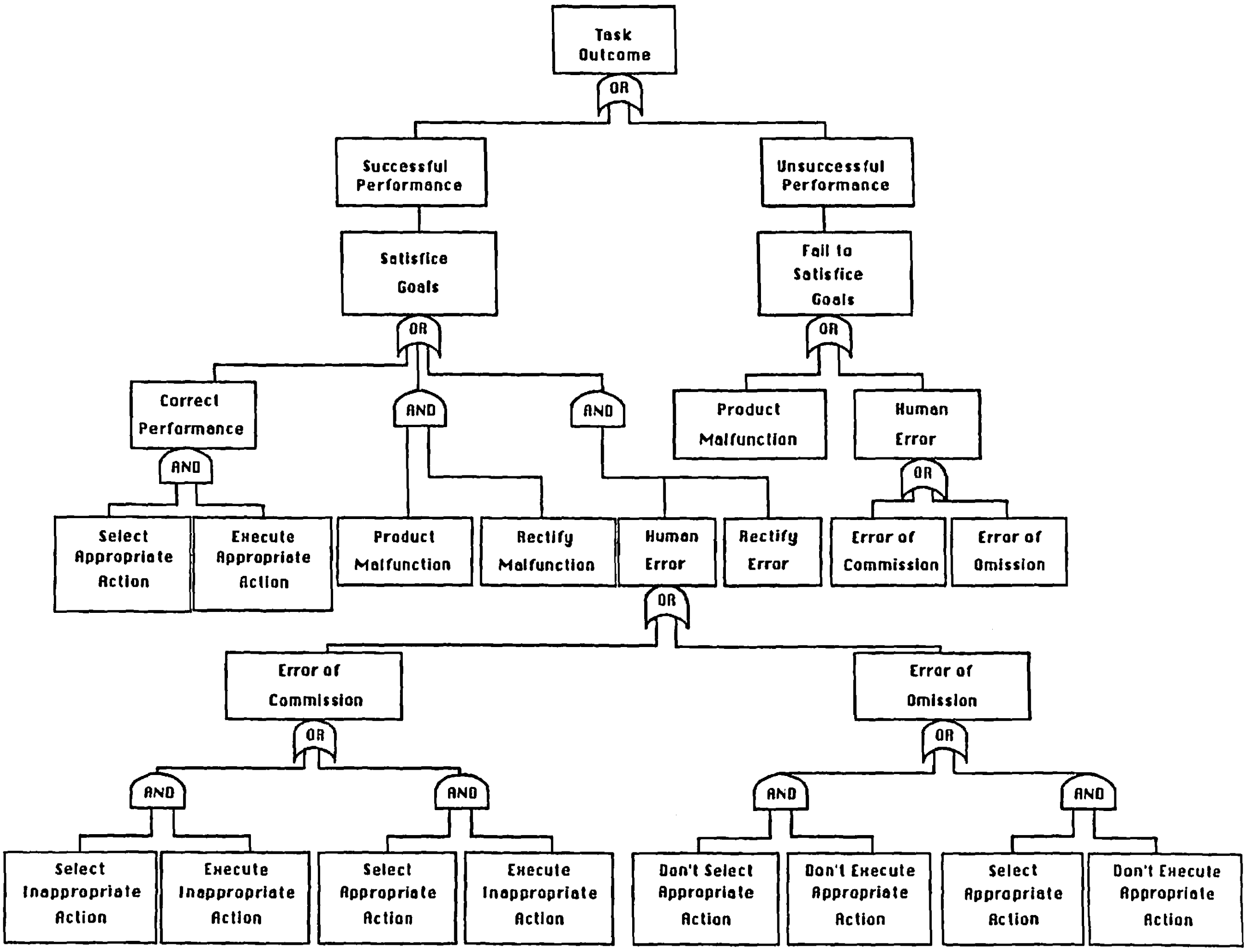


Figure 11−8 A Diagram Illustrating Global Concepts Imbedded Within a Task Performance Network. (Successful performance corresponds to a positive tree and unsuccessful performance to a fault tree.)

subtasks is recursive, this process of generating subtasks and executing subtasks continues until all the subtasks have been performed.

Figure 11−9 also shows how elemental tasks are related to tasks. The elemental tasks include 1) perceptual tasks, 2) memory tasks, 3) decision tasks, and 4) motor tasks. As shown in Figure 11−10, certain elemental tasks, such as motor tasks, will always contain other elemental tasks. As such, the elemental tasks described herein are more complex than traditional elemental tasks, wherein elemental tasks never contain tasks within themselves.

For example, the elemental decision, perceptual, and motor tasks described here will always contain memory tasks. Decision tasks may also contain perceptual tasks, and perceptual tasks may contain motor and decision tasks. Memory tasks are more modular than the other elemental tasks, but still may contain perceptual or motor tasks (i.e. external memory input and output). Also, the elemental tasks may contain themselves (i.e. retrieval from long term memory requires storage in short term memory). These traits are present because the elemental tasks are recursively defined in terms of even more detailed elements. As implied in the

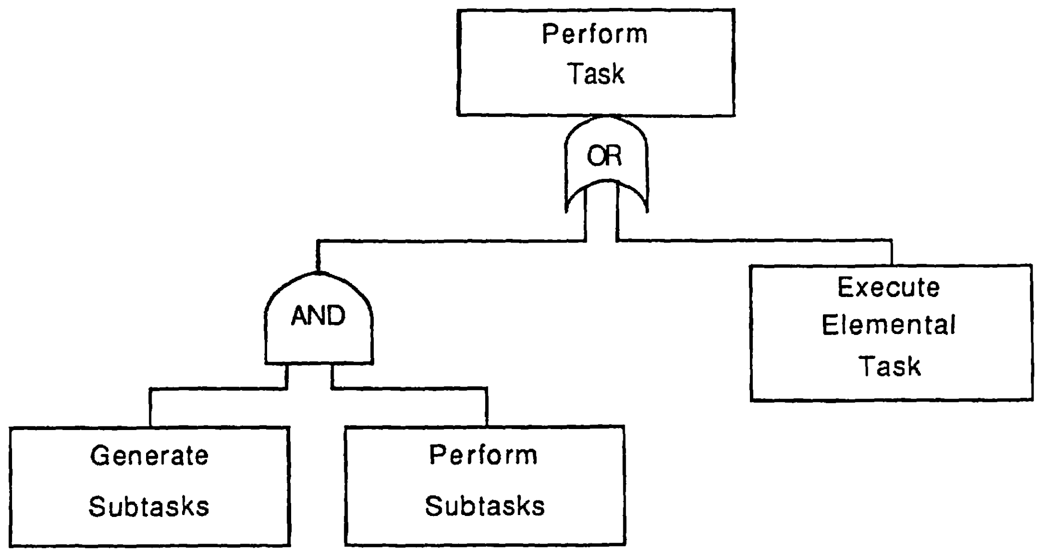


Figure 11−9 A Very High Level Task Description. (Note that this task description is recursive as the lower "perform subtask" node is the same as the top level node.)

introduction to this section, a task description can always be developed at an more detailed level. The following sections clearly illustrate this phenomenon.

It must also be emphasized that each elemental task is very context-dependent. In other words, the initial and goal states for particular elemental tasks are a function of earlier performed tasks. These earlier performed tasks specify a subsequent set of initial conditions and goals. The initial and goal states are explicitly considered only within decision tasks. For all other elemental tasks, the goals and initial states are implicitly defined by the context within which they are activated.

The successful performance of each elemental task requires a flow of information between successive information processing stages. Within each information processing stage there are certain elemental processes, many of which were discussed in Chapter 2. Along with these elemental processes, structural components (components of the human, product, and environment, as will be expanded upon in Chapter 12) are found within a task. Whether or not information successfully passes through the various information processing stages is largely determined by structural components and by events which modify these components. Elemental processes, structural components, and events which modify structural components can be arranged into tree structures which define elemental tasks.

The following discussion and the accompanying figures present such tree structures for each of the elemental task types shown in Figure 11−10. The presented tree structures do not, however, describe events which modify the structural components. Such descriptions are very application-specific and are defined by other trees (similar to fault trees) generated during hazard analysis. Chapter 12 will extend the method introduced in this chapter for combining such fault trees and the elemental task descriptions given in this chapter. In other words, this process involves developing task performance networks for particular design configurations of products.

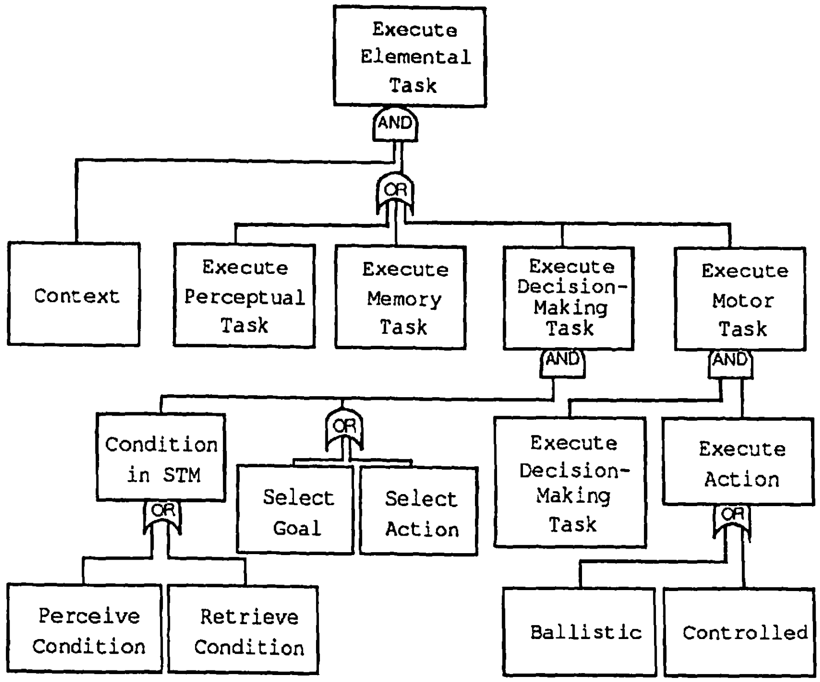


Figure 11−10 A Diagram Illustrating The Execution of an Elemental Task. (Each elemental task occurs within a specific context, and many elemental tasks require that other tasks be first performed.)

Perceptual Tasks At the most general level, perception can be modeled using a production system approach, as the transfer of conditions, actions, or both into short term memory from the environment. Many intervening activities that occur during perception can be summarized in a diagram that resembles the task performance network, as shown by Figure 11−11. This diagram corresponds to the link in Figure 11−2 that represents activity whereby information from external memory enters short term memory. Therefore, the top of Figure 11−11 corresponds to the entry of information into short term memory and the bottom of the figure corresponds to the emission of information from external memory or the environment.

The figure itself defines a positive tree that summarizes the many intervening steps that must be attained for the successful perception of information. Note that the elements below "sensory firing patterns" occur externally of the human. The higher level elements more directly correspond to procedural components or processes within the human. The lowest level elements, their value-specific influence, and methods of defining the events which modify them will be discussed in Chapter 12. Since perception has already been discussed in Chapter 2, the elements within the diagram will not be discussed in detail. Instead, since the diagram synthesizes a number of fairly complex concepts, the structure of this diagram will be emphasized.

At the very top of the diagram, a logical OR gate is used to distinguish between data-driven and goal-driven perceptions. The diagram uses the term "consciousness" to indicate that the emphasis here is on conscious rather than subliminal outputs of the perceptual process. (To be conscious of a stimulus is assumed to be equivalent to having the stimulus in STM). Data-driven and goal-driven perception differ, in that goal-driven perception involves a conscious

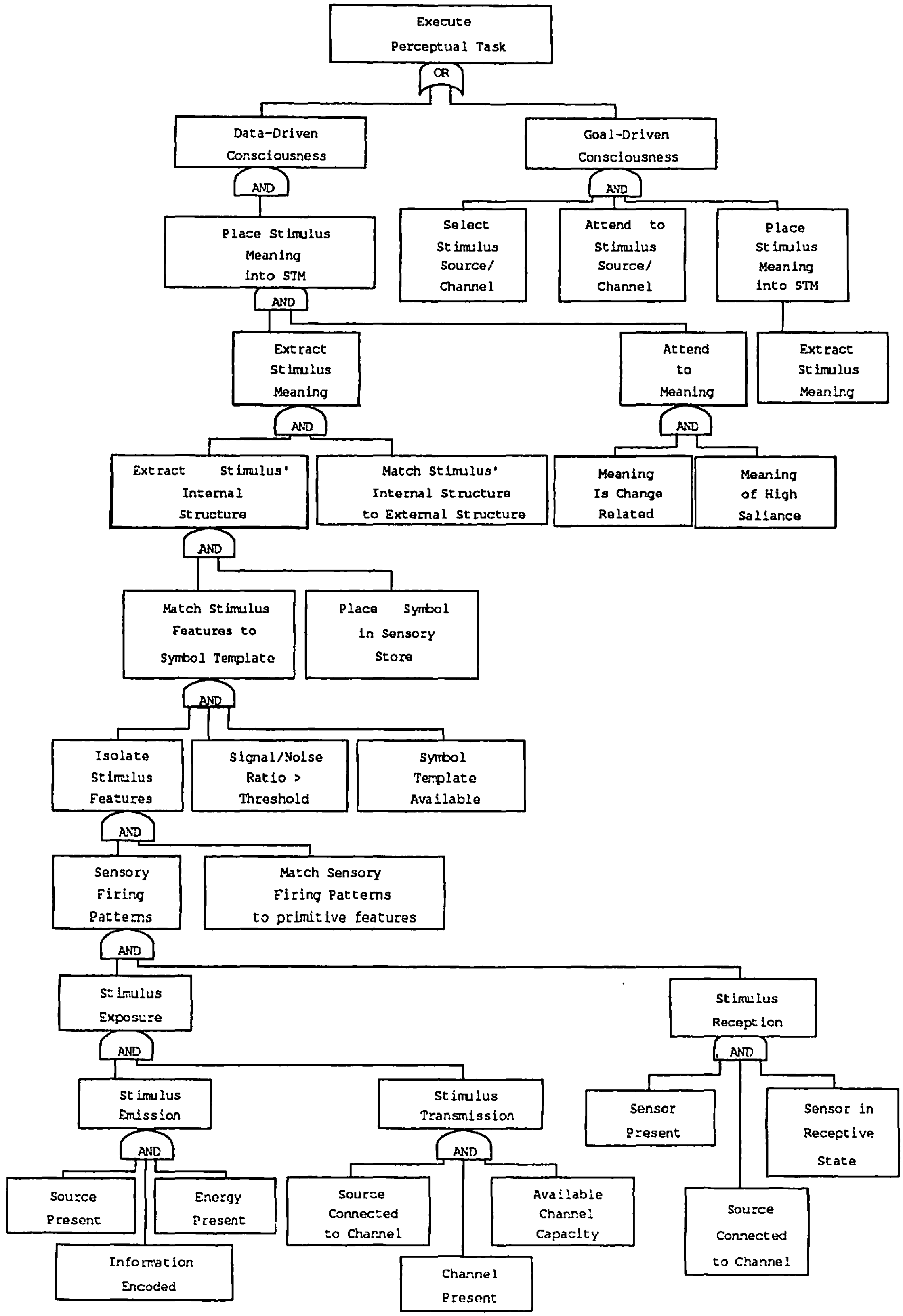


Figure 11–11 A Diagram Illustrating the Execution of an Elemental Perceptual Task. (Both data-driven and goal-driven conscious require that stimulus meaning be placed into short-term memory. Intermediate levels of figure correspond to intervening process within the human. The lowest levels correspond to events external to the human.)

decision as to which stimulus source/channel is attended, while data-driven perception occurs independently of a conscious decision. In other words, the outputs of goal-driven and data-driven perception are the same (i.e., the presence of stimulus meaning in STM), but they are performed differently. As shown in the figure, in goal-driven perception a stimulus source/ channel is selected and attended to before the perceptual processes result in the placing of a stimulus's meaning into short term memory. Such selection is, of course, a decision task.

Both data-driven and goal-driven perception require that the meaning of the stimulus be extracted. Recall that, in Chapter 2, a distinction was made between the internal and external structures of stimuli. This distinction is emphasized in Figure 11 − 11, where the process of meaning extraction requires that the stimulus's internal structure be extracted and that this internal structure be matched to its external structure. This matching process is modeled here as an elemental decision-making task that heavily emphasizes memory processes. The section in this chapter on decision-making tasks considers this matching process in greater detail.

The internal structure of the stimulus can be said to be extracted once the symbol enters the sensory store. This also involves a process where the stimulus's features are matched against a symbol template. Such matching also heavily emphasizes memory and decision processes, wherein various templates correspond to known symbols. Before matching can take place, a number of steps must occur: the stimulus's features must be isolated, the signal-to-noise ratios of the features must exceed some threshold, and the symbol template must be available. The isolation of a stimulus's features requires a number of additional steps. Before considering these steps, however, it should be emphasized that the signal-to-noise ratios of the features are a defining characteristic of the presented stimulus. The threshold these ratios must exceed, in turn, are determined by the receiver's expectations and task-related priorities (see Chapter 2), while the availability of a symbol template is determined by the receiver's knowledge and working memory.

The isolation of a stimulus's features requires that sensory firing patterns be present and that these sensory firing patterns be matched to primitive features. The presence of sensory firing patterns requires that both stimulus exposure and stimulus reception take place. Stimulus exposure requires that the stimulus be emitted and transmitted, and is solely determined by source-, channel-, and sensor-related states. Stimulus emission, transmission, and reception are the lowest level procedures and are defined primarily by structural factors related to the source, channel, and sensors.

Memory Tasks Figure 11 − 12 depicts an analogous positive tree for memory tasks. As was the case for the diagram illustrating perceptual processes, the diagram corresponds to activity represented by links in Figure 11 − 2. These links are between short term memory and either external or long term memory, and describe the transfer of information between these various forms of memory. As was also true for perceptual tasks, several levels are present in Figure 11 − 12. At the bottom of the diagram (beneath each of the lowest logic gates), a knowledge element is always in short term memory as the consequence of some earlier retrieval or perception-related process; the top of the diagram depicts the effect of placing an knowledge element in short term memory, which is storage in, or retrieval from, a particular type of memory.

In other words, knowledge components can be stored in, or retrieved from, short term memory (STM), long-term memory (LTM), or external memory (EM). Storage or retrieval are respectively distinguished in Figure 11 − 2 by the direction of information flow. Knowledge components, as discussed earlier, include facts, rules, and schemas, each of which can be broken down further into objects, actors, and predicates. To avoid making the figure unduely complex,

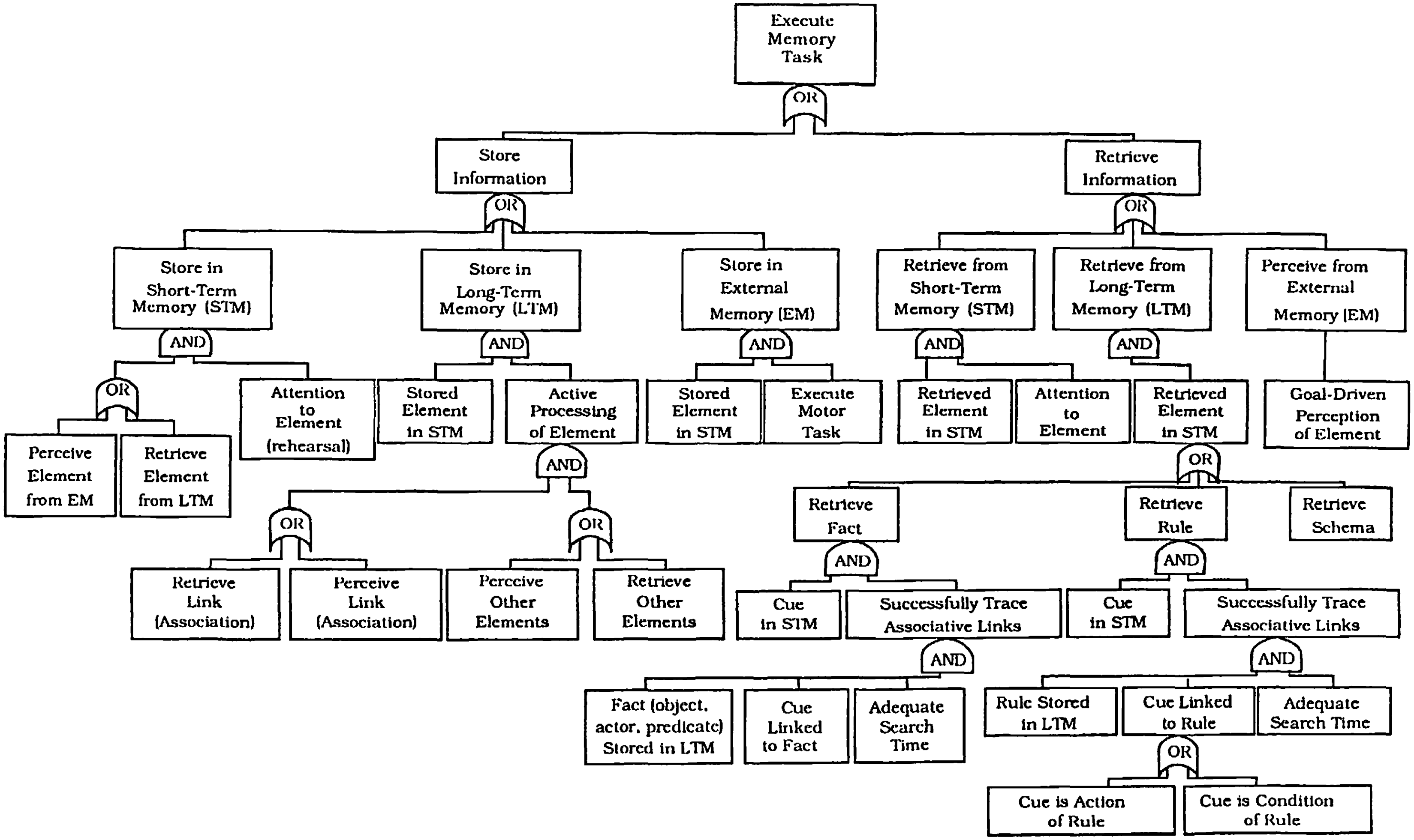


Figure 11–12 A Diagram Illustrating the Execution of an Elemental Memory Task. (This structure corresponds to links between the various forms of memory shown in Figure 11–2.)

the term element is usually used within each retrieval or storage related process to denote any of these knowledge components.

For information to be stored in STM, it must be either perceived from EM or retrieved from LTM (both perception and retrieval ultimately place an knowledge component in STM), and must be continually attended to (that is, rehearsed). Perceiving information from EM is equivalent to executing a goal-driven, perceptual task. Retrieving information from LTM requires a cue in STM and the tracing of associative links between the cue and the knowledge element to be retrieved. These links can be traced if the element to be retrieved is stored within LTM, links are available between the cue and element to be retrieved, and adequate search time is available. The figure separately shows how facts and rules are retrieved from LTM (note that schemas and rules are retrieved similarly).

To store information within LTM, analogously, requires that a knowledge component be within STM and be actively processed. The active processing of an knowledge component involves the building of associative links between the processed knowledge component and other knowledge components. Such links can be built only if the other knowledge components and associations are also retrieved or perceived. To store information within EM requires that a knowledge component be within STM and that a motor task be performed. Such performance of the motor task must change a component (that is, any physical element defined in terms of energy or material, other than information in short term or long term memory) in a way that encodes information.

Decision Tasks There are many variants of decision tasks, which makes them even less easy to model than perceptual or memory tasks. In general, decision tasks do not exactly correspond to any of the links shown in Figure 11−2. This is because decisions will frequently involve complex iterations between perceptual, memory, and motor tasks. Certain decisions are, however, primarily memory tasks; in the simplest case, such a task would be defined by a link between long term memory and short term memory. More complex versions of decision tasks can be defined by recursively performing perceptual, memory, and motor tasks. This, of course, is the approach taken here to define tasks in general.

With the realization that decision tasks may involve the repeated performance of the defined steps, a positive tree for decision tasks is depicted in Figure 11−13. At the top level of the diagram, decision tasks are subdivided into those involving the selection of goals, those involving the selection of actions, and those involving the matching of knowledge elements. Intermediate levels depict the processes within these tasks, while the lowest levels depict perceptual and memory tasks. Many of these perceptual and memory tasks also incorporate motor tasks. The following discussion separately considers selection and matching.

Selection Tasks. The selection of goals and the selection of actions are very much interrelated because an action is the procedure whereby a goal is attained. Certain goals directly specify actions, other more abstract goals only specify desired values of objects. (This follows from the production system approach where a goal can be either the consequent or antecedant of a rule.) Consequently, the selection of a goal is occasionally equivalent to the selection of an action. If a goal only specifies a desired condition, however, an action must be explicitly selected. The following discussion does not explicitly distinguish these two aspects of goals during goal selection. The distinction is explicitly considered only in regard to the selection of actions.

Goals and actions can be selected by either overlearned or problem-solving methods. An overlearned procedure simply involves the retrieval of goals or actions from schemas stored in LTM. Consequently, an overlearned decision procedure is equivalent to a memory task where a

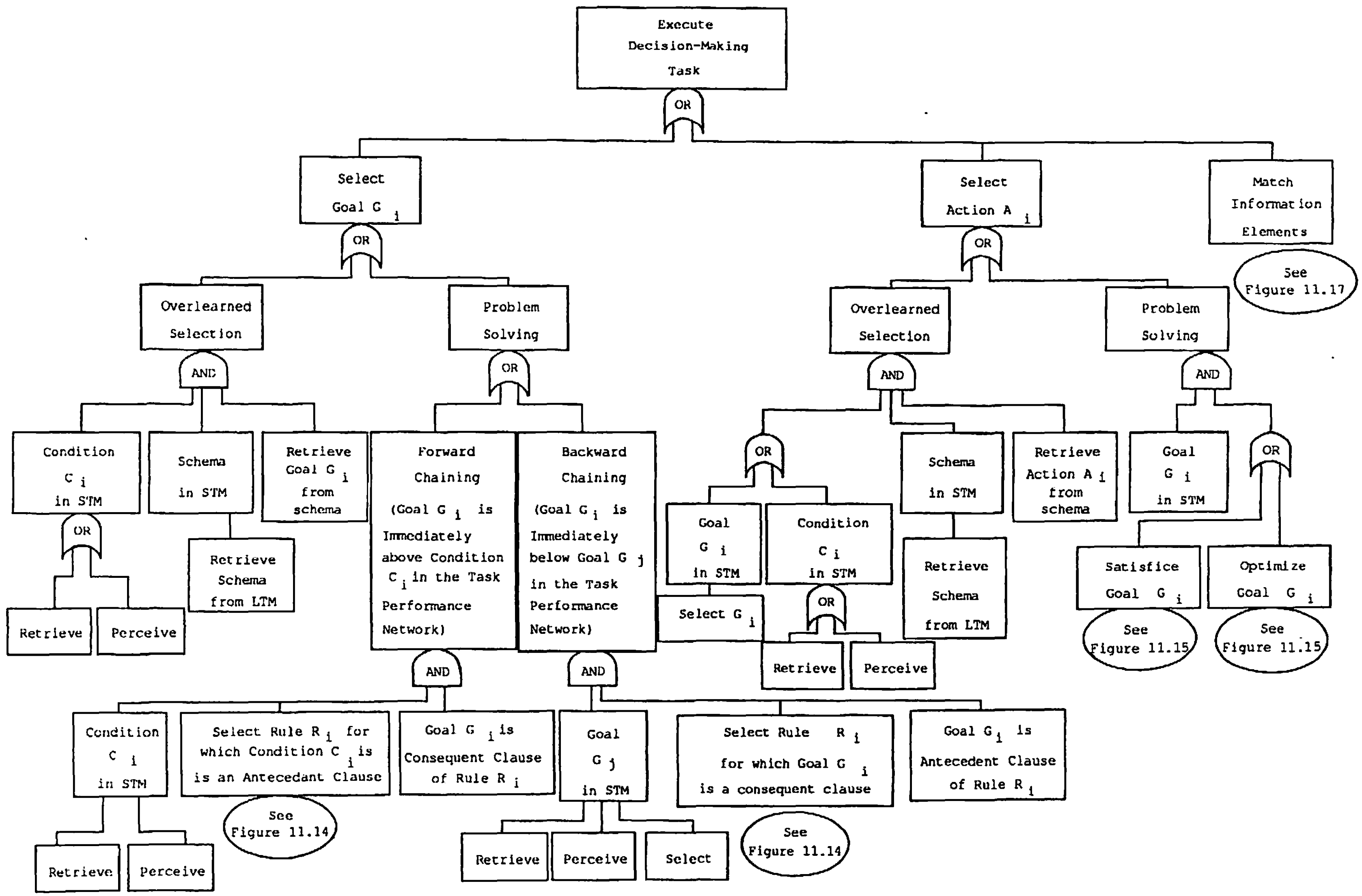


Figure 11–13 A Diagram Illustrating the Execution of an Elemental Decision-Making Task. (The three general types of decision tasks involve the selection of goals or actions, or the matching of information elements. Within selection tasks, overlearned selection is primarily a memory task. Problem solving involves complex recursion.

condition or goal (both conditions and goals are composed of knowledge components) acts as a memory cue. It should be noted that the overlearned selection of goals or actions as described in Figure 11 − 13 are nearly identical. The major difference is that when a goal is a desired condition, it must be present in STM for the selection of an action to take place.

The problem-solving selection procedure is more complex and involves the selection and application of rules. The application of rules corresponds to search through a problem space. Goal and action selection are very much interrelated here, as described below.

In goal selection, either forward chaining or backward chaining procedures can be applied. Forward chaining involves the selection of a goal located above (within the task definition network) the current condition defined by knowledge components in STM. As schematically shown in the figure, the goal is generated by retrieving a rule for which the current condition in STM is an antecedant; the generated goal is then a consequent of the retrieved rule. (Recall that a rule is composed of condition/action pairs. These are equivalent to antecedant/consequent pairs; the term antecedant is used here to avoid confusion between the current condition in STM and the condition which triggers a particular rule.) Backward chaining involves the selection of a goal immediately below (also within the task definition network) the current goal defined by knowledge components in STM. As shown in the figure, the goal is generated by retrieving a rule for which the current goal in STM is a consequent. The generated goal is then an antecedant of the retrieved rule.

In both the forward and backward chaining procedures, complex recursions may occur. Also, ways of selecting between conflicting rules may be applied. These more detailed processes are very specific to the particular problem solving process. Lower portions of Figure 11 − 14 beneath the box that depicts rule selection generically describe this process. Note the heavy emphasis on matching, and that at the very bottom of figure retrieval and perception occur. Also, the decision-making task can be reinvoked. This results in recursion.

The problem-solving process takes a similar form when actions are selected. Actions are selected once a goal is within STM. As referenced in Figure 11 − 13, Figure 11 − 15 shows how actions are selected which either satisfice or optimize the goal. The two procedures are similar, but differ in that the satificing procedure simply matches actions against the current goal until a satisfactory action is found, while the optimizing procedure compares actions until the best action from all the possible alternatives is found.

Both satisficing and optimizing require that actions be generated, evaluated, and matched against the goal. To generate an action, the goal must be further broken down if it is an aggregate goal. This is done by selecting subgoals until a primitive goal (that is, a goal consisting of a single condition or action) is defined. For a primitive goal consisting of a condition, further effort is necessary to find an appropriate action. Specifically, an appropriate rule must be first selected and parsed. The action from within the parsed rule must then be stored in STM. For a primitive goal consisting of an action, the generated action is simply the goal.

The action is then evaluated, leading to a decision based upon the extent to which it satifices or optimizes the current goal. The evaluation process can take many forms, and as such can not be defined in an entirely generic way. One very general approach is to assume that the action is taken, and then forward chain in the problem space to evaluate its effect. As indicated in Figure 11 − 13, a current goal and condition are always needed to evaluate such forward chaining effects. For the optimizing procedure, Figure 11 − 15 schematically describes the need for weighting and the storing actions during such evaluation. The exact nature of performance during such evaluation of an action is likely to be very complex, involving much

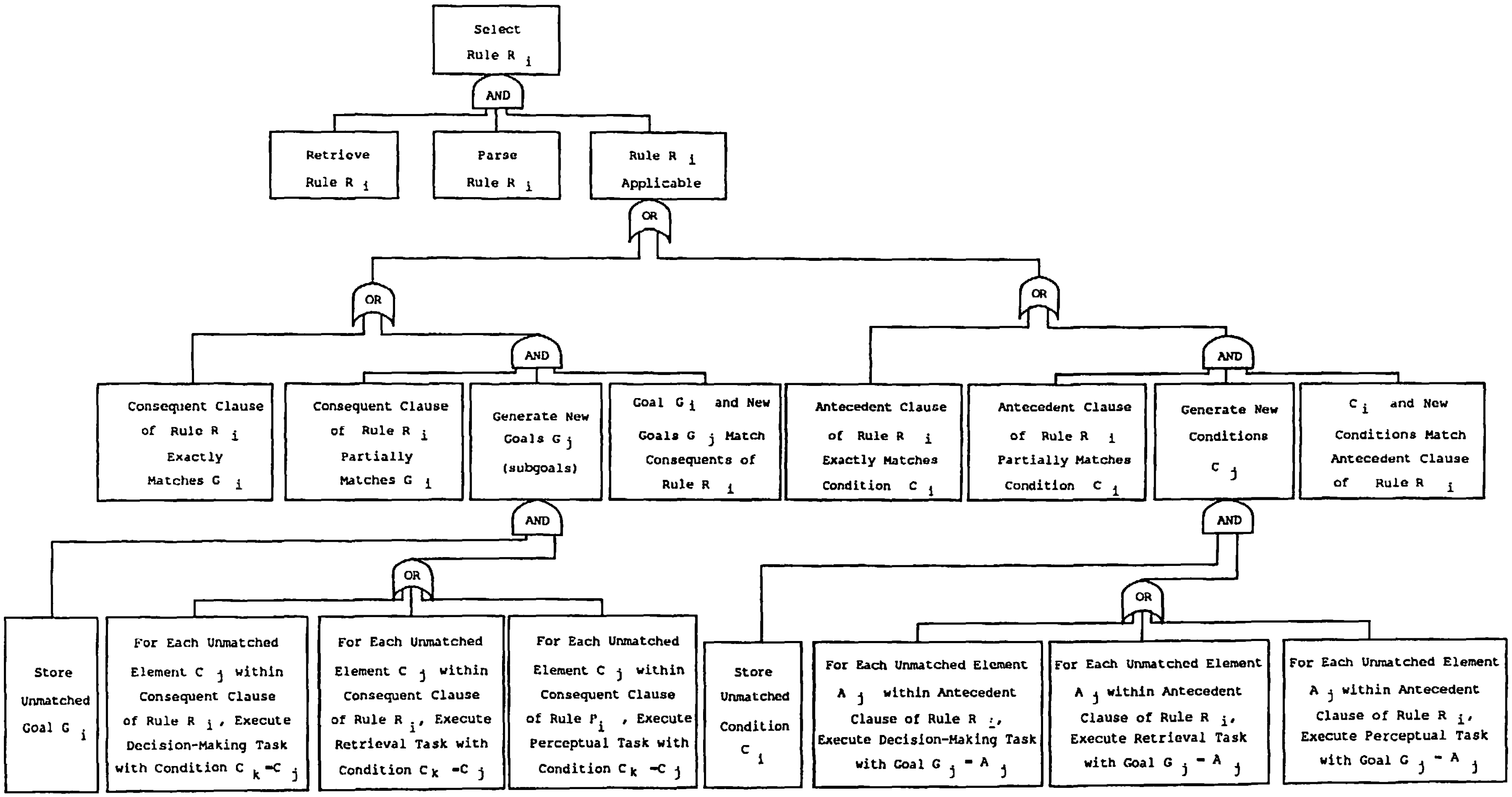


Figure 11-14 A General Description of the Procedure Whereby Rules Are Selected within Decision Tasks.

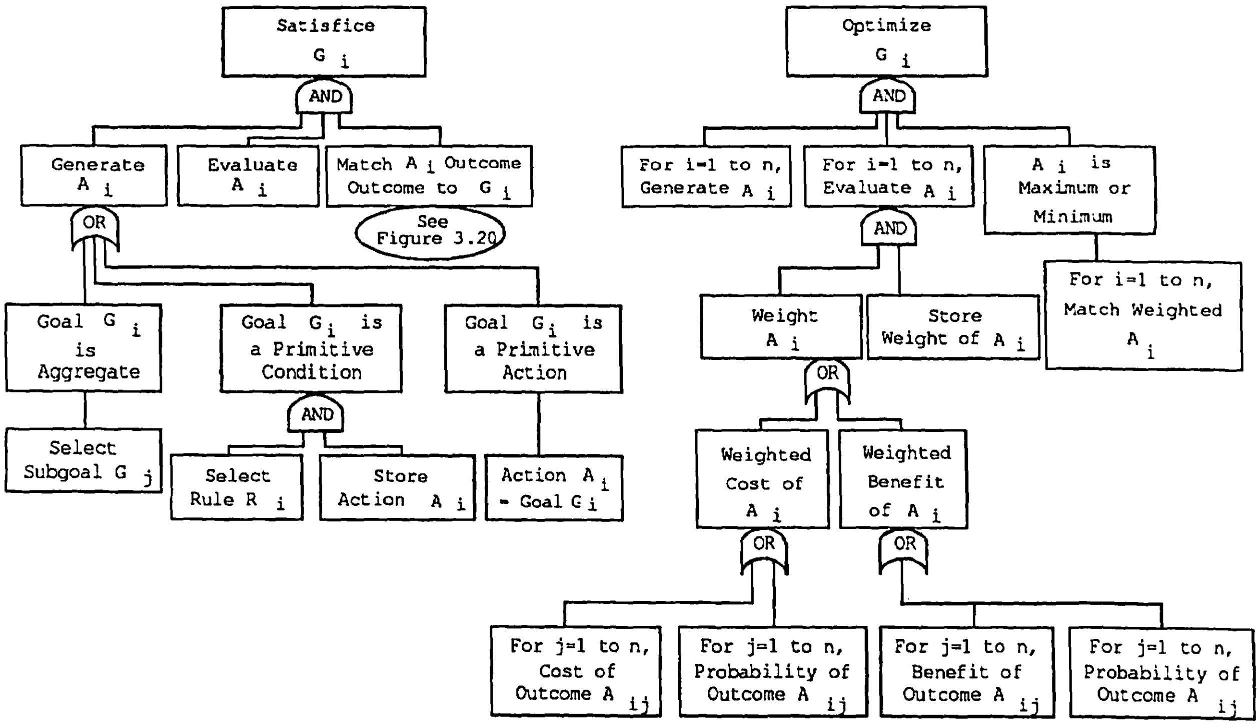


Figure 11−15 Determination of Satisfactory or Optimal Actions within an Elemental Decision-Making Task.

interaction with external memory. The complexity of such performance is illustrated by the protocols collected by Newell and Simon (1972).

Lastly, the evaluated actions must be compared to the goal in a matching task. As shown in Figure 11−15, when satisficing, the matching of evaluated actions continues until an action is found which is at least equivalent to the goal. When optimizing, evaluated actions must be matched until an action is found that is clearly a maximum or minimum. The following discussion considers matching in more detail.

Matching Tasks. Several forms of matching have been referred to earlier, including the matching of the internal structure of a stimulus to its external structure, the matching of sensory firing patterns to primitive features of a stimulus, and the matching of conditions or actions within rules to knowledge elements in STM. Each of these forms of matching are important within elemental tasks. The process of matching, as performed by the human, is not well understood. Several factors which influence matching include the representation within memory of the items which are to be matched, the difference measures used to distinguish items, the assignment of priorities and filtering, the influence of expectancies, and the search strategy which the overall matching process follows.

Matching is also a topic of great interest to researchers in artificial intelligence, especially among those researchers working in pattern recognition. A common conclusion is that matching objects to raw data (as might be given by a television camera) is a difficult problem, for which solutions tend to be very specific to particular applications. Many approaches have been developed that allow machines to recognize patterns, such as template matching, energy intensity based filtering, or surface modeling. However, Raphael (1976) states that "No widely useful general principles seem possible, since each type of object has unique characteristics that

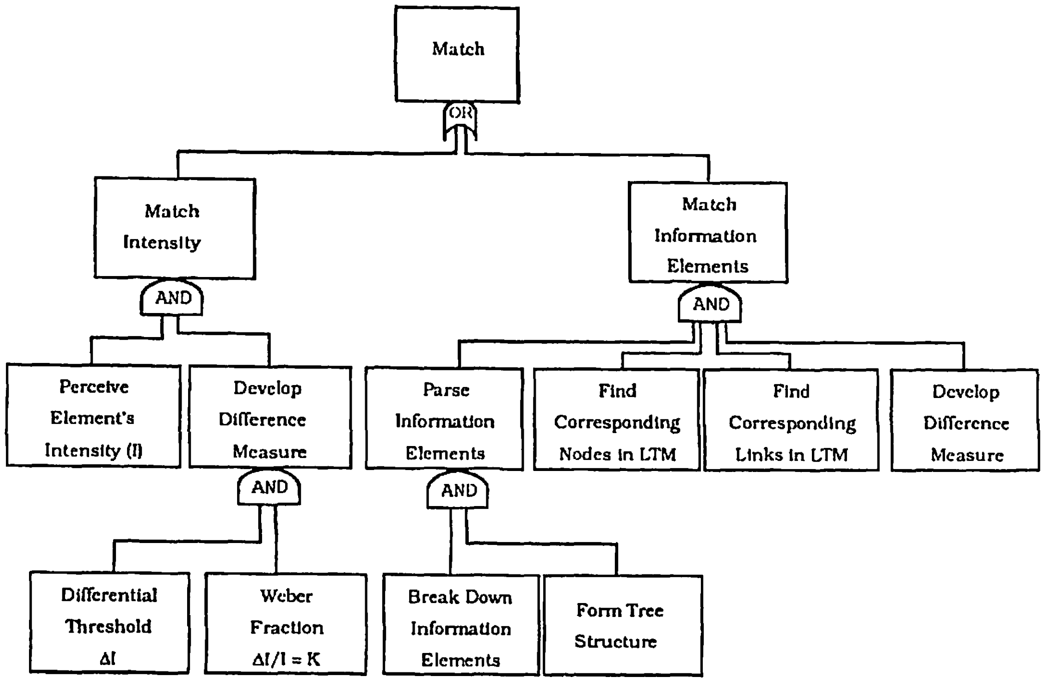


Figure 11−16 A Diagram Illustrating the Matching of Information Components within an Elemental Decision-Making Task. Also Shown is an Example of Intensity Matching, as Might Occur at a Lower Perceptual Level.

must be represented." Although psychology has made significant progress in defining the lower level processing of stimuli (as exemplified by the discovery of contrast sensitive cells in the retina, and other forms of feature detection (see Carlson 1977 for an overview)), it is difficult to model such effects in a practical way, making the conclusion of Raphael applicable here. Raphael goes on to state "Therefore most attention has been focused on the task of classifying objects once they have been represented." These points imply that a model of the matching process must be at a high level, if it is to be applicable here.

Consequently, we have chosen to develop a pragmatic approach for modeling the matching process that applies certain principles which researchers in artificial intelligence have applied to knowledge; no attempt is made to model the matching done at lower levels of processing. Also, this approach is intended to simply indicate what needs to done during matching rather than describe how the human does it.

Figure 11−16 summarizes the developed approach to modeling the matching of knowledge elements. The approach is similar to the MATCH procedure used in HAM, a computer program model of human memory (Anderson and Bower, 1973). In summary, the procedure summarized in Figure 11−16 initially consists of parsing knowledge elements within STM, as exemplified by a string of symbols (the string of symbols defines the information element in STM), into a tree composed of linked primitive knowledge components. The primitive knowledge components are simply objects, actors, and predicates; the parsed tree breaks a sentence down into clauses, which ultimately terminate into primitive knowledge components.

An example of such a tree is given in Figure 11−17. (Memory is also assumed to consist of such linked objects, as discussed in Chapter 2.) The parsing of the knowledge elements

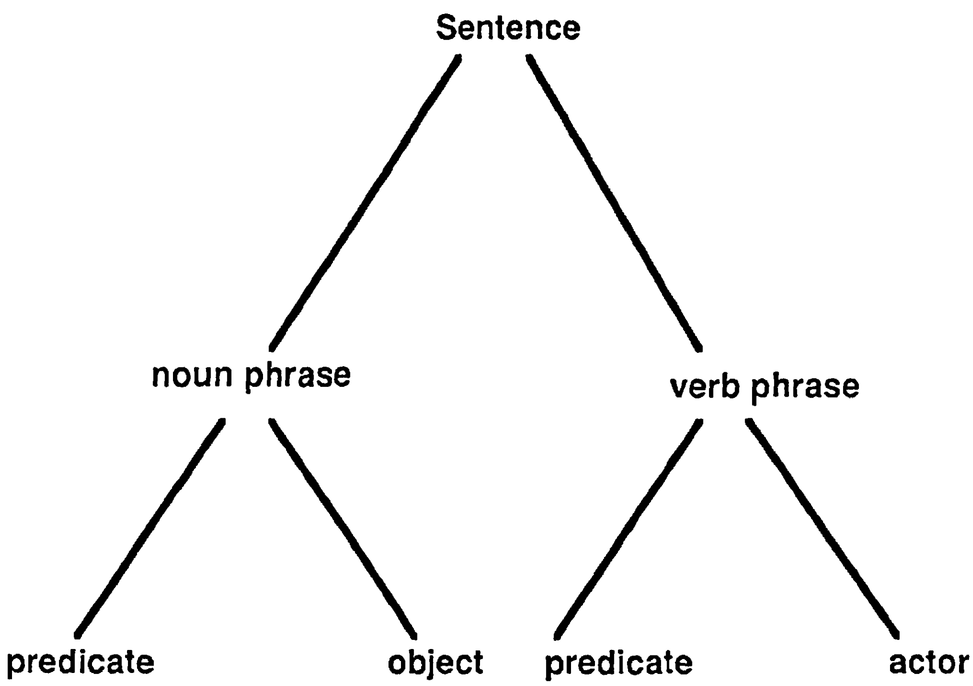


Figure 11 − 17 Example of a Tree Composed of Linked Primitive Objects. (The sentence is parsed into clauses which can then be parsed into primitive knowledge components.)

in STM is associated with a search within LTM for corresponding primitive knowledge components (nodes) and patterns formed by linking the nodes. A match between the parsed tree (called by Anderson and Bower, a probe tree) and a structure in LTM can be either exact or partial. The exactness of the match is described by a difference measure. Many obvious difference measures can be described in terms of the nodes, links, and patterns. It is likely that such a difference measure is highly influenced by transient conditions such as expectations and priorities. However, little available information indicates how such influences should be modeled.

Of particular importance is that this general matching approach describes the way the various meanings of knowledge components can be matched. Recall that meaning can be described in terms of semantics, syntax, and pragmatics. Matching on the basis of semantics is the simplest form, and simply requires that difference measures be developed between the nodes of the probe tree and the nodes within memory. Matching on the basis of syntax is somewhat more complicated, as it requires that difference measures be developed between the structure of the probe tree and the structure of node patterns in memory. (Structure is defined by the nodes and links as a whole.) Matching on the basis of context requires that the probe tree be augumented with contextual knowledge components. In other words, such a probe tree contains contextual information as well as the information within a stimulus.

This definition of the matching process is operationally applicable in the overall modeling approach, once the items to be matched have been defined in terms of primitive knowledge components. Determining the organization of a particular individual's LTM is of course difficult, and it is undoubtedly impossible to delineate the entire LTM of a individual. However, small portions can be modeled after performing protocol analysis. Such analysis of the matching process could be very useful during detailed forms of task analysis.

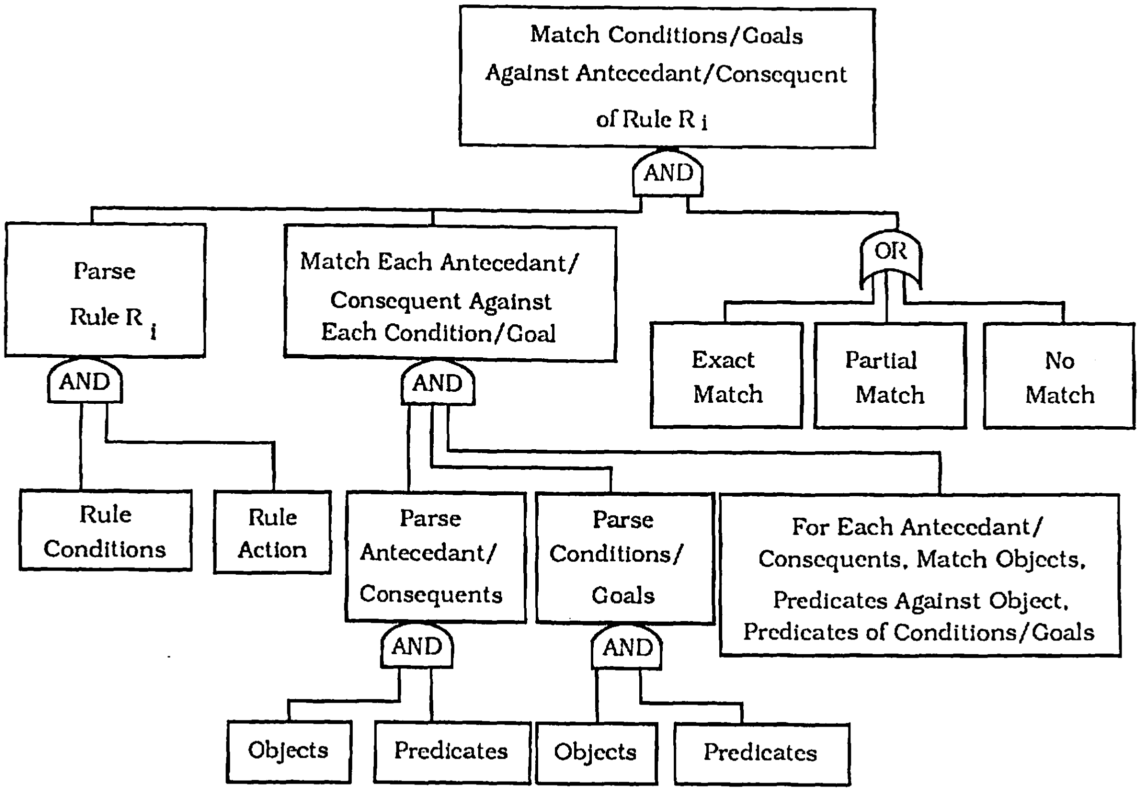


Figure 11−18 The Matching of Specific Knowledge Components within an Elemental Decision-Making Task.

In particular, this matching process combines with the decision model given in the earlier figures. Figure 11−18 depicts an abstract overview of how conditions can be matched against rules, and how actions can be matched against goals. The figure does not describe any of the detailed aspects of the matching process, and is only intended to illustrate how the knowledge components within rules break down into primitive objects. The primitive knowledge components can then be organized and evaluated within this model of the matching process, assuming that a portion of LTM has been mapped in terms of primitive knowledge components and links.

Motor-Response Tasks A motor task, as described by the links in Figure 11−2, defines the transfer of information from STM to external memory or the environment in general. The role of motor tasks in modifying external memory is particularly important. In other words, when a external object is modified, its state preserves information which can be retrieved using perceptual processes. Motor tasks are consequently a very important component in many decision tasks, since such storage of information in external memory makes up for the limited capacity of STM and the slow rate at which information can be stored in LTM. Motor tasks are also very important component of perception, as they result in the connection of sensors to sources of energy and materials.

As mentioned earlier, elemental motor tasks require that other elemental tasks be performed first. This extreme dependence upon context is shown in Figure 11−19 by the need for a condition, goal, and action in STM when performing the motor task. In general, the

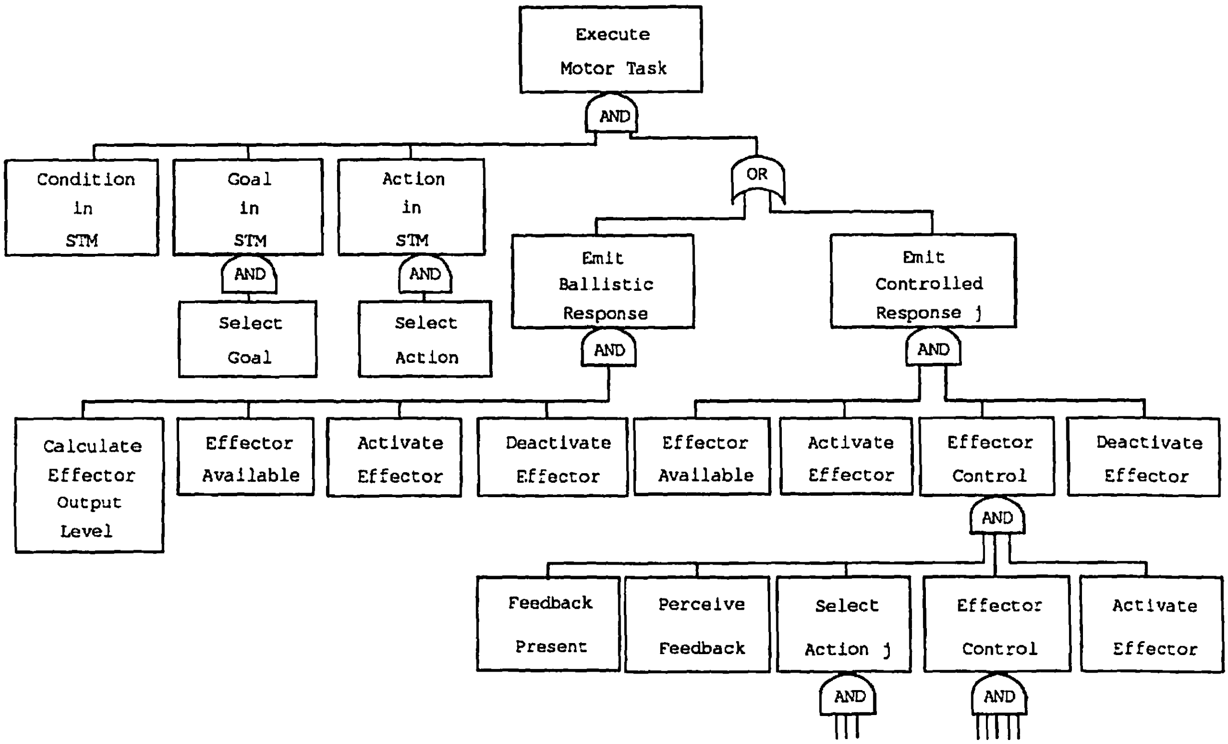


Figure 11 – 19 A Diagram Illustrating The Execution of an Elemental Motor Task. (Before execution, a context must be set by the presence of conditions, goals or actions in STM. The emitted response may be ballistic or controlled.)

condition either describes initial states of effectors and environmental objects (that is, any object external to the human), or their terminal states. Goals generally define desired states of effectors and environmental objects, while actions define the activity taken between the initial states and the terminal states (which will be goal states, if performance is successful).

Once a context is set, motor tasks can be divided into either ballistic or controlled responses (Figure 11 – 19). A ballistic response is simpler than a controlled response; it consists of the activation of an effector at a selected level without the use of feedback. A controlled response is similar, but differs in that it contains the process of effector control. Effector control can be recursively defined as a particular motor task which is performed within itself (Figure 11 – 19). Effector control also incorporates a decision task in which actions are selected based upon feedback that defines new conditions and goals. The feedback must be perceived, which defines another task within the effector control task. (The perception of feedback is a good example of the use of external memory.)

SUMMARY

This chapter represents a substantial effort towards combining approaches used in safety science, artificial intelligence, human factors engineering, and psychology. Among the addressed topics are 1) production systems, 2) network models of human performance, 3) network models of safety related activity, and 5) the general warning tree. The general warning tree is the culmination of the attention given to modeling safety related aspects of human performance.

There is little question that the general warning tree, as laid out in this section is too complex for ordinary application. However, additional development of the general warning tree, followed by its implementation using computerized tools is likely to result in a very powerful approach for analysis of the knowledge based warning issues. Chapter 12 will address several modeling issues which are related to the further development of the general warning tree. Of particular value will be the emphasis (in Chapter 12) on modeling the product and task, rather than the activity within the human emphasized in Chapter 11.

CHAPTER 12

A KNOWLEDGE BASED APPROACH TO TASK ANALYSIS

CHAPTER 12. CONTENTS

CHAPTER 12

A KNOWLEDGE BASED APPROACH TO TASK ANALYSIS

In this chapter, we take a fundamental, model-based approach to task analysis and initially consider some aspects of the warning design process. The approach is knowledge based, in that the human, product, and task are all equivalently represented in terms of related elements as knowledge. Much time is spent on describing a set of primitive elements and on ways of combining these elements to define larger concepts. The discussion quickly becomes quite complex, reflecting the ultimate need for computer implementation of the modeling approach.

In regard to task analysis, a knowledge based approach has great potential. With such an approach, human cognition and knowledge can be modeled in exactly the same way as are products and tasks, resulting in a common basis for analysis of the human, product, and task. Many advantages are associated with the provision of a common basis for analysis. In particular, models of the human, product, and task can be more easily combined, when such knowledge based rather than traditional modeling techniques are used.

This is not to say that knowledge based approaches are always the best for modeling products or tasks. Mathematical models, as used in finite element analysis, or in other computer aided design approaches, are very apt during certain forms of engineering analysis. However, to model the way people (when performing tasks) perceive, comprehend, or respond to products, the knowledge based approach is unquestionably advantageous.

This chapter is subdivided into four major sections. The first section, "Modeling Tasks and the Flow of Information," introduces some sophisticated approaches to task analysis. The second section, "A General Knowledge Based Modeling Approach," provides a very theoretical background necessary for the development of a knowledge based method of task analysis. The third section, "Modeling the Human, Product, and Environment," describes some ways the knowledge based modeling approach can be applied. The fourth section, "Modeling the Task," is also an applied section that makes use of the knowledge based modeling approach in reconsidering the first three stages of the design process described in Chapter 10. Many readers may find it useful to review the third and fourth sections before reading the second section.

MODELING TASKS AND THE FLOW OF INFORMATION

To specify the flow of information within a task, task analysis must be performed. The traditional objective of task analysis has been to specify a task with a restricted sequence of predefined elemental tasks. This sequence of elemental tasks then describes the general flow of information, energy, and material during the task. It is difficult, however, to directly define many tasks using the traditional predefined elemental tasks. This is especially true for fairly complex tasks composed of non-elemental subtasks or of subtasks that do not follow a linear sequence.

In regard to this difficulty, it should be noted that a task can be precisely defined with a set of declarative sentences which contain infinitive clauses. Theoretically, the sentences described in such an approach can be arranged in a hierarchy in which higher level sentences are directly defined by lower level sentences. The words from which such sentences are developed should consist of a limited set of natural language.

Jobs have been described in this way (Handbook for Describing Jobs, 1972), and the approach has potential value for describing tasks and subtasks in a hierarchy. This latter point logically follows because an initial task description comprised of general, abstract, sentences provides a way of organizing a detailed breakdown of the task.

Figure 12−1 illustrates how an abstract description of a task can be given by a single sentence composed of words taken from a limited set of natural language. As shown in the figure, the sentence can be parsed into two clauses that respectively define an activity and a goal within the task. The activity is a simple declarative sentence, while the goal is an infinitive clause. Both clauses can be directly parsed into predicated objects and actors (as shown in the figure), or can be described by more specific sentences to define a hierarchy of tasks and subtasks.

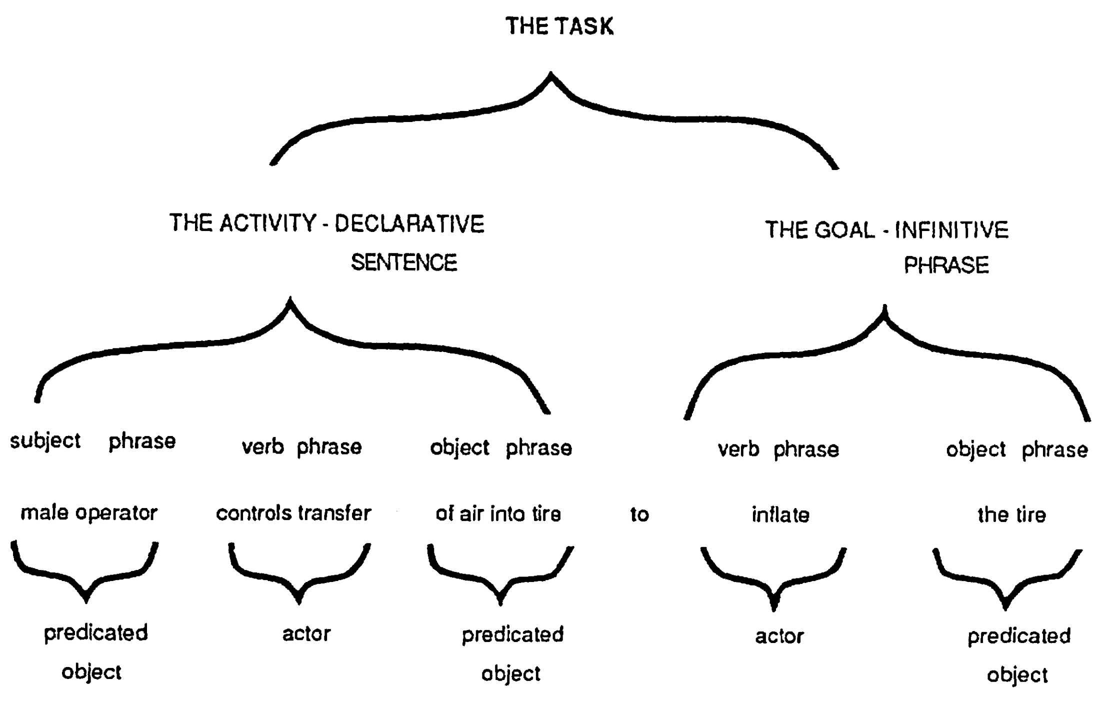


Figure 12−1 The Description of Tasks Using a Limited Subset of Natural Language.

A knowledge based modeling approach along these lines will be discussed in this chapter, after first reviewing some traditional approaches to task analysis and their relationship to modeling.

Modeling and Traditional Task Analysis

Existing approaches to task analysis, as typified by methods study and the development of process charts (Neibel, 1976), all have an underlying model (albeit the underlying model is rarely defined explicitly). Concepts within these models are very useful, such as the breakdown of tasks into elemental components or the sequential arrangement of elemental tasks to define processes. These traditional approaches have, however, been primarily applied to highly contrained problems which are quite well-defined in comparsion to the very general and unconstrained problem of product safety.

For these highly constrained problems considered in traditional task analysis or methods study, emphasis has been placed on those aggregate observable task elements which almost exclusively consist of repetitive motor activity performed in very specific settings. On the other hand, for the unconstrained problems of consumer product safety, the vast variety of products and associated uses initially appear to define an equally vast array of tasks. Also, much emphasis is required on the perception and decision related activity that occurs in these widely varying settings associated with consumer products.

Other approaches to task analysis have been developed and applied to more complex tasks than those normally addressed by methods study (Miller, 1953; Meister, 1971; Hodgkinson and Crawshaw, 1986; Handbook for Designers of Instructional Systems, 1973). Such approaches have incorporated concepts such as the hierarchical arrangement of tasks and subtasks, the linking of components, the flow of information, and the branching of activity which occurs when decisions are made. These approaches do not, however, specifically define a fundamental, theory based method that 1) generically represents the human, product, and environment with compatible and equivalent terms, and 2) explicitly allows generic task representations to be derived from these more basic representations.

All of the above referenced approaches to task analysis can ultimately provide useful task representations. The approaches are not, however, easily applied by non-experts or computer programs. The knowledge based modeling approach developed herein is intended to provide the theory from which similar task representations can be derived in a formulistic process.

A GENERAL KNOWLEDGE BASED MODELING APPROACH

In a very fundamental way, this proposed modeling approach taps the rich source of information provided by existing approaches to task analysis, as should become clear from the following discussion. In fact, three basic premises underlying this knowledge based approach are also essential to the traditional approaches.

First, it is assumed that components of the product, human, and environment can all be represented by a set of primitive terms that, when combined according to certain rules, will define the activities and goals within a task. In the specific knowledge based approach described here, the considered primitive terms are predicates, actors, or objects, and these primitive terms are combined to describe the flow of energy, material, and information from and to objects. These various flows, of course, can correspond to goals (before the flows occur), or activity (while the flows occur). By carefully specifying and recombining these terms, it should be possible to develop English-like task descriptions that are consistent with the production system based model of the human described earlier in Chapter 11.

Second, it is assumed that the components of the product, human, environment, and task can be modeled at several levels of abstraction. The more abstract components are specified by combining less abstract components, thereby defining a hierarchy of aggregate components down to elemental components. Third, it is assumed that this hierarchical breakdown will define modular categories of components for which analysis can be separately performed.

The following discussion will first provide an overview of the primitive terms. Attention then shifts to describing the relationships between the terms. The section ends by providing a more detailed description of activity described by combining the terms. In the discussion, equivalent material is frequently given in the text, figures, and tables. It should be emphasized that the material is presented in multiple formats, primarily because certain individuals are best able to comprehend material from one or another format. Also, because of the large amounts of information contained in the figures and tables, translating them into text would result in an excessively long tract. Consequently, there has been no great effort to comprehensively discuss figures or tables in the text.

Terms Used in this Modeling Approach

This modeling approach is somewhat complex, and it uses fairly specific terminology. In order to avoid the problems associated with a vast number of task-specific terms, very generic terms similar to those described by Lehto (1985) are defined. These terms are intended to be consistent with the approaches of object oriented computer programming, in which problems are decomposed into modular objects (Booch, 1986; Lehto, 1985) that are recombined in problem-specific ways. Although the terms are specifically chosen to reduce confusion, a brief overview of the terms should help avoid confusion during the discussion of the modeling approach. Certain readers may find it useful to quickly skim this section and move on to the more detailed sections.

The defined terms are either primitive or composite. Primitive terms are "objects," "actors," "predicates," or "states." Such terms describe the structure, actions, and conditions of product, human, and environental components. Composite terms are clauses composed from primitive terms and define "goals" and "activity" within a task. Figure 12−2 schematically describes primitive and composite terms; Table 12−1 provides a more detailed breakdown of objects and their predicates. There is some overlapping between the material in the figure and table, since the objects and predicates in Table 12−1 are particular primitive terms also found in Figure 12−2.

In the following discussion, the primitive terms are overviewed before considering the composite terms. No attempt is made to reference the appropriate figure or table, since the discussion is an overview and because such references would become highly redundant.

Primitive Terms As noted above, primitive terms correspond to objects, predicates, and actors. Actors are applied to objects, while predicates are generally used to more precisely describe objects. Consequently, these primitive terms are related to one another, as will be expanded upon later.

Objects. Objects correspond to nouns and are either "static" or "transient." Static objects define the structural components of the product, human, and environment, while transient objects define energy, information, or material that flows from object to object. This distinction

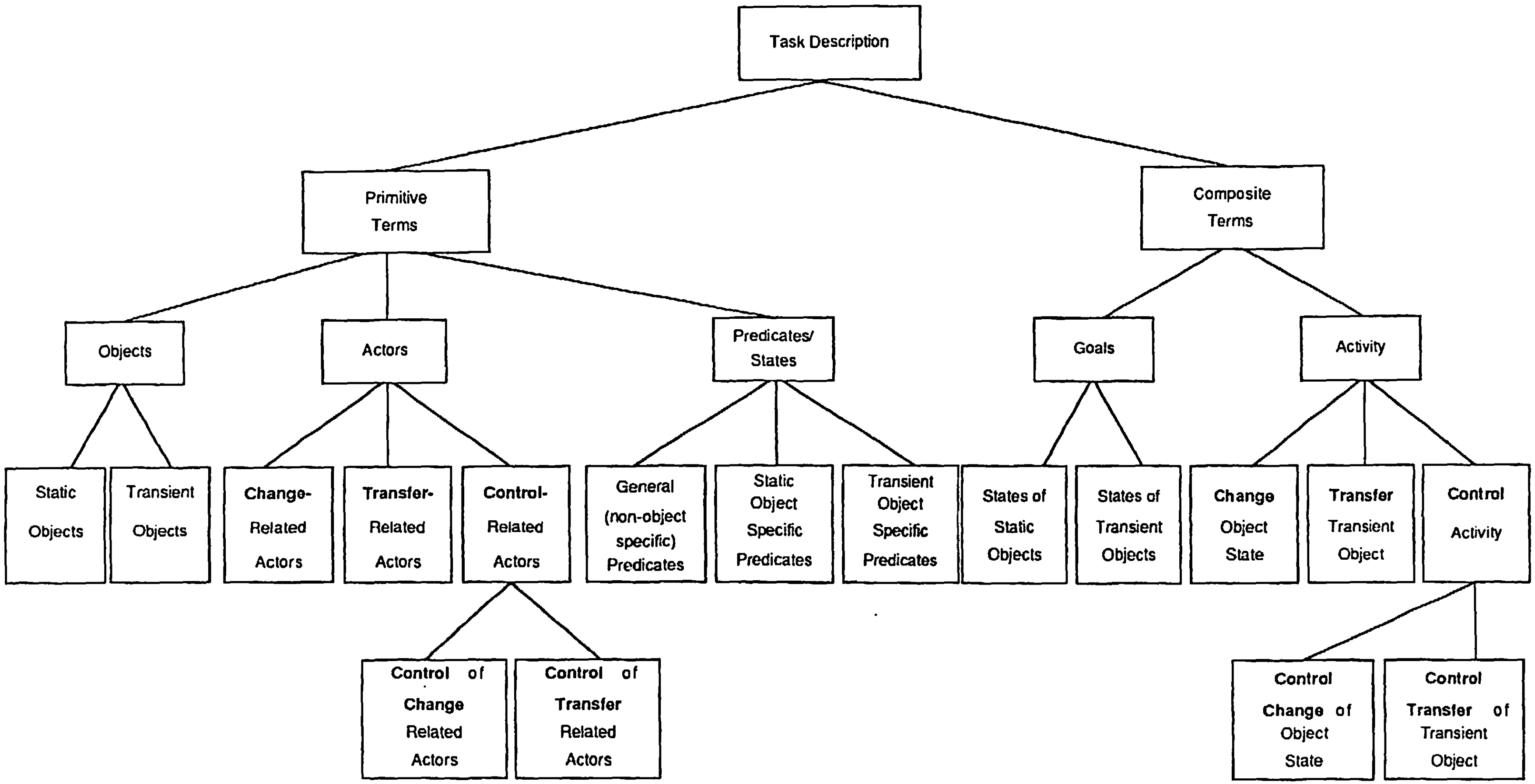


Figure 12−2 A Schematic Diagram Illustrating the Hierarchy of Primitive and Composite Terms Which Are Used to Describe Tasks.

Table 12–1
Primitive Objects and Their Predicates Used to Define Elemental Tasks During Task Analysis.

Static Objects – Aggregate or Elemental	Predicates/State of Transient Objects
Human Structural Components	Energy/Force Related Predicates/States
Product Structural Components	Energy/Force Category
Environment Structural Components	Thermal
	Mechanical
Transient Objects – Aggregate or Elemental	Electrical
Energy	Radiant
Information	Energy/Force Level
Material	Energy State
	Kinetic
Predicates/State of All Objects	Potential
Composition of Objects	Information Related Predicates/State
Sub-components	Information Code
Material Related Predicates/States	Spatial
Locations of Objects	Intensity
Connections of Objects	Temporal
Transient/Static	Meaning
Unidirectional/Bidirectional	Explicit Components
Conductivity of Connections	Implicit Components
Activation Related Predicates/States	Material Related Predicates/States
Objects – activated/deactivated	Material Type
Connections – connected/disconnected	Chemical Composition
Location – present/not present	Material Concentration/Level
	Material State
Predicates/States of Static Objects	Gas
Source/Sink	Liquid
Interface	Solid
Input/Output	
Controller	
Channel/Barrier	

between static and transient objects is abstract in nature, and does not always exactly correspond to different components, since many product, human, and environmental components are assemblies of both static and transient elements. However, such assemblies can be broken down into separate components which are either static or transient.

Both static and transient objects occur at different levels of abstraction, and have "state." The state of an object determines whether, where, and how flow occurs, and is simply the time specific value of an object's "predicate." State is determined by applying an actor to the predicated object.

Predicates. Certain predicates are associated with all objects, others apply only to static or transient objects. Predicates of all objects include object composition, location, connections, and activation. Predicates applied only to static objects abstractly specify the structure composed of connected static objects through which transient objects flow, and are explicitly associated with particular actors, as will be emphasized in the next section. Such predicates are given by the terms source/sink, channel/barrier, controller, and interface (input, and output). Predicates of transient objects specify the energy, information, or material from which a particular transient object is composed. For example, energy can be predicated using the terms "kinetic," "potential," "mechanical," and so on.

Certain predicates, not summarized in Figure 12–2 or Table 12–1, are applied to specific actors. For example, "rate," "efficiency," and "direction" are all predicates of actors rather than of objects.

Actors. Actors are verbs that specify changes in object states or specify the flow of energy, information, or material. Actors that specify changes in object states include the terms "activate," "connect," "change," "control," and "transform." Actors which specify flows include the terms "emit," "transmit," "control," and "receive." Other more detailed actors can be used to more precisely specify particular changes or flows, and will be further discussed in following sections.

Composite Terms Composite terms are formed by combining primitive terms and are subdivided into "activities" and "goals." Recall from Chapter 11 that an activity and a goal together define a task; when a composite term representing an activity is combined with a composite term representing a goal, a sentence is defined that specifies a task.

Activities. An activity is always defined by applying an actor to an object. Three abstract forms of activity can occur within a task, depending upon the general actor chosen. Such activities include those which "change," "transfer," or "control" the states of objects. More specific forms of activity can be defined by combining several objects, actors, and predicates together into sentences.

In particular, performing an activity can 1) "change" the state of either transient or static objects; 2) "transfer" a transient object; 3) "control" the "change" of either transient or static object states; or 4) "control" the "transfer" of transient objects. It should be noted that control activity is at a metalevel, since both change and transfer related activity can be controlled.

Goals. Two general categories of goals are present within a task, those respectively associated with the desired states of static versus transient objects.

The Relationship Between the Primitive Terms

It is assumed in this modeling approach that all tasks involve the flow or blockage of energy, information, or material from one object to another. Recall from Figure 12–2 that the primitive terms used to model flow or the blockage of flow are subdivided into objects, predicates, and actors and that there are more specific terms which specify particular types of objects, predicates, and actors. These more specific terms are intentionally chosen so as to explicitly separate the state and flow related aspects of a task. They fundamentally differ from terms which describe commonly used elemental tasks, since the traditional elemental tasks implicitly rather than explicitly separate state from flow. For example, the traditional elemental subtask "move" implicitly defines both a change of state (location) and a transient application of force.

When tasks are defined using the primitive elements defined here, the tasks become explicit combinations (or composites) of the primitive elements. This results in elemental tasks which are fundamentally defined and consistent with the modeling approach described in Chapter 11.

Relationships between the primitive terms can be described on the basis of their functional, structural, or temporal characteristics. The following discussion describes details regarding the nature of such relationships.

Functional Relationships Between the Primitive Terms Certain predicates assigned only to static objects define generic functions of product, human, and environmental components, and are therefore related to specific actors and transient objects. In Table 12−1, it was noted that such predicates include the terms source/sink, channel/barrier, controller, and interface (input or output). The correspondence between predicated static objects, transient objects, and particular actors is generally obvious. For example, a "source" (predicated static object) can "emit" (actor) "energy" (transient object).

Table 12−2 consists of a simple matrix that illustrates such functional relationships between objects, predicates, and actors. The predicated static objects and types of transient objects are listed on both axes of the matrix. Actors fill the cells within the matrix. The table itself can be divided into four quadrants, each of which contains several cells. The quadrants are separated by the dark lines within the table, and are denoted as follows: Quadrant #1 is the upper left section of the table. Quadrant #2 is the upper right section. Quadrant #3 is the lower left section. Quadrant #4 is the lower right section.

The developed table defines several "sentences," wherein the element on the y-axis is the subject, the element in the cell is the actor, and the element on the x-axis is the object. Each sentence generically defines a potential function (or equivalently an activity) of a product, human, or environmental component. Such functions can be combined to generically model a product, human, environment, and ultimately a task.

One category of sentences within this table corresponds to Quadrant #1, and describes the relationships between transient objects. A second category corresponds to Quadrants #2 and #4, and describes the relationship between static objects and transient objects. A third category corresponds to Quadrant #3, and describes the relationship between static objects. No attempt is made within the table to define detailed sentences; instead, the sentences are intentionally left in abstract form. This allows specific sentences for particular applications to be easily specified by assigning values to the objects and predicates.

Transient Objects Alone. Sentences which describe the influences of transient objects upon transient objects fall within the Quadrant #1 of Table 12−2. As shown in the table, nine cells are formed by the three subjects and three objects for each subject. The following discussion will separately consider those sentences for each subject (energy, information, and material).

When the subject of the sentence is "energy," one set of sentences uses the actors "change" and "become." These sentences simply state that energy can change its level or become another type. More precisely, potential energy directly adds to potential energy and kinetic energy adds to kinetic energy. Kinetic energy can become potential energy, or vica versa; electrical energy can become mechanical energy; mechanical energy can become thermal energy, etc. A second set of sentences uses the actor "encode," and simply state that energy or force can encode information. The third set of sentences uses the actors "change" and "contact." These sentences simply state that energy or force change material states and contact materials. Simple variants are easily defined; such as thermal energy changes material from solid to liquid states, concentrated mechanical forces cut materials, etc.

When the subject of the sentence is "information," less direct interaction is present. This follows because the influence of information on energy and material is indirect and takes place

Table 12−2
The Functional Relationship between Objects, Predicates and Actors. (Actors are the elements within cells of the matrix that describe the relationship between the objects.)

	TRANSIENT OBJECTS			PREDICATED STATIC OBJECTS			
	Energy/ Force	**Information**	**Material**	**Source/ Sink**	**Interface**	**Channel/ Barrier**	**Controller**
Energy/Force	changes (level), becomes (type)	encodes	changes (state, type), contacts	activate, deactivate, originate, terminate	activate, deactivate	activate, deactivate	activate, deactivate
Information	defines		defines	activate, deactivate, originate, terminate	activate, deactivate	activate, deactivate	activate, deactivate
Material	changes (level, state), becomes, contacts	encodes	changes (level, state), becomes, contacts	activate, deactivate, originate, terminate	activate, deactivate	activate, deactivate	activate, deactivate
Source/Sink	emits/receives, contains	emits/receives, contains	emits/receives, contains		connects		
Interface	connects, transforms	connects, transforms	connects, transforms	connects	connects	connects	connects
Channel/Barrier	transmit/ block	transmit/ block	transmit/block		connects		
Controller	controls	controls	controls		connects		

through the activity of static objects. Information only "defines" energy and material; obviously, energy and material can be described in great detail for any particular application, by specifying their values with predicates.

When the subject of the sentence is "material," another large set of sentences is defined. The first set of sentences uses the actors "change," "become," and "contact." Such sentences state that material can change energy levels and states, become energy, or contact energy. More specific verbs which describe changes in energy levels and states include the terms "absorb" and "transform" (i.e. a material can absorb or transform energy). Also, a material can "become" kinetic energy, as materials frequently store potential energy. The second set of sentences use the actor "encode," and simply state that materials can encode information. The third set of sentences also use the actors "change," "become," and "contact." Such sentences state that material can change the level, state, and type of a material, become a material, or contact a material.

Static and Transient Objects. Quadrants #2 and #4 describe relationships between static and transient objects. Recall that the static components are described using the predicates source/sink, controller, channel/barrier, and interface; the transient objects are described in terms of energy, information, and material. Both these predicates and transient objects become either the subjects or objects in the remaining sentences defined in Table 12–2. In Quadrant #2, transient objects are the subjects, while static objects are the subjects in Quadrant #4.

As shown in Quadrant #2, when a transient object is the subject of a sentence, it activates or deactivates a predicated static object, or originates or terminates from a source or sink. A source or sink is a particular type of predicated static object, as described in the next paragraph. The next paragraph and all of the following ones in this subsection primarily refer to those sentences described in Quadrant #4.

The terms "source" and "sink" are predicates that are respectively assigned to static components from which the flow of transient objects originates or terminates; a source emits transient objects and a sink receives transient objects; a transient object originates at a source and terminates at a sink. (A source is essentially the inverse of a sink.) Sources or sinks are activated when they are emitting or receiving transient objects, and deactivated if they are not emitting or receiving. The point of origination is arbitrarilly determined during analysis; for example, an electrical outlet rather than the power generation plant will usually be considered a source during the analysis of electrical tools. The point of termination is less arbitrary. Importantly, the transient objects emitted or received by a given source or sink can be composed of any particular combination of energy, material, or information.

The term "interface" is a predicate assigned to static components which transform transient objects. (This predicate is also assigned to certain static objects which connect other static objects together.) An object becomes an input interface if it receives transient objects or an output interface if it emits transient objects. An interface is active if it is receiving, emitting, or transforming a transient object.

The terms "channel" and "barrier" are predicates respectively assigned to static components which transmit or block the flow of transient objects. Consequently, a channel is the inverse of a barrier. A channel is activated when it transmits while a barrier is activated when it blocks or contains.

In conclusion, the term "controller" is a predicate assigned to static objects which control the flow of transient objects. A controller is activated when it controls the flow of transient objects.

Static Objects Alone. Quadrant #4 of Table 12−2 describes relationships between static objects alone, in terms of several simple sentences. These sentences are very simple in form, as they always consist of the actor "connect," an interface, and any other predicated static object.

Structural Relationships Between the Primitive Terms Predicated static objects connect to each other to define the structure of the modeled system. This structure specifies the flow of transient objects and can be graphically described by a flow diagram. (The development of flow diagrams is an important aspect of the model-building process discussed later in this chapter.) Figure 12−3 illustrates some of the permissible connections between predicated static objects. Connections may be unidirectional, in that they only allow flow to go in one direction, or bidirectional. Also, connections have specific conductivity for particular transient objects.

Important concepts which guide the specification of connections are: 1) transient objects arise from a source and ultimately terminate at a sink, 2) flow is over a channel, which may actually be composed of many components, and 3) interfaces are always found between different types of components. Recall that the static components of the human, product, or environmental components are of different types, as are the transient components described by different forms of energy, information, or material.)

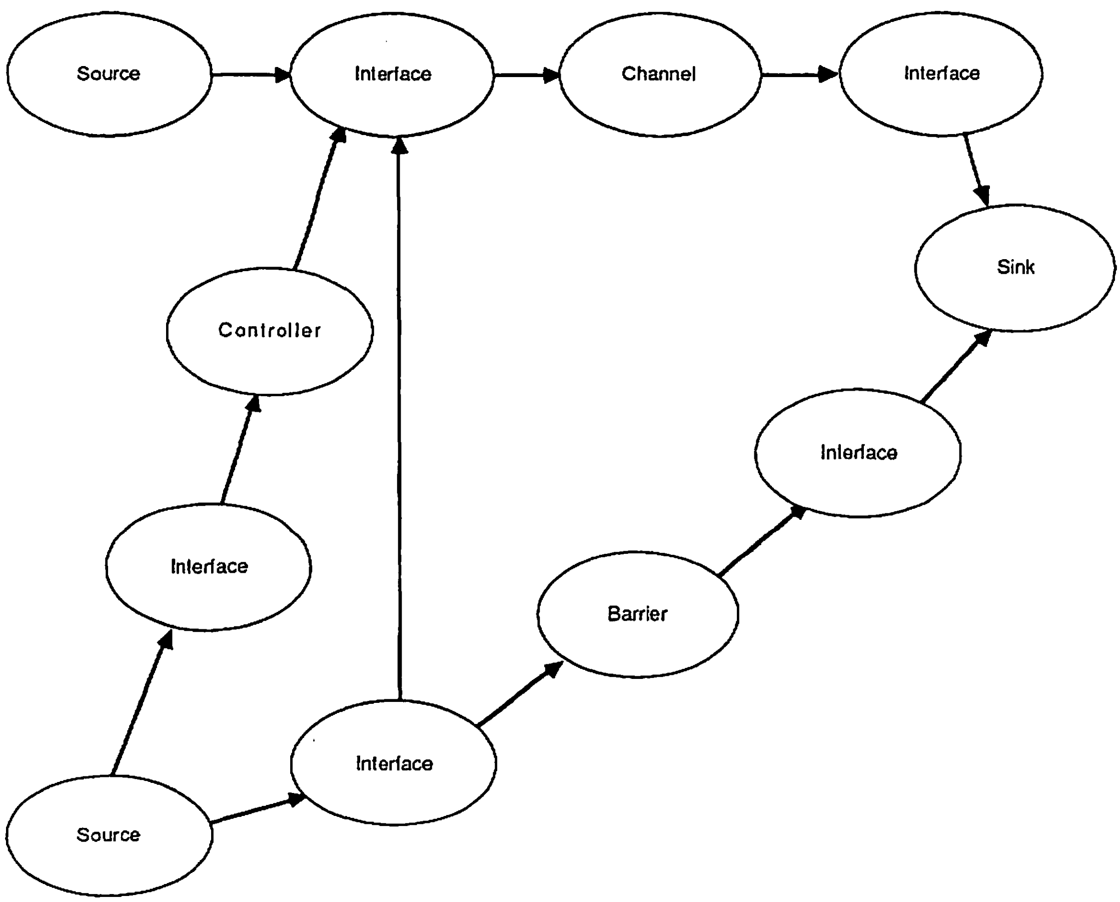


Figure 12−3 A Schematic Illustration of Permissible Connections between Predicated Static Objects. (Note that an "interface" always appears between different types of objects.)

Specifying Location. As well as specifying the flow structure in terms of connected networks of static objects, particular connections can also specify the locations of static and transient objects.

In explanation, a connection between two objects provides two points, but does not specify the distance between them. A measure of location that does not consider distance is generally adequate when abstractly modeling the flow of transient objects. However, when specifically modeling such flow, distance may become important. Distance can be measured on many dimensions, including uni-dimensional, bi-dimensional, tri-dimensional, or even higher order scales. The measurement units within a scale can also vary, as can the coordinate system.

The distance between the two points defined by a connection provides a simple uni-dimensional measure of location. If another location is specified as a reference point, a bi-dimensional measure of location is defined. Analogously, a tri-dimensional measure of location simply requires a reference frame composed of an origin and three orthogonal dimensions. An obvious higher order system would add time to the other three distance related, orthogonal, dimensions. The origin can be arbitrarily assigned, with all other locations defined by respective distances from the origin measured on the three dimensions. For modeling tasks, an origin located within the human's body provides great advantages. Since much of the emphasis here is on perceptual processes, the eye provides an useful origin; other locations such as the center of mass are useful when emphasis is on other processes. For modeling a product, any static component provides a feasible origin.

Transient Relationships Between the Primitive Terms Both functional and structural relationships between primitive terms can have transient aspects. In particular, predicated static objects may be either activated or deactivated; the actor associated with the predicate (source/sink, channel, etc.) is no longer active when a static object is deactivated. Similarly, connections may be connected or disconnected, and objects may be present or not present at locations. Of major interest here are the generic conditions that determine whether static objects are activated.

Activation Conditions. The activation of static objects is determined by the presence of particular transient objects and by the structural relationships between static objects.

In regard to the effects of transient objects, a source must contain a transient object before it can emit a transient object; a transient object must contact a channel, barrier, interface, or controller before it can be respectively transmitted, blocked, transformed, or controlled; and a transient object must contact a sink which has available capacity before it can be received. Additionally, these transient object specific effects may be dependent on the particular types and levels of transient objects, or upon sequences of transient objects. For example, certain channels might be activated by particular forms and levels of energy only after receiving specific information. Such a channel would, of course, contain a controller.

Structural influences on activation are less easy to specify in completely deterministic terms. One such principle is that any object must be connected to a source before it can be activated; such connections can be direct or involve intermediary objects and connections. Less specific principles that influence activation are as follows: 1) Particular interfaces might be required between certain objects and the source. 2) Certain objects might be required to be in particular locations. 3) Certain disconnections might be required. 4) Certain static objects might be required to be disactivated.

A More Detailed Description of Activity Within a Task

It was noted earlier in this chapter that actors are divided into those which "change" states, "transfer" or "contain" transient objects, and "control." The application of an actor from any of these categories (to an object) corresponds to an activity. Figure 12−4 provides a simple schematic that illustrates this. In the figure, all of the actors are in boldface type.

It should also be noted that the activity defined by combining actors with objects is modified both by predicating objects and actors. When objects or actors are predicated, certain more specific actors may be used. For example, if an actor "changes" the level of a transient object (such as energy) in some direction, more specific terms for the actor are "increase" or "decrease." Table 12−3 summarizes several cases where such modification of actors becomes possible. The boxes at the very bottom of Figure 12−4 also illustrate such effects.

Within each of these change, transfer, and control related categories, a very large set of activities are defined by the possible combinations of states, predicates, and actors. The first two sets of such activity shown in Figure 12−4, those which "change" states or "transfer" transient objects separately define changes in state and the process of flow. The third set of activity shown in the figure, "controls" the first two, and is therefore a metalevel activity. Control related activity is typically performed by the human, but may also be performed by machines (such as computers, or simpler controllers) which make decisions.

The following discussion will separately consider these three general sets of activity; 1) activity represented as a change of state, 2) activity represented as the transfer or containment of transient objects, and 3) activity represented as control of change or transfer. The discussion will closely follow the structure of Figure 12−4, but will also reference material in Table 12−3.

Activity as Change The first activity shown near the top of Figure 12−4 occurs when an object's state is changed. The changes may be in those states which are general to all objects, or in states specific to either static or transient objects. A change in state is analogous to an event or the consequence of some process, but is not the process of change itself. This point is important, as the intent here is to explicitly separate state from process. Such separation results in a more modular break-down of activity.

Change of General States. For states general to all objects (both static and transient), the three types of change are in regard to locations, connections, or activation. The actor "change" can be used for all three types of change associated with general states (see Table 12−3). Also, rate is a generally applicable predicate to the actor change. The three generic phrases that use the term change are: change composition of object from material to material; change location of object from location to location; change connection of object from object to object; and change activation of object from active to disactive. The actors connect/disconnect and activate/deactivate more specifically represent changes in connections and activation respectively.

Change of Static Object Specific States. In regard to those changes in state that are unique to static objects, the function based predicates (source/sink, controller, interface, and channel/barrier) can be changed to other function based predicates. For example, a channel might become a barrier or a source a sink. The actors change or become are exclusively used here.

Change of Transient Object Specific States. For the states of transient objects in particular, either the level or type of energy, information, or material can be changed. Energy, information, or material can change from some level to another, as described by the actors

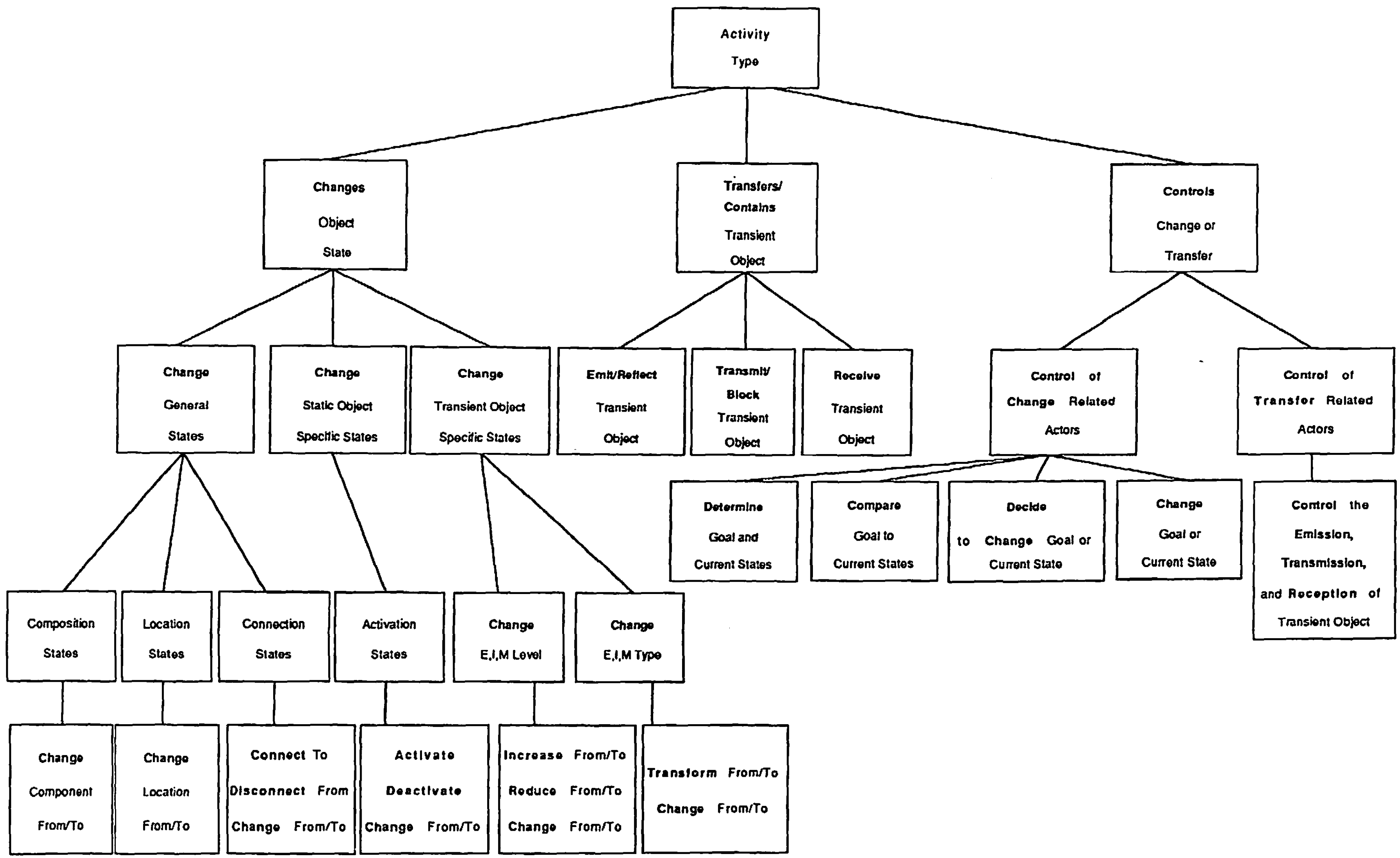


Figure 12–4 An Illustration of the Hierarchy of Actors which Fall within Particular Activities that Take Place within a Task. (Note that the highest level activities are change, transfer, contain and control. Within each of these activities, more specific activities can be described as a function of the type of object an actor is applied to. The type of object is determined by particular predicates. The most specific types of actors are listed at the very bottom of the figure.)

Table 12−3
Generic Actors and their Modifiers.

Generic Actor	Modifying Object of Actor	Modifying Predicate of Actor	Specific Actor
change	general state	rate	change
	composition	rate, efficiency	transform
	location	rate, precision	change
	connection	rate	connect/disconnect
	static object state	rate	activate/deactivate
	transient object state	rate	change
	level	rate	change
		direction	increase/decrease
	type	rate	transform
transform	energy to information	rate	sense
	material to information	rate	sense
emit	transient object	rate	emit
reflect	energy, or energy	rate	reflect
	and material	reflectance	reflect
			apply
transmit	transient object	rate, range	transmit
		attenuation	attenuate
		accentuation	amplify
	information to STM		perceive
contain	transient object	inside	contain
or block		outside	block
receive	transient object	rate	receive
absorb	pure sink	rate	absorb
store	sink and source	rate	store

increase or decrease. They can also change from one type to another, as described by the actor transform.

Activity as Transfer or Containment The second activity shown near the top of Figure 12−4 occurs when a transient object is transferred or contained. This form of activity exclusively represents flow; as such it is explicitly separated from changes in state.

Activity related to the transfer or containment of transient objects consists of several subactivities described by combining particular actors with particular transient objects. Such subactivities include emitting/reflecting, transmitting/blocking, and receiving (the various actors) energy, information, or material (the various transient objects). Objects and predicates that often modify the actors associated with these subactivites are listed in Table 12-3.

Activity as Control The third activity shown near the top of Figure 12 − 4 occurs when either changes in state of any objects or the flow of transient objects are controlled. Control is a higher level activity than either the change of state or the transfer of transient objects, since both state changes and flow are controlled during control activity. Control activity is defined by four other subactivities which include: determining goal and current states, comparing goal to current states, selecting changes in goal or current states, and changing goal or current states.

Change versus Transfer. As shown in Figure 12 − 4, the control of change and the control of transfer are very similar. The primary difference is that the control of transfer is subdivided into the control of emission, transmission, and reception, within which the determining, comparing, selecting, and changing of goals and states takes place. The actors used during the four control related activities do not differ for change and transfer; however, different objects and actors are present within the controlled change and transfer activities. These objects and actors are, of course, respectively the same ones used to define change and transfer related activity.

Control Related Subactivity. The four activities within control are consistent with the activities described by the model of the human specified in Chapter 11. This is to be expected, since much human activity is almost entirely control related. The following discussion will briefly consider each of these activities, and relate them to human information processing. Much of this discussion refers back to Chapter 11. As such, it is very terse.

The first step in control is to "determine" the current states and goals. This can be done only by transmitting information. The human does this by perceiving or receiving current states and retrieving goals. Recall that perception as described in Figure 11 − 11 begins with the transmission of a stimulus to the human's sensors and ends with information in short term memory. That figure provides a detailed view of how the information is transmitted within the human, once energy or material is transformed into information by sensors. Other analysis is necessary to determine the transmission of the stimulus to the human's sensors. Similarly, Figure 11 − 12 provides a detailed view of how goals or current states can be retrieved from memory. Such retrieval can be simply the transmission of information from long term memory to short term memory, or may involve a more complicated interplay with perception.

The second step in control is to "compare" the current state to the goal state. In the description of the human given in Chapter 11, this process is viewed as matching which occurs within decision tasks. Such matching requires that both the goal and current state be broken into dimensions that are then matched. Matching is a complex process that is poorly understood.

The third step in control is to "select" an action, based upon the discrepancy between the goal and current state. The selection of an action, as shown in Figure 11 − 13, may involve retrieval from memory or a more complex problem solving process.

The fourth step in control is to "change" the current condition or goal. The human may change the current condition by executing a motor response as shown in Figure 11 − 19. A motor response, of course, involves the flow of transient objects and the change of states. Alternatively, the human may select a new goal, as shown in Figure 11 − 14.

MODELING THE HUMAN, PRODUCT, AND ENVIRONMENT

The primitive and composite terms described in the previous sections defined the basic building blocks from which models of the human, product, environment, and task can be constructed. This section briefly describes how such models are constructed. Constructing such models is essential to completing the design process in a formulized way, as becomes necessary if such analysis is to be done by a computer program.

Since a vast variety of products and environments exist, each step within the model-building process must be generically defined. This model-building process involves several sequential steps, which include: 1) the elemental breakdown of the product, human, and environment into static and transient components, 2) the related assignment of predicates and actors, and 3) the synthesis of these components. Most of the emphasis here will be regarding the product and environment, since earlier portions of this book (Chapter 11 in particular) describe such a model of the human.

The Elemental Breakdown and Assignment of Predicates

The previous sections provide a generic format for breaking down the product and environment, which will be applied here. This section also provides an example breakdown of several product components and of the human. Importantly, the product, human, and environment are broken-down by following the same procedures. Rather than redundantly discussing this procedure for the product, human, and environment respectively, discussion will focus on the product.

The model-building process begins by simply breaking the product down into its elemental assemblies and components. Once this is done, the classification of product components into static and transient categories may be initiated. This process is rather straight-forward, and easily understood simply by examining typical examples of such breakdowns. Table 12−4 presents an example of such classification of common product components into static and transient objects, and also illustrates the associated predicates and actors. Table 12−5 illustrates a similar breakdown of human components. These two tables are presented for illustrative purposes, and as such are by no means exhaustive.

As shown in both tables, the functional aspects of each example component are defined by combining particular predicates of static objects, an actor, and a predicated transient object. For example, a battery is a source which contains or emits electrical energy, assuming that it is activated. (Note that the table implicitly assumes the source is activated.) Similarly, a fuel reservoir is a source which contains or emits material and potential energy.

Components with Multiple Functions The classification procedure becomes more complicated when applied to aggregate components, because aggregate components (and even some elemental components) will frequently have multiple functions. For example, a battery, which is a simple example of an aggregate component, becomes a sink that receives electrical energy when it is being charged, and the outer shell of the battery is a barrier that blocks material from within the battery from being transmitted to the environment. Although there is no fundamental problem with the assignment of multiple functions to components, it is frequently desirable to break down the component further into components which more specifically perform the multiple functions. For example, the battery can be further decomposed into terminals (interfaces), outer shell (barrier), plates (source), acid (channel), etc.

Table 12-4
An Example Classification of Common Product Components into Predicated Static and Transient Objects.

Predicated Static Object	Actor	Predicated Transient Object	Example Components
source	emits and contains	electrical energy	battery, outlet
		mechanical energy	fly-wheel
		thermal energy	heat reservoir
		material and mechanical energy	pressure reservoir
		material and potential energy	fuel reservoir
		radiant energy and information	printed matter
		information	memory
sink	receives or contains	information	memory
		thermal energy	heat sink
		electrical energy	ground, battery
		mechanical energy	fly-wheel
interface	connects and/or transfers	electrical energy to channel	connector, plug, wire wrap
		mechanical energy to channel, or static to static objects	connector, screw, washer, weld gasket, rivet, bearing
		thermal energy to channel	connector
		human to product	handle, control, switch
		mechanical energy to sink	blade, head, sole, tread
		thermal energy to sink	heater or radiator coil
		material to sink	mouth
	transforms	energy to information	sensor
		material to information	sensor
		material to thermal energy	combustion chamber
		electrical to mechanical energy	coil, motor
		electrical to thermal energy	heater-coil
		mechanical to electrical energy	generator
		radiant to electrical energy	semi-conducting diode
		electrical to radiant energy	diode, light

Table 12–4
(continued)

Predicated Static Object	Actor	Predicated Transient Object	Example Components
	transforms	thermal to mechanical energy	heat engine
channel	transmits	radiant energy electrical energy thermal energy mechanical energy thermal energy and material mechanical energy and material information	air, water, glass wire, other conductor heat conductor drive-shaft, belt, chain pipe, duct, hose pipe, duct, hose data bus
barrier	blocks	radiant energy electrical or thermal energy mechanical energy materials information	outer shell insulation, gap barrier, guard, gap outer shell noise
controller	controls	electrical energy mechanical energy thermal energy mechanical energy and material information	regulator, relay, switch control, clutch, switch thermo-couple valve, regulator, computer computer, integrated display

Table 12–5
An Example Set of Generic Objects and Predicates Used in Task Analysis That Represent the Human.

STATIC OBJECT NAME	PREDICATES OF THE STATIC OBJECT	ACTOR	TRANSIENT OBJECT	PREDICATES OF THE TRANSIENT OBJECT
Memory	Source,	Emits,	Information	
	Sink	Receives	Code	Spacial, Verbal
Retina	Input Interface	Receives	Energy	
		Transforms	Type	Radiant
			Threshold	$10^{-6}-10^{-4}$ mL
	Channel	Transmits	Information	
			Code	Spacial, Intensity
Cochlea	Input Interface	Receives	Force	
		Transforms	Type	Mechanical
			Threshold	$2x10^{-4}-10^{-3}$ dyn/cm^2
	Channel	Transmits	Information	
			Code	Spacial, Intensity
Vestibular System	Input Interface	Receives	Force	
		Transforms	Type	Mechanical
			Threshold	.02 to 8 G's
	Channel	Transmits	Information	
			Code	Intensity
Tactile (mechano-ceptors)	Input Interface	Receives	Force	
		Transforms	Type	Mechanical
			Threshold	.04 to 1.1 erg
		Transmits	Information	
			Code	Intensity
Tactile (thermo-ceptors)	Input Interface	Receives	Force	
		Transforms	Type	Thermal
			Threshold	15 x 10^{-5} – 22 x 10^{-2} gm-cal/cm^2/sec
	Channel	Transmits	Information	
			Code	intensity
Gustatory	Input Interface	Receives	Material	
			Type	Liquid
			Composition	Salt, Sour, Bitter, Sweet
			Threshold	varies extensively
	Channel	Transmits	Information	
			Code	unknown

Table 12−5 (continued)
An Example Set of Generic Objects and Predicates Used in Task Analysis That Represent the Human.

STATIC OBJECT NAME	PREDICATES OF THE STATIC OBJECT	ACTOR	TRANSIENT OBJECT	PREDICATES OF THE TRANSIENT OBJECT
Olfactory	Input Interface	Receives	Material	
			Type	Gas
			Threshold	varies extensively
	Channel	Transmits	Information	
			Code	unknown
Stretch Receptor	Input Interface	Receives	Force	
			Type	Mechanical
	Channel	Transmits	Information	
			Code	intensity
Effector	Channel	Transmits	Force	
			Type	Mechanical
			Level	varies
	Output Interface	Emits	Energy	
			Type	Mechanical
Nerve	Channel	Transmits	Information	
			Code	temporal, intensity, spacial
Cerebellum	Control Interface	Controls	Energy	
			Type	Mechanical
Motor Cortex	Control Interface	Controls	Energy	
			Type	Mechanical
Skin	Output Interface	Emits	Energy	
			Type	Thermal
			Material	
			Composition	Liquid
Skin	Barrier	Blocks, Contains	Energy	
			Type	Thermal, Mechanical Electrical, Radiant
			Material	
			Composition	Gas, Liquid, Solid
Skin	Channel	Transmits	Energy	
			Type	Thermal, Mechanical Electrical, Radiant

Care must be taken when such decomposition is performed, since certain functions arise from the interaction of components. For example, a tire-wheel assembly (comprised from a rim, a tubeless tire, and pressurized air) is a barrier that blocks pressurized air from being transmitted to the environment. (Obviously, it also has other functions.) However, no single component can be isolated that performs this function. Consequently, the decomposition should always be heirarchically performed, beginning from top level aggregate components and ending at elemental components.

An Example Product Breakdown Table 12−6 provides an example of a partially developed classification matrix for a tire/rim assembly. In developing this matrix, analysis began with the aggregate assembly, and worked down to elemental components. At each stage in analysis, the classification process was first guided by assigning the specific function based predicates to product components to define static objects, and then analyzing the transient objects, actors, and predicates associated with the particular static objects. The resultant matrix illustrates the functional complexity of a product which initially appears to be quite simple. The resultant matrix also shows that this very generic and simple classification procedure can generate very detailed and specific outputs.

Synthesizing the Elemental Components into a Model

The classification of components, as described above, provides a substantial step toward model development. The remaining step is to organize the defined objects and actors within a network that describes the product, human, or environment in a form that can be further analyzed with minimal effort. Along these lines, Chapter 11 has already provided a defining network model of the human, what remains is to define networks for particular products and environments. Such networks must specify the remaining predicates which define states, as well as describe the flow of transient objects.

In particular, a way must be developed for systematically describing the activation of the functions specified by the classification. It is assumed here that the clearest method of describing activation conditions is to develop networks that explicitly show the connections between objects and then relate them to logically describe events.

This overall process consists of two major steps. The first is to develop a flow diagram which describes the flow of transient objects. The second step is to develop a logic-state diagram which describes the activation conditions for these flows.

Development of the Flow Diagram The first step in model development is to specify the flow of transient objects. This is done by developing a flow diagram in which the static objects are nodes and the transient objects together with actors are links. Recall that static and transient objects, as well as actors are defined by developing the earlier referred to classification matrix (Table 12−6).

A flow diagram contains the same information given within the classification matrix, but provides it in a format that is easier to interpret. In particular, for added simplicity, separate flow diagrams can be respectively developed that abstractly model energy, information, and material flow. Although the flow diagram is easier to interpret, the classification matrix is easier to develop. Consequently, the methodology proposed here emphasizes both the development of the classification matrix and the flow diagrams.

Table 12-6
An Example of a Partially Completed Matrix that Breaks Down or Classsifies a Tubeless Tire.

STATIC OBJECTS			Predicated Actor	TRANSIENT OBJECTS		Primary Activation Condition
Component Name	Specific Predicates	Generic Predicates		Name	Predicates/ States	
TIRE-RIM ASSEMBLY	source	connects to axle, road	contains (within)	air pressure	material (gas, .5−2 ft^3), force (mechanical, 25−35 psi)	air pressure > 15 psi
			emits (release)	air pressure	material, force, energy	barrier (connected tire components) deactivated
			emits (reflects)	light and Information	radiant energy, information	radiant energy connects to source
	interface	connects axle to road, tire/ rim to environment channel	transforms (low efficiency)	impact to heat	mechanical to thermal	car is energized
			transforms (channel change)	impact to noise	mechanical to mechanical	car is energized
	channel	connects to axle, road	transmits (attenuates)	impact	energy (mechanical)	connecting car to road, and energizing car
	channel	connects to axle, road	transmits (direct)	weight of car	force (mechanical)	connecting car to road

Table 12–6 (continued)
An Example of a Partially Completed Matrix that Breaks Down or Classifies a Tubeless Tire.

STATIC OBJECTS			Predicated Actor	TRANSIENT OBJECTS		Primary Activation Condition
Component Name	Specific Predicates	Generic Predicates		Name	Predicates/ States	
	sink	within object connection	receives (absorbs)	heat	thermal energy	tire/rim transforms impacts to heat
SELECTED COMPONENTS						
Tread	interface	connects sidewall to road	receives	impact	energy (mechanical)	car is energized
			emits	motive force	force (mechanical)	car is energized
			transforms	impact to noise	mechanical energy to mechanical energy	car is energized
Sidewall	interface	connects tread to bead, connects to air	transforms (low efficiency)	impact to heat	mechanical to thermal	activated by energizing car
stamped message	source	connects to sidewall, environment	emits (reflects)	light and information	radiant energy, information	radiant energy connects to source
Bead	interface and barrier	connects rim to sidewall	blocks (within)	air pressure	material (gas, .5–20 ft^3), force (25–35 psi)	connecting bead to rim
Valve Stem	interface	connects sidewall to valve	transfers (to/ from)	pressurized air	material (gas), force (mechanical)	connect environmental source to valve
Valve	interface and controller	connects valve stem to source	control transfer (rate)	pressurized air	material (gas), force (mechanical)	air pressure

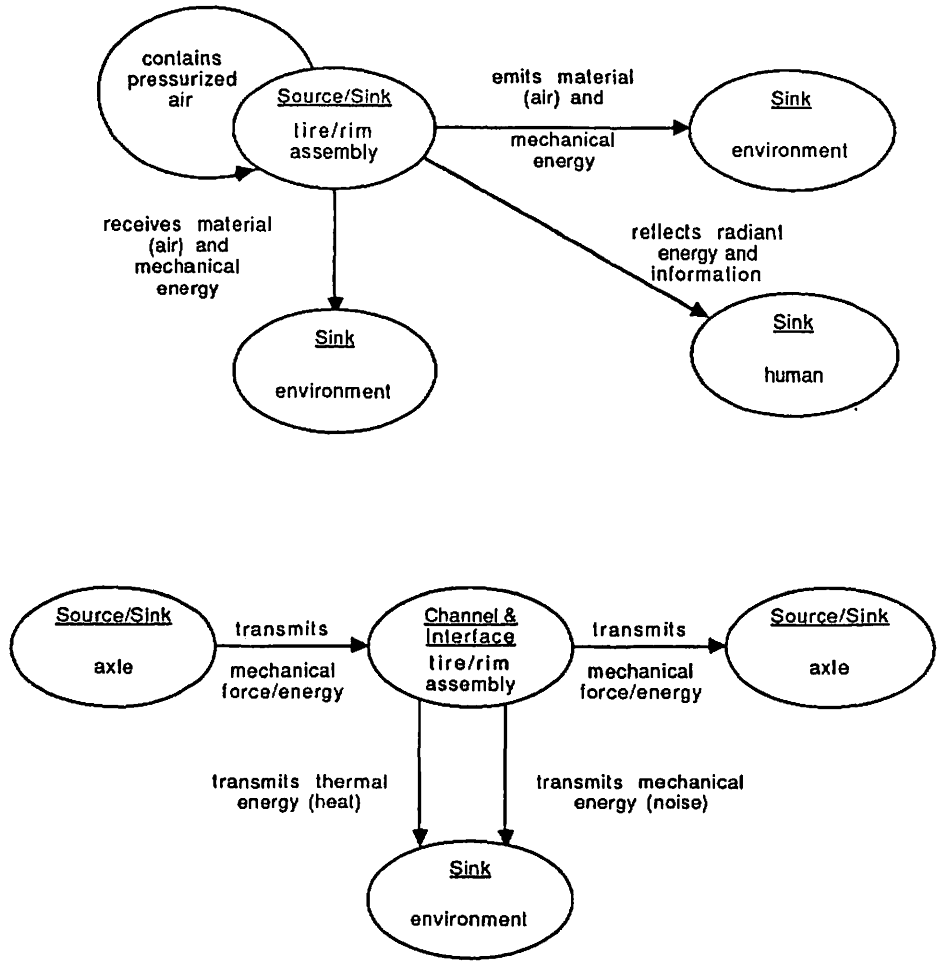


Figure 12–5 High Level Flow Diagram for Tire/Rim Assembly.

Example Development of the Flow Diagram. Figure 12–5 provides a simple example of a flow diagram developed for tire-wheel assembly described in Table 12–5; Figure 12–6 provides a somewhat more complex diagram for a hair dryer. Each of these example diagrams are developed at the general level of abstraction associated with assemblies of components, rather than the detailed level of abstraction associated with elemental components. Similar diagrams can be developed for the elemental components.

These more detailed diagrams should be separately developed for each of the functions described by the general diagrams, because a single diagram consisting of all elemental components is likely to become very complicated.

Development of the Logic State Diagram After specifying the flow of transient objects, the next step is to develop a network which models the flow-related activation conditions and other states. It is necessary to develop such a diagram to represent when and why flows occur; the flow diagram only describes how they occur.

The diagram which does this is called a logic state diagram. The logic state diagram uses logic gates to relate elements of the flow diagram to activation conditions. Recall that

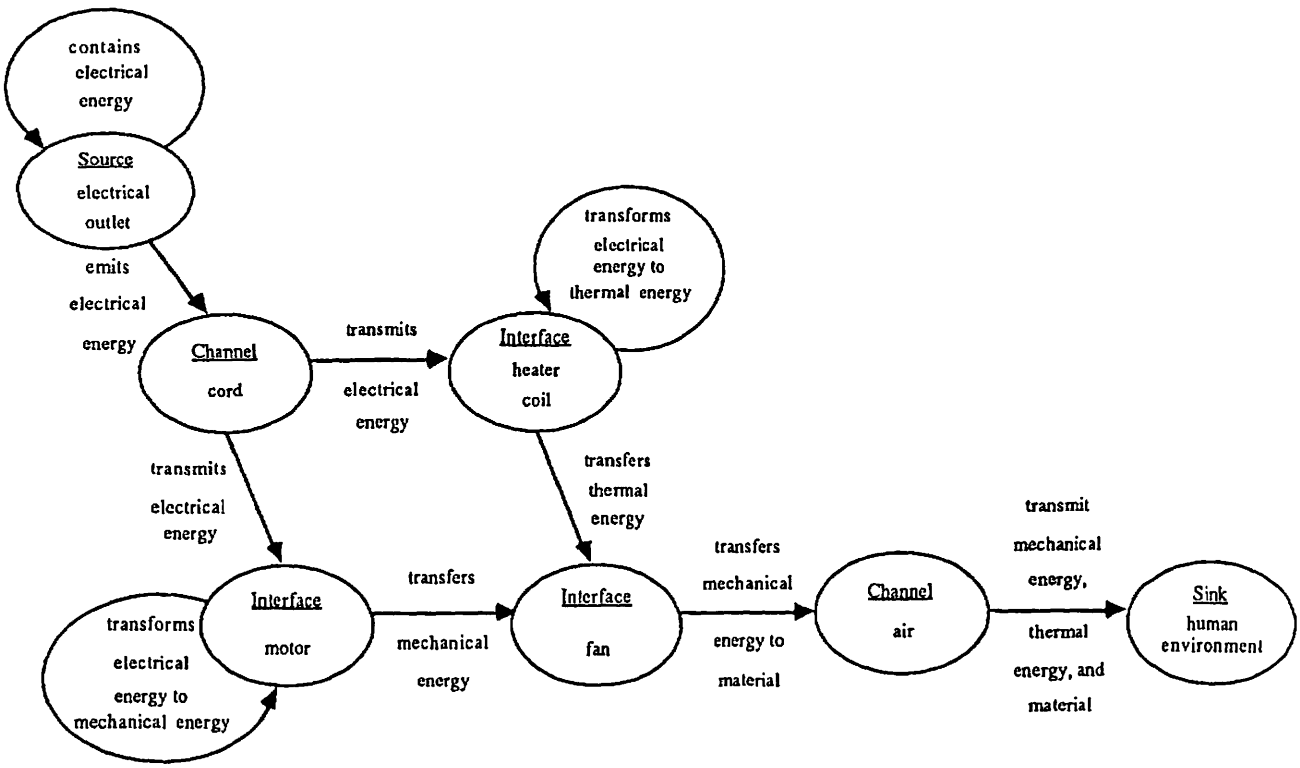


Figure 12−6 A High Level Flow Diagram for a Hair Dryer.

activation conditions were discussed earlier in the section on transient relationships between primitive elements.

During the development of a logic state diagram, the hierarchical specification of assemblies and components should be emphasized, as should the further breakdown of activities to determine activation conditions. Development of the logic state diagram begins with the high level functions described in the classification matrix and the flow diagram. Each of these functions has an associated set of activation conditions which are then further defined by the functions of less aggregated components.

Example Development of the Logic State Diagram. Figure 12−7 illustrates the generic structure of the logic state diagram. At the top level of the diagram, it is shown that the product description consists of several generic functions. These functions are described by the generic predicates of static objects (at this level the predicates are assigned to modular assemblies of the product) and are also found on the abstract flow diagrams. Each function has associated activation conditions that are described by another set of generic functions. These generic functions are analogously described by assigning the same predicates to elemental components. As also shown in the figure, the generic functions at this lower level are either based upon elemental components alone or the interaction of elemental components. Interactions, of course, are generally defined by subassemblies or combinations of elemental components. Interactions are also described by defining activities in more detail.

Figure 12−8 illustrates an example of a partially completed logic state diagram. This diagram is derived from and includes much of the flow diagram illustrated in Figure 12−5. To show the correspondence between these two figures, consider the channel/barrier defined

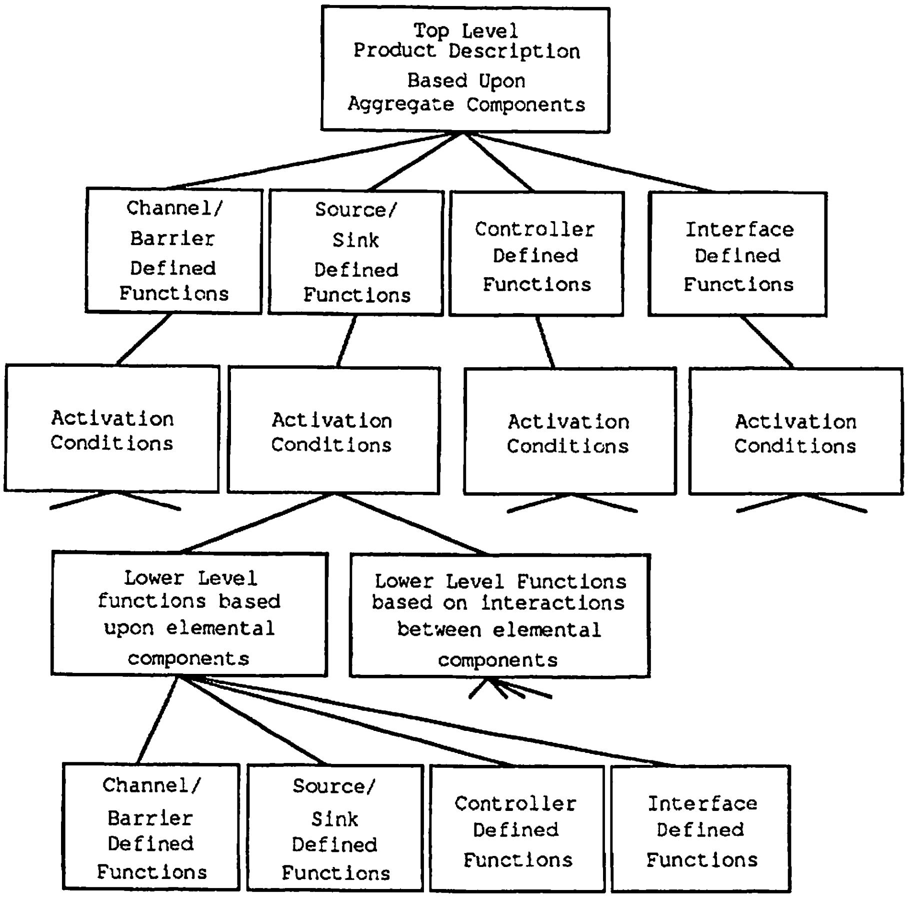


Figure 12−7 A Generic Description of the Logic State Diagram for Products.

functions defined in Figure 12−8. The two functions shown below the OR gate simply provide an state or event based description of part of the flow illustrated in Figure 12−5 (the flow between the channel and the two source/sinks representing the axle and road). These two functions, represented as events, are activated when other events take place. Activation related events are not shown by the flow diagram, but follow directly by further decomposing the tire/rim assembly and applying the definition of the actor transmit. (Recall that Figure 12−4 describes the actor transmit.)

Each of the other high level functions in Figure 12−8 can be further described with the same approach to ultimately provide a detailed description of the product.

MODELING THE TASK

In this section, discussion is directed toward describing a knowledge based approach that corresponds to Stages 1, 2, and 3 within the design process discussed in Chapter 10: The first section "Elemental Tasks and Their Sequences," corresponds to Stage 1 which was entitled there as "Specify the General Information Flow." The second section "Deriving the Criticality of Tasks," corresponds to Stage 2 which was entitled "Isolate Critical Information Transfers."

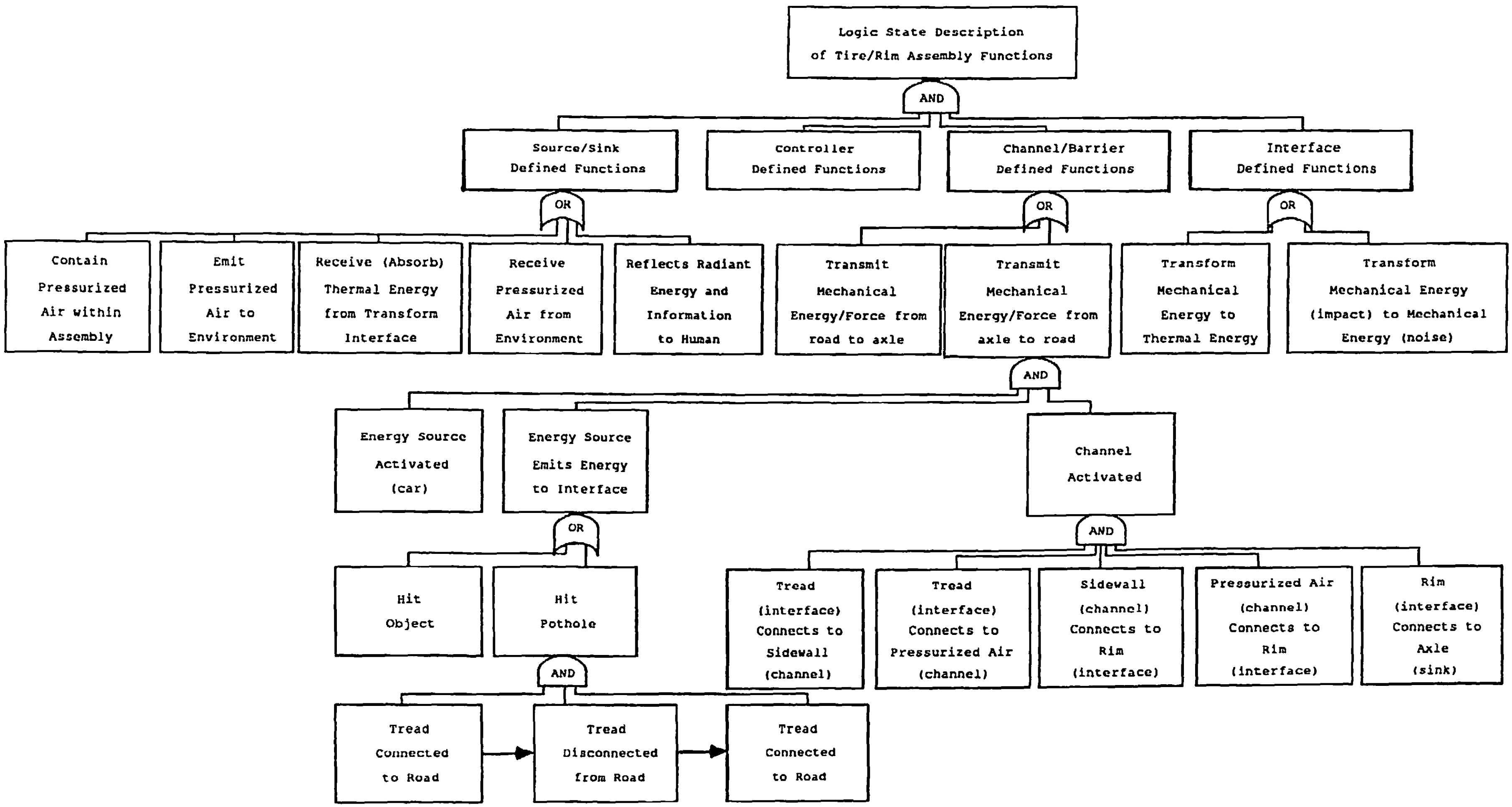


Figure 12-8 A Partially Completed Logic State Diagram that Describes the Functions of a Tire/Rim Assembly.

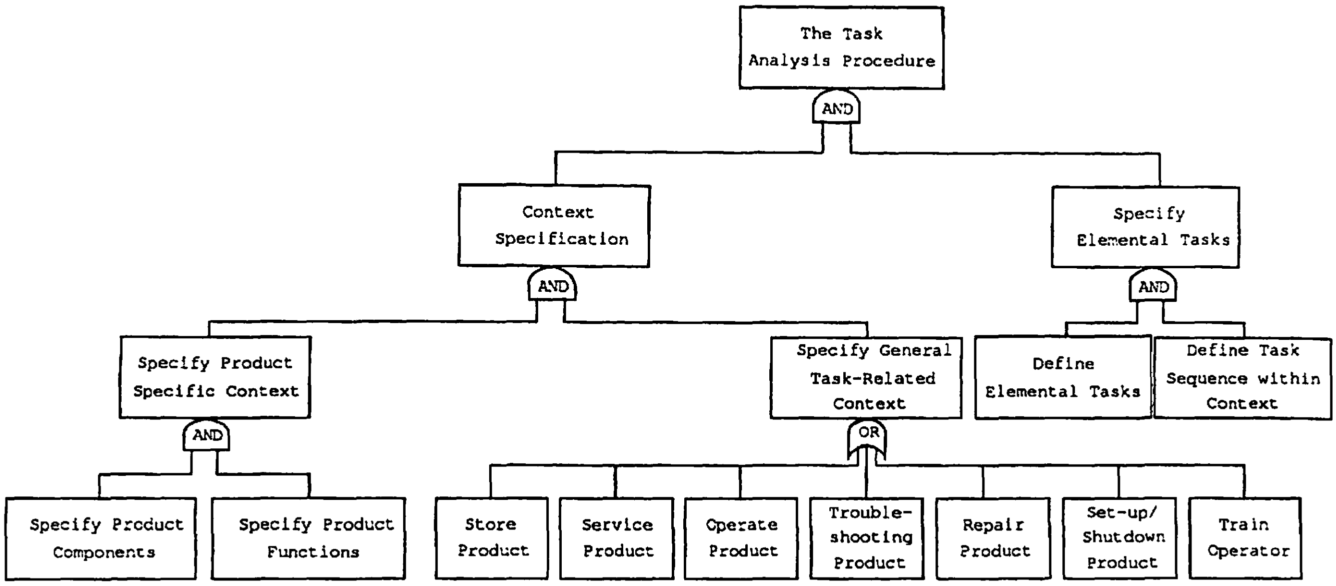


Figure 12–9 General Overview of Task Analysis Procedure.

The third section "Modeling the Message," corresponds to Stage 3 which was entitled "Describe Critical Information Transfers."

The discussion is heavily oriented toward applying the modeling techniques described in the earlier sections of this chapter. As such, it supplements the more easily applied concepts described in Chapter 10.

Elemental Tasks and Sequences

As noted earlier, the models of the human, product, and environment can be combined to define a task. A task is defined by developing a task definition network (see Chapter 11), where a task definition network simply defines each task heirarchically in terms of related subtasks. The relationships between tasks are represented by sequentially connecting the tasks within the network. These elemental tasks and their relationships are developed during task analysis.

Figure 12–9 summarizes a general model that describes the process of task analysis. The model essentially subsumes the elements of task analysis discussed earlier in Chapter 10. Since much of that earlier discussion remains relevant, only those aspects of task analysis unique to this modeling approach are described.

As shown in Figure 12–9, task analysis requires that both the context and elemental tasks be respectively specified, the latter always within specific contexts. Product- and task-related contexts are distinguished in this modeling approach. The product related context is specified by developing a model of the product, as outlined in the previous section. The task related context is specified in terms of particular use phases (also described in Chapter 10), which include storage, service, operation, trouble-shooting, repair, set-up/shut-down, and training. Within each of these use phases, tasks are performed. Such tasks are specified within each context by developing a task definition network.

Specifying the Task Definition Network The specification of a task definition network is guided by the product- and task- related contexts. In particular, the functions of the product, as described by its model, act as a map that guides analysis; for each function, certain tasks immediately are defined. As an extreme example, no tasks are associated with a product that has no interfaces. Analogously, a product with an interface, lets say a handle, immediately suggests that analysis should be performed regarding the control of energy and information flow.

The task-related context plays a similar role during this process. Figure 12−10 schematically illustrates how the task related contexts helps organize the analysis. Listed beneath the very highest box in the figure are the task-related contexts. Within each context, the tasks are defined by the initial states, activity, and the goal states. As also shown, the states and activity within each defining aspect of the task are significantly contrained by the product's functions. Furthermore, such activity can be broken down into that associated with state changes, flow, and control.

Steps in Development. To develop the task definition network, the following steps can be followed: 1) determine which use phases are relevant, 2) for each use phase determined to be relevant, specify the initial states and goal states, 3) analyse the activity between the initial and goal states in terms of control.

In regard to the first step, a rough rule is that (for most products) each use phase will be relevant. This follows because the listed use phases are extremely general. It is likely, however, that certain use phases are relevant only for particular user groups.

In regard to the second step, it appears that the initial and goal states associated with each use phase will usually be obvious. For example, most static objects will be deactivated at the beginning of the task; a goal during "set-up" might be to activate a particular static object. Similar simple examples can be given regarding the initial and goal states associated with the locations and connections of static objects, or in regard to the flow of particular transient objects.

The primary emphasis is on the third step during this phase of task analysis, because the models of the product, human, and environment define and constrain many of the state change and flow related activities. To analyse control activity, the general approach is to specify a sentence within each use phase along the lines of "Use phase (service, operate, trouble-shoot, set-up/shutdown, repair) product (assembly, subassembly, component) using object." Within each use phase, the obvious tasks are then suggested by the functions related to static objects. These functions are all listed at the top level of the product's logic state diagram, as shown in Figure 12−8 for the tire rim example.

An Example Network. Rather than further discuss the process of task analysis, an example illustrating a partially defined task definition network is given in Figure 12−11. In this example, the product is a tire and a portion of the "operation" use phase is considered. Note that at the top level, the tasks are respectively to 1) activate the source of energy and information (the car), 2) control the energy flow to the tire, and 3) deactivate the energy source.

These elements occur in a sequence, which is represented by the connections between the tasks. The control task is further defined using a logic network where the lower level tasks are subtasks. The lowest levels of the diagram simply describe the transmittal of force in the same way that was used earlier in Figure 12−8 to model the product. By examining this figure, it becomes apparent that use phases and high level subtasks are too general to describe accident influencing events. Instead, such descriptions must be described in terms of elemental tasks.

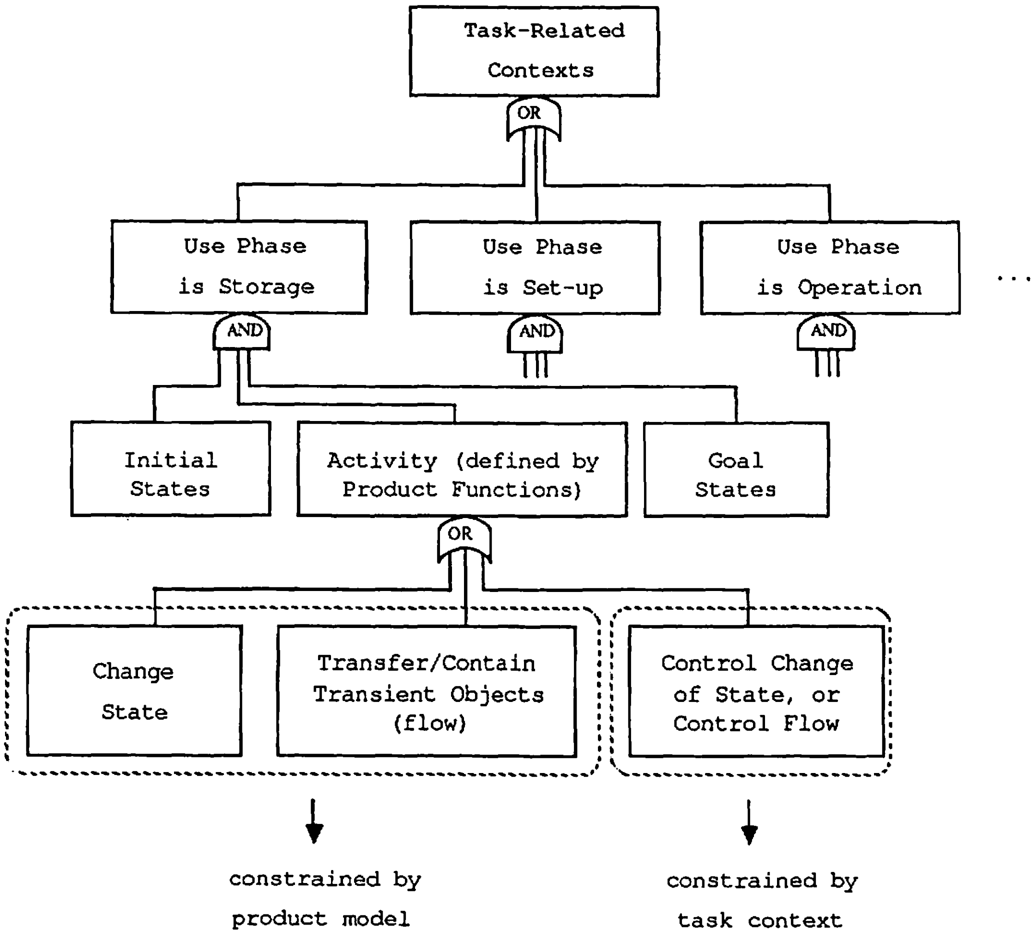


Figure 12–10 The Product Use Phase Tree.

Deriving the Criticality of Tasks

The model of the task (developing this model corresponds to completing Stage 1, discussed in Chapter 10) is a task definition network or, in other words, a positive tree which describes safe performance of the task. The task definition network is the complement of, what is called here, a failure network. Both task definition networks and a variety of failure networks are used within task performance networks. The task performance network, as discussed in Chapter 11, documents both desired and undesired events during the use of a product.

In deriving the criticality of tasks, the first step involves developing a task performance network. After developing such an network, the critical tasks therein described must be isolated. Completion of these two steps is equivalent to completing Stage 2 in the Chapter 10 design process.

The Task Performance Network The task performance network is specified by systematically assuming that certain elemental tasks are not performed adequately or that product failures occur, and then evaluating the effects. Consequently, performing this procedure is equivalent to performing Failure Modes and Effects Analysis (FMEA).

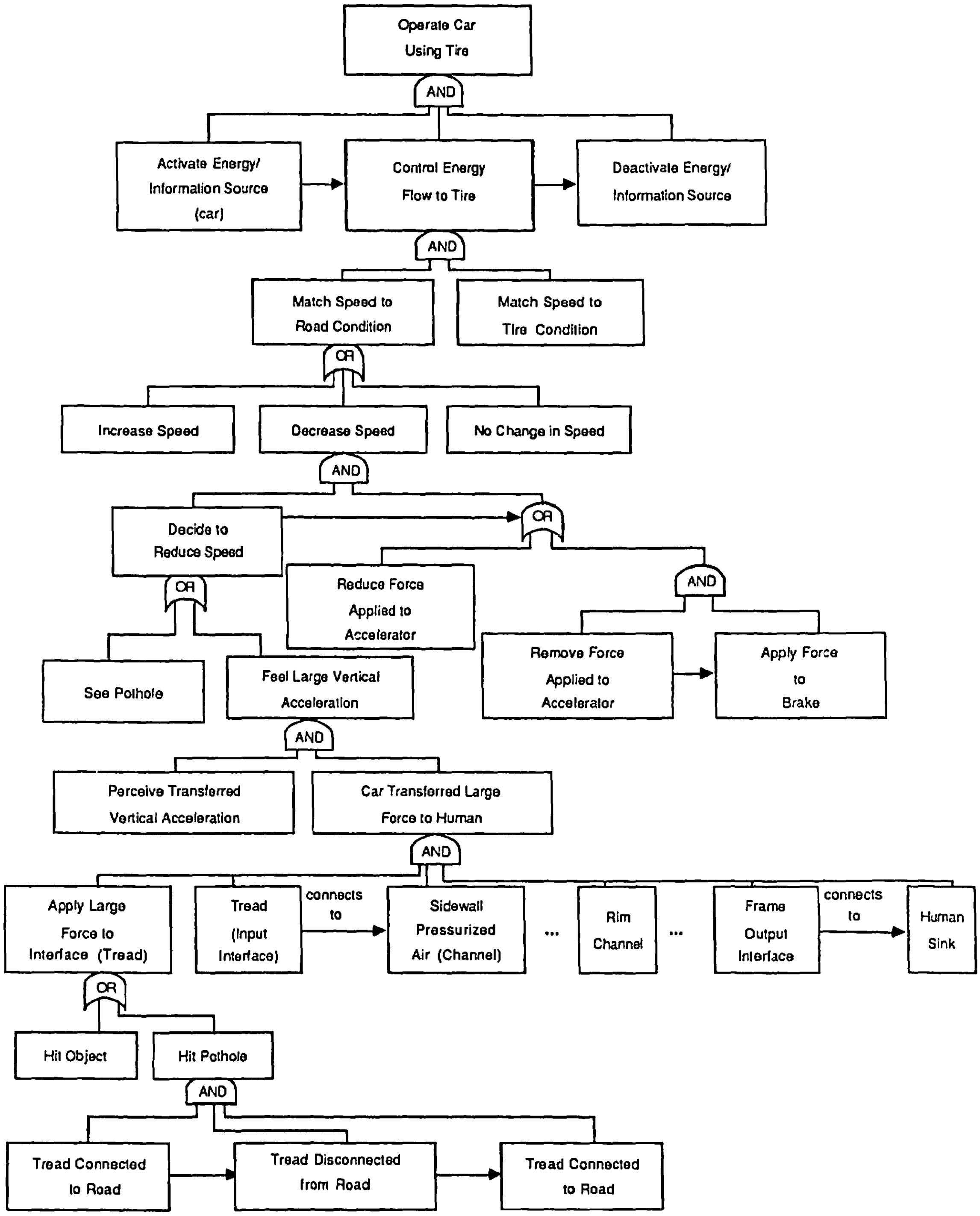


Figure 12−11 An Example Illustrating the Flow of Energy and Information in the Use of a Tire.

Development of the task performance network involves the following steps: 1) develop the task definition network − the positive tree developed during task analysis, 2) develop the task failure network − an initial failure network defined by failures on subtasks, 3) develop the product failure network − an initial failure network defined by failures of product components, and 4) develop the environmental perturbation network.

Final specification of the task performance network is then accomplished by replacing successfully performed subtasks, product functions, and environmental functions with the corresponding elements of the task failure, product failure, and environmental perturbation networks.

Developing the Failure Networks. Before the respective failure networks can be developed, the respective models of the human, product, and task must be developed, as given by the task definition network or product logic event diagram. It is also necessary to specify the types of failures which might occur, since the failures themselves are organized in these failure networks. The earlier sections have described these needed models, the following discussion briefly considers other topics specific to the development of the failure network.

A general method of specifying subtask and product failures is to alter the states within the task definition network and the product's logic event diagram. Such alterations include breaking designed connections or forming other non-designed connections, deactivating or activating objects, changing the locations of objects, or increasing or decreasing flows. In many cases, this can be simply done by using the inverse of the actor used to define an activity (replace connect with disconnect, activate with deactivate, transmitt with block, etc.). In other cases, such effects are induced by changing transient objects to different levels or types.

To develop or build the respective failure networks, the simplest procedure is to initially begin with the positive tree that defines the task. Failures on subtasks then propagate directly up the tree in accordance with its logical structure. In other words, a failure on a subtask below an AND gate will cause the task above it to fail; also, each subtask below an OR gate must fail to cause the task above it to fail. This concept is schematically illustrated in Figure 12-12. (The successful versus unsuccessful performance of Task 1, as shown in the figure illustrates these concepts.) A topdown approach can also be taken for defining events other than task failures. In other words, failures can result in new events which are not specified in the task definitionnetwork. Such events can describe accidents, and are also schematically illustrated in Figure 12-12. In particular, undesired events 1 through 5 are not included in the task definition network but appear in Figure 12-12.

Figure 12-13 provides a simple example of how a subtask failure can cause an event which is not within a normal task. In this example, lubricating a tire bead is a subtask ANDed below the assembly task wherein the rim is connected to the tire. The failure to lubricate and the activity of a tire changing machine combine to define an event in which the bead of the tire is damaged. This damage can then combine with other activity to define further accident related events.

Combining the Failure Networks. The final step in specification of the task performance network involves combining the respective failure networks into an overall task performance network. Such development augments those events defined by the respective failure networks.

In other words, failures on one network can be related to failures on a different network, when they are combined within a larger more encompassing network. For example, consider the effects of incorporating a product failure network within a task performance network. A basic result is that a failure of a product component may degrade subtask performance, thereby providing a more detailed description of subtasks. Also, product failures can cause events to occur which were not originally documented within the task performance network, since the subtasks are originally created with the assumption that the product is functional.

A portion of Figure 12-12 illustrates how the performance of an elemental task (e_2) depends upon product related functions. In particular, the elemental task can fail if force is not transferred from the (product's) interface to (its) sink. Not shown in the figure is that breaking

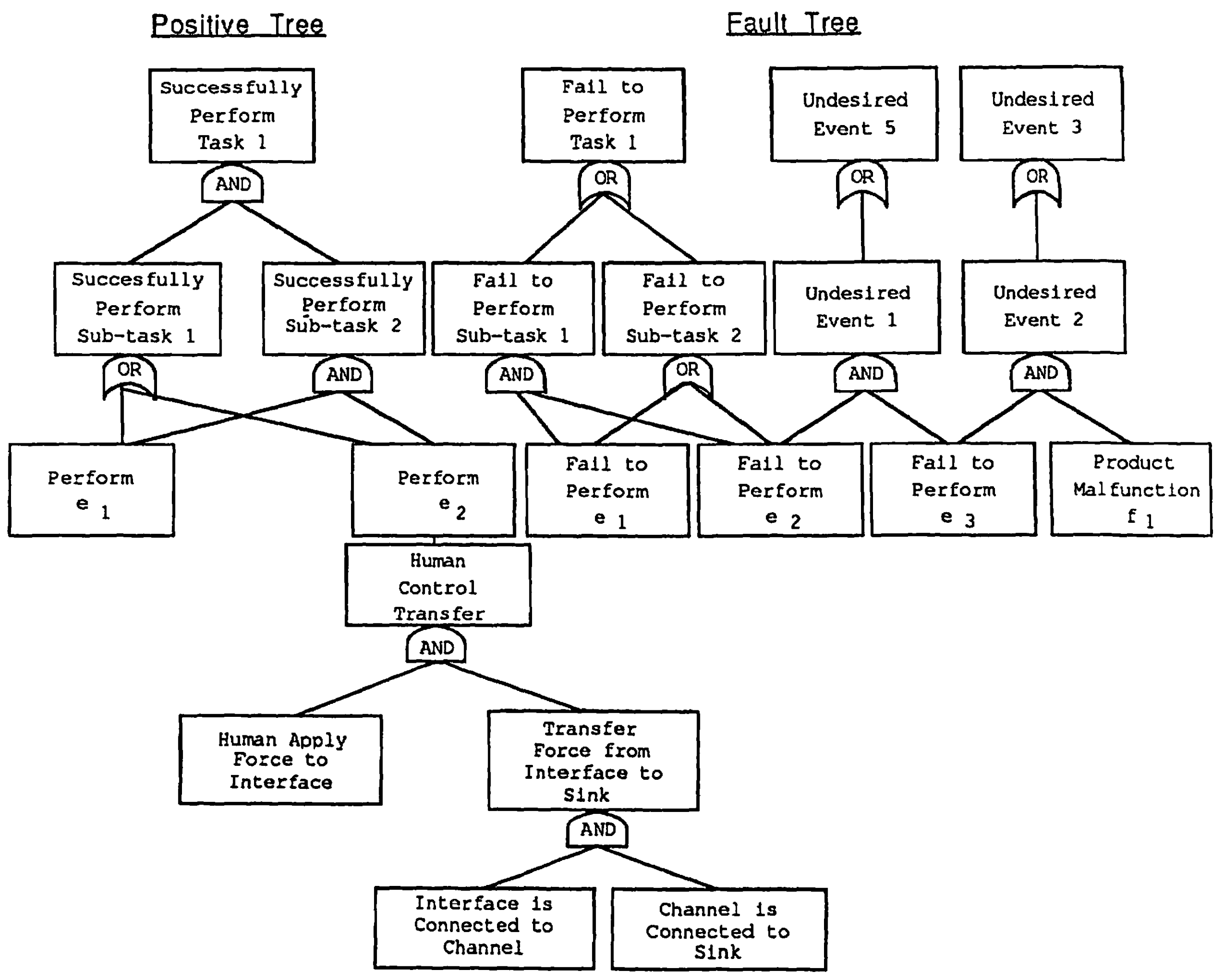


Figure 12 – 12 A Schematic Illustration of the Way Subtasks and Product Failures Combine Within the Task Performance Network.

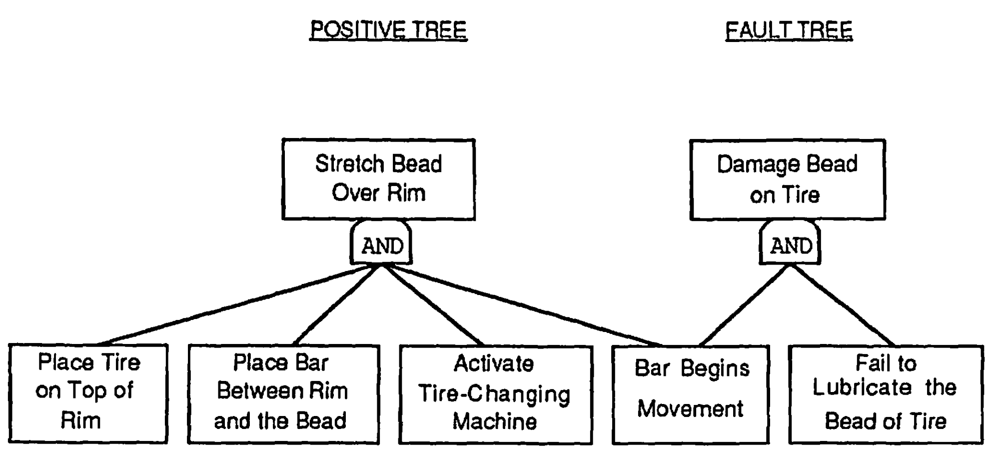


Figure 12 – 13 An Illustration of How a Subtask Failure in the Tire/Rim Example Can Cause Events not Shown in the Task Definition Network.

a connection, or some other product malfunction, will cause the force not to be transferred. This product-failure-related logic is independent of the task, explaining why the product failure network can be developed independently of the task, and then be inserted into the task definition network to influence task performance.

Criticality Assessment From the simplest perspective, critical subtasks are those for which a failure causes significant damage-related events. Accordingly, critical information transfers are those flows of transient objects to the human which are essential to successful performance on critical subtasks. Analogously, critical product failures are those failures which can cause damage-related events. Information transfers which indicate critical product failures are also critical.

In the example illustrated by Figure 12−13, the critical information transfers are those flows of transient objects which convey the potentially hazardous condition of an unlubricated bead and the damage to the bead. In the example of Figure 12−11, two critical information transfers are present that define road conditions. These transfers can respectively be described in terms of the flow of mechanical and radiant energy. Of interest is that, in each of these cases, the critical information transfers can be directly inferred from the task performance networks.

As noted in Chapter 10, criticality analysis should also emphasize the probability and magnitude of damages. Such analysis will not be considered here, since the earlier discussion in Chapters 8 and 10 has already addressed this issue. It should be emphasized, however, that such analysis can also be guided by the task performance networks, since the networks themselves are isomorphic to those generated during FTA or FMEA.

MODELING THE MESSAGE

The final topic considered in the chapter refers to the process of modeling messages. Such analysis, of course, corresponds to performing Stage 3 of the process described in Chapter 10. The topic is not addressed in detail here; many additional points of interest are given in Chapters 10 and 11. In particular, Chapter 11 describes the process in which meaning is derived from stimuli and also considers ways of describing safety information in terms of the primitive knowledge components described in this chapter. Chapter 10, on the other hand, applies the taxonomies of warning types and scenarios to document particular warnings. Since the material shared between Chapters 10 and 11 is reasonably comprehensive, this chapter only considers some correspondence between the elements of the defined models and aspects of message meaning.

The first and most obvious point is that each model referenced in this chapter is specified in terms of the primitive objects referred to as describing components of message meaning in Table 11−4. For examples, the reader can refer back to Table 12−6, Figure 12−5, and Figure 12−6. Many other tables and figures in this chapter provide similar descriptions of actual product, human, or task components described in accordance with these primitive objects. A second and also obvious point is that these primitive objects can be recombined into conditions and actions that relate to the higher elements of safety meaning in a way entirely consistent with the hierarchy of risk-related knowledge documented in Table 11−4.

As implied by the above two points, this approach allows human cognition and knowledge to be modeled in exactly the same way as are products, tasks, and messages, which results in a common basis for analysis. Many advantages are associated with a common basis for analysis. In particular, models of the human, product, and task can be combined into larger models which have implications toward the design of specific messages. Specifying the detailed relationships between these various models would, however, be a tedious time-consuming process for a human. Fortunately, many of these relations are well captured by the generic categories and combinations of knowledge primitives described here. This latter point indicates that computerized approaches have significant potential as a means for implementing this modeling approach. As such, there is a great need for further research and development.

SUMMARY

In this chapter, a fundamental approach to task analysis is first described and then related to the warning design process. The approach is knowledge-based, in that the human, product, and task are all equivalently represented in terms of related components as knowledge. Much time is spent on describing a set of primitive knowledge components and on ways of combining these elements to describe larger concepts. These primitive and composite elements describe the basic building blocks from which models of the human, product, and environment can be constructed. As a consequence, the material in this chapter is highly inter-related with that in Chapter 11, which describes a consistent way of modeling the human. Both chapters emphasize the same basic knowledge components and organize them within task definition and task performance networks.

Emphasis is also placed on describing the model-building process in terms of several sequential steps, ranging from 1) the elemental breakdown of the product, human, and environment into static and transient components, 2) the related assignment of predicates, and 3) the synthesis or recombination of these components within networks. The correspondance between this model-building process and the sequential warning design process, described in Chapter 10, is noted in the latter portions of this chapter. Several simple examples are provided during that discussion. The ability to generate detailed examples with a minimal effort illustrates that the fundamental nature of the modeling approach poses many advantages.

In conclusion, we feel that the knowledge-based approaches, as described here and within Chapter 11, present many advantages. As a means of analysis during the design of products, these approaches have strong potential; and particularly so in regard to the analysis of messages and (product) user knowledge. Because of the great importance of the "cognitive" issues, both to warnings and other more general aspects of human/product interaction, knowledge based techniques and their application represent a significant advance in the state-of-the-art.

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